INDOOR LIVING WALLS IN CANADIAN DWELLINGS

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August 2020

A Report Submitted to
The Faculty of Graduate Studies and Research
In Partial Fulfilment of the Requirement
Of the Degree of Master of Architecture

ABSTRACT

Current social and environmental challenges including global warming and society's overly consumptive lifestyle have led to the rethinking of residential designs. In addition, communities must rely on imported food sources due to food insecurity, resulting in costly fresh produce. Accordingly, this research report discusses the potential use of indoor living walls' in North American homes for agricultural and air purification purposes. The study offers a preliminary descriptive analysis on current global issues caused by the traditional food chain production and its effect on the environment.

In the introduction, the author explains how the development of living walls for food growth can facilitate and shorten the traditional food production chain, while reducing certain global environmental threats such as climate change. The author then reviews current practices and identifies effective design strategies of indoor living walls for agricultural transformation. The author questions which interior design strategies of edible living walls need to be implemented in order to have living walls produce accessible, safe, and affordable fresh food. Additionally, this work includes a review of the technical aspects of indoor living walls that will serve as a foundation for edible living wall development. The discussion throughout this report lead to guidelines for effective and affordable design strategies.

The findings show that current indoor living wall preoccupations can be transformed into a more useful source of fresh food, reducing the environmental impact and altering the state of the traditional food chain. Technical aspects of indoor living walls and its contemporary applications, shown by a detailed analysis of case studies, summarizes and identifies fundamental criterion for the future development of indoor edible living walls. The study provides valuable information and guidelines for various indoor living wall functions, offering innovative potential for the design of indoor living environments.

Key words: living wall, vertical garden, urban agriculture, interior living wall, edible living wall, food production.

RÉSUMÉ

Les enjeux sociaux et environnementaux actuels parmi lesquels figurent le réchauffement climatique et le surcroît de la société de consommation amènent à repenser les stratégies de design actuelles affectant l'échelle résidentielle. De plus, la question de l'insécurité alimentaire amène les collectivités à dépendre des sources de produits importés, rendant les produits saisonniers dispendieux. Ce rapport de recherche fait état du potentiel usage de murs verts intérieurs dans les espaces domestiques nord-américains à des fins agricoles et dans un souci de purification d'air. L'étude présente une description préliminaire des problèmes mondiaux actuels causés par la chaîne de production alimentaire traditionnelle ainsi que ses effets sur l'environnement.

En introduction, l'auteure expliquera comment le développement de murs végétalisés intérieurs comestibles peut faciliter et raccourcir le schéma de production alimentaire traditionnel et atténuer ses effets néfastes sur les changements climatiques. L'auteure passera ensuite en revue l'ensemble des démonstrations actuelles et identifiera les stratégies de design de murs végétaux les plus efficaces pour la transformation agricole. L'auteure évaluera ensuite les différentes stratégies de design pouvant être mises en place pour que les produits alimentaires générés soient accessibles, sécuritaires et économiques. Aussi, cette recherche comprendra une revue des aspects techniques qui servira de base au développement du concept de mur végétalisé comestible d'intérieur. L'objectif de cette recherche sera d'articuler les lignes directrices de potentielles stratégies de design efficaces et accessibles.

Les résultats démontrent que les formes actuelles de murs végétaux intérieurs peuvent être améliorées et générer des sources alimentaires plus importantes, modifiant ainsi l'état de la chaine de production alimentaire traditionnelle et réduisant ses effets néfastes sur l'environnement. L'analyse et l'étude de cas détaillées des aspects techniques des murs végétalisés intérieurs et ses applications contemporaines permettront d'identifier et de résumer les critères fondamentaux nécessaires au bon développement futur de ces murs végétaux. Enfin, ce rapport permettra de clarifier et d'approfondir les différentes fonctions portées par ces jardins verticaux, et présentera par la même occasion le potentiel innovant qu'ils suggèrent pour le design des espaces habitables intérieurs.

Mots clés: mur végétalisé, jardin vertical, agriculture urbaine, mur vert intérieur, mur végétal comestible, chaine alimentaire.

ACKNOWLEDGMENTS

On the very outset of this research report, I would like to extend my sincere acknowledgments and heartfelt obligations towards all the people who have helped me in this endeavor.

I would like to express my deepest appreciation to my research supervisor, Professor Avi Friedman, for providing invaluable guidance and support throughout our work. I express my profound gratitude for his knowledge, time and effort dedicated to the work on this research report. My completion of this project would not have been accomplished without his motivation, passion, dynamism, and his spirit of adventure, which has deeply inspired me to pursue this study.

Moreover, I would like to express my deepest gratitude to the committee members and administration of Peter Guo-hua Fu School of Architecture for all the learning possibilities they have provided and a chance to study at McGill University. I am extremely grateful to all my professors of the Urban Design and Housing program for their immense contribution to my knowledge and research skills during our fascinating and precious classes.

I owe a special thanks to the graduate secretary of Peter Guo-hua Fu School of Architecture, Marcia King, for all the support, faith, care, and dedication from the beginning to the end of this journey.

Nobody has ever been more important to me in the pursuit of my goals than the members of my family who have always believed and encouraged me to strive for my dreams, pushing me farther than I thought I could go. I cannot express enough gratitude to my caring, inspirational, and loving mother, whose footsteps of an architect I have always desired to follow. I am extremely grateful for the countless time, effort, sacrifices, and immense knowledge that was given, which has helped me become the person I am today. I owe my gratitude to my wise, warmhearted, caring, and kind grandmother for all her prayers, advice, and priceless love.

I would like to express my sincere appreciation to the friends I have met during my studies for their support, understanding, help, and continuous encouragement. Whenever I was in need, they were there behind me.

My heartfelt thanks.

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CHAPTER ONE: INTRODUCTION

1.1. RATIONALE OF STUDY

The research report concentrates on the review of indoor living walls suitable for North American dwellings and provides an analysis of current living wall preoccupations as well as technical parameters and requirements for successful food production.

According to "Green Facades and Living Walls-A Review Establishing the Classification of Construction Types and Mapping the Benefits" (Radić et al., 2019), living walls are a designed and well-maintained, multi-functional system with various potential environmental benefits such as microclimate, aesthetics, reduction of energy cost, and air purification (Fowdar et al., 2017). Living walls are complex systems where vegetation is integrated in the construction of a wall (Susorova, 2013). Unlike vertical gardens and green walls, living walls include both planting media and a vegetated cover placed on a wall's surface (Susorova, 2013). Living walls can be grown not only on a wall's surface, but also on a separate structure or freestanding system (Fowdar et al., 2017; figure 1.1).

An "edible living wall" can be defined as a combination of the structure and requirements of a regular living wall with the potential for food growth such as tomatoes (cherry), basil, chives, peas, cilantro, dill, and other vegetables.

Figure 1.1: Interior Living Wall Designed by Envirozone for Residential Facility in Montreal in 2019. Chateaubriand. (n.d.). Retrieved from http://envirozonedesign.com/en/portfolio_page/chateaubriand-2/

The drive towards the development of indoor edible living walls derives from the social necessity for a qualified source of fresh produce, its potential user accessibility, affordability, air purification benefits, and environmental urban improvement.

1.1.1. Background

The drive towards sustainable development of living walls derives from various catastrophic global issues. Nowadays, our world is experiencing dramatic climate changes that were caused by a resource-intensified lifestyle and unconscious constant consumption. On June 17th, the Canadian House of Commons parliament declared a national climate emergency which postulated a greater reduction of greenhouse gas emissions towards the required targets of 1.5 degrees Celsius under the Paris Agreement (Aiello, 2019). In February 2019, over 300 Quebec municipalities created *a* Déclaration d'Urgence Climatique, where Normand Beaudet, a member of North Shore Action Environnement Basses Laurentides of Montreal, proposed the urgent development of strategies towards greenhouse gas emissions curtailment (Aidt, 2019). As shown on NASA's temperature spike graph (Data.GISS; figure 1.2), the distinction of temperatures between 1921-1969 and 1970-2018 is immense and reaches up to a 7 degree difference.

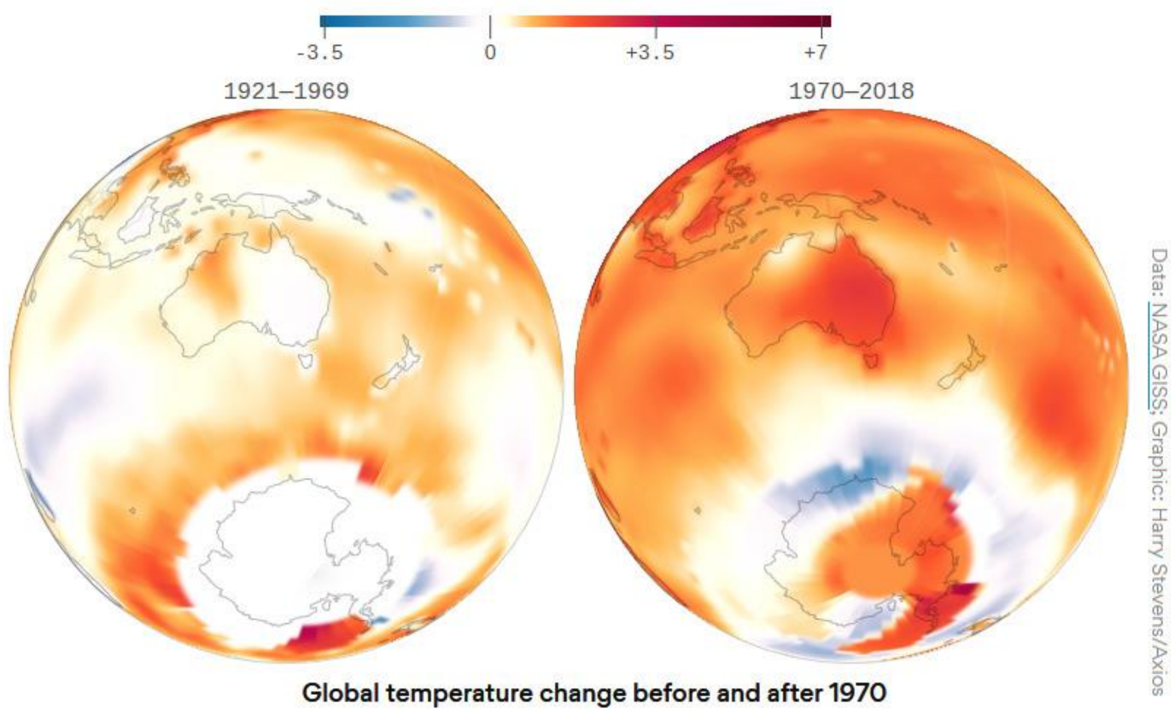


Figure 1.2: Global Temperatures and Baselines – NASA's Temperature Spike Graph. Editor, W. (2016, October 1). Climate Science. Retrieved from https://climateemergencydeclaration.org/climatescience/.

Despite the fact that this research concentrates on indoor living walls, it is clear that major causes and consequences are interrelated. Daily human activities such as fossil fuel burning, deforestation, and agriculture are the three most influential factors of global temperature change (Canada, 2019). According to the Government of Canada (Canada, 2019), the reduction of carbon dioxide emissions is conceivable from the potential decline of industrial processes and human fossil fuel burnout.

1.1.2. Global Problems of Food Production

The life cycle of Agricultural Products consists of seven stages: food production, distribution and aggregation, food processing, marketing, purchasing, preparation and consumption, and resource and waste recovery. Modern society is accustomed to food in stores that are prepared for consumption, but practically nobody realizes the complexity and environmental aftermath of each production stage. Nearly 60 Mt CO_2 eq (8.5%) out of 704 Mt CO_2 eq (100%) total are emissions caused by agricultural processes, while 199 Mt CO_2 eq (28.3%) falls on energy consumption and transportation, which is a critical stage of the entire food chain (Environment and Climate Change Canada, 2018; figure 1.3). Besides energy and water expenditure, waste generation used for packaging is dramatic and directly harms the environment.

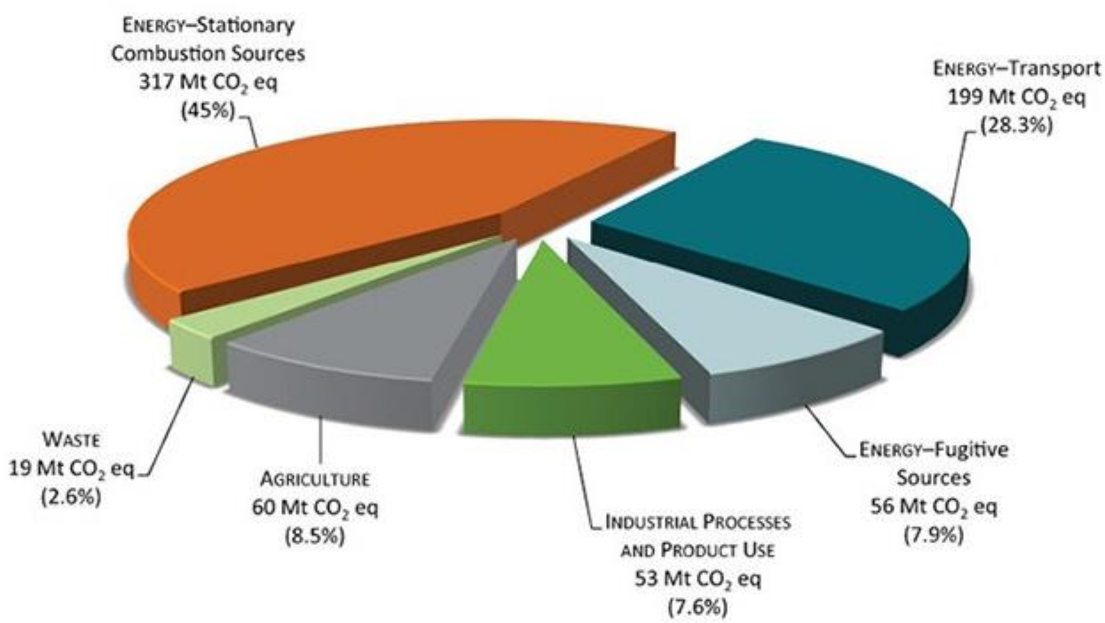


Figure 1.3: Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2016). Environment and Climate Change Canada. (2018). National inventory report 1990–2016: Greenhouse gas sources and sinks in Canada.

According to Kissinger (2012), 30% of all agricultural and food products consumed in Canada are imported from other countries and continents, which result in “food miles” of more than 61 billion tonnes km. Consequently, this creates 3.3 million metric tons of carbon dioxide yearly (Kissinger, 2012). Nevertheless, Canada is the world’s second biggest country with its abundant resources and relatively small population where over 80% of fruits and 45% of vegetables are imported (Kissinger, 2012; figure 1.4).

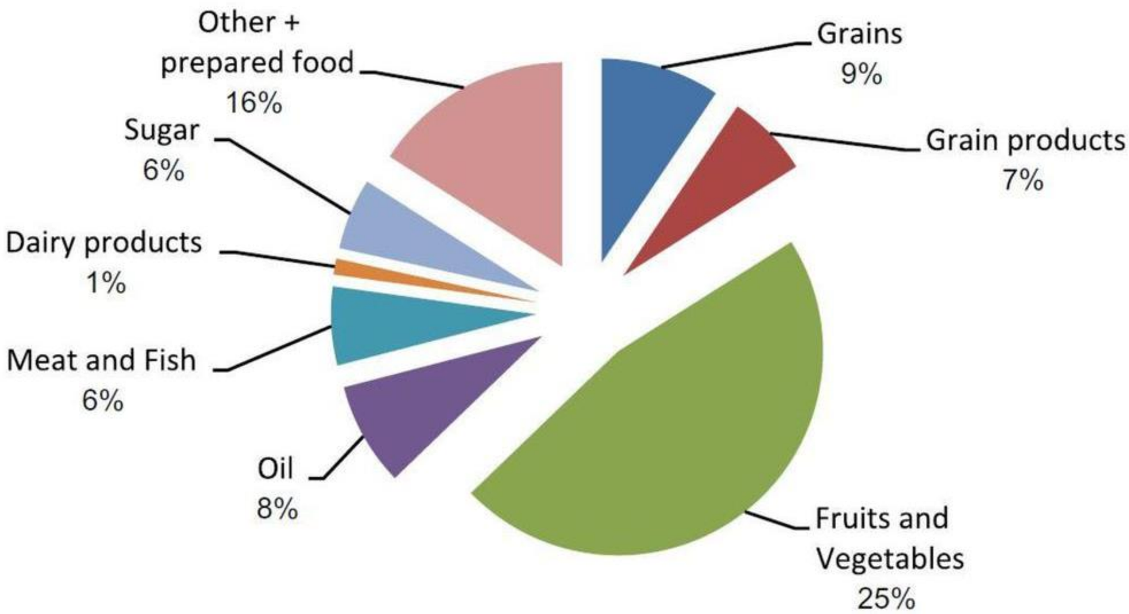


Figure 1.4: Canada’s Food Miles Related CO2 Emissions by Specific Food Group. Kissinger, M. (2012). International trade related food miles–The Case of Canada. Food Policy, 37(2), 171-178.

By analyzing the CO2 emissions breakdown of Canada and its relation to fruits and vegetables, it is obvious that to prevent potential catastrophic collapses, innovative design strategies and sustainable food systems have to be proposed in order to reduce the overall climate change condition. Vegetated indoor living walls in residential properties can become a grassroot movement, where with an accessible distance to food and less need for delivery, packaging, gas, and energy, the overall food supply chain will be reduced.

With the constant population growth in Canada (figure 1.5), cities experiencing considerable reduction of naturally vegetated cover. This caused by the expansion of housing market due to population increase. With the advent of ongoing construction, society has lost its significant connection with nature by leaving it far to suburban places and saturating city life with soulless gray infrastructure. Consequently, rapid demographic increase causes rise of built structures and a reduction of natural vegetation and green spaces. This problem directly affects and limits the potential spaces that can be converted for food production. Buildings should not only be a space for living and ongoing consumption, but an interconnection between human beings and the environment (Precht, 2019). Nowadays, cities lack free space, but living walls can serve dense urban areas, small houses, and apartments. Vertical gardens can be utilized to grow a variety of crops without any space reduction. According to Precht (2019), vertical farming can produce a diverse number of crops and plants per planted area without reliance on weather conditions.

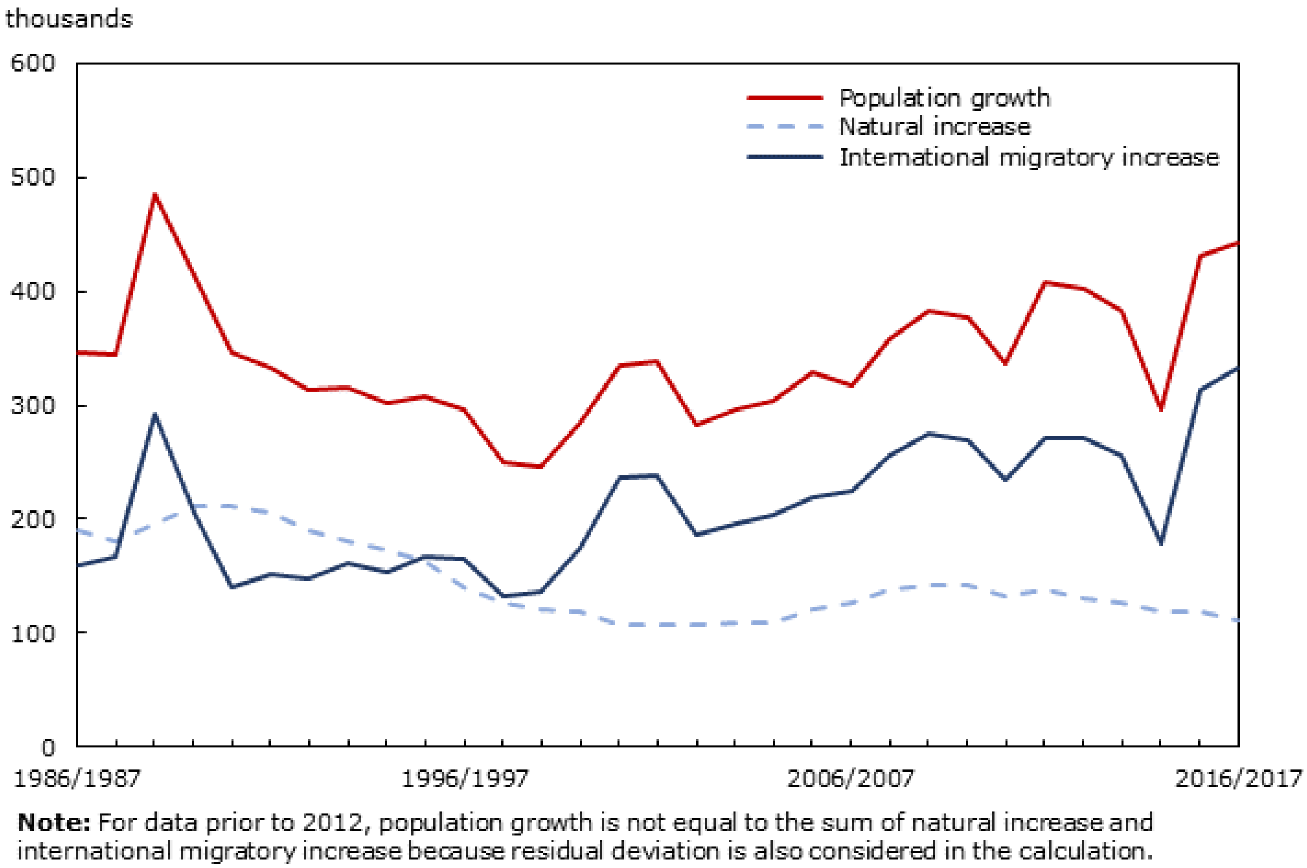


Figure 1.5: Population Growth in Canada. Statistics Canada. (2018, March 27). Canada at a Glance 2018 Population. Retrieved from https://www150.statcan.gc.ca/n1/pub/12-581-x/2018000/pop-eng.htm

Nowadays, society faces major challenges of food insecurity (figure 1.6) and inaccessibility caused by high prices and low quality of vegetables and fruits. Unfortunately, not everyone has access to a sufficient amount of safe, fresh food. According to Roshanafshar and Hawkins (2015), a child in lone-family has the highest rate of food insecurity problems of 22.6%

(2011-2012), while Nunavut region has the rate of food insecurity of 36.7%. It is important to create a new source of accessible food to supply those who are in urgent need.

Besides food insecurity, the overall quality of vegetables and fruits produced and sold in markets are low. The price index for fresh vegetables and fruits has rapidly increased from 90-100 (2004) to 130 (2015) and is continuously raising today (Roshanafshar, Hawkins, 2015). Moreover, to propose a more accessible source of food, the Government of Canada supports the use of Genetically Modified Crops that undoubtedly harms one's state of health. According to ISAAA (2016), Canada is one of the top five countries growing genetically modified crops, where nearly 50% of all food production are fruits and vegetables (ISAAA, 2016).

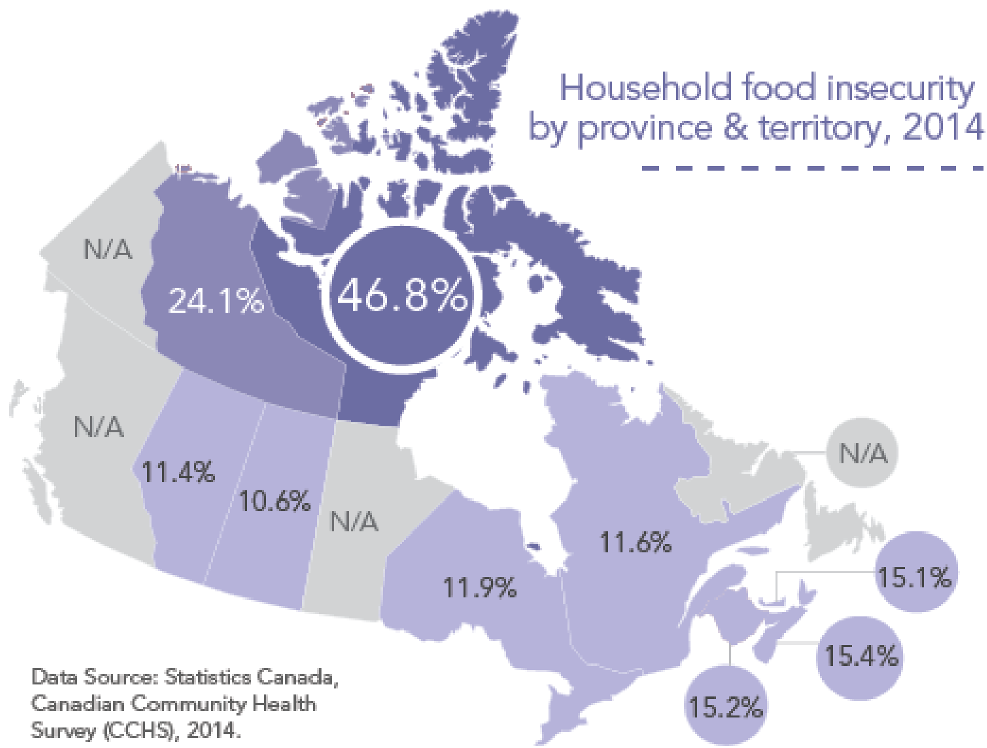


Figure 1.6: Household Food Insecurity Map of Canada by Province & Territory, 2014. Tarasuk, V, Mitchell, A, Dachner, N. (2016). Household food insecurity in Canada, 2014. Toronto: Research to identify policy options to reduce food insecurity (PROOF). Retrieved from http://proof.utoronto.ca

1.1.3. Health Problems Caused by Indoor Air Contamination

The World Health Organization (WHO, 1999) states that over 90% of the time, people spend indoors, but nearly nobody realizes what indoor air truly consists of. Indoor air is composed of outdoor pollutants such as air, soil, structural materials, water, and indoor contaminants such as furniture, machines, appliances, and cleaning equipment (Yildirim, 2018). These resources consist of particles, substances that constantly harm our health condition (figure 1.7).

According to National Aeronautics Space Administration (NASA), air contamination issues, such as 107 Volatile Organic Compounds (synthetic particles), were identified in the 1970s inside the spacecraft (Yildirim, 2018). Subsequently, NASA developed a study and identified that living organisms such as plants are able to clean up the air from contamination (Yildirim, 2018). Besides experiments from the NASA team, researchers have studied that the inclusion of plants in houses helps reduce diastolic blood pressure and heart rate offering other psychological and environmental benefits.

Chemical Emission Sources	Formaldehyde	Xylene/Toluene	Benzene	TCE
Adhesive Materials	x	x	x	-
Biologic Substances	-	x	-	-
Carpets and Fabrics	x	-	-	-
Bonding Elements	x	x	x	-
Interior Coating	x	x	x	-
Cosmetic Products	-	-	-	-
Printers and Printed Materials	-	x	x	x
Particle Boar	x	x	x	-
Plywood	x	-	-	-
Painting and Varnish	x	x	x	-
Tobacco Smoke	x	-	x	-

TCE: Trichloroethylene.

Figure 1.7: Interior Emission Sources. Yildirim, N. N. (2018). THE EFFECTS OF LIVING WALLS ON USERS AT THE COMMERCIAL INTERIORS. Journal of Strategic and International Studies, 13(1), 95.

The monitoring study of “Living Wall influence on microclimates: an indoor case study” conducted by Gunawardena and Steemers (2019; figure 1.8) shows that the development of indoor living walls can reduce the space-conditioning loads of buildings and indoor microclimates. It was concluded that the presence of indoor vertical gardens shows relatively lower temperature results and higher humidity levels (Gunawardena, Steemers, 2019). On the other hand, in the winter season, living walls create thermal comfort conditions and bring up various benefits to occupants (Gunawardena, Steemers, 2019).

In 2019, young architect Precht, a co-founder of design studio Penda, stated that **“**our cities need to become part of our agricultural system. Climate change is forcing us to rethink our way of life and to reconnect agriculture back into our urban fabric" (Precht, 2019). The development of indoor living walls in Canadian dwellings might become an incentive to improve climate change conditions and create a sustainable food system. The interconnection between the greenery of living walls and human beings can bring up a variety of social, global, and psychological benefits that in the future, can change our resource-intensive lifestyle.

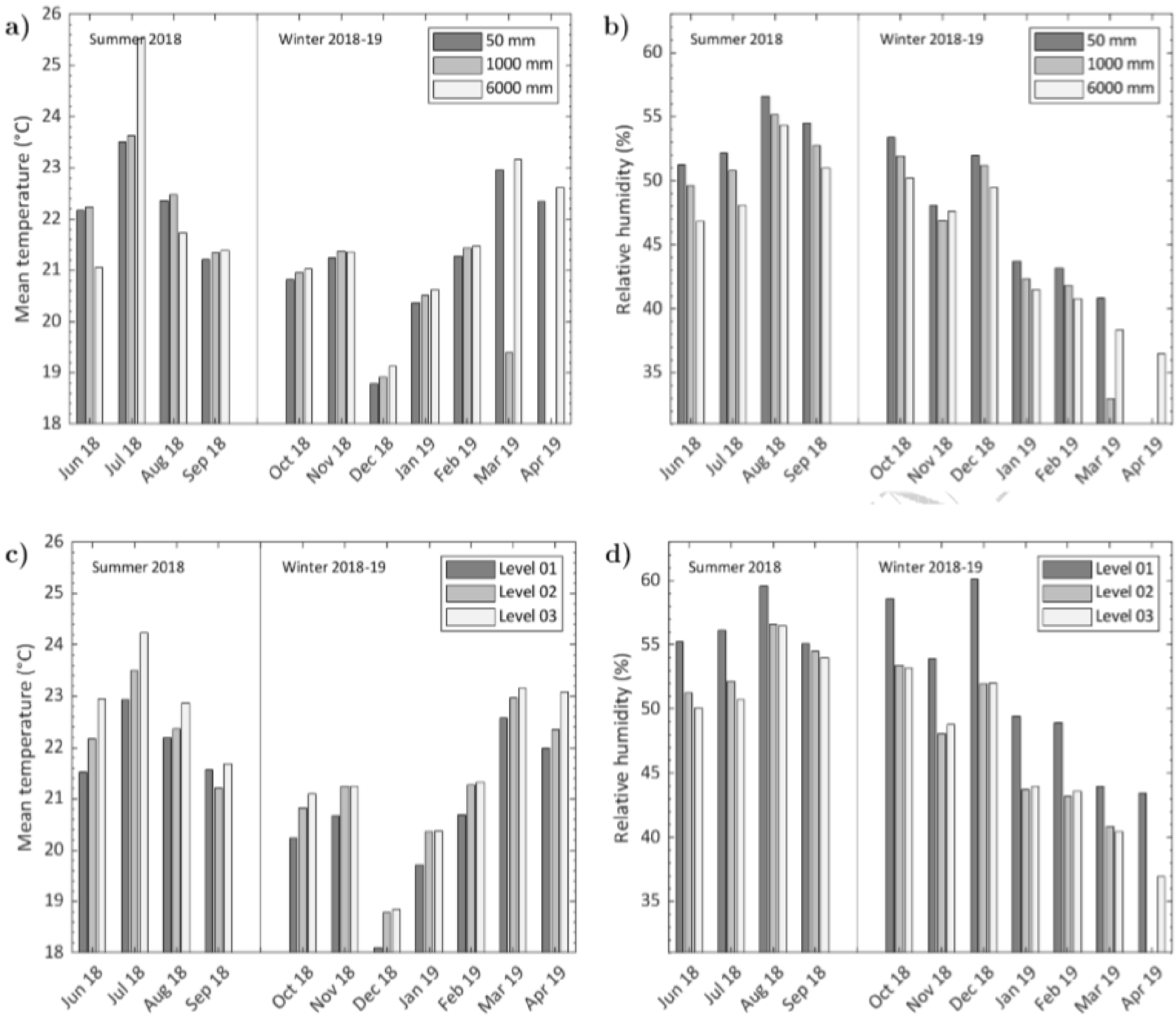


Figure 1.8: Monthly Breakdowns of Horizontal Distribution of Temperature (a) and Relative Humidity (b) Means; and Vertical Distribution of Temperature (c) and Relative Humidity (d) Means. Gunawardena, K. R., & Steemers, K. (2019, November). Living wall influence on microclimates: an indoor case study. In Journal of Physics: Conference Series (Vol. 1343, No. 1, p. 012188). IOP Publishing.

1.2. RESEARCH ARGUMENT

Today, it is becoming more apparent that our unconscious consumptive lifestyle and environmental ignorance leads to catastrophic collapses such as floods (figure 1.9), hurricanes, fires, and tornadoes causing death, poverty, and potential climate anomalies all over the world. Living in a fast-growing world, society spends more energy than ever before. Nevertheless, in reality, no one realizes that soon, all reserved resources might exhaust, which will lead to greater environmental calamities and severe biological collapses. According to the World Health Organization (2014), in the following years leading up the 2030s, climate change consequences will lead to a dramatic increase of deaths of 38,000 elderly individuals due to heat exposure and 95,000 children due to nutritive unsustainability. Between 2030 to 2050, about 250,000 additional deaths are projected due to climate change (World Health Organization, 2014).

Figure 1.9: Flooded Street in Gatineau, Quebec, 2017. Council of Canadian Academies, 2019. Canada's Top Climate Change Risks, Ottawa (ON): The Expert Panel on Climate Change Risks and Adaptation Potential, Council of Canadian Academies.

Taking into account potential collapses, society is in urgent need for expeditious decisions and actions towards a more sustainable environment. Climate change consists of systematic problems and should not only include the reduction of energy and water consumption, but also the development of new systemic solutions including sustainable food systems. "Our cities need to become a part of our agricultural system" (Precht, 2019). Social organisms need to remind itself of its origin and culture to bring traditions back into homes (Precht, 2019). If food has always been a source that has helped build cities, then why is this relationship so non-reciprocal? Focusing on this question, this report will identify design strategies for indoor edible living walls in the residential sector in Canadian regions. According to Green Roofs for Healthy Cities (Sharp et al., 2008), the conversion of living walls for agricultural purposes can provide the foundation for a better community relationship, improve accessibility to fresh produce to solve food insecurity in poor neighbourhoods, and reduce environmental impact of the traditional and complex food chain.

1.3. RESEARCH QUESTION

In addition to focusing on the theoretical part of living wall development, this research report will examine the effective strategies and propose design guidelines for indoor edible living walls in residential properties in North American regions. The concentration of this work is an elaboration of new and accessible sources of fresh produce that can be used to serve occupants' needs. The research question of the report is:

Which interior design strategies of edible living walls need to be implemented to make it an accessible, safe, and affordable source of fresh food while providing air purification benefits?

SUB QUESTION

What materials, systems, and instructions should be used to assemble a living wall?

1.4. RESEARCH GOALS

1. To investigate affordable and effective indoor design strategies of edible living walls suitable for North American dwellings;
2. To explore the potential benefits of food production for users in comparison with prices of food from stores;
3. To offer guidelines and criteria for future intended audience;
4. To find how the development of living walls for food production purposes can facilitate and shorten the traditional food production chain and reduce global environmental threats of climate change.

1.5. RESEARCH OBJECTIVES

The research report will attempt to demonstrate, through literature revision, a case study analysis of living walls to determine the effectiveness of edible vertical gardens. The main objectives of the report are the following:

1. Historical review of the origin of living walls and their evolution to modern practice;
2. Review of existing literature and case studies of indoor living walls;
3. Study of plant typologies to identify what plants are suitable to grow vertically and indoors in North American dwellings;
4. Review a plant selection matrix for plant combinations that are suitable to grow together;
5. Study lighting systems to identify the necessary amount of illumination for successful plant growth, and photoperiodism to understand timing for plant light relief;
6. Explore internal climate conditions, moisture, temperature, and humidity levels needed for plants;
7. Examine irrigation methods; appropriate watering levels and nutritive patterns.

1.6. INTENDED AUDIENCE

The target audience for this research report mainly consists of designers and architects whose mission is to implement and install living walls. The second target group is scholars and students who are working on a research report in the same field and topic. It aims to provide readers with recent indoor living wall practices, identify design strategies, show literature references and explain an idea of agricultural living wall development. Lastly, the research aims to provide homeowners with design guidelines, benefits, as well as potential outcomes.

1.7. RESEARCH METHODOLOGY

The research report includes four stages:

Stage one:

The first stage introduces the main background problems such as climate change and its interrelation with the traditional food system chain in order to address the significance of indoor living walls for agricultural purposes. Information of the first stage will be primarily gathered from literature (books, articles, research reports) and the news. Furthermore, background problems are provided with an interconnection to interior living wall application, which can potentially help to solve major problems.

Stage two:

After an analysis of problems and reasons, the information about indoor living walls are gathered from books, reports, and articles in order to examine technical components of indoor living walls such as irrigation, drainage, support structure, and lighting. Provided material from different sources will be evaluated and compared with each other to identify the best solution, which will help to meet occupants' target.

Stage three:

The third stage concentrates on recent case studies to illustrate effective design strategies of modern applications. Information on these case studies is gathered from books, websites, and journals. Obtained materials will be compared to each other to identify the experience of the user and designer as well as to identify objective feedback with pros and cons of interior living walls.

Stage four:

In result, after a detailed analysis of the provided information, effective design strategies and guidelines are presented to illustrate the potentiality for future adaptation to food production. The fourth stage will aim to provide primary decision-making aspects that will help designers and occupants identify the type of living wall system and its components that meet their initial target.

1.8. RESEARCH OUTLINE

The research report is subdivided into four chapters. Chapter 1 includes the rationale of the research, factors, and background problems related to further research analysis.

Chapter 2 introduces the technical approach of living walls and their main components, as well as classifications of existing living walls. It analyzes technical aspects such as irrigation, maintenance, growing conditions, installation, and species that are suitable for indoor vertical growing.

Chapter 3 includes applications of interior living walls in residential facilities to evaluate effective design strategies and current preoccupations. The case study analysis concentrates on North American and European dwellings, which will help identify specificity, tendency, and requirements for living walls.

Chapter 4 will provide major guidelines for effective interior living walls and strategies that can become a fundamental aspect for edible living wall development. It will aim to advise designers and occupants with the initial decision-making process and following implementation requirements.

1.9. SCOPE AND LIMITATIONS

After revision of existing literature, it is concluded that modern applications of indoor living walls are primarily based on aesthetic performance rather than converting it for agricultural purposes. This research will be focused on the basic indoor living wall concept, which can be used in edible living wall designs. Besides the fact that this research focuses on food production for occupants, the use of living wall indoors as a source of fresh produce does not limit the advantages of health benefits, internal microclimate stability, energy efficiency, and air quality improvement. As a result, on top of all the advantages of basic modern examples, a living wall will have an additional function of food growth. Due to lack of data and case studies that target agricultural application of indoor green walls, the research will include current practices of living walls in residential facilities of Northern America and Europe. In addition, since the research concentrates on edible living walls, it is essential to examine what fruits and vegetables are suitable to grow indoors and what conditions should be met for successful food production.

CHAPTER TWO: TECHNICAL ANALYSIS

2.1. INTRODUCTION

One of the largest gaps identified during preliminary analysis of indoor living wall design was related to the lack of data about edible indoor living walls or living walls for indoor agricultural purposes. To enhance the knowledge and highlight the significance of this research various resources were combined to create one “uniform picture” of edible living walls.

It may seem as though a living wall is a simple organism. However, implementing a living wall that meets necessary requirements of irrigation, maintenance, and lightning might be challenging without proper knowledge. Not only is the first stage of living wall development important, the most crucial period is its exploitation, which will reflect the success of food production. The main domain of this chapter is the technicality of edible living walls in indoor environments. To make an edible living wall accessible and cost-competitive, as well as to bring a better understanding to the significance of the topic, design and research efforts are needed to form a guide for potential users. According to Boyd (2007), without recognition of economic value of living walls, there might be a potential to undervalue regulating and, supporting the cultural ecosystem of living walls. The significance of food production becomes an incentive for edible living wall development in contemporary cities in urban fabric (Nagle et al., 2017).

This chapter will include the review of technical design aspects of edible indoor living walls, as well as living walls for aesthetics and air purification purposes. The first part of the chapter will analyze the typology of living walls including structures and components of LWS. Based on the presented classification of living walls, technical aspects such as irrigation, drainage, growing media, soil, and fertilization will be examined. Plant selection, nutrition, species compatibility and root cycle will be studied for the use of edible LWS. Additionally, the chapter will concentrate on maintenance, lighting, installation requirements along with an explanation of LWS for air purification, including the mechanisms of filtration, indoor air pollutant examination, and potential diseases caused by contaminated indoor air.

2.2. CLASSIFICATION OF LIVING WALLS

2.2.1. Background

The growing tendency towards living wall development is rapidly increasing, which is characterized by the issues of global warming and its consequences on the environment. Despite the fact that living walls are relatively recent innovation, the root idea began a long time ago with the emergence of green walls. According to Kmieć (2014), climbing plants have been used as a design and decorative tool for centuries dating back to Egypt, Babylon, and Greece, where grapevines and ivy played a significant role in the cultivation of plants. One of the first attempts of vertical greening appeared in ancient civilizations in Hanging Gardens of Babylon, (figure 2.1) where it included gardens, trees, terraces with vegetation and fountains that led to the preservation of the area (Virtudes, Manso, 2012). This made it seem suspended and visible from a far distance (Virtudes, Manso, 2012). Greek and Roman empires have used olive trees and grapevines to ornament buildings' structures (Newton et al., 2007).

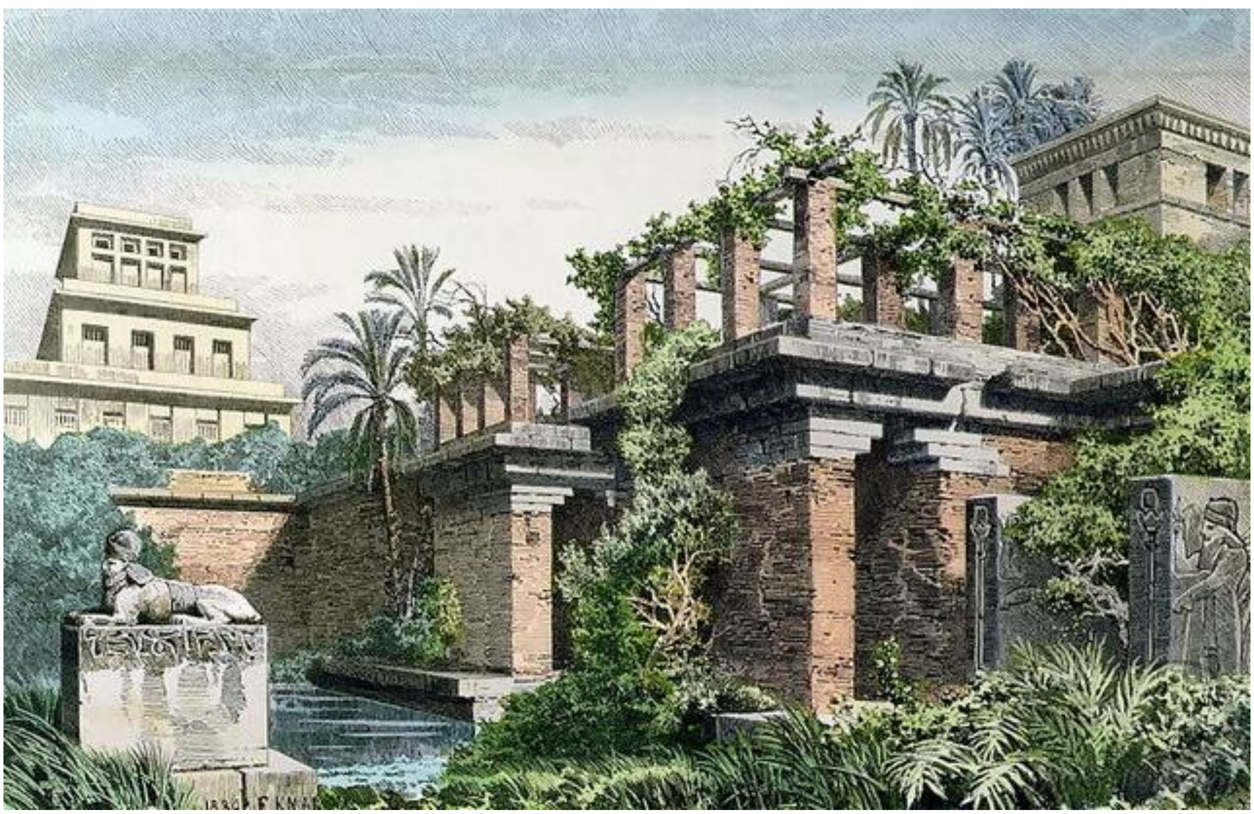


Figure 2.1: Hanging Gardens of Babylon. Cartwright, M. (2020, February 15). Hanging Gardens of Babylon. Retrieved from https://www.ancient.eu/Hanging_Gardens_of_Babylon/

With the advent of industrial technologies, the integration of green infrastructures into urban fabric became an essential design strategy of preserving the connection between nature and the fabricated environment. Continuous population expansion and city densification have isolated cities from nature and human beings. To link into an intimate correlation, researchers and designers tried to analyze free surfaces of built structures that can be adapted to any geometry, have light structure, and can be maintained without soil. As stated by Sadeghian (2016), in 1988, Patrick Blanc (figure 2.2) was the first scientist and designer who patented a first modern green wall device, which allowed plants to grow without soil on a vertical surface. His first vertical garden installation, which was created in 1988 for the Cité des Sciences et de l'Industrie, Paris, combined metal frame elements, PVC layer, polyamide felt, automated fertilization and water management systems (Gandy, 2010).

Figure 2.2: Patrick Blanc's House. Admin. (2019, November 2). Patrick Blanc's House. Retrieved from https://www.verticalgardenpatrickblanc.com/realisations/paris/patrick-blancs-house

2.2.2. Living Wall Typologies

Over time new variations of green walls and living walls have occurred (figure 2.4), - so it is essential to identify and classify all existing green vertical systems in order to concentrate directly on the research of living walls (figure 2.3). Green Wall or Vertical Garden is the term used to refer to all forms of green surfaces (Sharp et al., 2008). Green walls are subdivided into two main categories: Green Facades and Living Walls (Sharp et al., 2008). The main distinction between Green Facades and Living Walls is that Green Facades are composed of climbing plants and directly grow on a wall or supporting surfaces rooted to the ground, while Living Walls consists of modular panels, containers, irrigation systems, growing media, and vegetation which allows for more flexibility for plant cultivation (Sharp et al., 2008).

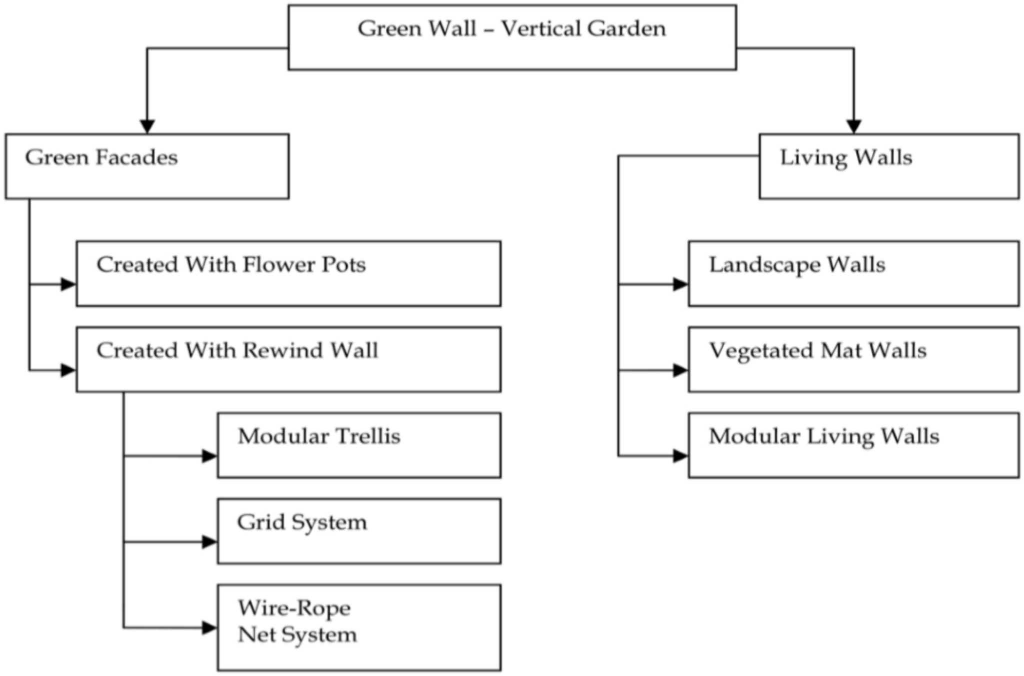


Figure 2.3: Flowchart of Classification of Vertical Garden. Sharma, P. (2015). Vertical gardens. An innovative element of green building technology.

Living walls are composed of modular vertical systems, planted blankets or prepared vegetated panels that is usually made of plastic, polystyrene, synthetic fabric, clay, metal and concrete (Sharp et al., 2008). The flexibility and variety of living wall structures creates a diversity and density of plant species.

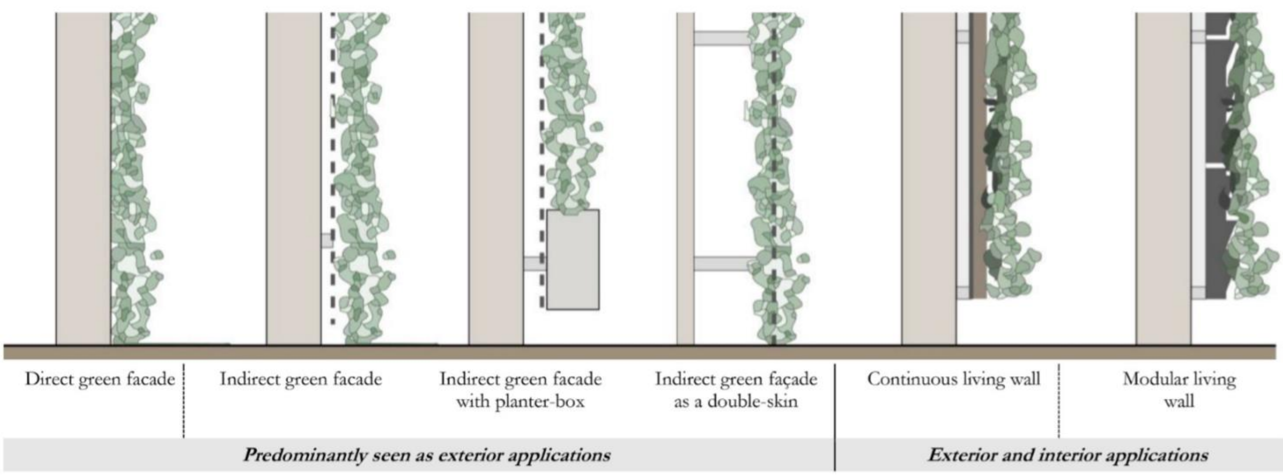


Figure 2.4: Vertical Greening Categories and Some Exemplar Variants. Gunawardena, K., & Steemers, K. (2019). Living walls in indoor environments. Building and Environment, 148, 478-487.

Due to the diversity and density of plants, living walls require more protection and maintenance than green facades.

2.2.3. Living Wall Structures and Components

Despite the variety of green walls, each of them relies on specific needs, context, and purpose of plant cultivation. Generally, Living Walls have three main systems: landscape walls, vegetated mat walls and modular living walls (Sharma, 2015; figure 2.5). The choice towards one specific system will be defined according to the preference of the client and designer.

Landscape Walls are an expression of "living" architecture, which characterized by organically created natural fabric which typically appears to have a sloped angle in opposition to vertical greening (Timur, Karaca, 2013). These structures are meant to be used for slope stabilization and noise reduction along roads and streets to protect the micro-environment of neighborhoods (Timur, Karaca, 2013). Landscape Walls are usually made with the support of stacking material of plastic or concrete with a space left for growing media and plants (Sharp et al., 2008).

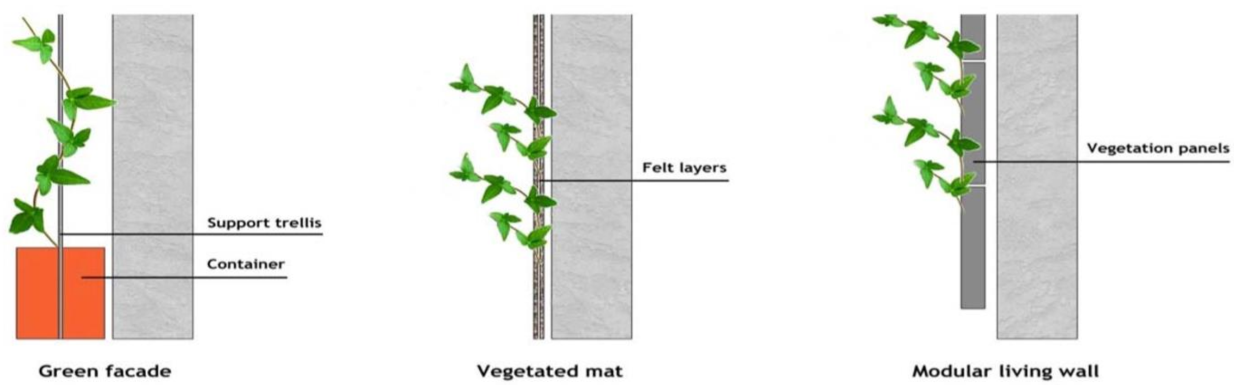


Figure 2.5: Three Main Types of Living Walls. Stav, Y. (2016). Transfunctional living walls-designing living walls for environmental and social benefits (Doctoral dissertation, Queensland University of Technology).

Vegetated Mat Walls is a unique system of living walls, which was first proposed by Patrick Blanc (Sadeghian, 2016). It includes two layers of synthetic fabric with pockets for physical support of plants (Timur, Karaca, 2013). The system is fully supported by a frame and covered with waterproof membrane to protect the structure of the building's wall. Moreover, it includes a cycle irrigation system which allows water to flow from top to the bottom, enabling plant nutrition (Sharp et al., 2008).

Modular Living Walls are composed of squares and rectangular panels that produces a diverse number of species in each element and supports the structure and growing media (Sharp et al., 2008). This type of living wall is widely used in interior design to create flexible patterns and adapt to design criteria or preference. It allows more flexibility and freedom to create modular living wall designs with a different shape or pattern than any other living wall structures.

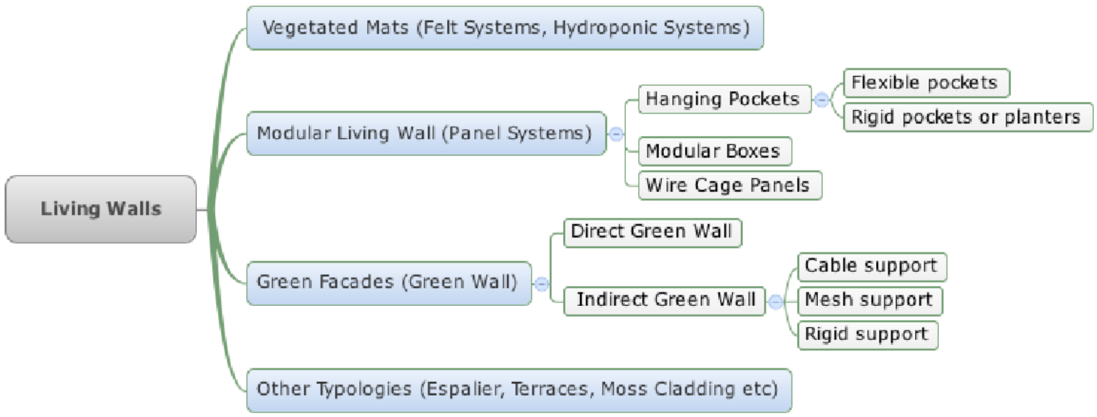


Figure 2.6: Classification of Living Wall Typology Reflected in Literature Review. Stav, Y. (2016). Transfunctional living walls-designing living walls for environmental and social benefits (Doctoral dissertation, Queensland University of Technology).

In comparison to traditional green walls that have no structural support and rely mostly on the capacity of climbing plants, which are naturally attached to vertical surfaces, living walls require structural support and commonly includes a frame. This frame holds all the components of the living wall together and supports growing media and plants. Continuous Living Wall System is based on the installation of a frame attached to the wall with a void space in between, which protects plants from humidity (Manso, Castro-Gomes, 2014). Following the frame, base panels form the next layer which is covered with permeable material, including root proof screens stapled to the base of the system (Manso, Castro-Gomes, 2014). The finishing layer composed of screens is cut into pockets formed to insert plants individually (Manso, Castro-Gomes, 2014).

Modular LWS (or living wall system, a name given by Patrick Blanc) is a relatively new and innovative approach to living wall application. It not only varies in composition in comparison with other systems, but also in weight and the method of assembly. Modular LWS includes trays, vessels, planter tiles and flexible bags (Manso, Castro-Gomes, 2014).

- **Trays** are attachable to each other system, consists of containers, and holds the weight of plants and substrates (Manso, Castro-Gomes, 2014);

- **Vessels** are the most commonly used support for living walls as they can be fastened or attached to a vertical surface (Manso, Castro-Gomes, 2014);
- **Planter tiles** are used as elements of interior and exterior design with a vegetation layer and functions as a modular cladding system to insert the plants (Manso, Castro-Gomes, 2014);
- **Flexible bags** are composed of lightweight materials which allows the design of different shapes, patterns, or sloped surfaces (Manso, Castro-Gomes, 2014).

As stated by Weinmaster (2009), modular living wall substrates can be composed of rockwool, coco-coir, potting soil, or peat. However, nowadays, the substrates that are used for living walls are more diverse and can be classified into the following characteristics:

- **Loose substrates** (potting mix, artificial substrate) (Stav, 2016);
- **Solid substrates** (rockwool) (Jørgensen et al., 2014), **fytocell** (Welleman, 2004);
- **Mat substrates** for vegetated mat walls (nonwoven textile made of polyester, polyurethane or polyamide-polypropylene) (Franco et al., 2012).

Components	Direct Green	Indirect Green	Indirect Green With Planter Boxes	Living Wall System
Structural support member	–	Stainless steel bolts, anchor, spacer brackets	Stainless steel bolts, anchor, spacer brackets—steel profile	Steel profile and anchors
Water proofing material	–	–	–	PVC foam plate, PP, etc.
Supporting system/panel		Steel mesh, wood trellis, plastic mesh, etc.	Steel mesh, wood trellis, plastic mesh, etc.	Felt, HDPE planter boxes, geotextile, etc.
Growing material	Substrate soil	Substrate soil	Potting soil	Potting soil or wool fleece or mineral wall, etc.
Irrigation system	–	–	PE pipes	PE pipes
Water demand	Ground water	Groundwater	Tapwater + nutrients	Tapwater + nutrients
Vegetation	Climbing plant	Climbing plant	Climbing plant	Climbing plant and shrubs

Figure 2.7: Components and Materials of Some Vertical Greening Systems. Perini, K. (2018). Life Cycle Assessment of Vertical Greening Systems. In Nature Based Strategies for Urban and Building Sustainability (pp. 333-340). Butterworth-Heinemann.

Besides three main living wall typologies, living walls can be characterized into two systems: hydroponic and soil-cell systems (Riley et al., 2019). **Hydroponic** systems, discovered by Patrick Blanc, usually uses a dense mat and felt components as growing media (Riley et al., 2019). This hydroponic system is lightweight and saturated with nutrients, where roots grow on and between layers of chosen substrate (Riley et al., 2019). Hydroponic living wall systems can be modular or composed of big panels fixed via brackets with a space in between the main wall. Plants are usually anchored to inert growing media like horticultural foam, mineral fiber or a felt mat which acts like a sponge and retains the water (Carpenter, 2014).

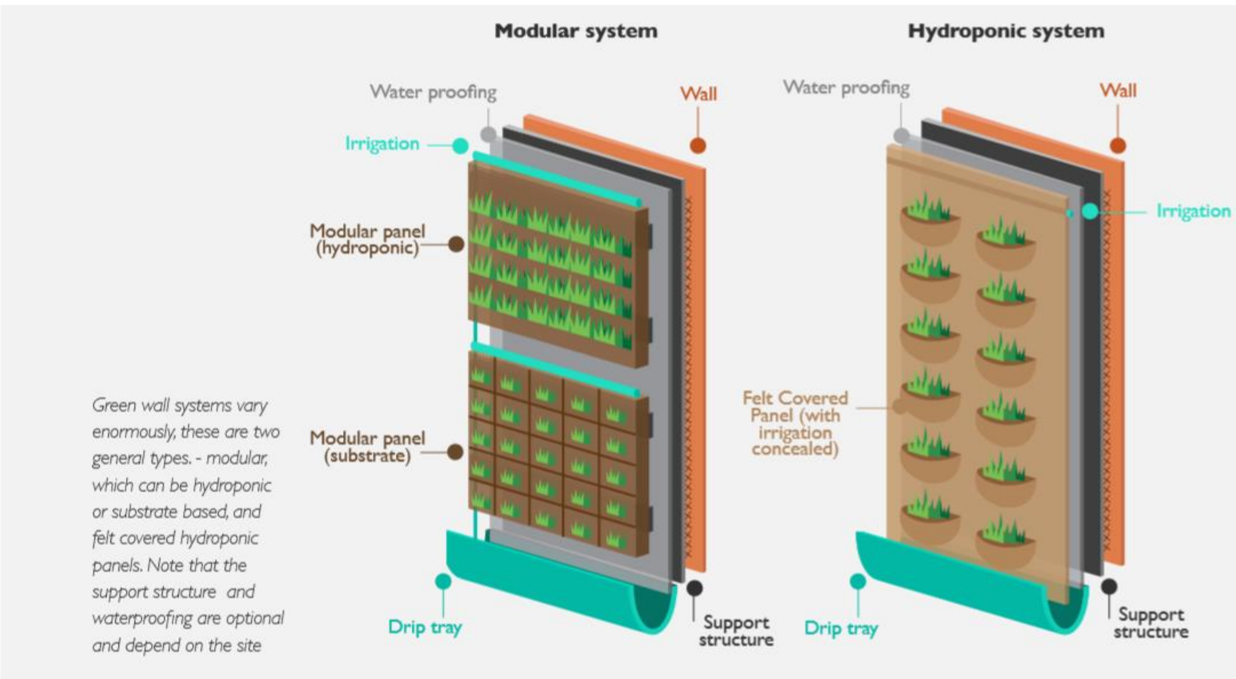


Figure 2.8: Types of Living Wall Systems. Carpenter, S. (2014). Growing Green Guide: A Guide to Green Roofs, Walls & Facades in Melbourne and Victoria, Australia. Australia: State of Victoria, 142.

On the other hand, **soil-cell** systems are subdivided into individual compartments and grouped together in panels to attach to the frame and control the growth of plants (Riley et al., 2019). Substrate-based systems consist of plastic or metal where substrate is subdivided and placed into compartments in a water-permeable fiber material (Riley et al., 2019). These compartments can either be installed to the wall or have an independent metal rack or framework system (Riley et al., 2019). The flexibility of individual containers allows for the removal of units in case maintenance or replanting. The substrate-based system, similar to the hydroponic system, is usually designed with a built-in irrigation system. However, the growing media in substrate-based systems require less management in terms of water, air and plant nutrition (Carpenter, 2014).

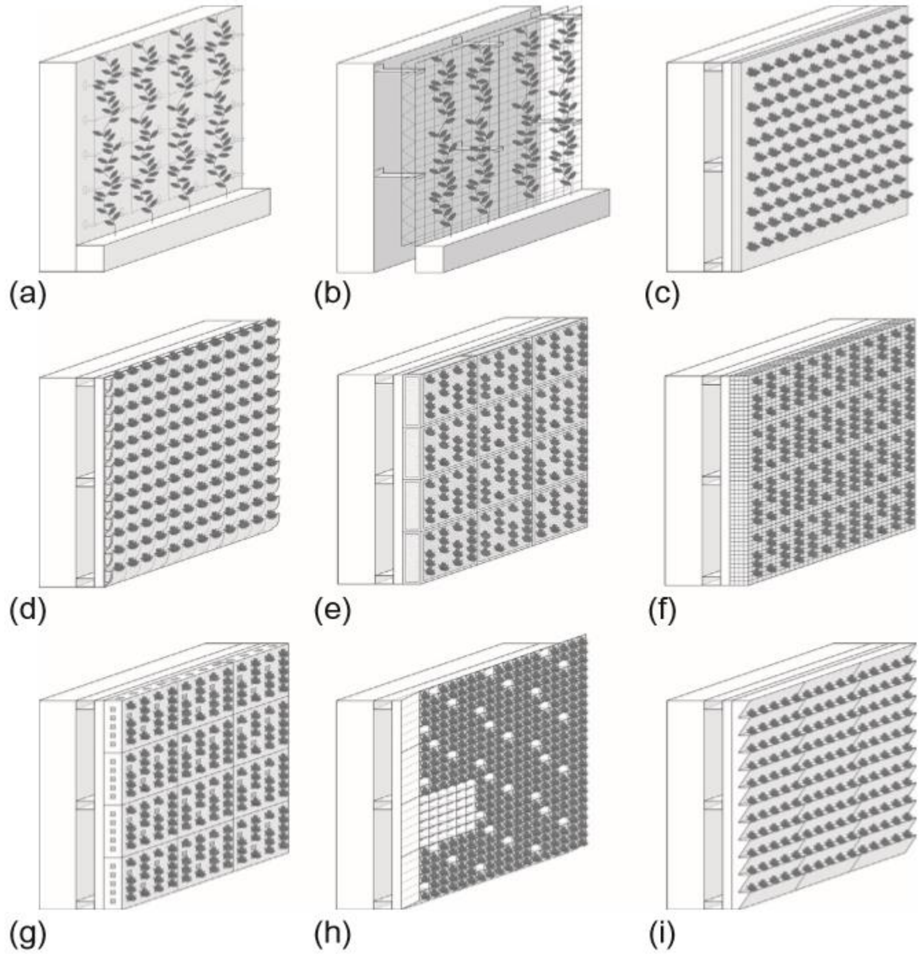


Figure 2.9: Different Types of Green Walls. (a) Indirect Green Facade with a Two-Dimensional Trellis, (b) Indirect Green Facade with a Three-Dimensional Trellis, (c) Vegetated Mat Living Wall System, (d) Hanging Pocket Living Wall System, (e) Framed Box Modular Living Wall System, (f) Wire Cage Modular Living Wall System, (g) Perforated Box Modular Living Wall System, (h) Slanted Cell Box Modular Living Wall System, and (i) Trough Planters. Susorova, I. (2015). Green facades and living walls: vertical vegetation as a construction material to reduce building cooling loads. In Eco-Efficient Materials for Mitigating Building Cooling Needs (pp. 127-153). Woodhead Publishing.

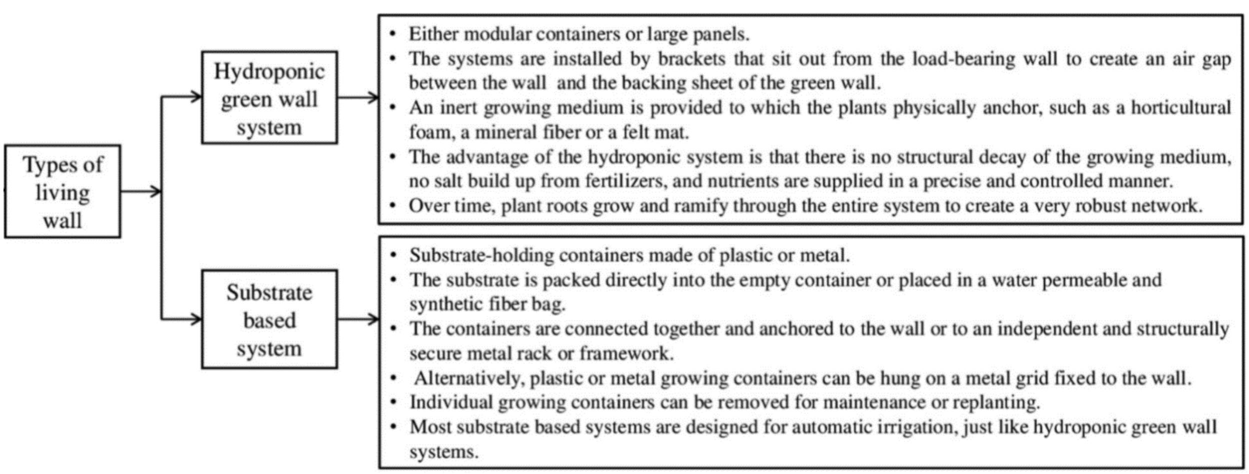


Figure 2.10: Details of Living Wall Types. Pradhan, S., Al-Ghamdi, S. G., & Mackey, H. R. (2018). Greywater recycling in buildings using living walls and green roofs: A review of the applicability and challenges. Science of The Total Environment, 652, 330-344

2.3. LIVING WALL TECHNICAL ASPECTS

Preliminary analysis has shown that current applications of living walls focus on aesthetic and air purification benefits. Despite the fact that living walls can serve various functions, this research report will concentrate on the use of indoor living walls in residential properties, specifically for food production. Studies of indoor living walls show that in order to provide a general understanding of the significance of edible living walls, it is necessary to cover all possible topics related to the implementation, maintenance and use of living walls in an indoor environment. Principally, this study investigates a strategy to proliferate the use of edible living wall, which can produce shrubs and vegetables to create a new accessible source of fresh produce into homes. This will be explained later in the chapter. Consequently, edible living walls will improve the traditional agricultural chain and lower waste and energy generated from the production cycle.

The use of living walls for agricultural purposes can bring a variety of benefits, not only to residents of the property, but our environment as well. Diverse Canadian climate resulting in cold winters and short cold summers in northern parts, cold winters and hot summers with relatively sparse precipitation in central southern areas, hot, humid summers and cold, snowy winters in Southern Ontario and Quebec (Morton, Nicholson, 2020). Therefore, it is more efficient to focus on adaptable indoor living walls rather than exterior green walls to adjust to any weather and environmental condition. According to Deelstra and Biggelaar (2003), further development of urban agriculture or the proliferation of living walls as an agricultural source can substantially reduce urban ecological footprints. In addition, indoor edible living walls can provide other benefits such as better access to fresh food, a reduction in environmental impacts generated from the traditional food chain, air purification of indoor air, and strengthening the relationship between human beings and nature (Stav, 2016).

2.3.1. Irrigation

The irrigation system is dependent on the type of living wall system that is chosen, the plant type, and indoor condition. Irrigation systems help provide water needed for plants to grow. It is usually enriched with nutrients, fertilizers, and minerals, which improve the proliferation of plants. The most important element of the irrigation system in **continuous living wall system** is the water tube located at the top connected to the central irrigation system where water is distributed equally by the screens to all parts of the living wall (Manso, Castro-Gomes, 2014). These tubes can be made out of rubber, piping thermoplastic, silicone and an irrigation hose with outputs such as a sprinkler, drip or pipe (Manso, Castro-Gomes, 2014). In addition, to prevent the irrigation system from clogging, filtration elements can be installed (Manso, Castro-Gomes, 2014).

Modular living wall systems with trays composed of an irrigation tube inserted at the top with trays that include holes, helps to distribute water equally, including underneath the modules as well (Manso, Castro-Gomes, 2014). To prevent high water waste, a rainwater recovery system and sensors that control water levels can be included in the system. The circulation of water waste can be reached by the installation of a gutter in the base of living walls (Manso, Castro-Gomes, 2014). Furthermore, sensors will allow one to control the level of fertilizers and nutrients according to the needs of plants (Manso, Castro-Gomes, 2014).

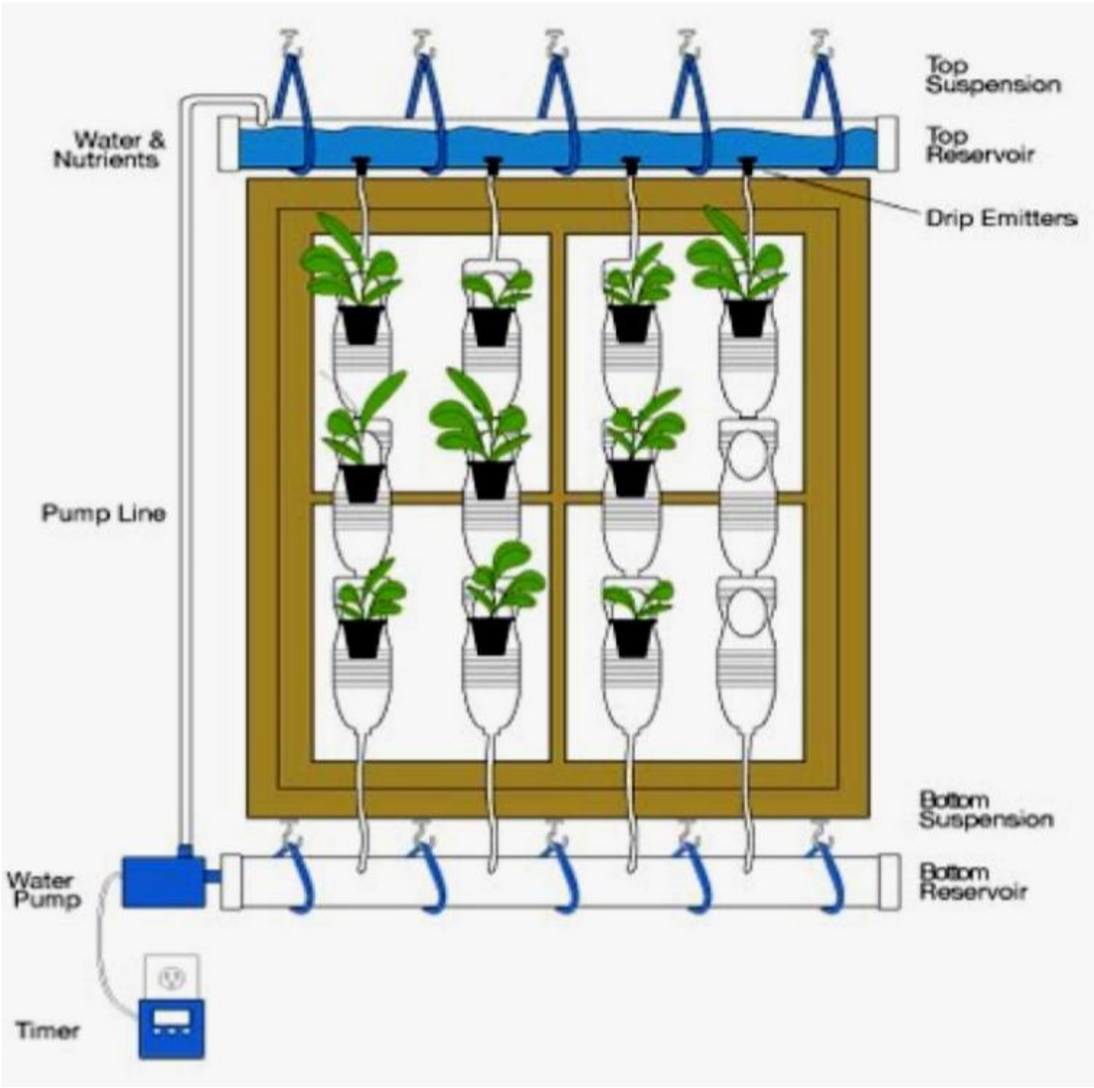


Figure 2.11: Living Wall Irrigation System. Sharma, P. (2015). Vertical gardens. An innovative element of green building technology.

2.3.2. Drainage

To prevent root proliferation, continuous and modular living wall systems include geotextile material with the combination of permeable membranes to accelerate drainage. To improve the drainage system of trays formed in living walls, the bottom of a living wall can include inclined and perforated concave or a porous absorbent material (Laurence, Sabin, 2011; figure 2.12). In case of vessels mentioned previously in the chapter, filter material is applied to the bottom of the module (Deutsch-Aboulmahassine, 2009). As stated by Manso and Castro-Gomes (2014), some modular living walls can include the insertion of grooves and holes on the sides of living walls to reduce excessive moisture in the substrate and improve air circulation. Overwatering or water insufficiency of plants will have harmful impacts including brown or dead plants. In this case, the installation of sensor and automated system will help maintain the optimal level of water and nutrition for plants.

2.3.3. Growing Media

As have been mentioned before, **continuous living walls** do not compose of substrate. This system is lightweight and includes screens for absorption where plants are inserted individually into pockets. Due to the lack of substrate, **hydroponic continuous living walls** require permanent water and nutrient supply. The irrigation system with the use of screens allows soil-less plant growth, where the lack of substrate is compensated by constant irrigation system (Manso, Castro-Gomes, 2014). On the opposite side, **modular living walls system** (figure 2.11) is composed of growing media for root proliferation, which is made of inorganic compounds or inorganic material (Manso, Castro-Gomes, 2014). As a result, the system has reduced weight. According to Manso and Castro-Gomes (2014), usually, growing media in modular systems include a mix of light and granular material in order to gain a good water capacity, where the substrate itself can be filled with nutrients and fertilizers for proliferating plant growth. Sometimes it is more appropriate to use geotextile bags to prevent growing media from detachment. Additionally, these bags can allow the insertion of multiple plant species into a single unit.

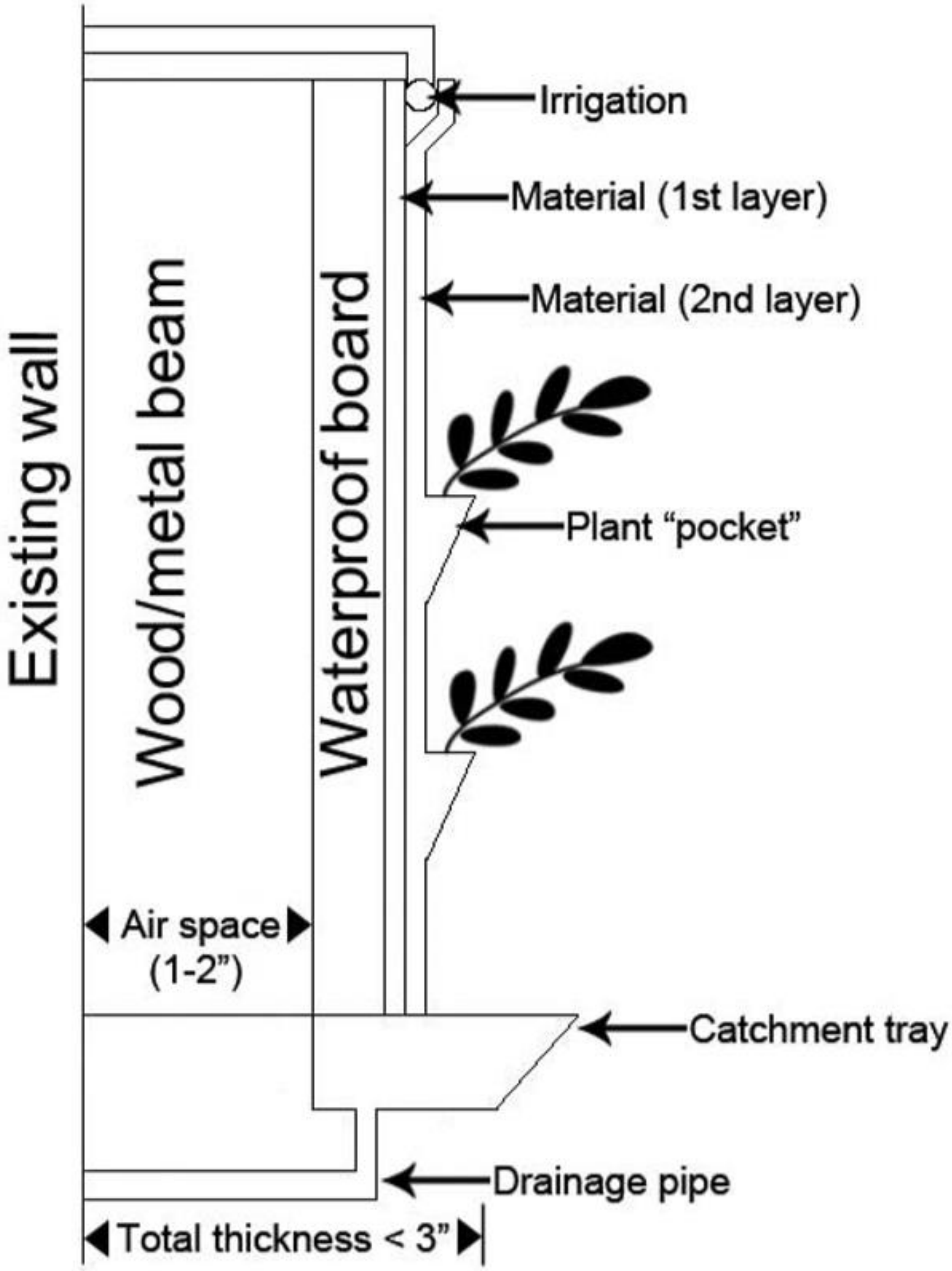


Figure 2.12: Side View of a Hydroponic System. Weinmaster, M. (2009). Are green walls as "green" as they look? An introduction to the various technologies and ecological benefits of green walls. Journal of Green Building, 4(4), 3-18.

2.3.4. Soil and Fertilization

The right choice of soil or growing media is the fundamental and most important factor in beginning implementation. This is due to the fact that different types of soil will have a different impact on loads and structural requirements of the living wall system (Pradhan et al., 2018). To have less impact on the structure, the media should be light and have the necessary level of porosity and water-holding capacity. A high level of porosity does not guarantee lightness of the media and as a result directly depends on soil composition. As have been mentioned before, to implement a well-designed and prosperous living wall, a good drainage system should be developed along with a plant benefitting balance of soil composed of nitrogen, phosphorous, potassium, organic carbon and other nutrients (Pradhan, et al., 2018).

According to Pérez-Urrestarazu and Urrestarazu (2018), living walls can be fertilized with the application of substance into the irrigation water, where it should be subdivided between lost and recirculating systems. Hydroponic systems with hollow roots will require more fertilization compared to the system that requires growing media (Pérez-Urrestarazu, Urrestarazu, 2018). Recirculating systems with hollow roots also require more management as over-fertilization might reach toxic levels in nutrient capacity due to the lack of growing media. To have the right level of fertilization, one should take into account the following principles:

- Fertilization and nutrient compounds should be monitored continuously, specifically in recirculating systems with bare roots;
- Use of organic nutrients and fertilizers;
- Periodic checking of water nutrient solution to analyze deficiencies or toxicities;
- Aminoacid-based nutrients allow stimulation of plants after biotic and abiotic stress period.

(Pérez-Urrestarazu and Urrestarazu (2018)

There are three main types of fertilization can be found (Live Wall; figure 2.13):

- **Automatic Fertilization;**
- **Manual Granular Fertilizer;**
- **Manual Liquid Fertilizer.**

Automatic Fertilization is composed of a fertilizer injector, which is fixed into the irrigation system and distributes nutrients equally into the living wall (Live Wall). According to Live Wall, automatic fertilization controls the dose necessary for fertilization and reduces potential expenses or overdoses. Fertilization is used with each irrigation cycle and fully controlled by automated system.

Manual Granular Fertilizer is used for manual fertilization and composed of nutritive granules that used once annually (Live Wall). Based on LiveWall, one annual application of granular fertilizer is sufficient for plants to grow properly. Teaspoon can be used to distribute fertilizer equally across the soil surface (Live Wall). The dosage will depend on the size of the indoor living wall, density of plants, spacing, and the irrigation system. Consequently, small indoor living walls will require less fertilizer and a big one twice as much as small one.

Fertilization Options	Irrigation Method		
	Hand Watered (small indoor walls only)	Drip Emitters	Spray Nozzles
Automatic via Liquid Fertilizer Injector	NO	✓	✓
Top-Dressed with Granular Controlled Release Fertilizer	✓	NO	✓
Manually Watered with Liquid Plant Food	✓	NO *possible*, but impractical	NO *possible*, but impractical

Figure 2.13: Fertilization Options. LiveWall. (2020, June 04). How do I fertilize my green wall? Retrieved August 05, 2020, from https://livewall.com/faq-items/how-to-fertilize-a-living-wall/

Manual Liquid Fertilizer is used for living walls that do not have automatic fertigation system (LiveWall). According to LiveWall, Manual Liquid Fertilizer should be used every six to twelve months according to plants species, living wall size, irrigation system and density of plants. To apply liquid fertilizer evenly, a watering can or hose can be used (Live Wall).

2.4. PLANT SPECIES FOR FOOD GROWING

When planning a living wall installation, it is important to examine what living wall structure and plant species pattern will best suit the specific indoor environment. Therefore, it is necessary to identify plant species that have root spread and height features that will not damage the wall structure (Fowdar et al., 2017). Users should understand the mechanisms of living walls and horticulture to choose the most suitable space with proper light, water, humidity and temperature conditions. Different categories of plants require specific adjustment and grows in a variety of growth patterns according to such adjustments (Pradhan et al., 2018; figure 2.14).

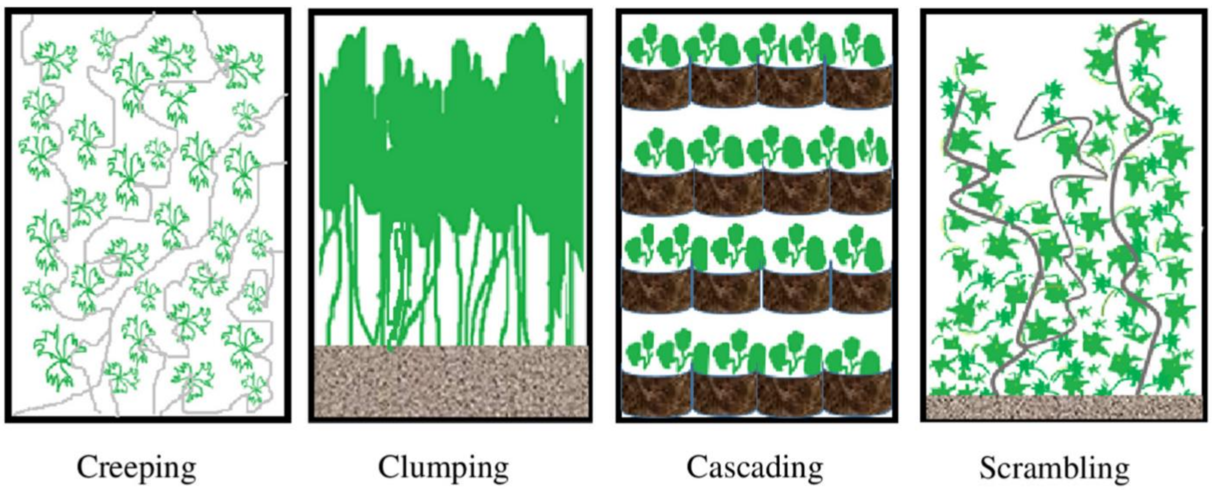


Figure 2.14: Types of Growth Patterns of Plants in Living Wall. Pradhan, S., Al-Ghamdi, S. G., & Mackey, H. R. (2018). Greywater recycling in buildings using living walls and green roofs: A review of the applicability and challenges. Science of The Total Environment, 652, 330-344.

Creeping and scrambling patterns are suitable for single planted beds at the base including supportive structures for consistent and direct growth (Pradhan et al., 2018; figure 2.14.). On the other hand, **clumping and cascading** patterns require modular configurations to provide consistent coverage of wall areas (Pradhan et al., 2018; figure 2.14.).

When making a selection of plants, one should determine what plants (including vegetables, fruits and herbs) will be suitable to grow vertically and in an indoor context. The verticality of the growing media (figure 2.29) where plants grow perpendicular differs from regular agricultural methods and thus, requires special attention to the selection of plants (Jørgensen et al., 2018).

2.4.1. Plants Selection

The weight of the plants plays an important factor in the selection of plants. The optimal choice would be lightweight species. During the selection process, users should think, in advance, about the rate of plant growth, nutrient requirements and sensitivity to local indoor context such as temperature, moisture, height and shade. Proper choice of plant species guarantees the survival and prosperous stability of food production. LWS can be planted with various plants species which are selected to specific context. According to Sarkar (2018), living walls can take three applications: the first one being **a separate structure or stand-alone composition**, while the second one can be designed as a **room divider**, and last one being the placement of LWS **against a wall or on already existing wall**. During the work, users may refer to the service supplier who will recommend suitable plant species for their exact location. Plants can be chosen based on preference towards single species or a combination of species, such as mixed groups. The selection of plants for indoor and outdoor purposes varies and thus requires specific identification of indoor suitable plants.

Figure 2.15: Edible Living Wall Vegetables (types were taken from: Edibles. (n.d.). Retrieved from https://livewall.com/plant-selection/edibles/)

According to Sarkar (2018), some of the suitable plants for indoor decorating and air purification purposes growing are the following (figure 2.19):

- **Epipremnun aureum** (Australian Native Monstera): do not require high maintenance, but can be toxic to animals;

- **Aeschynanthus** (Lipstick Plant): suitable for warm and humid indoor microclimate. Grows well with moist soil and need great levels of light;
- **Hoya carnosa** (wax flower): perfect choice for small living wall projects. Can be creeped along walls or other objects, thus helping to create flexibility in design;
- **Adiantum aethiopicum** (maidenhair fern): requires a large amount of water supply and nutrients; can be placed on the edges of LWS or be composed of scattered patterns;
- **Acacia cognata** (limelight bower wattle): requires good drainage management, but can survive with a little amount of water in cold indoor conditions;
- **Climbing vines:** have natural tendency to climb at vertical surfaces, requires high amount of light;
- **Herbs and Veggies:** sprouts, lettuce, herbs, spinach, peas, lavender and rosemary.

Based on Sarkar (2018), although most types of vegetables are suitable to grow in containers can be accommodated in living wall system, some vegetables and fruits may work better than others (figure 2.15-2.17).

Figure 2.16: Edible Living Wall Greens and Berries (types were taken from: Edibles. (n.d.). Retrieved from https://livewall.com/plant-selection/edibles/)

Figure 2.17: Edible Living Wall Herbs (types were taken from: Edibles. (n.d.). Retrieved from https://livewall.com/plant-selection/edibles/)

Figure 2.18: An Example of Indoor Living Wall. Winick, K., & Winick, K. (2019, January 25). Vertical Gardens Are the Perfect Small Space Solution for Plant Lovers. Retrieved from https://www.marthastewart.com/1535870/vertical-garden-how-to

Figure 2.19: Suitable Plants Species for Indoor Decoration and Air Purification Purposes. Mobilane. (n.d.). Bespoke Green Wall: Bespoke Living Wall: Mobilane UK Live Panel. Retrieved from https://www.mobilane.com/en/products/livepanel/

2.4.2. Plants Compatibility

The number of species grown on a single living wall will create root competition among different species. The competition of plants can take two types (Jørgensen et al., 2018):

1. **Intraspecific:** the competition of plants among same species (Jørgensen et al., 2018);
2. **Interspecific:** the competition of plants among different species (Jørgensen et al., 2018).

The use of specific root growth strategies such as **strong avoidance or aggressive root growth strategy** (de Kroon, 2007) can help create little to no response to competition (Maina et al., 2002; Semchenko et al., 2007). By creating less or no competition, plants will not invest their own resources and nutrients to the development of competing plants. The response, which plants give to the strategy, characterizes the natural habitat that it is adapted to; plants suitable for dry and shallow soils may use a root system that is less compatible with deep soils (Poot, Lambers, 2008; Renton et al., 2012), while species that are more suitable to the density of plants have methods to assist in a coexisting environment (de Kroon et al., 2012; Mommer et al., 2011).

According to Jørgensen et al. (2014), the compatibility and well-developed root strategy, in response to competition among species, will define its suitability for indoor living wall use. It is important to understand that the selection of plants should be based not on aesthetic effect or user preference, but on their ability to coexist in a mixed plant society. Jørgensen et al. (2018) proposed the following hypothesis regarding plant compatibility and root competition:

- Different types of plants will result in the use of different methods and reactions to root competition including aggressive or avoidance root strategies;
- Root growth will be characterized by the mix of plants and its vertical context;
- The absorption of nutrients from competing plants in the same ecosystem will be determined by root competition and their position of plant media from other plants as well.

2.5. MAINTENANCE

Besides having a well-developed living wall system, the most decisive factor that will enable a successfully implemented wall is on-going maintenance. According to Mathew and Salot (2014), both hydroponic and cellular living wall systems have life expectancy of fifteen to twenty-five years and as a result, will require replacement. The better the maintenance provided to the care of living wall, the less likely there will be a need for replacement and additional lifecycle costs. The automation of basic living wall needs, such as light, water, and nutrients, allows the growth of healthy plants and in consequence reduces maintenance demand (Sharma, 2015). Generally, plants are irrigated by an automatic system with prepared vertical and horizontal pipes behind the soil where water is equally distributed to the plants (Dunnett, Kingsbury, 2008).

During the life cycle of a living wall, the user should periodically study the "working process" of living walls and plant health to make sure that their living wall and all its components were successfully integrated into the indoor environment. Generally, living walls with highly nutritive vegetation will require more maintenance compared to living walls with vegetation that have evolved from less nutritive or poor environments (Sharp et al., 2008). The level of required maintenance will also depend on which plant was chosen and its level of flourishing. To be prepared for necessary allocation of maintenance time, all issues should be discussed and developed with the user or client in the early stages of design to ensure that all components of LWS and requirements were addressed.

Maintenance can be subdivided into two processes (Giordano et al., 2017):

1. **Routine maintenance:** includes control of the irrigation system, vegetation growth check, examination of harvest and in-service control of materials and components of LWS (Giordano et al., 2017);
2. **Special maintenance** (subsequent maintenance): reparation of irrigation system, components and anti-parasitic treatments (Giordano et al., 2017);

2.5.1. Moisture

The presence of living walls in indoor environments directly contribute to bio-protective moisture levels, whereas self-generating humid microclimate helps to sustain proper plant health (Gunawardena, Steemers, 2019). It has been conducted that plants increase indoor humidity levels by releasing moisture and consequently improving the level of indoor comfort (Aydogan, Montoya, 2011).

2.6. LIGHT

Despite the fact that direct natural lightning can deliver more than 100-1000 lux, although 900 lux is sufficient for some species of plants, it is important to develop a periodic lighting system suitable for all plants according to their needs (Sharma, 2015). Lighting system is required for prosperous plant development. Taking into account that different species have a higher demand for light than others, the selection of species and their compatibility should be studied beforehand. For instance, a single living wall should only be composed of plants that have the same demand level. Otherwise, some plants will experience difficulties of proliferation and will not bring harvest as expected. Artificial indoor light is required even for the least light-demanding plants to grow and depends on the amount of natural light. Special low-energy fixtures can be fixed to provide extra light. The presence of artificial lighting should be considered not only to aid plant survival and growth but also to provide an aesthetic effect.

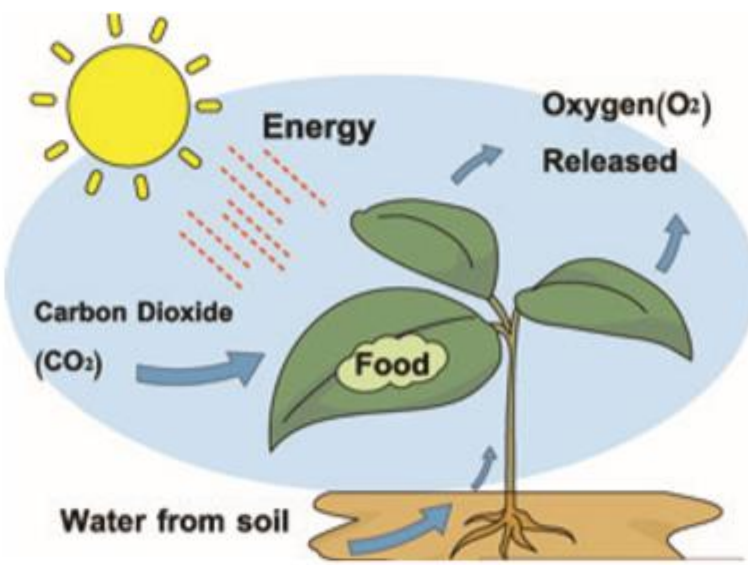


Figure 2.20: Plants Photosynthesis. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

According to Jain and Janakiram (2016), one of the suitable sources of artificial light is the metal halide that produces the necessary amount of light that distributes equally as a wave-lengths system. Based on Sarkar's study (2018), to provide a long-life span, plants should be subdivided into three groups according to their level of light demand:

1. **Group 1:** plants species suitable to grow under limited amount of light (700-1500 lux);
2. **Group 2:** plants species needing an average light context (1500-3000 lux);
3. **Group 3:** plants species requiring a well-lit sunny location (3000 lux and over).

2.6.1. Natural light

Compared to artificial sources of light where there is a need to adjust to the necessary amount of light, sunlight has a much wider color spectrum (figure 2.21) of light including infrared and ultraviolet. Commonly, indoor environments do not have as wide of a color range as outdoor spaces where excessive heat can easily damage plants. Despite this, it is important to develop qualified lighting system for successful plant growth.

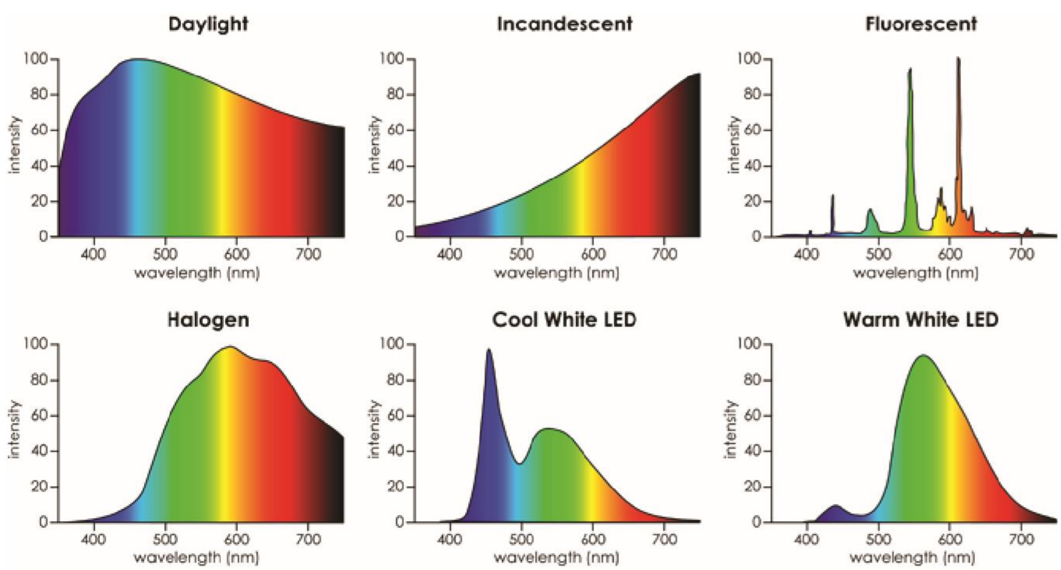


Figure 2.21: Color Spectrum Comparison of Natural Light and Artificial Sources of Light. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

2.6.2. Artificial Indoor Lighting

In spaces with a low level of light or no light, it is crucial to develop artificial indoor lighting according to light intensity and color temperature. Artificial indoor lighting should include the balance development of quality, intensity and photoperiod. According to Egea et al. (2014), the **quality of light** is defined as a special composition of lighting source where plants absorb an equal amount of light. Different species require different wavelengths for their photosynthesis, where blue and red color indicate an absorption by chlorophylls (Hopkins, 1999; Pinho et al., 2012). The distance from lighting sources can be decreased with an increase of **light intensity** that refers to the amount of light absorbed by plants. Based on Niinemets (2006), the amount of needed light will depend on the selection of species. For instance, some plants refer to shade-tolerant species and they can develop under low lighting conditions. Photoperiod is the lasting of species with daily exposure to light and is considered to be an important factor of growth development (Mortensen, Grimstad, 1990; Mortensen, Gislerod, 1999; Mattson, Erwin, 2005).

The most common sources of artificial lighting are the following:

1. **Incandescent;**
2. **Fluorescent;**
3. **High-intensity discharge lamps (metal halide and high-pressure sodium);**
4. **Light-emitting diodes;**
5. **Halogen bulbs.**

Incandescent lamps (IL) are considered the most affordable type of lighting, but have low electricity efficiency with an active radiation spectrum of 400-700mm and the total power input (Thimijan, Heins, 1983; figure 2.22). Additionally, they have low light emission, short lifetime span and unstable radiation region in blue color. However, they can still be used for plants that need red or far-red radiation (Pinho et al., 2012).

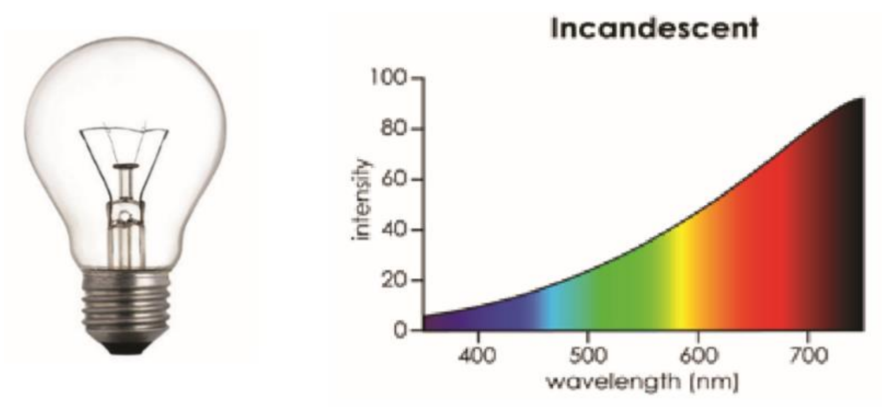


Figure 2.22: Incandescent Lamp and Color Temperature. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

Fluorescence lamps have a media lighting efficiency between Incandescent and high-intensity discharge lamps (figure 2.23). The duration is usually the same as for metal halide lamps. One of the advantages of Fluorescence lamps (FL) is the range selection from cool inexpensive white lamps to full-spectrum lamps for supplementary or replacement purposes (Mortensen, Grimstad, 1990; Mortensen, Gislerod, 1999; Mattson, Erwin, 2005). Metal halide lamps have one of the greatest lighting efficiencies and has a longer duration than Incandescent lamps.

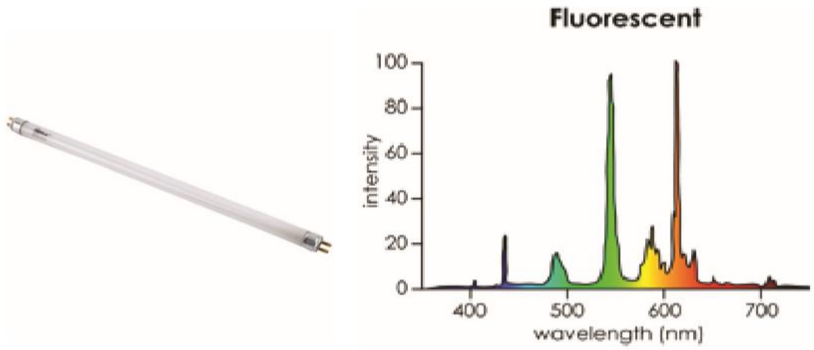


Figure 2.23: Fluorescent Tube and Color Temperature. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

High-pressure sodium lamps (HPS) have a great amount of light emission, high electricity efficiency and long duration. One of the drawbacks is the low spectrum of blue light and thus can only be applicable as an extra source of light or in combination with other lamps (Wheeler et al., 1991; Mortensen, Fjeld, 1998).

Light-emitting diodes are the least affordable sources of light. On the other hand, they are long lasting and have low radiant heat output along with a great flexibility and potential adjustment to necessary spectral emission (Morrow, 2008; Yeh, Chung, 2009; figure 2.24).

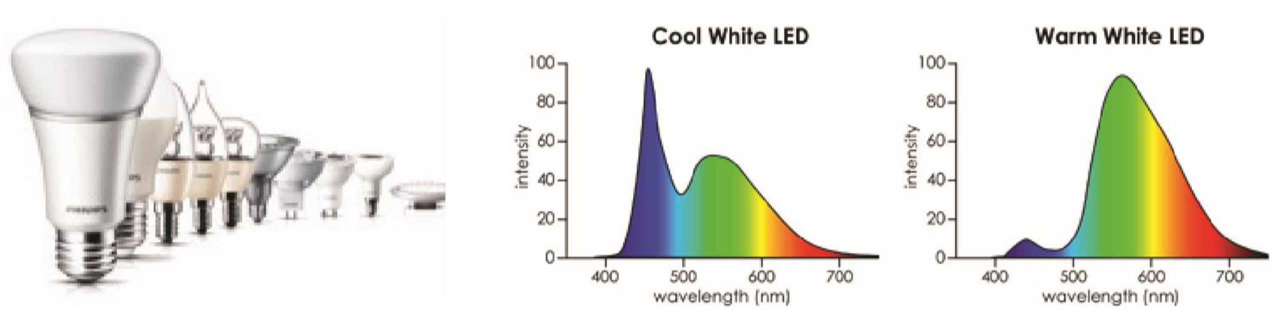


Figure 2.24: Light Emitting Diodes and Color Temperature. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

Halogen bulbs produce a clean white color with an average temperature of 3200K (figure 2.25). Comparing to incandescent light, halogen bulbs are more efficient and more affordable including its average life span of 2000-4000 hours and high CRI levels (Westerduin).

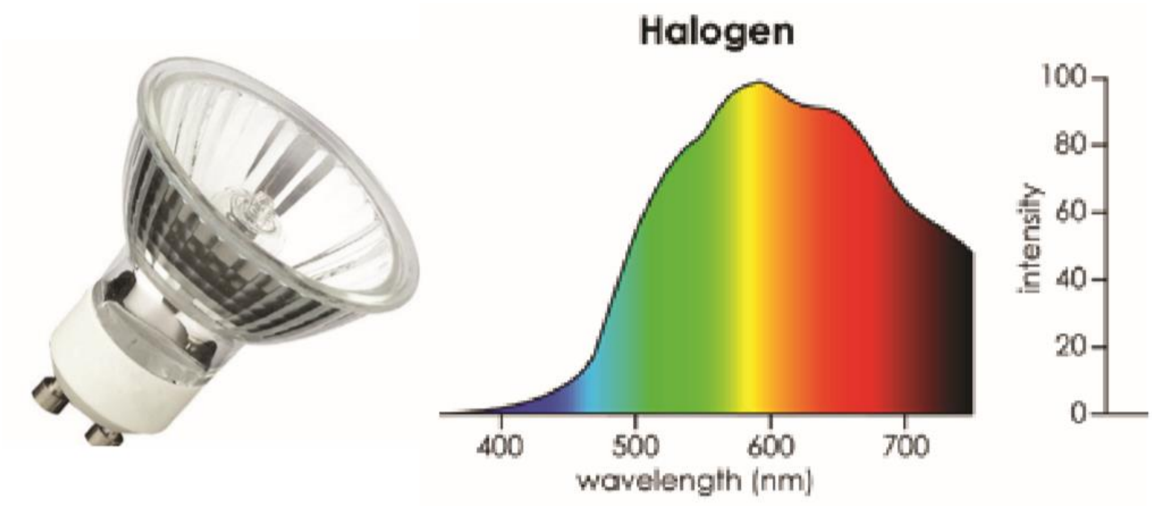


Figure 2.25: Halogen Bulbs and Color Temperature. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

2.6.2.1. Light Intensity

Light intensity is defined as the strength of light and the quantity of lighting sources used with its proximity to the growing media. It refers to the total amount of light as well as the degree of brightness that the lighting source emits. According to Westerduin, light intensity is generally measured in foot-candles and lux and thus, can be easily identified with a shelf light meter. Based on ANS Global, photosynthesis of plants requires at least 1000 lux intensity, while specific plants may need higher levels of 2500 lux. Outdoor natural light usually reaches up to 30,000 lux (ANS Global). Therefore, it will be inappropriate to provide the same illumination levels for indoor spaces since minimum light intensity of 250 FC is required for indoor living walls (ANS Global). The intensity of light should be determined in advance, at the stage of plant selection, in order to provide proper light needs.

2.6.2.2. Light Color Temperature

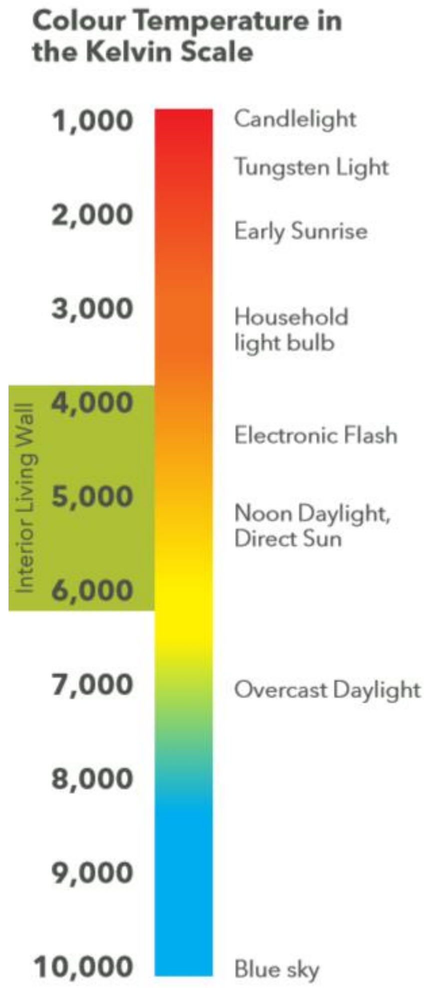


Figure 2.26: Color Temperature and Appropriate Interior Living Wall Level. ANS Global. ANS Global Brochure 2020. Retrieved from https://www.ansgroupglobal.com/living-wall/technical

The color of light we see in daily life is composed of a range of colors where each is determined by wavelengths. Long wavelengths for the red and orange spectrum have less energy than shorter wavelengths for the purple and blue color spectrum that have a high energy output. It is worth mentioning that excessive heat (infrared) or ultraviolet (UV) radiation can damage plants resulting in dry leaves and bleached spots from the destruction of chlorophyll synthesis (Westerduin).

Light color temperature is measured in Kelvin (K) (figure 2.26). Natural lighting provides a full spectrum of color temperature. Thus, different plants will receive the same light balance. However, indoor living walls require the adjustment of color temperature according to the specific species (figure 2.27). The color temperature will determine the future of the plants and their ability to develop leaves, stems, and flowers (ANS Global). The prosperity of flowers is especially important for the production of food. The color of blue over 5,000K allows the growth of good leaf and stems, while the red and orange color between 2,700-3,000K promotes flowering (ANS Global).

According to ANS Global, the success of a living wall is guaranteed if the color temperature is within the range of 4,500K to 6,000K.

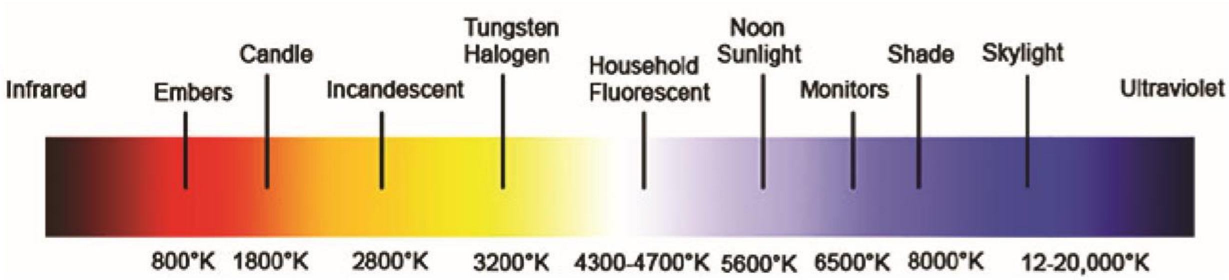


Figure 2.27: Scale Showing Different Light Sources and their Approximate Temperature. Westerduin, E. The Ultimate Guide to Living Green Wall Lighting. Retrieved from https://www.newprocontainers.com/blog/resources/the-ultimate-guide-to-living-green-wall-lighting/

2.6.3. Light Duration and Photoperiodism

PHOTOPERIOD	EDIBLE	ORNAMENTAL
qualitative (obligate) long-day	chicory, cilantro, dill, endive, oregano, spinach	bachelor's buttons, fuchsia, gazania, lobelia, monkey flower, sweet pea, strawflower, certain hybrid petunias, such as 'Purple Wave'
quantitative (facultative) long-day	beets, carrots, chard, lettuce, mint, peas, thyme	ageratum, calendula, dianthus, pansy, grandiflora petunia, snapdragon, salvia, sunflower, viola
qualitative (obligate) short-day	cannabis, common bean, potatoes, sweet corn, sweet potatoes, strawberries; onions and garlic for bulbing	African marigold, fuchsia, hyacinth bean vine, poinsettia
quantitative (facultative) short-day	potatoes, sweet corn, sweet potatoes, yams for root development	cosmos, globe amaranth, moonflower, morning glory, zinnia
day-neutral	eggplant, peppers, tomatoes	amaranthus, centranthus, cleome, stock, verbascum

Figure 2.28: Examples of Photoperiodic Plants. Halleck, L. F. (2018). Gardening under lights: The complete guide for indoor growers. Timber Press.

Different species will require individual light duration. According to Westerduin, plants need 12-20 hours of light, while some species demand a few hours in darkness daily (figure 2.28).

Photoperiodism is defined as the time of "rest" for plants when no artificial lightning or other types of lighting sources are used. ANS Global recommends designing a lighting system that will allow one to control the illumination levels and switch-off photosynthesis when needed.

2.7. INSTALLATION

The initial preparation of indoor living wall begins with a study of the indoor environment including temperature, light, moisture and the potential location itself. Investigating such elements will frame the context and thus, determines suitable species based on indoor conditions, aesthetic, preferences and availability (Sharma, 2015).

First of all, users should identify what type of supporting structure will be used, what irrigation system will be most suitable for this supporting structure, and be prepared for the irrigation process itself. The surface will only be ready for plantation after the completion of the technical details such as mounting the felt and the integration of the drip-tube (Sharma, 2015).

To begin the installation and design of LWS, one should make a plan of the main components and factors such as location, indoor climate, availability of materials, supporting structures and irrigation methods. The plan for further installation would look as following (Jain, Janakiram, 2016):

1. **Structural support** (the equal distribution of load from the media based on chosen materials);
2. **Irrigation system** (the choice of main supplements and nutrients);
3. **Lightning system** (necessary allocation of natural and artificial lighting including the time for photoperiodism);
4. **Waterproofing materials** (to protect the indoor wall from the living wall's moisture);
5. **Plants selection** (the choice between food growing type or a basic aesthetic living wall);
6. **Planting matrix** (organic, such as soil, or inorganic, such as plastic or synthetic fibers).

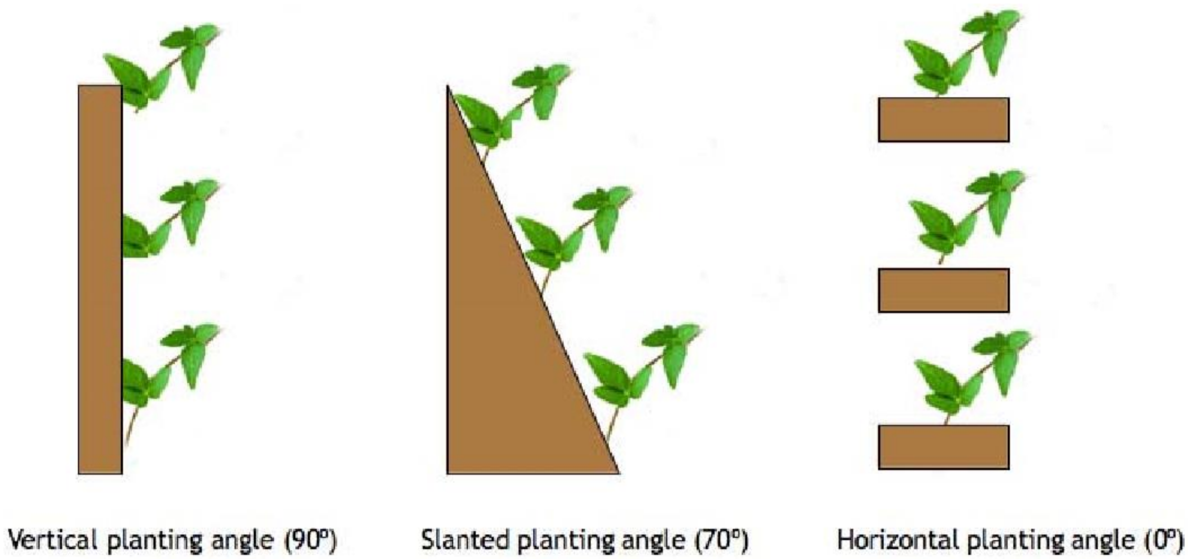


Figure 2.29: Planting Angle Parameters. Stav, Y. (2016). Transfunctional living walls-designing living walls for environmental and social benefits (Doctoral dissertation, Queensland University of Technology).

One of the main benefits of LWS is its flexibility in adapting to a specific context. It can be installed on any surface and almost any location of indoor spaces. The rise of living wall development is a great opportunity to provide dense areas with an affordable, and fresh food source.

During the process of installation, materials are delivered to the construction site where afterwards, the user can mount the system by using a drill and screwdriver to fasten all the components.

2.7.1. Waterproofing

Waterproofing treatment (figure 2.30) is considered an air gap between a living wall system and a wall. This space guarantees the prevention of water movement between the wall and a planting system, as well as prevents growth of mold. During the LWS installation, additional waterproofing operations, such as roller-applied liquid waterproofing treatments and membranes, should be taken into consideration (Carpenter, 2014).

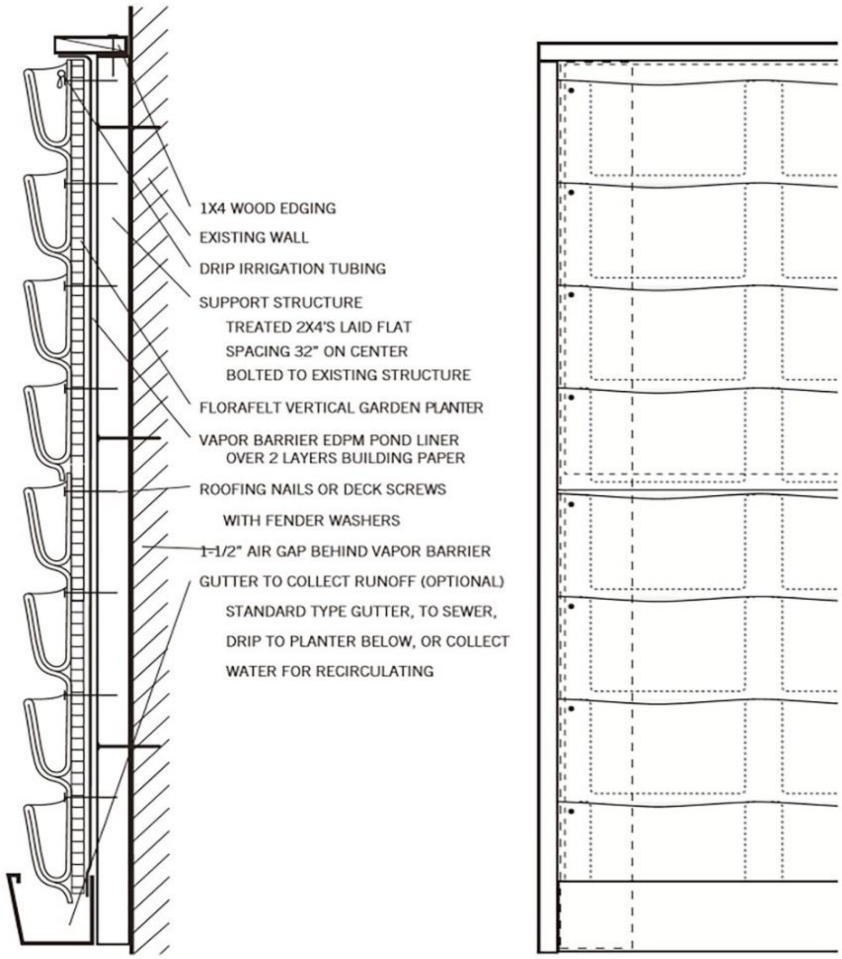


Figure 2.30: Florafelt Wood Framed Vertical Garden. Vapor Barrier. Florafelt Living Wall Systems. (n.d.). Retrieved from https://florafelt.com/

2.7.2. Installation and Maintenance Cost

The cost of living wall installation depends on characteristics and components used for the design of LWS. Despite the fact that living walls have a relatively consistent concept applied to them, every single wall will vary and have individual cost calculations (figure 2.31-2.32). When designing a living wall, the following assessments should be taken into consideration (Sharp et al., 2008):

- The size of LWS project;
- Design services costs;
- The type and material of supporting structure;
- The sophistication of design and customization or standard application of components;
- The location of the wall including following indoor environmental conditions;
- The cost of installation work;

- Availability of materials and LWS components;
- Short- and long-term upkeep;
- Typology and choice of plants;
- Project timeline;
- Type of irrigation, nutrition and drainage system;
- The need of artificial lightning.

Type of Green Facade	Perspective	Category	Cost	Cost Range (€ m^{-2} Facade)	Time Frame
Living wall system	Private and social	Initial	Design	6%–10% of installation cost	One time
			Panels, installation, and transportation	160–450 (€ m^{-2})	One time
			Plant species	25–50	One time
			Irrigation system	25–35	One time
		Maintenance	Pruning and panels adjustment	12–18	Annual
			Irrigation (H2O)	1.0–1.5	Annual
			Panels replacement (5%)	5–8	Annual
			Plant species replacement (10%)	3.5–5.0	Annual
			Pipes replacement (15%)	2–3	Annual
		Disposal	Green layer disposal	180–240	One time (end of lifespan)
	Social	Tax incentives	Tax reduction	Depends on local regulation	One time or annual

Figure 2.31: Private and Social Costs Related to Living Wall System. Rosasco, P. (2018). Economic Benefits and Costs of Vertical Greening Systems. In Nature Based Strategies for Urban and Building Sustainability (pp. 291-306). Butterworth-Heinemann.

Type of VGS	Type of Construction	Results	
		Location	Price
Green facade	Grid system	Europe	40–75 €/m^2
Living wall	Trough planters	Europe	400–600 €/m^2
Living wall	Framed boxes modular living wall	Europe	750–1200 €/m^2
Living wall	Geotextile felt system	Europe	350–750 €/m^2
Living wall	Carrir system	Dubai	288 US$/$m^2$
Green facade	Cable wire	Turkey	34.87 €/m^2
Living wall	Geotextile felt system	Turkey	415.649 €/m^2
Living wall	Geotextile felt system	Turin, Italy	400 €/m^2

Figure 2.32: Installation Costs. Radić, M., Brković Dodig, M., & Auer, T. (2019). Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits. Sustainability, 11(17), 4579.

2.8. AIR PURIFICATION

The integration of living walls inside residential properties, whether it is designed for air purification or food growing purposes, improves the efficiency of indoor spaces and brings up ecological and environmental benefits to its users. Besides its aesthetic value, living walls offer numerous positive impacts on the indoor comfort and well-being of users. According to Sutton (2014), living walls play an important role in the development of a livable environment. For instance, it has been demonstrated with the study involving hospital patients that indoor greening provides psychological and health advantages, including a faster recovery rate of patients and higher resistance to diseases (Sutton, 2014).

2.8.1. Air Pollutants

An indoor vegetated living wall will help clean the air and remove airborne pollutants such as toluene, ethyl benzene, xylene, and other volatile organic particles (Sharma, 2015). As stated by Susorova (2015), indoor air is composed of building materials, pollutants, and various volatile organic, chemical and toxic compounds that in consequence, negatively influence our health. Indoor vegetated living wall with at least 5cm thickness composed of pollutant-regarding plants is a good way to create a biofilter for the indoor context that could potentially remove up to 80% of the formaldehyde, 50% of the toluene, and 10% of the trichloroethylene pollutants (Susorova, 2015).

Chemical Emission Sources	Formaldehyde	Xylene/Toluene	Benzene	TCE
Adhesive Materials	x	x	x	-
Biologic Substances	-	x	-	-
Carpets and Fabrics	x	-	-	-
Bonding Elements	x	x	x	-
Interior Coating	x	x	x	-
Cosmetic Products	-	-	-	-
Printers and Printed Materials	-	x	x	x
Particle Boar	x	x	x	-
Plywood	x	-	-	-
Painting and Varnish	x	x	x	-
Tobacco Smoke	x	-	x	-

TCE: Trichloroethylene.

Figure 2.33: Interior Emission Sources. Yildirim, N. N. (2018). THE EFFECTS OF LIVING WALLS ON USERS AT THE COMMERCIAL INTERIORS. Journal of Strategic and International Studies, 13(1), 95.

The World Health Organization (WHO) states that for the average person over 90% of time is spent indoors, but nearly nobody realizes what indoor air consists of. Indoor air is composed of outdoor pollutants such as air, soil, structural materials, and water. As well, it consists of indoor contaminants such as furniture, machines, appliances and cleaning equipment (Yildirim, 2018). These resources consist of particles, substances and materials that constantly harm health conditions (figure 2.33).

According to National Aeronautics Space Administration (NASA), air contamination issues, such as 107 Volatile Organic Compounds (synthetic particles), were identified in the 1970s inside the spacecraft. Subsequently, NASA developed a study and confirmed that living organisms, such as plants, are able to rid the air of contamination (Wolverton et al., 1989; Yildirim, 2018).

Based on Environmental Protection Agency, people who live and work in an environment of man-made materials inhale more than 300 pollutants every day (EPA, 2009). Being indoors over 90% of the time (American Physical Society, 2008) causes the absorption of indoor contamination composed of toxic fumes such as formaldehyde, VOCs, trichloroethylene, carbon monoxide, benzene, toluene, xylene and many others (Wolverton, 1996). It is essential to note that some specific plants are more efficient in air purification than others (figure 2.34). According to Weinmaster (2009), studies have shown that contaminants such as formaldehyde and carbon monoxide can be cleared up by plants leaves, while VOCs, TCE, benzene, toluene, xylene can be removed by plants roots or microorganisms around the roots (Wolverton et al., 1989).

Indoor pollutant(s)	**Green wall plants**
Formaldehyde (CH_2O)	Peace lily (*Spathiphyllum* sp.) Boston fern (*Nephrolepis exaltata* "Bostoniensis") English ivy (*Hedera helix*)
Carbon Monoxide (CO)	Spider plant (*Chlorophytum comosum*) Janet Craig Dracaena (*Dracaena deremensis* "Janet Craig") Ficus *sp.*
Volatile Organic Compounds (VOCs)	Golden Pothos (*Scindapsus aures*) Devil's ivy (*Epipremnum aureum*) Philodendron *sp.*
Trichloroethylene (TCE)	Mother-in-law's tongue (*Sansevieria trifasciata* "Laurentii") Chrysanthemum (*Chrysantheium morifolium*) Dracaena *sp.*
Benzene (C_6H_6) / Toluene (C_7H_8) / Xylene (C_8H_{10})	Kimberly Queen Fern (*Nephrolepis obliterata*) Orchid sp. (*Phalenopsis sp.*) Dieffenbachia *sp.*

Figure 2.34: Common Indoor Pollutants and Plant Species that are Best at Removing them. Wolverton, B. C. (1996). Eco Friendly Houseplants, Weidenfeld and Nicolson, London. Released in US as How to Grow Fresh Air.

2.8.2. Allergies and Diseases

The contamination of indoor air and its toxicity increases the probability of respiratory and cardiovascular diseases. According to ANS Global, children exposed to polluted air are most likely to have lung dysfunction and asthma disorders when they get older. “Pollution is much more than an environmental challenge – it is a profound and pervasive threat that affects many aspects of human health and wellbeing” (Professor Philip Landrigan, ANS Global). According to Fell (2011), the existence of indoor living wall can result in better productivity and general health improvement. It has been conducted that the use of living walls for air purification purposes reduces coughs up to 30% and dry throat up to 20% (Ottelé et al., 2011).

At the stage of plant selection, it is necessary to examine the presence of allergens associated with specific species, pollen and other potential allergic reagents. Allergic reactions might occur when plants start to thrive and produce pollen or smell. Hence, plants selection should be conducted carefully in order to avoid health and allergy issues.

Furthermore, besides experiments conducted by NASA, some researchers have revealed that the interconnection of plants in houses reduces diastolic blood pressure and heart rate as well, thus offering psychological and environmental benefits.

2.8.3. Indoor Living Wall Purification

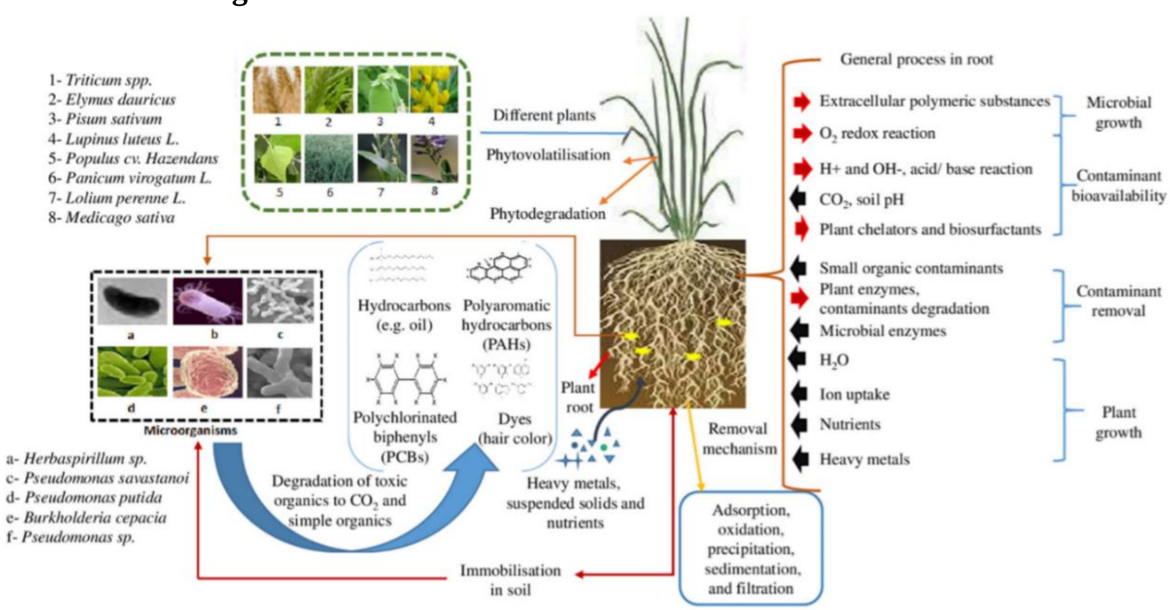


Figure 2.35: The Removal Mechanisms of Plants, Media and Microbes. Sharma, P. (2015). Vertical gardens. An innovative element of green building technology.

Based on Pugh et al. (2012), indoor living walls can moisturize and oxygenate air according to selected plant species, enhance air quality by collecting dust particles, and absorb pollutants such as formaldehyde which is most common in indoor environments (figure 2.35). According to Sharma (2015), most North Americans spend 80-90% in indoor environment and are under the influence of indoor air circulation system. Living walls are able to filter pollutants out of indoor air flushed from traditional ventilation (Sharp et al., 2008). Poor indoor air quality is mostly composed of outdoor polluted air in combination with additional indoor pollutants and contaminated particles. Based on Soreanu et al. (2013), green components such as roots, micro-organisms, and media assist in biodegradation while leaves absorb toxic gases from the air (figure 2.35). One of the most popular living wall types used for air purification is called an "active living wall" (figure 2.36).

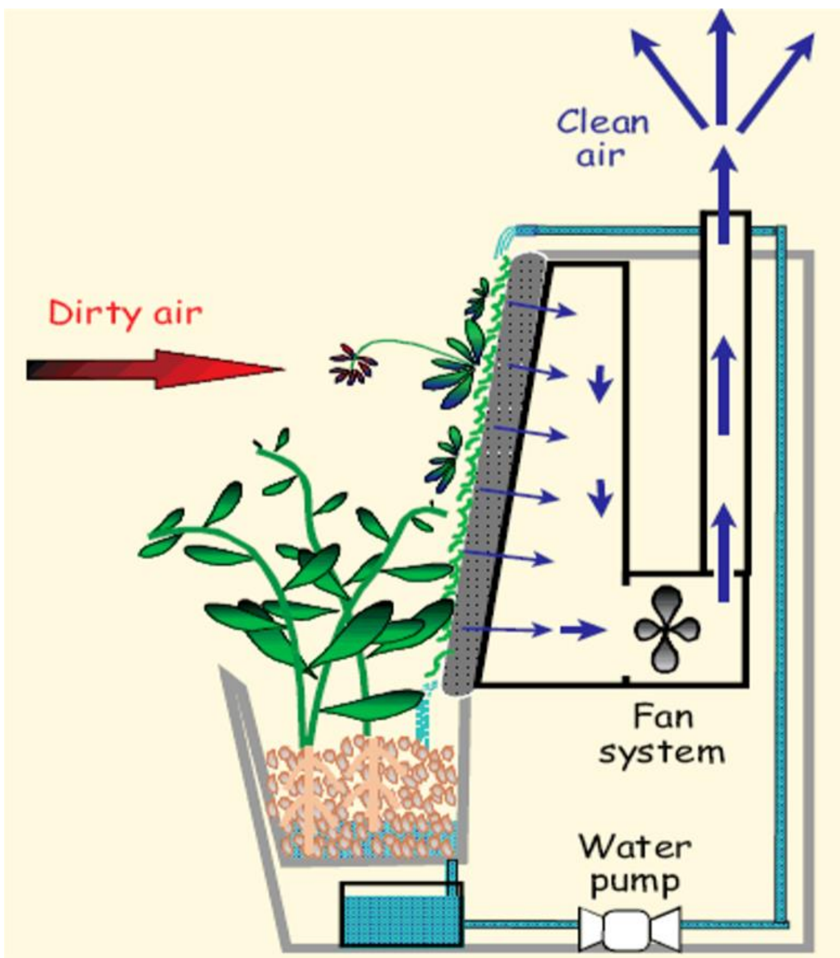


Figure 2.36: The Basic Mechanics of a Biofiltration Wall. Sharp, R., Sable, J., Bertram, F., Mohan, E., & Peck, S. (2008). Introduction to Green Walls: technology, benefits & design. Toronto: Green Roofs for Healthy Cities.

The main purpose of this LWS is to create a bio-filtering system that will filter the air with the assistance of natural air filtration through the plants to emit the flow of clean air. According to Sharp et al. (2008), active living walls are defined as a hydroponic system composed of nutrient water supply which is circulated from a manifold and collected in the bottom of the LWS; roots are connected by two layers of microbe supportive fabric that helps to remove VOCs (volatile organic compounds). In result, active living wall plants produce pure air controlled by the fan and consequently distributed throughout the indoor environment.

2.9. CONCLUSION

The chapter examined the most important technical and design aspects of indoor walls, specifically for food production and air purification purposes. While preparing for the design of indoor living wall, it is crucial to take into account the presented material, details and specifications. The first step is to choose the primary purpose of the living wall, whether you decide to develop an edible living wall, which will produce fresh vegetables and herbs, or a living wall for air purification purposes, which will also contribute to aesthetics of one's place as it is filled with decorative plants. It is necessary to understand the affordability, which will reflect on the choice of automated or manual irrigation, fertilization and drainage systems.

The next chapter will focus on case studies of indoor living walls primarily from the residential sector. Case studies will concentrate on technical information of implemented examples of indoor living walls, including the specification of the irrigation and drainage system, plant selection, lighting sources as well as maintenance and installation information. Case studies will provide step-by-step information on the performance and the benefits of well-designed LWS, which will show how living walls work, what the challenges are, and what be the final result could be. The chapter will illustrate how design process flows into implementation and, include all necessary equipment and technology that was used for the process itself. Case studies will help to form a cost-benefit matrix of living walls, which will explain design, implementation and maintenance expenses as well as short and long-term expenditures. A group of case studies will analyze the current degree and design technologies used for indoor living walls which will examine the perspective and potentiality of LWS.

CHAPTER THREE: CASE STUDIES

3.1. INTRODUCTION

Having examined technical aspects of indoor living walls in Chapter Two, it is time to understand how indoor living walls are implemented in practice in the residential sector. Taking into account the main technical components such as living wall type, supporting structure, waterproofing and growing media, irrigation and drainage system, lighting type, and cost performance, Chapter Three will concentrate on the identification of common ground elements that are fundamental to indoor living wall implementation. The chapter will examine case studies of residential indoor living walls which will provide detailed information, similarities, and distinctions of LWS's integration in an indoor environment. To analyze such case studies, a table of technical aspects will be provided in the fourth chapter, allowing one to explore the reason and the choice of specific elements according to its context and requirements. The case studies will be technically evaluated individually by providing information about the name of the project, its location, year of implementation, name of design firm. It will allow for a clear analysis on the performance of indoor living walls and the choice of components and materials. As well, it will help form an assessment of fundamental components to evaluate advantages and drawbacks of each, later forming the best option for a design suiting the client's preferences, affordability and context requirements.

3.2. METHODOLOGY

In the case studies, the author will analyze the implemented indoor living walls for air purification and food production purposes of residential sectors primarily from North American regions and Europe. They will aim to illustrate technical information and the insertion of indoor living walls in real-life settings. It is necessary to consider which materials have been used as well as cost performance, implementation and maintenance expenses. The main objective of the chapter is to identify the similarities and differences of implemented living walls, its technical components, and what suites best and has a more affordable and accessible index. Case studies will be evaluated separately by providing detailed technical information about irrigation, maintenance and installation process including plans, elevations, and details of LWSs.

In order to analyze the living walls together, a table of main components including location, company, LWS type, supporting system, waterproofing, irrigation and drainage system will be proposed in the beginning of the fourth chapter. This will aid in examining the result of analysis of the chapter that will indicate the common ground elements or the differences of current LWSs implementation practices and its dependence to initial decision-making process.

The chapter includes an analysis of ten design firms that specialize in interior living wall implementation. Backgrounds and design focus' of each firm will be provided in the beginning of each section, identifying the main vision and incentive of indoor living wall development, reflecting on their products and components. Following that, case studies will include detailed drawings such as plans, sections and elevations that will be described and evaluated.

The main focus of the chapter is to evaluate how living walls are currently being used and what components they consist of. The following analysis will determine the distinctions of living wall classifications and its reflection on the choice of materials and elements as well as the overall indoor space improvement.

3.3. CASE STUDIES

3.3.1. GSky Company

GSky is a company that includes living wall specialists who bring nature to residential properties, commercial spaces and indoor public areas. Hal Thorne, the CEO of GSky company, stated that their mission is to enhance the environment by providing psychological, aesthetic and purification benefits (GSky). The company concentrates on delivering living wall systems that fully adapt to the context and its requirements, as well as providing client support on all stages of design and maintenance. GSky Company was founded in 2004, implementing corporate offices in British Columbia (Vancouver), and Florida (Delay Beach), and sales offices in Colorado, California, and Germany (GSky). The GSky system is based on irrigation by low flow drip emitters including the use of recycled materials and a highly efficient drainage system. Currently GSky has installed over 825 living walls in 19 countries representing various functions and designs (GSky).

GSky offers four green wall systems (GSky):

1) The Versa Wall (interior);
2) The Versa Wall XT (exterior);
3) The Pro Wall (exterior);
4) The Basic Wall (exterior).

As per the direction of research, an indoor living wall system, “Versa Wall” prototype, will be studied and analyzed by providing technical information and implemented design project private residence.

Versa Wall System

Versa Living Wall is a system that contains modular trays and is highly adjustable to interior design requirements. The diverse dimensions of modules that can be easily fixed around windows, corners or columns. It is predominantly used in indoor environments for commercial, residential, healthcare and hospitality spaces (figure 3.1). This chapter will evaluate the work of indoor living wall in residential sector in order to indicate how suitable and affordable it can be for indoor residential spaces.

The fundamental components of the Versa Wall System include 4 inch (10cm) pots that can be placed into the system creating diverse patterns as well as a species selection that provides high flexibility for design (GSky). The main advantage of the system is that it does not require ‘repotting', meaning that there will not be additional material expenses and thus, the pots can be used permanently, avoiding potential waste generation (GSky).

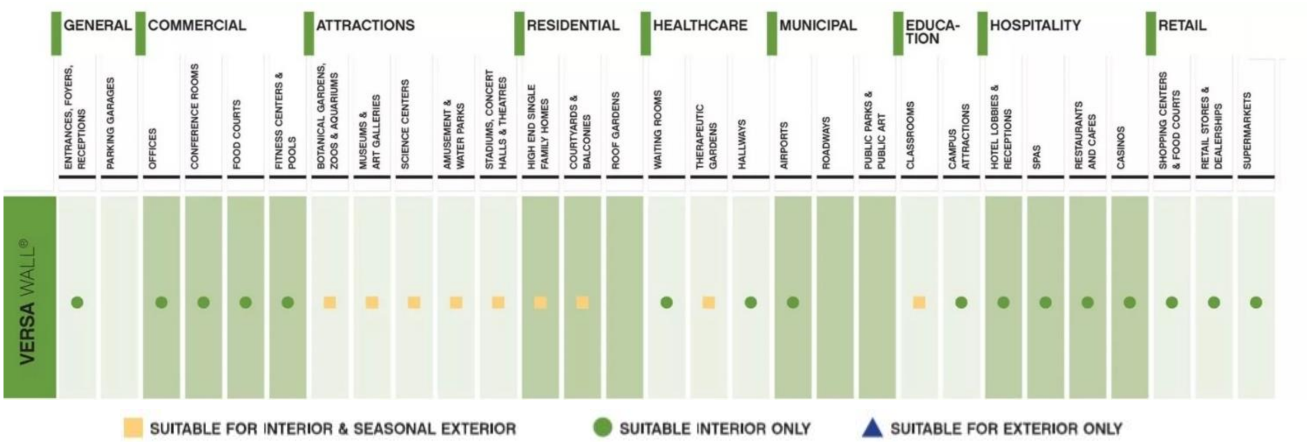


Figure 3.1: Versa Wall Suitability. Versa Wall Install. (2020, March 2). Retrieved from https://gsky.com/versa/install/

The flexibility of the pot system creates a variety of tropical plants combinations, which makes the Versa Wall suitable for any interior environment and client preference. Gsky's main idea was to create eco-friendly, customizable, durable, and cost-efficient indoor living wall systems that will allow for planting addition and design that will suit the taste of each client.

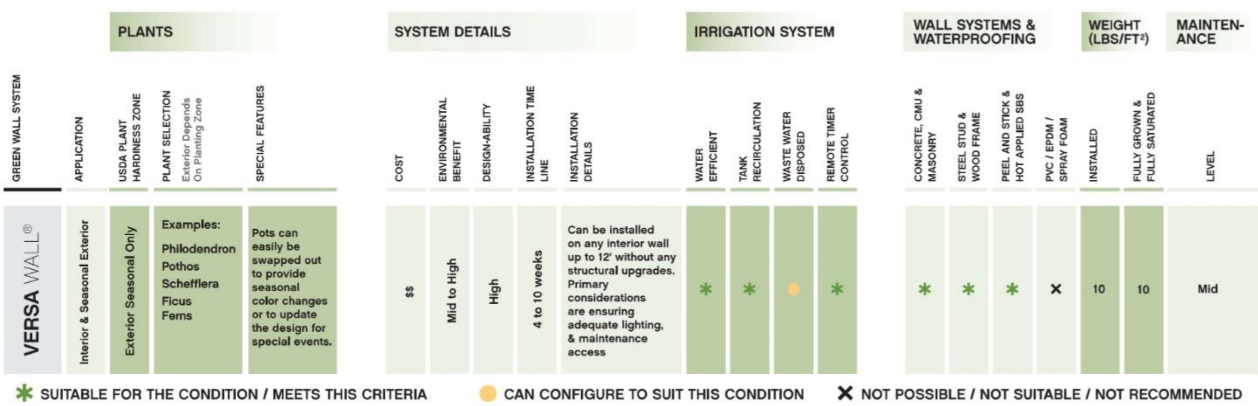


Figure 3.2: Versa Wall System Specification. Versa Wall Install. (2020, March 2). Retrieved from https://gsky.com/versa/install/

The Versa Living Wall can be installed on an interior wall up to 12 feet and will not require additional expenses for upgrades (GSky). However, the life cycle of living wall will depend on appropriate lighting levels, maintenance, humidity and temperature conditions.

Versa Wall has twelve system types which varies from manual to automated watering and irrigation including ICU at Wall/Remote (above and on floor), Tanks at Wall, Hose Water, Remote Tanks, and Hand Water (GSky). This case study will cover Versa Wall Above the Floor/ICU Below Wall VTI-70.

Figure 3.3: Versa Wall Above the Floor/ICU Below Wall VTI-70. Versa Wall CAD & Specs. (2020, March 2). Retrieved from https://gsky.com/versa/cad-specs/

Versa Wall (figure 3.3) represents a self-contained automated system, which guarantees efficient water management and the prevention of soil or water spills. The trays of the Versa Wall system are designed to optimize water consumption through the recirculation of water through the plants and automated pipes that allow further use of the same water (GSky). This system requires less maintenance compared to the Hand Water Versa Wall type. In which case, it is good for people who lack free time or are unable to manage watering and irrigation by hand. Such efficient water system will allow reduction in water consumption and subsequently, will lower monthly water consumption bills due to the fact that exceeding water is used and recirculated for the next watering cycle.

Installation consists of five phases (GSky):

1) **Design.** This stage includes the development of drawings according to design, chosen system, context, and preferences. The first phase is a fundamental process. This process takes 2-4 weeks and it is when all the materials, components and plants species are chosen and then presented through drawings for further work (GSky);
2) **Setup.** The setup phase concentrates on the fabrication of materials including the supporting system, LWS components, containers, as well as the preparation of irrigation and drainage systems;

3) **Plants.** This phase includes the process of pre-growing plants, which is required for all types of Versa Walls;
4) **Hard Material Installation**. This phase usually takes 2-3 days and includes the installation of hard surfaces such as backing, framing, trim, irrigation and lighting equipment. The entire structure should be ready prior to plants' arrival (GSky);
5) **Plants Installation.** When the system, plumbing and irrigation is ready, plants can be installed into the wall. All the components must be fixed beforehand in order to avoid dusty work, which can harm plants This stage takes approximately 2-3 days (longer for large walls) (GSky).

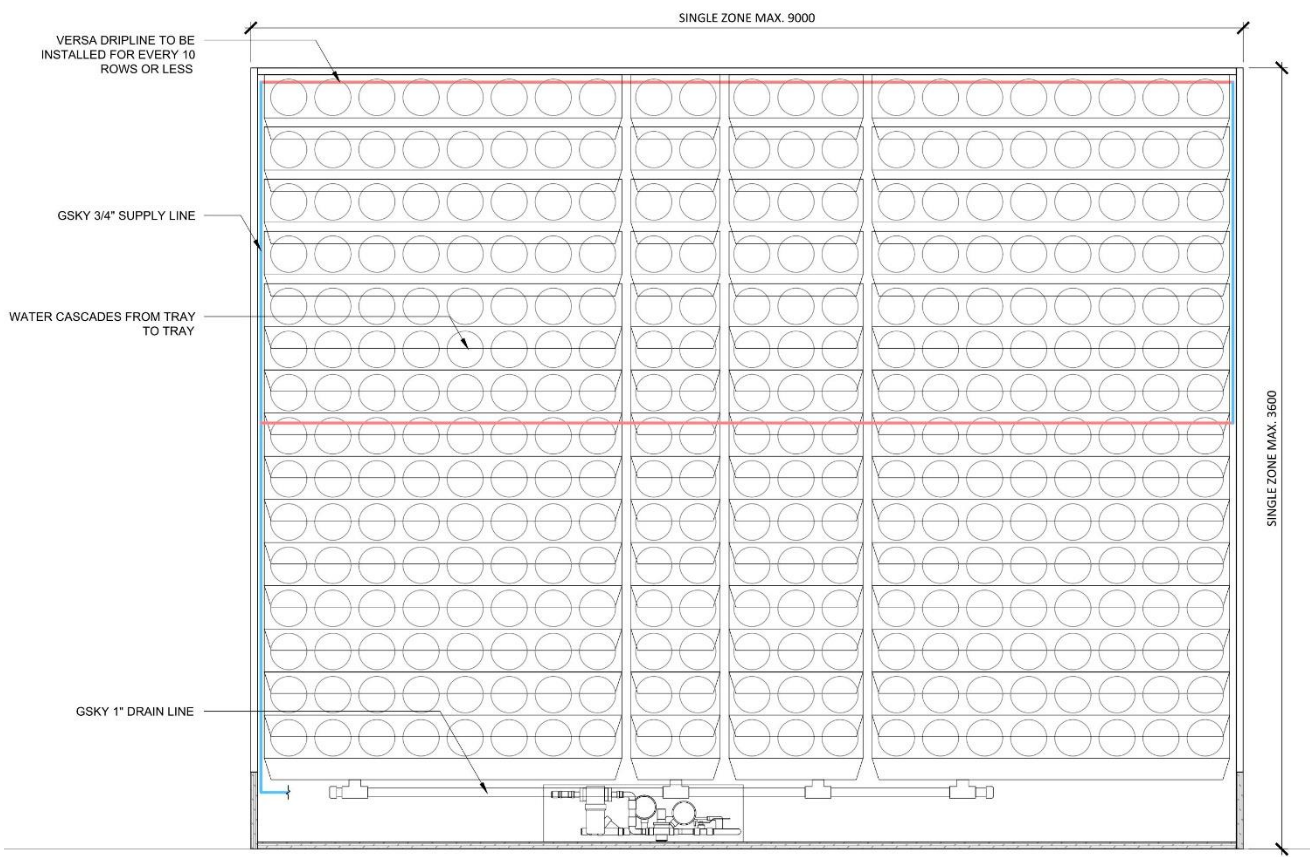


Figure 3.4: Versa Wall Above the Floor/ICU Below Wall VTI-70 Elevation. Versa Wall CAD & Specs. (2020, March 2). Retrieved from https://gsky.com/versa/cad-specs/

The installation of Versa Wall requires plywood backing fixed to the studs and its waterproofing prior to the insertion of trays into the living wall (GSky). Concrete, CMU, wood/metal frame or structural steel are suitable walls for installation of the Versa Wall (GSky). The size of mounted plywood is 3/4", which is fixed to the studs or the wall itself. The main advantage of the Versa Wall is the use of recycled materials such as polypropylene with ABS drain fitting (GSky). The dimensions of trays can vary according to context and design from 2-Pot Trays to 8-Pot trays as shown on figure 3.9.

The irrigation system composed of drip line (different types for 2,3,8 Pot-Tray system), controller including timer, pumps, filter and regulators, fittings, tanks and drainage (direct or recirculating) (GSky).

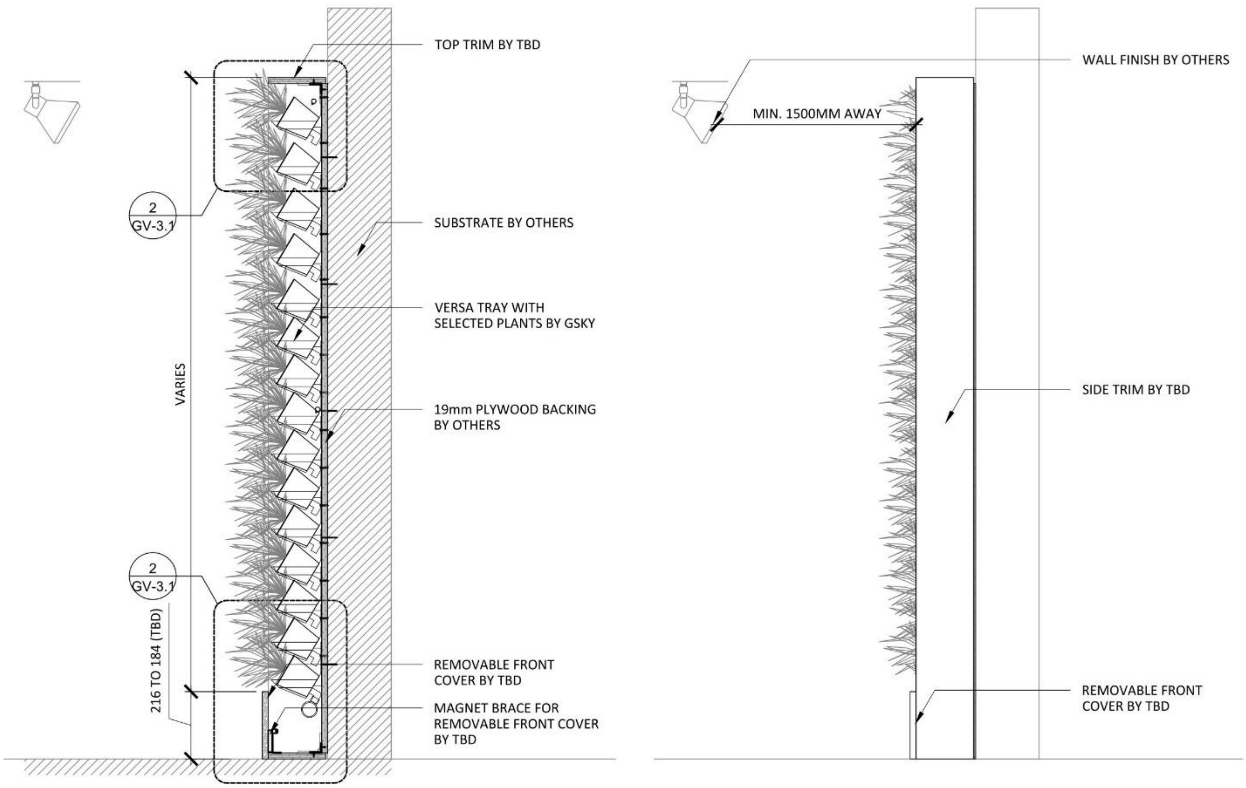


Figure 3.5: Versa Wall Above the Floor/ICU Below Wall VTI-70 Section View (left) and Side View (right).
Versa Wall CAD & Specs. (2020, March 2). Retrieved from https://gsky.com/versa/cad-specs/

Typically, Versa Wall is installed with a recirculating system that consists of tanks where water is collected in the bottom and then send back to the tanks. The recirculation system includes a UV filter that allows water to be re-used for the next watering cycle. Recirculating water supply is directed back into the trays by a water supply pump (GSky).

Lighting is another fundamental aspect of any living wall system that requires the calculation of necessary light temperature level and duration. The level of lighting will depend on the amount of natural light available in the indoor space where the living wall is planned to be installed.

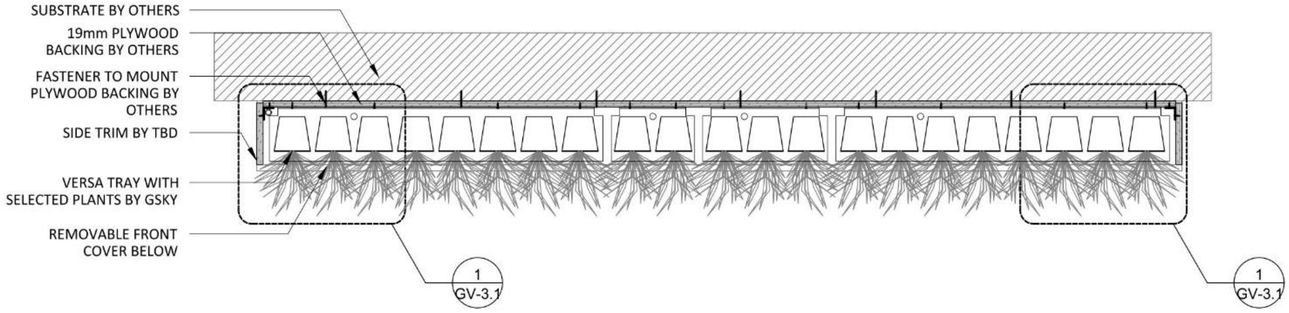


Figure 3.6: Versa Wall Above the Floor/ICU Below Wall VTI-70 Plan. Versa Wall CAD & Specs. (2020, March 2). Retrieved from https://gsky.com/versa/cad-specs/

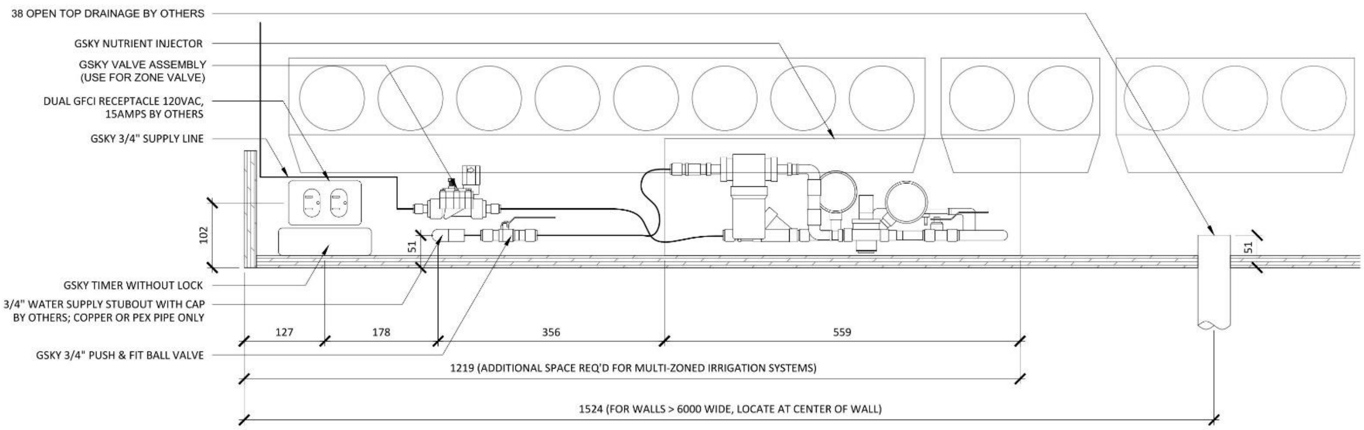


Figure 3.7: Versa Wall Above the Floor/ICU Below Wall VTI-70 Elevation of Irrigation Layout. Versa Wall CAD & Specs. (2020, March 2). Retrieved from https://gsky.com/versa/cad-specs/

GSky recommends using a minimum of 150-foot (1,500 lux) light intensity to allow plants to thrive (GSky). Successful photosynthesis requires the adjustment of colour temperature, 4,500K as stated by GSky, using the Versa Living Wall (GSky). Additionally, GSky stated that 10-12 hours of light including the use of LED or Metal Halide lamps is necessary for the plants on the Versa Wall to thrive (GSky).

Versa Wall consists of trays that are designed to hold water for each individual plant in order to avoid competition among plants. The closed watering system allows no soil and water to spill out which guarantees the exception of structural and material damage. According to GSky, Versa Wall should be watered every 7 to 10 days according to the size of the wall and density of the plants.

The Versa Wall includes the trim, which is used to “hide” technical and mechanical components such as irrigation and drainage systems. There are four trim design types: standard wood trim, custom wood trim, custom metal trim, and recessed (GSky).

GSky developed a program of plant availability, which is suitable for the Versa Wall and can be subdivided into three categories (GSky):

1) **Standard Plants.** It is a long-term durable sector of plants that work well on vertical surfaces. Standard category includes Philodendron Cordatum, Neon Pothos, White Butterfly Nephthytis, Schefflera 'Luseane', and Golden Pothos (GSky);
2) **Accent Plants.** These types of plants are used for creating an accent. They are predominantly used in small quantities and includes Ficus Elastica Burgundy, Pink Syngonium, Silver Satin Pothos, Austral Gem Fern, and Anthurium (GSky);
3) **Color program.** These types of plants are used to integrate colour into the living wall and includes Poinsettias, Bromeliads, and Kalanchoe (GSky).

Once the type of plant has been chosen, a client can select a design option or a pattern if preferred.

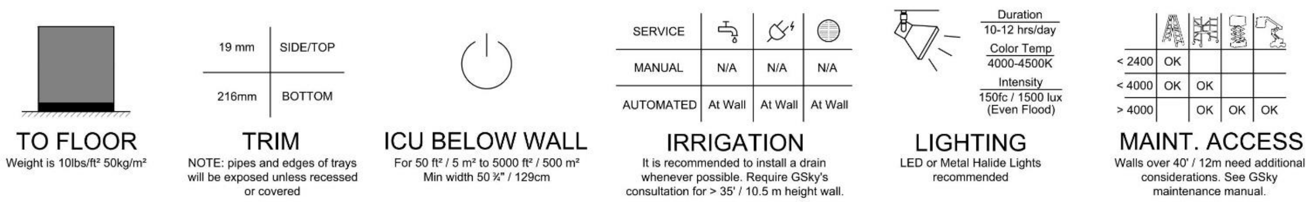


Figure 3.8: Versa Wall Above the Floor/ICU Below Wall VTI-70 Implementation and Maintenance Requirements. Versa Wall CAD & Specs. (2020, March 2). Retrieved from https://gsky.com/versa/cad-specs/

Versa Wall System was successfully implemented in a private residence in Brooklyn in 2012 (GSky). The project was designed based on GSky's Versa Wall System with BAXT INGUI ARCHITECTS in conjunction with DEBBIE KOTALIC plant designer (GSky). The project represents 180 SQ FT area in the central part of the residence. The flexibility of the Versa Wall System allowed for the extension of the living wall through the second story of the home. The predominance of natural light source stabilized energy consumption used for artificial lighting. Additional LED light was installed on the top of the staircase following the distance, light intensity, and light temperature requirements.

This living wall system concentrates on air purification and aesthetic purposes, cleaning the space from indoor air pollutants and filling the area with colour and fresh air. It consists of main Versa Wall components such as plywood backing support, versa trays, versa dripline, nutrient injector, and an automated irrigation system (figure 3.3-3.7). As can be seen on figure 3.10, the intent of the client was to combine plant species to create a pattern filled with different colours following the combination of GSky's plants program (figure 3.10-3.11).

SPECIFICATIONS		VERSA WALL®
Description		Patent protected tray design that holds and waters industry standard 4" pots on the wall
Suitable Walls		Concrete, CMU, wood or metal frame, structural steel
Mounting		3/4" plywood mounted to the structure
Trays	Material	100% recycled polypropylene with ABS drain fitting
	Growth Media	Typical nursery growth media
	Dimensions	8-Pot Tray: 4-3/4"H x 39-3/8"W x 6-3/8"D (120 x 1000 x 160) 3-Pot Tray: 4-3/4"H x 14-3/4"W x 6-3/8"D (120 x 375 x 160) 2-Pot Tray: 4-3/4"H x 9-7/8"W x 6-3/8"D (120 x 250 x 160) Corner 3-Pot Tray: 4-3/4"H x 8-1/8"W x 6-3/8"D (120 x 206 x 160) back wall surface dimensions
Irrigation	Drip Line	Versa Wall® Drip Line 8-Pot, eight (8) 0.5GPH emitters on a 39-3/8"W PEX pipe length Versa Wall® Drip Line 3-Pot, three (3) 0.5GPH emitters on a 14¾"W PEX pipe length Versa Wall® Drip Line 2-Pot, two (2) 0.5GPH emitters on a 9-7/8"W PEX pipe length
	Controller	Timer, pumps (or valves), filter, regulators, UV filter
	Fittings	Standard Versa Wall® PEX pipe and brass Push & Fit fittings system
	Tanks	Stainless steel Versa Wall® tanks (standard recirculating system)
	Drainage	Direct to drain or recirculating using standard Versa Wall® tanks
Growth Time		Minimum order is 4 weeks depending on size and plant availability
Maintenance		Required, 1 year minimum. Maintenance access by lift or ladder must be planned for.
Warranty		Trays 5 years, Irrigation 2 years, plants under GSky maintenance contract

Figure 3.9: Versa Wall Specifications. Products Catalogue. (2020, March 2). Retrieved from https://gsky.com/products-catalogue/

The advantages of Versa Wall System in Brooklyn Residence (GSky):

1) Quick installation process;
2) Pot system allows to easily replace plants;
3) Automated water-recirculation system provides better water efficiency;
4) Recyclable materials;
5) The system is designed to be easily mounted on plywood, which is attached to the main structure (wall);
6) The system can be updated if needed, including an addition of tanks, hoses, or auto-fills.

The benefits of Versa Wall System in Brooklyn Residence (GSky):

1) Allows to create designs and various patterns due to the flexible pot system that can mixed plants of various colours;
2) Brings nature to the home and acts as an air purifier, which removes toxins and indoor air pollutants;
3) Reduces stress and produces oxygen, which enhances well-being and overall personal productivity;
4) Reduces noise and creates a good source of acoustic insulation.

Figure 3.10: Versa Wall in Private Residence in Brooklyn. GSky Green Wall in Private Residence - Brooklyn, NY. (2020, March 2). Retrieved from https://gsky.com/portfolio/brooklyn-private-residence/

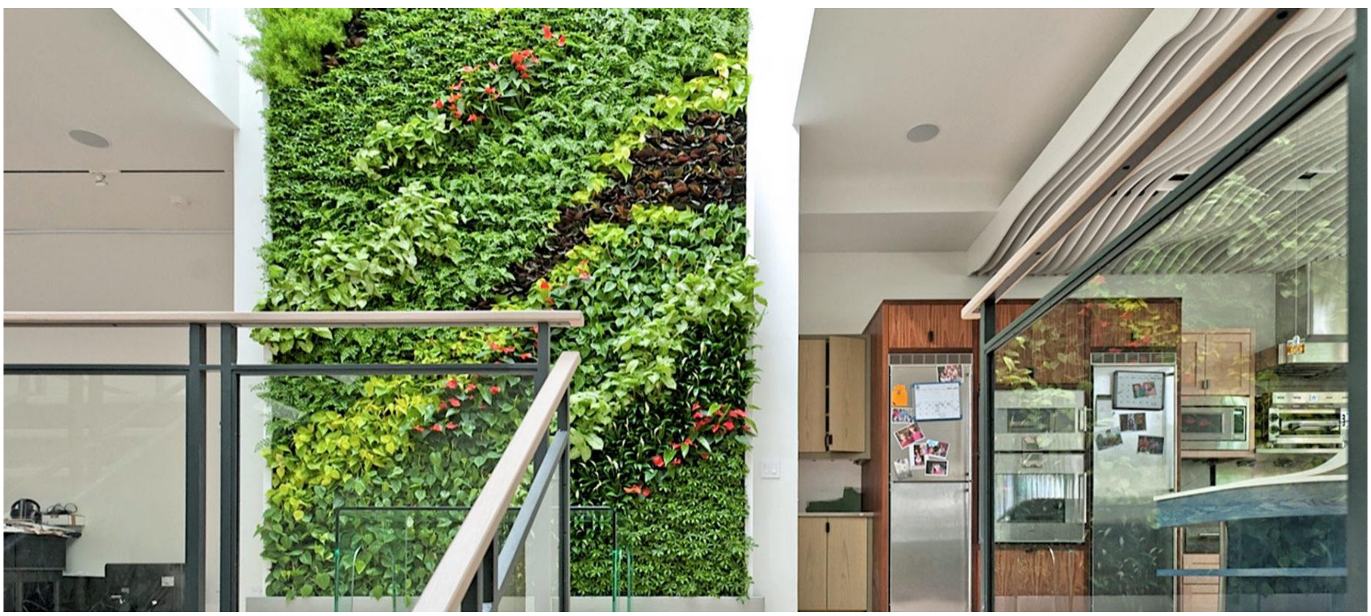


Figure 3.11: Versa Wall in Private Residence in Brooklyn. GSky Green Wall in Private Residence - Brooklyn, NY. (2020, March 2). Retrieved from https://gsky.com/portfolio/brooklyn-private-residence/

Conclusion

The analysis of GSky Versa Wall helped to reveal the flexibility and efficiency of the system. First of all, the use of Versa Wall will help to optimize energy and water consumption comparing to the use of hand watering or hose system, where water spills or water excess occurs.

Additionally, the use of recycled materials brings a huge environmental advantage, which avoids potential harmful impacts.

The developed plants availability system provides a great opportunity to create unique designs that will suit any client’s preferences. Automation of the system allows less in-person maintenance, however, requires additional expenses. Compared to the Hand Watering system presented on GSky website, this Versa Wall uses pumps, generators, and regulators which may be an expensive advantage. Despite the advantage of full automation, Versa Wall Above the Floor/ICU Below Wall VTI-70 might not be affordable for all groups of people. On the other hand, GSky company provides a full variety of Versa Walls including the most affordable system without additional expenses on tanks, generators, and regulators. In other words, GSky company concentrates on providing easy solutions for any type of situation. As a result, an analysis of Versa Wall helped identify materials and components that can be used in a more flexible, accessible, and affordable way, taking into account the context and priority of a client.

3.3.2. Live Wall, LLC

Live Wall, LLC is an eco-friendly living wall company based in Spring Lake, Michigan (Live Wall). The company focuses on manufacturing and supplying living wall systems including all necessary components, plants, and further maintenance and installation processes. It is a division of Hortech, Inc, which is one of the leading growers of sustainably grown plants (Live Wall). Live Wall is led by the inventor and founder of Live Wall, horticulturalist Dave MacKenzie (Live Wall). Originally Hortech Inc led to the development of a new company called LiveRoof Global, LLC (2006), which worked on green roofs as a main contributor to green building designs (Live Wall). During the LiveRoof Global work, Dave MacKenzie was testing plants species and their reaction to the roof top environment. Subsequently, he learned that forcing plants to grow sideways, growing them in soil-less or insufficient soil condition lead to various root diseases, insects causing constant maintenance, and high expenses (Live Wall). As a result, Dave and his team decided to implement a living wall, where plants could get appropriate irrigation, grow in soil with a rich nutritive compound, have upright stem orientation, and have downward root growth (Live Wall). Furthermore, a team of designers and engineers helped to create flexible and easily installed LWS, which could have adaptable design options, easy replanting, and long-lasting components. Since then, the direction and the name of the company changed to Live Wall, LLC (Live Wall).

According to Dave MacKenzie, Live Wall is a logical and a simple system, which can be installed by a person with basic construction and horticultural knowledge. Their website provides a full specter of information, including videos, instruction, and specifications that will help anyone install and maintain a living wall. Their goal is to create a balance between hard and green spaces which will positively affect our environment, by providing all necessary services, equipment, and information.

Live Wall. LLC offers four main products (Live Wall):

1) **Live Wall Outdoor** (only for outdoor purposes);
2) **Live Wall Indoor** (indoor living walls);
3) **Live Screen Mobile** (movable and flexible indoor and outdoor living wall on wheels);
4) **Norb Botanic Light** (white energy-efficient LED grow bulbs for plants).

According to the direction of the research, Live Wall Indoor will be examined and analyzed by providing important technical data, instructions, elevations, sections and installation guidelines.

Live Wall Indoor

Live Wall Indoor is an indoor living wall system that provides an eco-friendly environment for plants in interior spaces. Based on Live Wall, Live Wall Indoor acts as an air purifier, which cleans out the air from volatile organic compounds (VOS's), humidifies the indoor environment, and connects people with nature. Due to potential water contamination, which is common for indoor living walls and plants, Live Wall developed an indoor drip-free living wall, guaranteeing high quality and healthy plant growth.

Indoor Live Wall composed of four main components (Live Wall):

1) **WallTer Wall Planters**: a structure that holds the inserts with plants including the weight of soil and plants. The flexibility and adaptability of the system makes replanting or repair simple if needed. There are two sizes of WallTer Wall Planters can be found (figure 3.12) (Live Wall):

- **Standard WallTer:** used for annuals, vegetables, herbs, and perennial plants. There are two options: a full length (16") and half length (8"). Each size has eight colour options (figure 3.12);
- **Large WallTer:** mostly used for tropical plants and robust perennials. Comes with a full-length size (16"), with or without a water collection system and five available colour options (figure 3.12).

2) **WallTer Inserts:** inserts filled with soil and plants and inserted into the WallTer modules, which can be used as an off-site nursery for plants;
3) **WindClip:** used for a living wall higher than two stories in order to provide strong support and security against uplift forces;
4) **HideAway Concealment Brackets:** used to hide technical equipment with a flashing or sliding material that fits in indoor settings.

Live Wall Indoor includes a rear-draining operation with a hose drainage system that holds runoff water (Live Wall). Comparing to outdoor living walls, indoor living wall systems hold twice the soil volume, which needs to be properly maintained.

In order to prepare for the installation process, technical components need to be taken into account beforehand in order to forecast the durability and strength of the LWS. One of the biggest advantages of Live Wall is the provision of each and single detail needed for indoor living wall implementation.

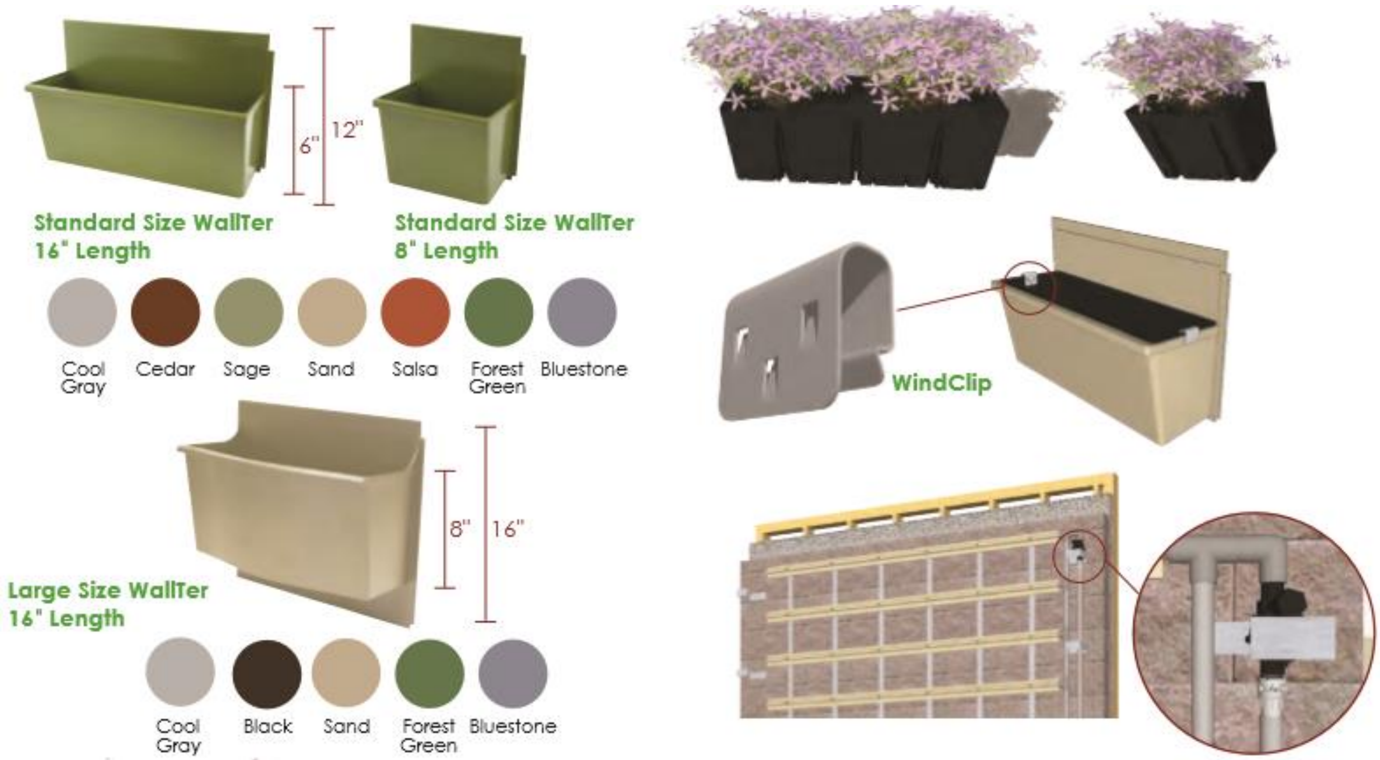


Figure 3.12: Live Wall Components and Accessories. Idea Guide and Designer's Checklist. (2020, January 8). Retrieved from https://livewall.com/designer-checklist/

Live Wall provides clients with a full variety of components needed for indoor living wall implementation such as furring strips, rain and slot rails, irrigation feeds, spray or drip watering, planters, main line irrigation, fasteners, irrigation concealment, and underlying materials (Live Wall).

Furring Strips (VertiRail®, figure 3.13)

Furring Strips are fundamental components from which the installation of LWS structure begins. They allow air circulation through entire LW system and create levels for wall structure.

Live Wall provide customers with three furring strips options (Live Wall):

- **Furring Strip** (1.5” VertiRail for Side Irrigation Feed): 2” wide x 1.5” deep and stocked in 96” and 51.5” lengths;
- **Double Furring Strip** (1.5” VertiRail for Side Irrigation Feed): 4” wide x 1.5” deep and stocked in 96” and 51.5” lengths (not applicable for indoor living walls with bottom-draining planters);

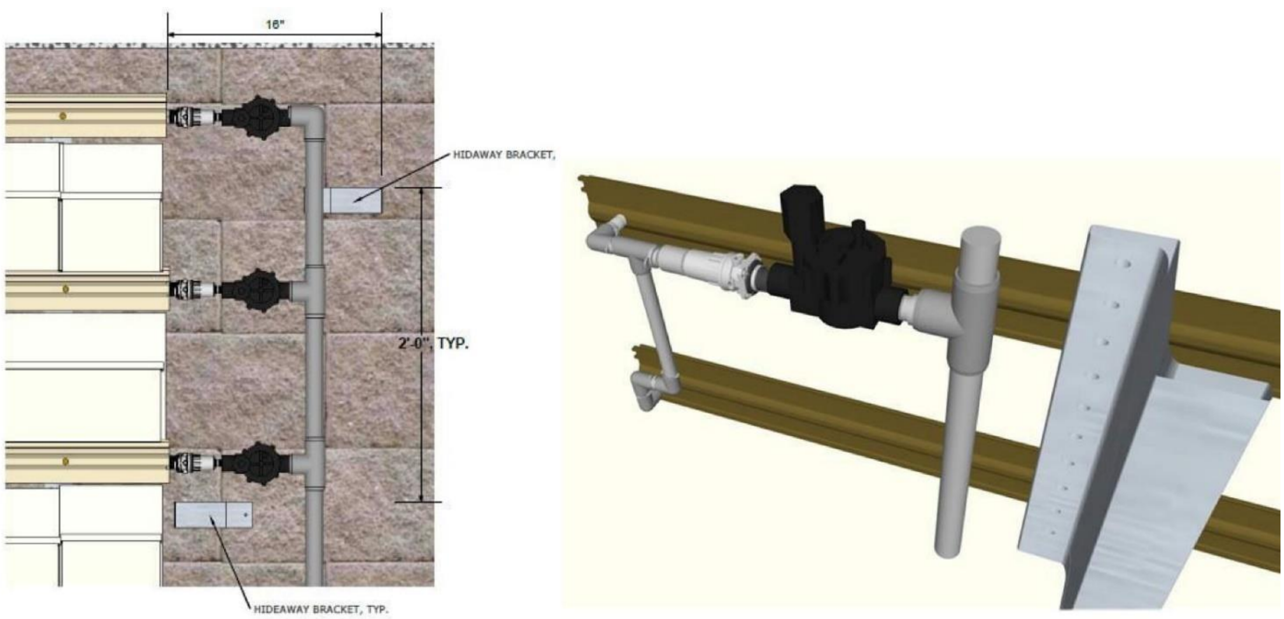
- **Furring Strip (5” VertiRail for Rear Irrigation Feed):** 4” wide x 5” deep and stocked in 96” and 51.5” lengths.

Furring Strip (1.5″ VertiRail® for Side Irrigation Feed) | Double Furring Strip (1.5″ VertiRail® for Side Irrigation Feed) | Furring Strip (5″ VertiRail® for Rear Irrigation Feed)

Figure 3.13: Furring Strips Options. Components. (2020, March 19). Retrieved from https://livewall.com/technical/components/

The choice of furring strips will depend on the chosen irrigation system. **Live Wall has two irrigation system options** (Live Wall):

1) **Side Irrigation Feed:** more affordable, easily installed, and thinner in size system. However, it requires wide facing treatment (figure 3.14);
2) **Rear Irrigation Feed:** full wall to wall coverage, potential elimination of facing treatment, on the other side, more expensive, thicker size, and takes more time for installation (figure 3.14).



Side Irrigation Feed | Rear Irrigation Feed

Figure 3.14: Irrigation Options. Components. (2020, March 19). Retrieved from https://livewall.com/technical/components/

Mounting Slot Rails/Irrigation Conduit (figure 3.15)

Live Wall provides clients with three Mounting Slot Rails options (Live Wall):

- **Slot Rail (H-Rail):** able to hold planters on the bottom of a living wall with an automated irrigation system, comes with 3.375” H x 0.6” D with 0.1” minimum thickness, stocked in 32”, 48” and 96” lengths;
- **RainRail:** hollow structure serves as irrigation conduit, comes with 3.375” H x 1.5” D with 0.1” minimum thickness, stocked in 16”, 32”, 48” and 96” lengths (adjustable width connection);
- **RainRail (Rear Irrigation Feed 1/2” Female Thread):** holes are drilled for irrigation feed behind the LWS, comes with 5” deep furring strips.

Figure 3.15: Mounting Slot Rails Options. Components. (2020, March 19). Retrieved from https://livewall.com/technical/components/

- **GapTool Spacers:** provides accurate horizontal spacing and available in two sizes (Standard and Large planters sizes)
- **Fasteners:** Stainless Steel Screws necessary to assemble LWS (please see recommendations on figure 3.16).

Irrigation components

RainRail Irrigation Hook-Up (figure 3.17)

- **RainRail Fittings:** can be connected to each other or to an irrigation feed, designed with multiple sizes and options that fit any living wall requirements. Each element includes screws placed in pre-drilled holes (Live Wall);
- **Valves & Pressure Regulators:** can be regulated up to 25 PSI, individually designed during the preliminary drawing process (Live Wall);

- **Pipe and Fittings:** connects RainRail end with valves and pipes according to drawings, black fittings typically used outdoors and gray pipe and fittings for indoor living walls (Live Wall).

Wall Material	Fastener Type	Size	Pilot Hole	MFG/ Vendor	Part
Brick	Torx Hex Washer Head Screw Anchor	1/4″ x 1-3/4″	1/4″	HILTI	KWIK-CON II+1/4″ x 1-3/4″ THWH St Steel
	ITW Red Head Tapcon Screw Anchor	1/4″ x 1-3/4″	1/4″	Fastenal	0131211 1/4″ x 1-3/4″ Hex Washer, Hex Drive, St Steel
CMU	Torx Hex Washer Head Screw Anchor	1/4″ x 1-3/4″	1/4″	HILTI	KWIK-CON II+1/4″ x 1-3/4″ THWH St Steel
	ITW Red Head Tapcon Screw Anchor	1/4″ x 1-3/4″	1/4″	Fastenal	0131211 1/4″ x 1-3/4″ Hex Washer, Hex Drive, St Steel
Mortar Joints	Not Recommended				
Poured Walls	Torx Hex Washer Head Screw Anchor	1/4″ x 1-3/4″	1/4″	HILTI	KWIK-CON II+1/4″ x 1-3/4″ THWH St Steel
	ITW Red Head Tapcon Screw Anchor	1/4″ x 1-3/4″	1/4″	Fastenal	0131211 1/4″ x 1-3/4″ Hex Washer, Hex Drive, St Steel
Steel Studs	Ballistic Point, Single Fastener	0.157-1″	N/A	HILTI	X-U 27 P8 TH Metal "Tophat" & 8mm Plastic
Aluminum Studs	Ballistic Point, Single Fastener	0.157-1″	N/A	HILTI	X-U 27 P8 TH Metal "Tophat" & 8mm Plastic
Wooden Studs	Torx Hex Washer Head Screw Anchor	1/4″ x 1-1/4″	1/4″	HILTI	KWIK-CON II+1/4″ x 1-1/4″ THWH St Steel
	ITW Red Head Tapcon Screw Anchor	1/4″ x 1-1/4″	1/4″	Fastenal	0131211 1/4″ x 1-1/4″ Hex Washer, Hex Drive, St Steel
EIFS	Varies, fasten through Exterior insulation and finish system (EIFS) to structure below.				

Figure 3.16: Wall Materials and Recommended Fasteners. Components. (2020, March 19). Retrieved from https://livewall.com/technical/components/

Plant Watering Components

According to Live Wall, a drip irrigation system is the best option for indoor living walls.

- **Spray Nozzles:** resistant to calcium, available in 0.1, 0.15, and 0,2 GPM flow rates. Higher pressure spray nozzles used on top rows and lower pressure for lower rows (Live Wall).

- **Drip Emitter Assembly:** T-fitting (two 8” long tubes and two flow stakes), 0.5 GPH (lower rows) and 1 GPH (for top rows) (Live Wall).

RainRail Fittings | Valves & Pressure Regulators | Pipe and Fittings

Figure 3.17: RailRail Irrigation Hook-Up. Components. (2020, March 19). Retrieved from https://livewall.com/technical/components/

Main Line Irrigation Components (Live Wall; figure 3.18)**:**

- **Backflow Preventer:** required by local code and supplied according to the type of Live Wall System;
- **Screen Filter:** used to filter the water from contaminants and particles that plug valves or nozzles;
- **Disc Filter:** can be used instead of screen filters for larger living wall projects;
- **Controller:** used to control supply and fertilization levels, requires electricity;
- **Fertilizer Injector:** recommended for living walls with drip irrigation system;
- **Fertilizer:** can be supplied by Live Wall with a following instructions;
- **Descaling Housing and Cartridge:** used when supplies hard water;
- **Hose Timer:** includes irrigation feed lines and timer.

Backflow Preventer | Screen Filter | Disc Filter

Figure 3.18: Irrigation Components. Components. (2020, March 19). Retrieved from https://livewall.com/technical/components/

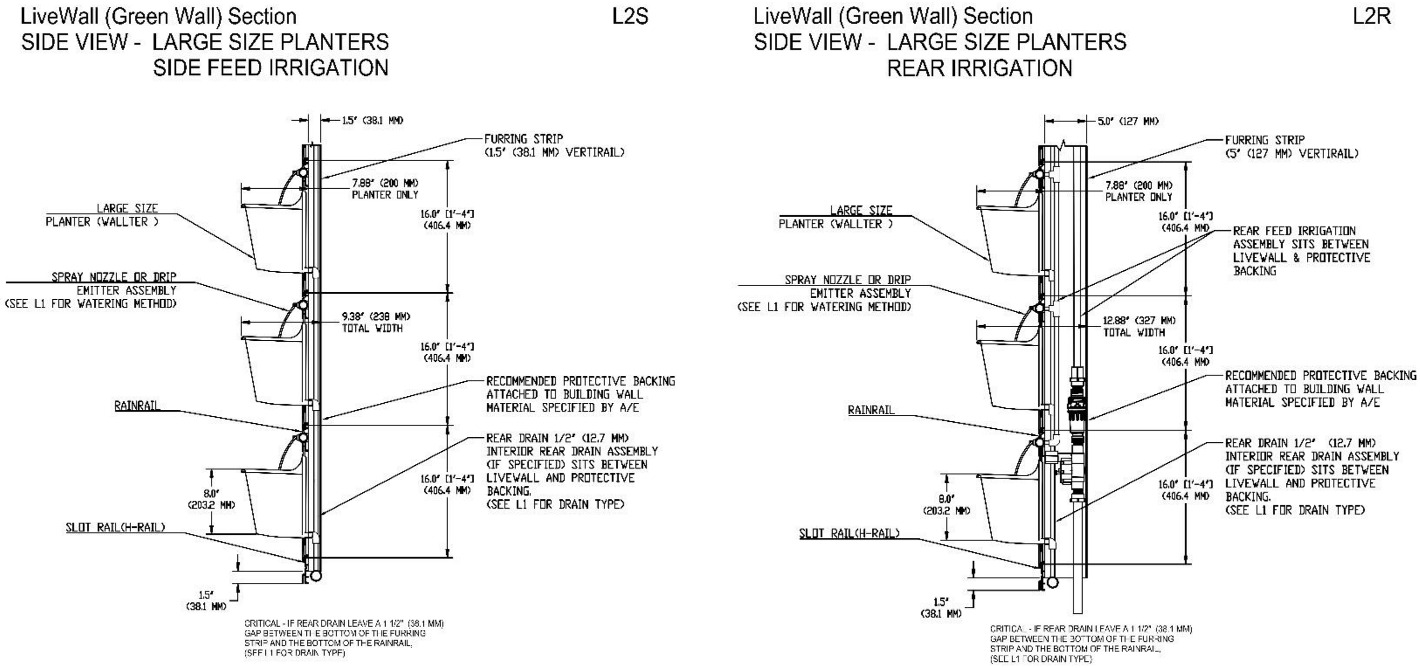


Figure 3.19: Side View of Side Feed Irrigation (left) and Rear Irrigation (right). Technical Details. (2020, March 20). Retrieved from https://livewall.com/technical/details/

The Live Wall watering system is made to provide sufficient amount of water distributing equally to all parts of the living wall. The backflow preventer is fixed to a feed line with a pressure between 25 PSI and 85 PSI (Live Wall). The pressure of flow can be regulated by the booster pump in order to provide even watering.

In order to avoid hard water which can damage and harm nutrients and plants themselves, Live Wall recommends buildup cartridges that prevents the system from blockage and clogs. Descaling Cartridges should be changed every year and can be ordered from Live Wall's website (Live Wall).

When all elements are prepared, an installation process can begin. Live Wall provides two main options of irrigation: side feed irrigation and rear irrigation as shown on figure 3.19. The installation process and the components will depend on the choice of irrigation system, which will then reflect on details, maintenance process, and further expenses.

The installation process begins with a measurement of the main wall. It can easily be done by marking the corners and borders of the living wall. According to Live Wall, side feed irrigation requires more extra space on the sides compared to rear feed irrigation. When the first step is done and the dimensions of living wall are projected onto the main wall, protective backing can be applied. Protective backing is a waterproof membrane, such as 20 mil polypropylene or EPDM, that protects the main wall from humidity and water leakage from the living wall or any other water related accidents (Live Wall). Protective backing should be slightly extended beyond the perimeter of the measured living wall structure. In order to apply a waterproof membrane strictly parallel to the main wall, horizontal level or chalk line can be drawn.

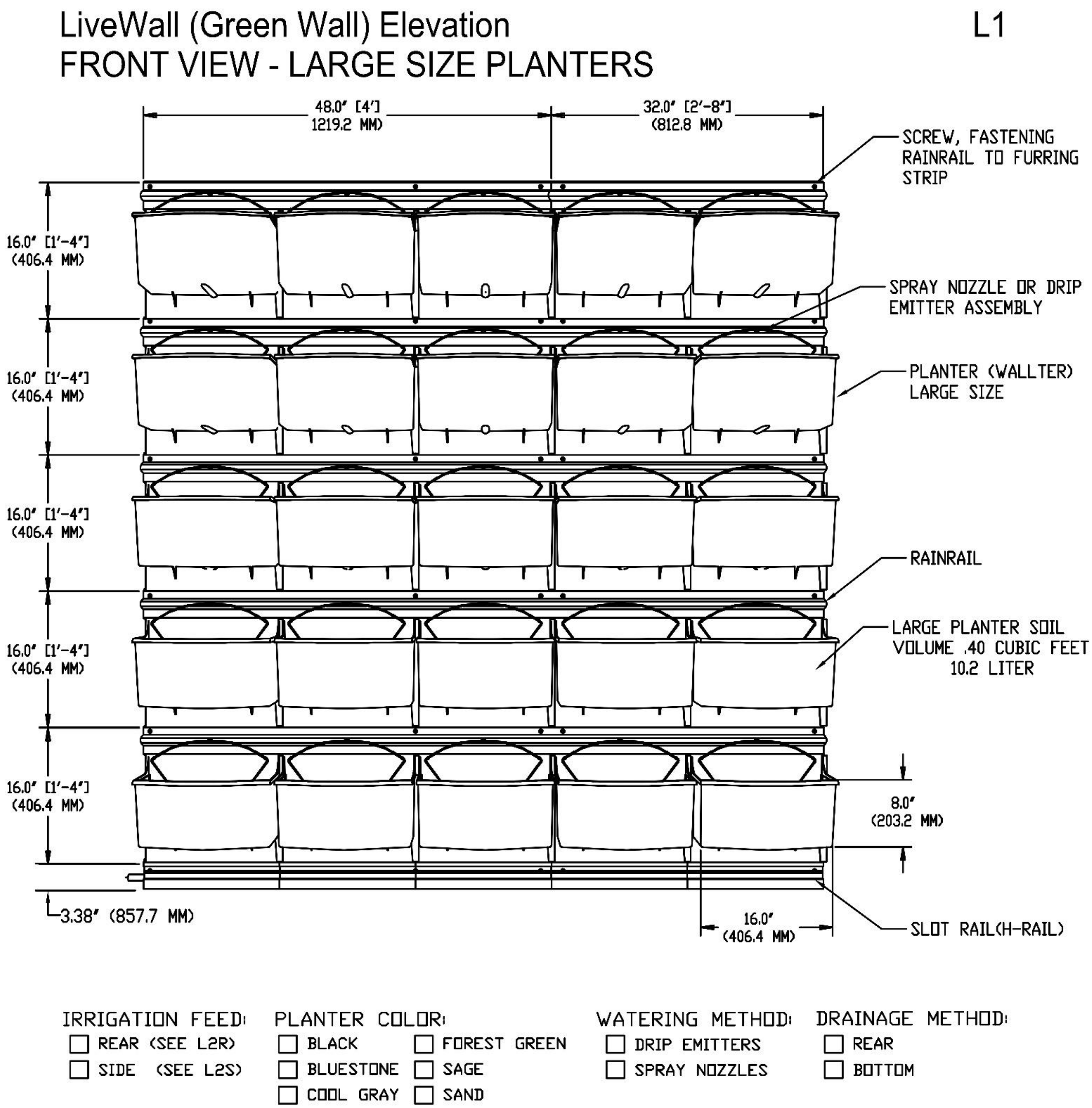


Figure 3.20: Living Wall Front View. Technical Details. (2020, March 20). Retrieved from https://livewall.com/technical/details/

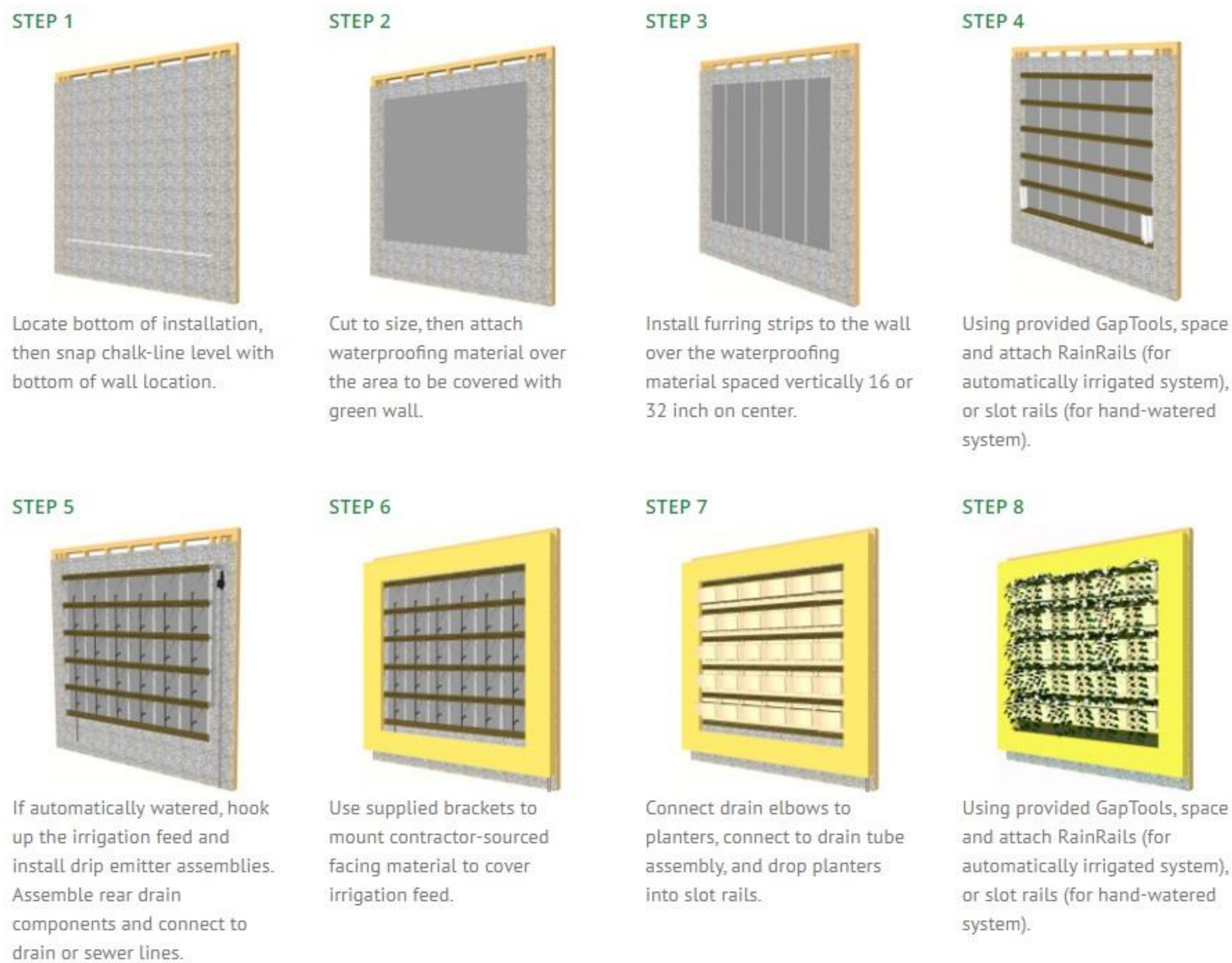


Figure 3.21: Installation Process. Indoor Living Walls. (2019, October 16). Retrieved May 24, 2020, from https://livewall.com/products/indoor/

For clients' convenience, Live Wall created the step-by-step assembly diagram in figure 3.21 that guides users through the self-installation process. The next step includes the installment of the furring strip (VertiRail). Tape or drawn vertical lines can help place furring strips vertical to the main wall. Typically, indoor furring strips are placed with a 32" in between from the center of strips (Live Wall). The next step is to install Slot Rails, that hold the bottom row of planters in place (Live Wall). The alignment of furring strips with the slot rail will depend on the choice of drainage. In the case of bottom drain, the bottom of the slot rail should be fixed with the bottom of the furring strip, whereas in the case of rear drain, a gap of 1.5" is made between the foot of the slot rail and the base of the furring strips to connect rear drain hose across in this gap (Live Wall).

The next step includes the installment of RainRails and Fittings. The placement of RainRails and Fittings will be dictated by the size of the wall structure and the type of irrigation system. To begin, a GapTool is placed at the end of the bottom slot rail (knob side down) where it is tightened to hold the tool in place. ¼ pilot holes in the v-notch should be leveled, marked, and drilled (Live Wall). RainRails are put back in place and screwed through the pilot holes to mount the RailRails to furring strips (Live Wall).

Next step includes putting the Irrigation Main Line fixture into the system. Irrigation components should be connected to a ¾" mainline with a minimum of 25 PSI water pressure (Live Wall). The Irrigation Main Line includes a backflow preventer, descaling housing and cartridges, a fertilizer injector, and mount controller (Live Wall). Afterwards, the Irrigation Feed is installed. Irrigation valves should be connected to pressure regulators, supply pipe, and fittings (Live Wall). The installation of Irrigation Nozzles and Drip Emitters is the next step. Drip Emitters should have a size of 1.0 GPH on top rows and the 0.5 GPH on all other rows (Live Wall). In the system with Side Feed Irrigation, brackets are installed every 2 feet from each other, and an 8" width concealment is required if the valves are stacked and a 16" width is needed if the valves are aligned with the RainRails (Live Wall). Afterwards, facing materials, such as aluminum, painted sheet material or cedar and wall planters, are installed (Live Wall).

According to Live Wall, three main types of fertilization can be used (figure 3.22):

- **Automatic Fertilization;**
- **Manual Granular Fertilizer;**
- **Manual Liquid Fertilizer.**

Automatic Fertilization is composed of fertilizer injector, which is fixed into the irrigation system and distributes nutrients equally into the living wall (Live Wall). According to Live Wall, automatic fertilization allows control of the necessary dose of fertilization and reduces potential expenses or overdoses. Fertilization is used each irrigation cycle and fully controlled by the automated system.

Manual Granular Fertilizer is used for manual fertilization and composed of nutritive granules that are used once, annually. Based on Live Wall, one annual application of granular fertilizer is sufficient for plants to grow properly. A teaspoon can be used to distribute fertilizer equally across the soil surface (Live Wall). The dosage will depend on the size of the indoor living wall, the density of plants, spacing, and the irrigation system. Consequently, small indoor living walls will require less fertilizers and a big one requires twice as much as the small one.

Fertilization Options	Irrigation Method		
	Hand Watered (small indoor walls only)	Drip Emitters	Spray Nozzles
Automatic via Liquid Fertilizer Injector	NO	✓	✓
Top-Dressed with Granular Controlled Release Fertilizer	✓	NO	✓
Manually Watered with Liquid Plant Food	✓	NO *possible*, but impractical	NO *possible*, but impractical

Figure 3.22: Fertilization Options. Components. (2020, March 19). Retrieved May 24, 2020, from https://livewall.com/technical/components/

Manual Liquid Fertilizer is used for living walls that do not have automatic fertigation system (Live Wall). According to Live Wall, Manual Liquid Fertilizer should be used every six to twelve months according to the plants species, living wall size, irrigation system and density of plants. To apply liquid fertilizer evenly, a watering can or a hose can be used (Live Wall).

Live Wall Indoor System was installed in one private residence of Hubbard Apartments in Chicago (figure 3.23). The system included the following living wall components: slot rails, large planters, spray nozzles, drip emitters, furring strips and screws. The system was installed according to the installation guide and currently maintained by the user and Live Wall as well. It provides great air purification and humidification power, which helps clean indoor air from contaminants. The lighting is installed right above the living wall keeping minimal distance from the plants.

The living wall includes a mix of plants, giving the wall a unique design. Live Wall can be transformed into an edible living wall by using herb and vegetable plants. According to Live Wall, an indoor living wall can grow basil, dill, parsley, spinach, strawberries, romaine lettuce, beans, cucumbers, and other herbs.


Figure 3.23: Indoor Live Wall in Hubbard Apartments, Chicago. Hubbard Street Apartments in Chicago. (2019, October 23). Retrieved May 24, 2020, from https://livewall.com/portfolio-items/hubbard-street-apartments-in-chicago/?portfolioCats=227

Conclusion

The guidelines, specifications, and information presented on the Live Wall website allows an easy self-installation process. However, it might require the presence of a few people in order to fix the rain rails, furring strips, and other big components. Detailed descriptions of the elements allow for future living wall systems to be adaptive to any indoor condition. One of the greatest advantages is the flexibility of plant choice selections, which ranges from annuals to long-lived succulents, perennials, herbs, and vegetables. Live Wall allows a transformation into an edible living wall, providing residents with fresh vegetables and herbs.

Despite its various benefits, an Indoor Live Wall may be costly and will require additional professional maintenance. Figure 3.21 indicates the number of components needed for installation and shows its complexity, which means that a high investment should be expected. This living wall is a unique system that can combine two or more functions such as air purification, humidification, and food production. The installation of an indoor Live Wall will help reduce heating and cooling energy consumption, making it have additional financial benefits.

3.3.3. ANS Global

ANS Global is one of the world's leaders in green roof and living wall industry. The company is based in United Kingdom (ANS Global). It is a company that concentrates on designing indoor and outdoor living walls and green roofs for commercial and residential sectors. The plant wholesale business began in June 1996 on Aldingbourne Nurseries (ANS Global). In March 2005, ANS Global started supplying and installing green roofs (ANS Global). In August 2008, ANS Global started researching and developing living wall systems (ANS Global). September 2010 marks the first living wall installment completed in United Kingdom at Westfield Shopping Centre (ANS Global). Ince then, ANS Global has expanded their business and installed their first indoor living walls. Now, ANS Global has completed 5,740 projects, installed over 100.6m plants in 21 countries (ANS Global)

ANS Living Wall

ANS Global provides outdoor and indoor pre-grown living walls, enhancing the environment and well-being of people. ANS Global uses natural soil and recyclable modules, that can be then recycled according to a cradle-to-cradle model (ANS Global).

The design and installation process of ANS Global indoor living wall includes **four stages** (ANS Global):

Design: The project begins with a detailed planning and design stage, including visualizations of the future space and indoor living wall. The project proposal comprises costs, technical visualizations, specifications, and timescales;

Planting: When the project proposal is approved by the client and the plants are chosen, ANS Global begins to work on the planting plan. A team of specialists will determine the requirements for the chosen plants and then plant them into ANS Living Wall modules. Typically, it takes 3-4 weeks to pre-grow the plants for indoor living walls and around 6-8 weeks for outdoor living walls;

Installation: When all the components are ready, the installation process can begin. According to ANS Global, the standard method is to fix LWS to an existing concrete, brickwork, steel, or timber frame structure. The living wall modules with pre-grown plants are fixed instantly to provide a positive impact from the first day of installation;

Maintenance: Based on the LWS, ANS Global will determine the maintenance schedule and timing needed for a successful future for living wall. The maintenance process will be dictated by the location, plant mix, lighting, and other aspects.

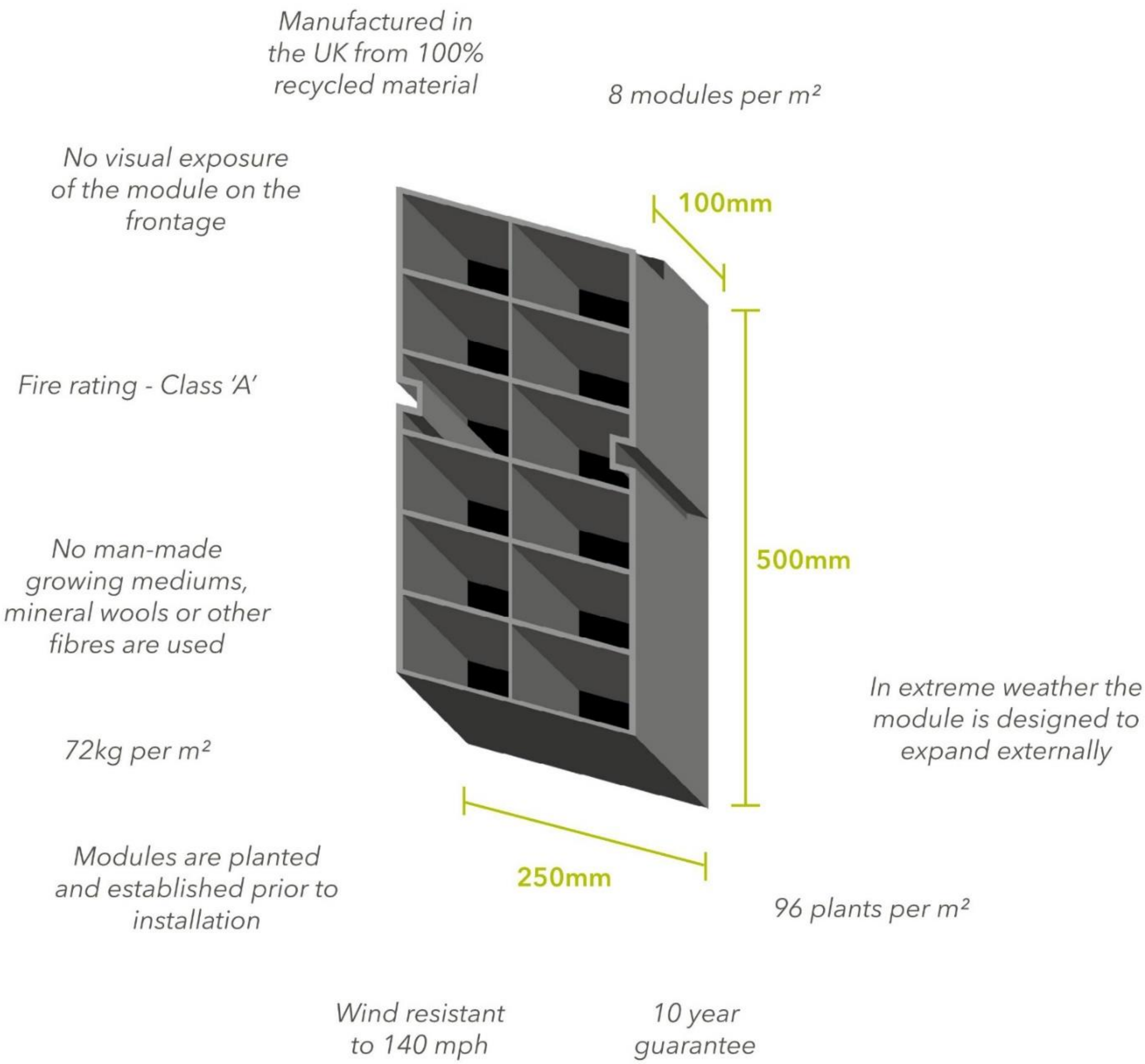


Figure 3.24: ANS Global Living Wall. ANS Global (2019). ANS Living Wall Guide. Retrieved from https://www.ansgroupglobal.com/sites/default/files/fields/downloads/files/ANS_Living_Wall_Product_Guide%202019.pdf

ANS Living Wall is composed of natural soil, which allows plants to grow in their natural environment (ANS Global). LWS creates customized designs by adding a wide range of plant species, shapes, patterns, and designs. The longevity of the system is protected by the presence of natural soil that preserves plants' roots.

ANS Living Wall includes a built-in irrigation system with hidden pipes in the back, which preserves the unique design of the system and its fusion into indoor environment (ANS Global).

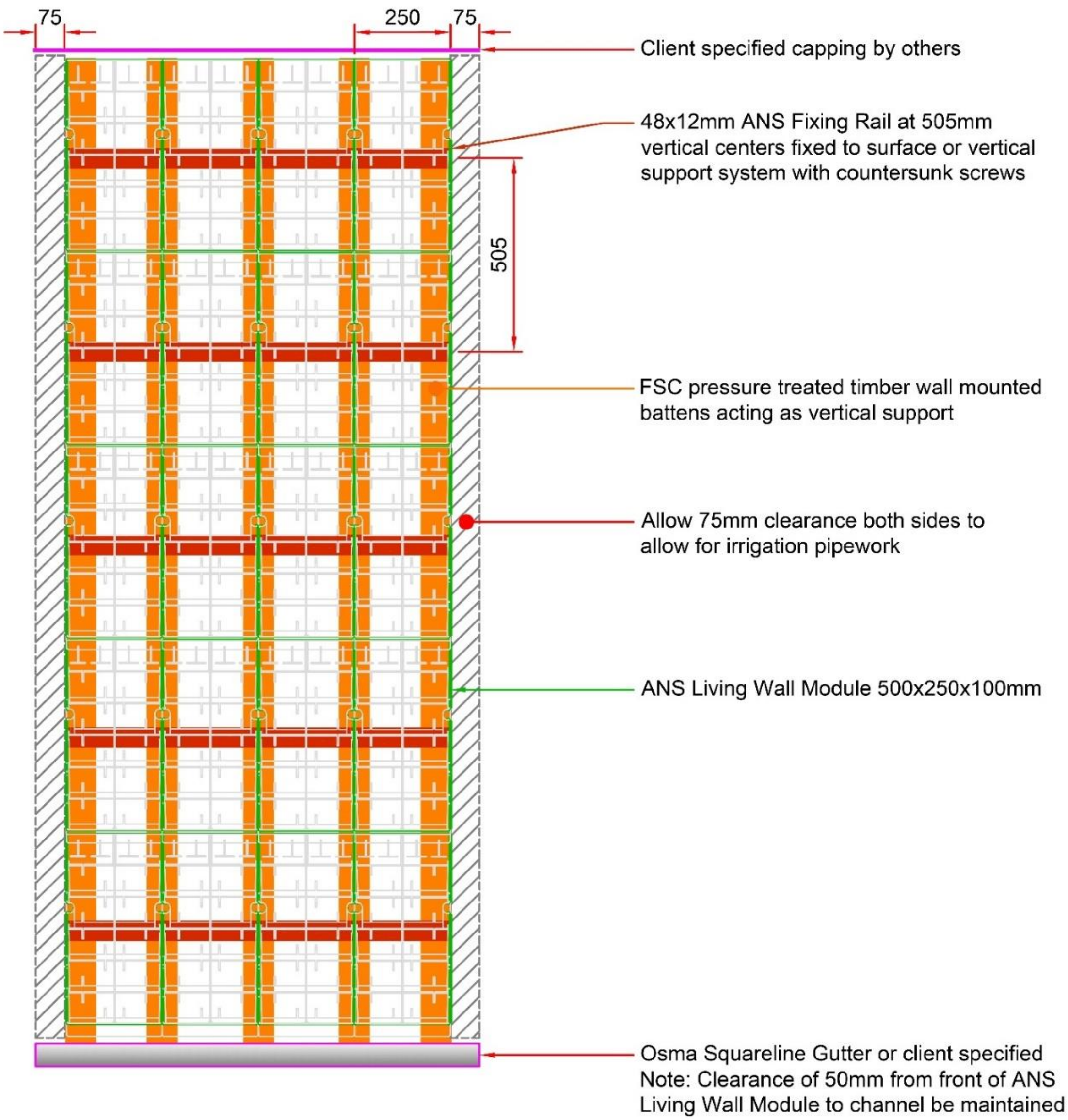


Figure 3.25: ANS Living Wall Front Elevation. ANS Global. ANS Living Wall CAD DWG Files. Retrieved from How Does a Living Wall Work? (2019, February 18). Retrieved May 25, 2020, from https://www.ansgroupglobal.com/living-wall/technical

ANS Living Wall consists of various components that should be fixed together one-by-one as shown on figure 3.28. It includes ANS Fixing Rails, FSC pressure treated timber wall, which acts as a vertical support, ANS Living Wall Modules 500x250x100mm, and Osma Squareline Gutter (ANS Global). It can be seen on the top section (figure 3.26) that an ANS Living Wall also includes waterproof membrane, capping, and 16mm irrigation pipework.

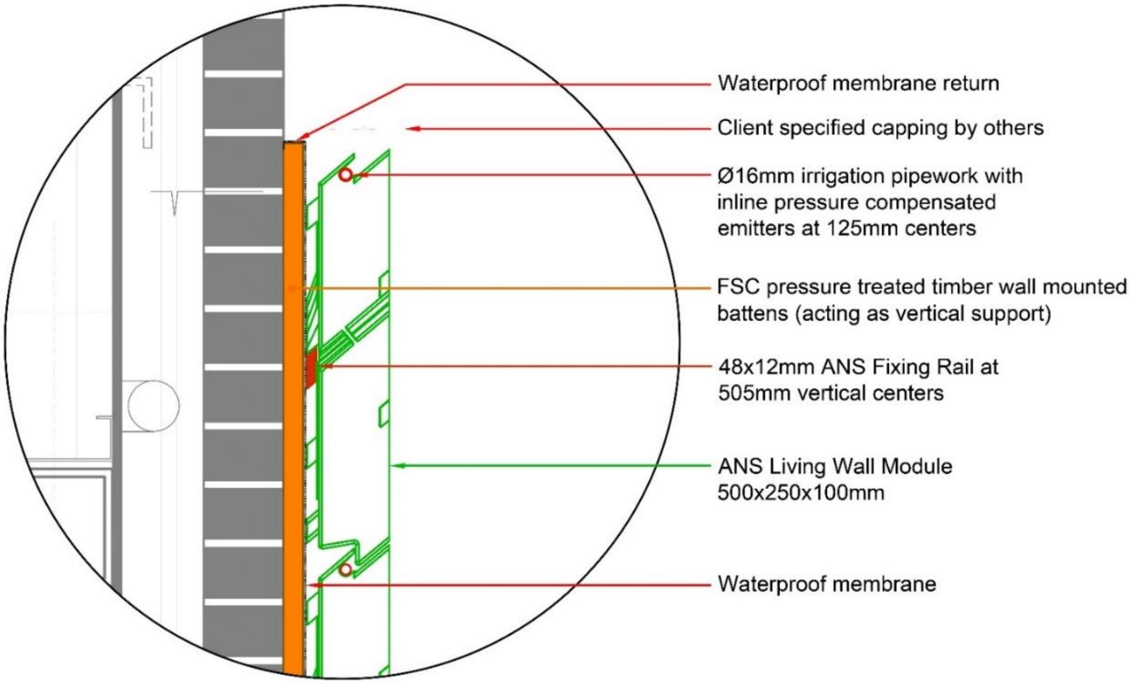


Figure 3.26: ANS Living Wall Top Section. ANS Global. ANS Living Wall CAD DWG Files. Retrieved from How Does a Living Wall Work? (2019, February 18). Retrieved May 25, 2020, from https://www.ansgroupglobal.com/living-wall/technical

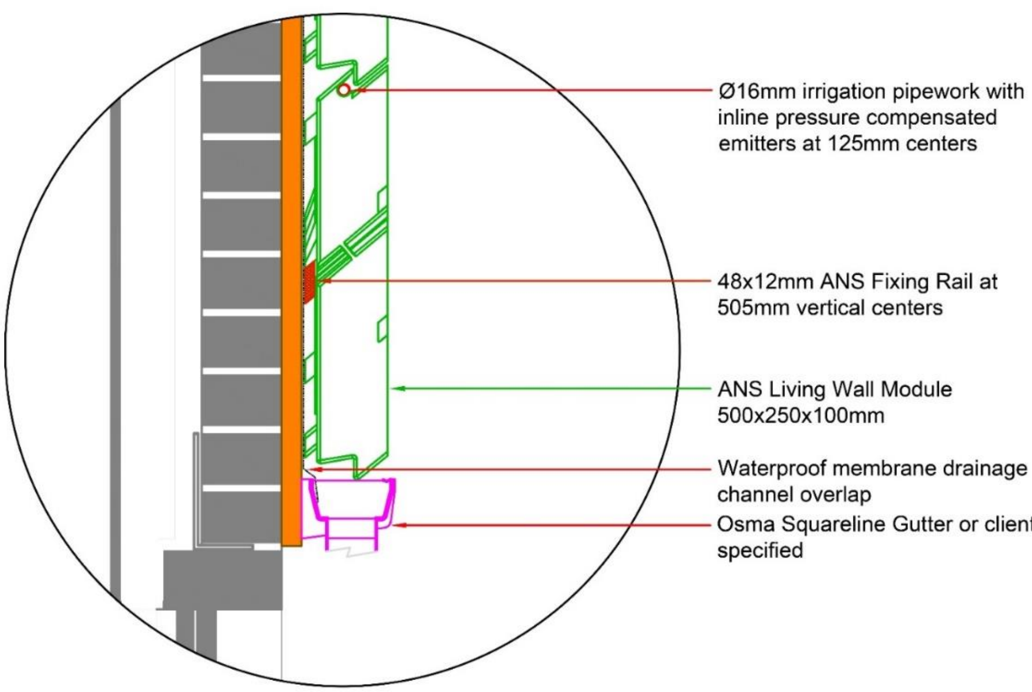


Figure 3.27: ANS Living Wall Bottom Section. ANS Global. ANS Living Wall CAD DWG Files. Retrieved from How Does a Living Wall Work? (2019, February 18). Retrieved May 25, 2020, from https://www.ansgroupglobal.com/living-wall/technical

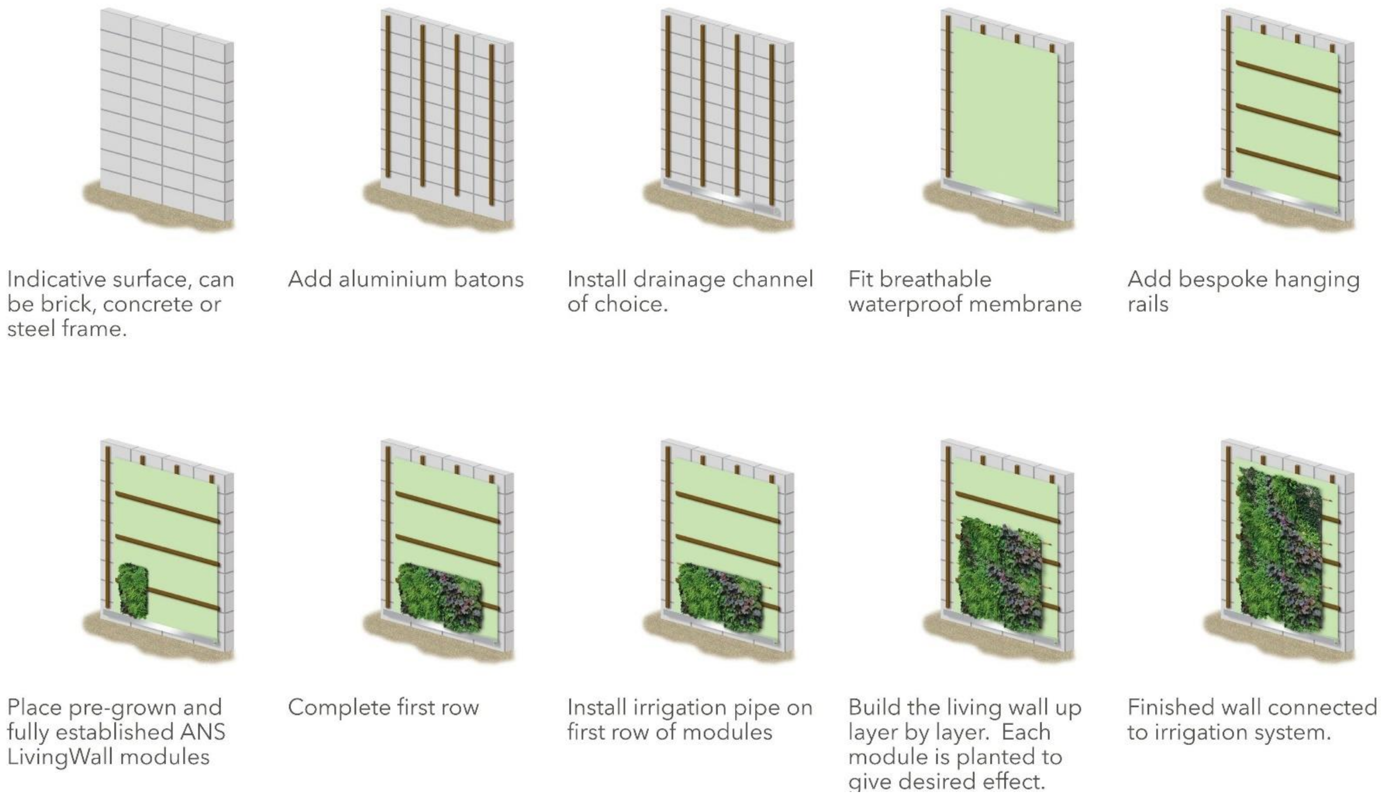


Figure 3.28: ANS Global Living Wall Assembly Diagram. ANS Global (2019). ANS Living Wall Guide. Retrieved from https://www.ansgroupglobal.com/sites/default/files/fields/downloads/files/ANS_Living_Wall_Product_Guide%202019.pdf

The technology of ANS Global was used in designing an Indoor Living Wall at Marley Heights House (ANS Global; figure 3.29). In 2014, the project in the United Kingdom was completed (ANS Global). According to ANS Global, the installation process of the indoor living wall took one week. It was placed in the middle of the dining room with a bright word "eat" highlighted by using plant combinations on the living wall. This living wall is used only for air purification and aesthetics purposes. The client noted, the presence of an indoor living wall added a significant value when it came time to sell the house.

ANS Global worked on plant combinations, which included the insertion of more than seven species including Tradescantia zebrina, Maranta leuconeura "Kerchoveana", and Codiaeum "Sunny Star" (ANS Global). They help to filter out pollutants from the air, absorb dust particles, and deflect noise.

In order to provide sufficient lighting, both natural light and artificial lighting was used. Despite the abundancy of natural light, a minimum of 3000K temperature and 250 FC of light intensity was used in the system (ANS Global).

Figure 3.29: ANS Indoor Living Wall at Marley Heights House, United Kingdom. Marley Heights. (2018, November 08). Retrieved May 25, 2020, from https://www.ansgroupglobal.com/living-wall/case-studies/marley-heights

Conclusion

ANS Global Indoor Living Wall represents a fully recyclable system manufactured in the United Kingdom. One of its greatest advantages is the absence of man-made growing media, mineral wools, and other fibers. The modular system enables flexibility and convenience for the user. Materials presented on the ANS Global website, including those that were presented in this paper such as an assembly diagram, top and bottom section, and elevation, can easily help to install your own indoor living wall without additional services. Guidelines and living wall specifications presented on the ANS Global website explains how a living wall functions and demonstrates what is needed to provide the best environment for plants. Depending on the size and complexity of the chosen living wall system, it might require professional maintenance including an inspection of irrigation, drainage, and growing media. For small indoor living walls, the maintenance guidelines can be used to provide proper living wall care. One of the biggest advantages of ANS Global is that it gives the opportunity to install living walls not only in the residential sector, but commercial, public, and health care industry. As can be seen on figure 3.29, ANS Global living wall is only used for air purification and aesthetic purposes, where a client additionally chose a plant's pattern or a mix of plants to bring diversity to the indoor space. ANS Global living walls are efficient in providing proper heat reduction and cooling as well as the disease of energy consumption, which can help one save some money. LWS additionally brings air purification benefits by cleaning the air from contaminants, which positively affects the health of residents.

3.3.4. Florafelt

Florafelt is a company founded by the inventor of the Florafelt Living Wall System, Chris Bribach (Florafelt). This company designs indoor and outdoor pocket living wall systems (Florafelt). Florafelt is based in Norcross, Unites States. The story of Florafelt emerged from a personal experience of Chris Bribach, who studied in architectural school, that was closely located to Frank Gehry's office, where natural ideas were found (Florafelt). The concept of the pocket system emerged from the works of Patrick Blank, a pioneer of living walls (additional information can be found in chapter 2). From Patrick Blanc's technology, Chris Bribach realized that plants can be grown hydroponically, removing the demand for soil growth (Florafelt).

Florafelt Living Wall System

Taking into account different living wall applications, Chris Bribach invented a lightweight, non-toxic plastic board, in order to allow easy planting (Florafelt). The innovation of the pocket system was granted a patent "Vertical Garden Panel" in September 2010 (Florafelt). The Florafelt system is made from recycled plastic water bottles and can be re-melted to create other products. Florafelt provides several living wall options and related products (Florafelt):

1) **Florafelt Pocket Panels:** lightweight Pocket Panel system, which uses soft felted pockets for living walls;
2) **Florafelt Compact Living Wall Kit:** compact design option of a living wall for a quick and easy installation;
3) **Florafelt Recirc Systems:** a living wall system made of stainless steel, which contains tank, pump, irrigation tubing and timer;
4) **Florafelt Pro System:** rigid living wall system made from stainless steel 304 wire grid that can handle extreme conditions (mainly used outdoors);
5) **Florafelt Grow Felt:** a fabric of which Pocket system is made, which allows to customize your own design;
6) **Florafelt Irrigation** includes drip irrigation kit and drain tray 32-inch;
7) **Florafelt Root Wraps:** the fabric allows to adapt future living wall to any location, dimensions and requirements.

Florafelt Pocket Panel System was chosen for analysis and a detailed review. Florafelt Pocket Panel System has various capacity options: 12-Pocket, 24-Pocket, and 4-Pocket Panel Living Wall System (Florafelt).

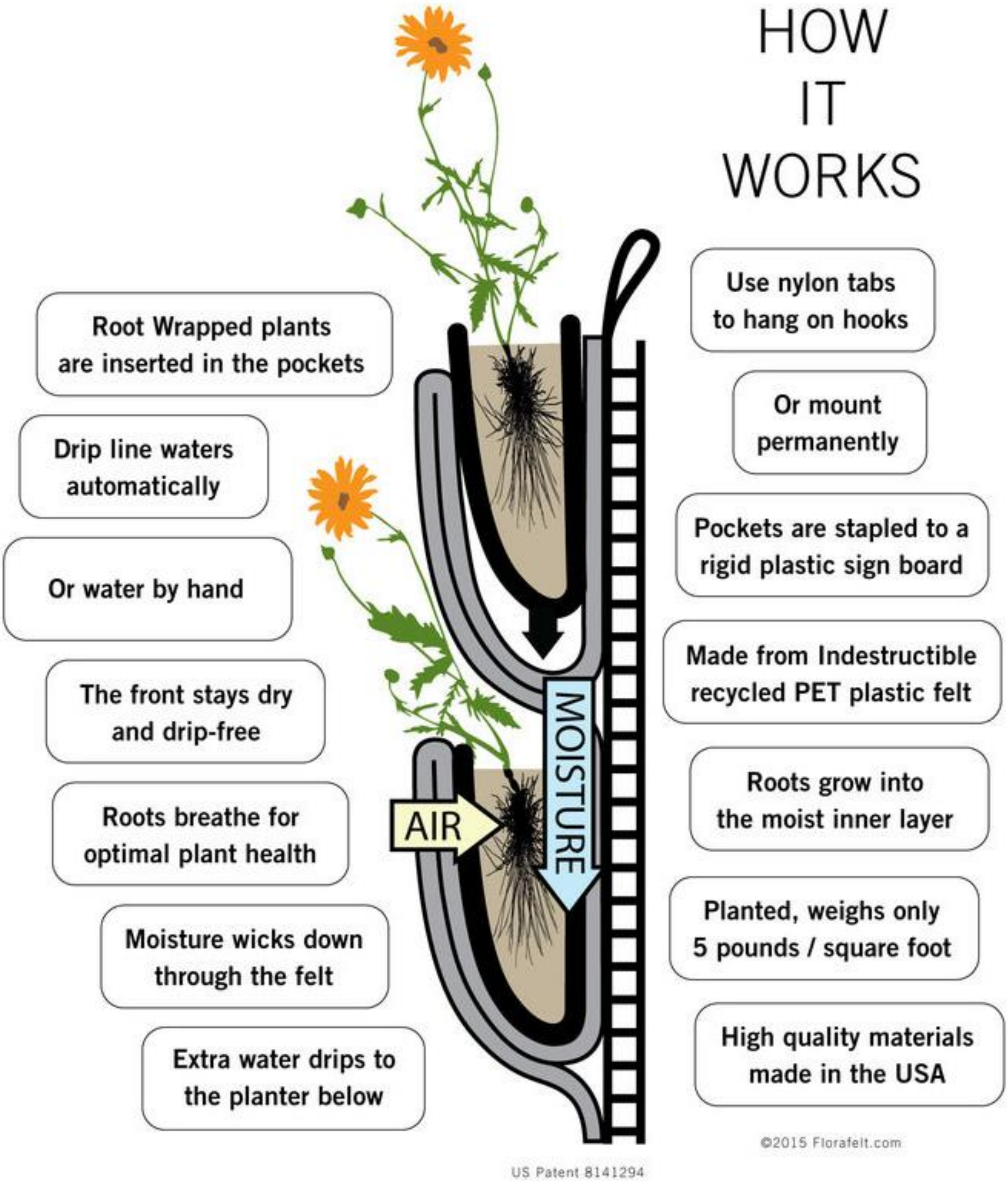


Figure 3.30: The Florafelt Living Wall Planter. Florafelt Living Wall Guide. (n.d.). Retrieved May 25, 2020, from https://florafelt.squarespace.com/florafelt-living-wall-guide

Florafelt living wall is an innovative design, which allows air penetration through the system and reduces the risk of structural damage (figure 3.30). The system can be easily fixed onto a lightweight plastic board. Watering is ensured from the top of the system in order to let water run down through the system. Roots grow into the moist fabric, which also allows the felt to gather nutrients. The felt is made from recycled plastic water bottle that can be easily recycled in the future for other components (Florafelt).

Florafelt system is an affordable way to create an indoor living wall. The system is fixed onto the waterproof rigid plastic board, to keep the main wall dry (Florafelt). Living wall can be mounted using tabs or screws onto the waterproof surface (Florafelt). The pockets are then attached to a plastic board by using hanging tabs, hooks, nails, or deck screws. When pockets are installed, it is necessary to stretch each of them about 2 ½ inches before planting (Florafelt). The Florafelt living wall uses minimal soil, but an irrigation should provide an even amount of water to all the pockets.

The system requires daily watering, which is arranged through the pockets, where moisture is collected at the bottom of each pocket. It is important to make sure that roots touch the bottom of the fold so they can receive the necessary moisture.

Florafelt suggests using an automated irrigation system with a precise watering schedule. Typically, watering occurs 4 times in approximately 5-10 minutes cycles (Florafelt). For the convenience of customers, Florafelt offers a drip irrigation kit, which is easy to use and includes irrigation and bottom emitters, timber, or a filter unit ($289.00) (Florafelt). Florafelt provides two watering options: drain-away (drip irrigation) and recirculating system. Before the plant's insertion, plants should be root-wrapped first (Florafelt).

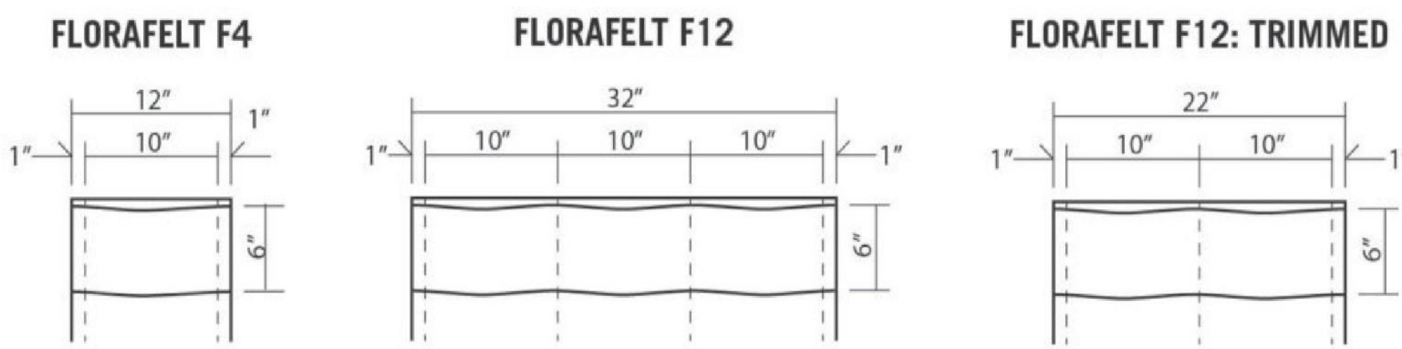


Figure 3.31: Florafelt Custom Sizing. Custom Sizing Guide. (n.d.). Retrieved May 25, 2020, from https://florafelt.com/custom-sizing-guide

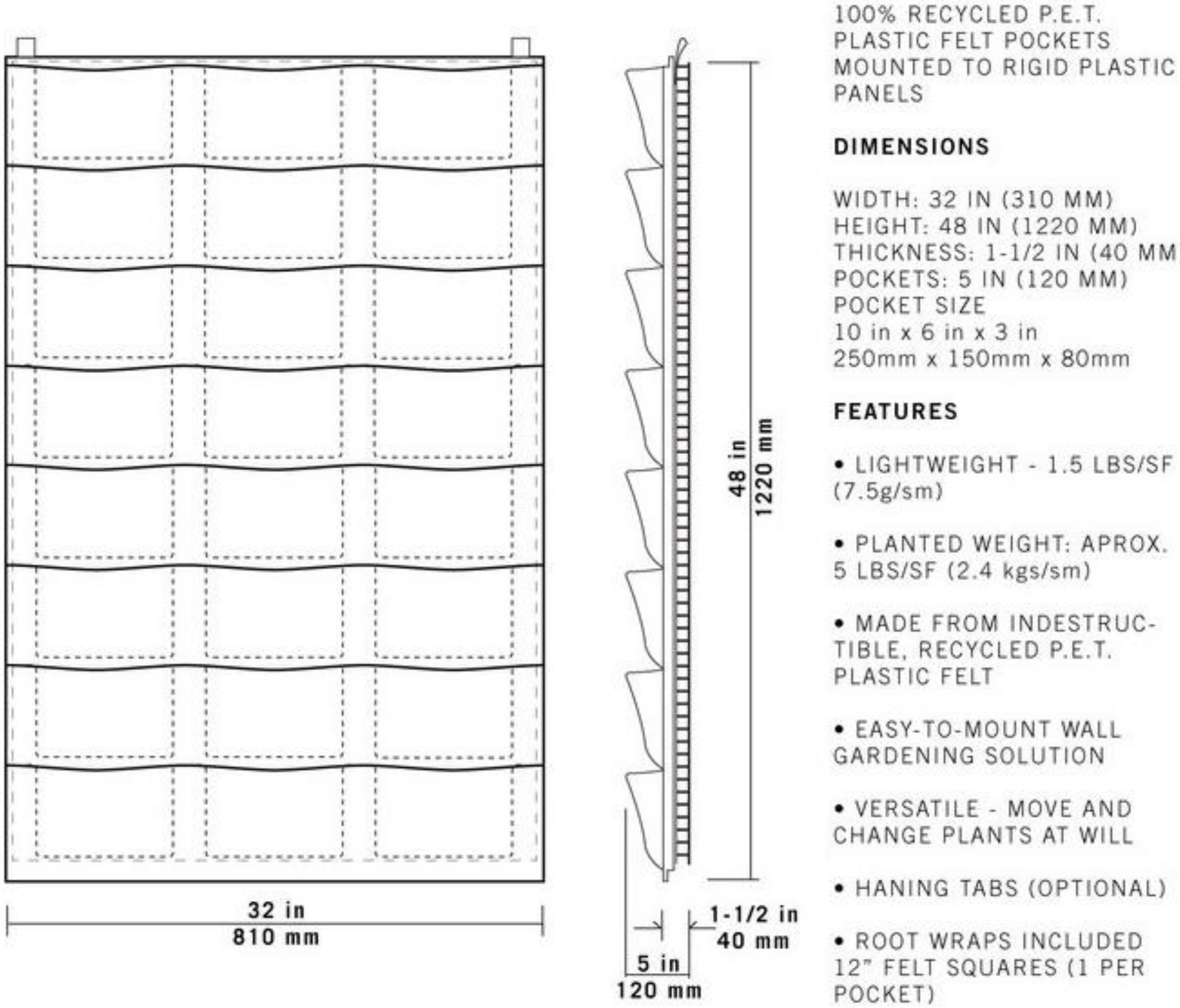


Figure 3.32: Florafelt 24-Pocket Living Wall Planter. Florafelt Pocket Panels Spec Sheets. (n.d.). Retrieved May 25, 2020, from https://florafelt.com/florafelt-pocket-panels-spec-sheets

Felt Pockets are made from 100% recyclable non-woven fiber felt (Florafelt). It has a great thermal insulation value and acoustical properties. The structure is hypoallergic, safe, and does not contain irritants and carcinogens (Florafelt). The drainage system is prepared before planting and connects at the bottom of the living wall. The excess water can be reused and recycled either for further living wall watering or the watering of other plants. The water source is provided on site and is ready prior to planting as well. Florafelt does not provide the built-in irrigation system, which means that it is necessary to develop your own before the installation process begins. According to Florafelt, irrigation systems typically include electromagnetic control valves, filter, pressure regulators, sensors, batteries, and other irrigation accessories.

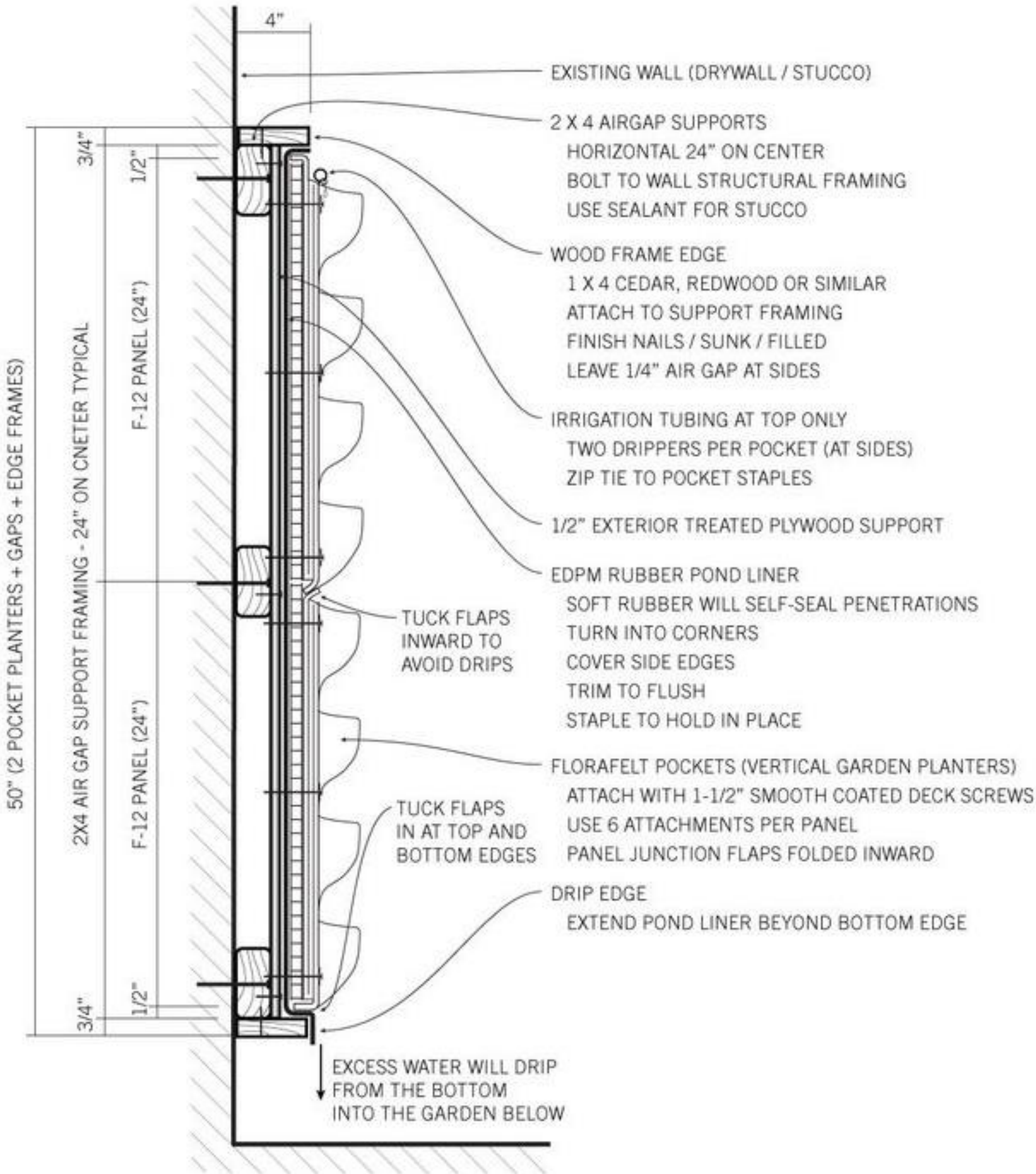


Figure 3.33: Wood Frame Installation Detail. Mounting Methods. (n.d.). Retrieved May 25, 2020, from https://florafelt.com/mounting-methods

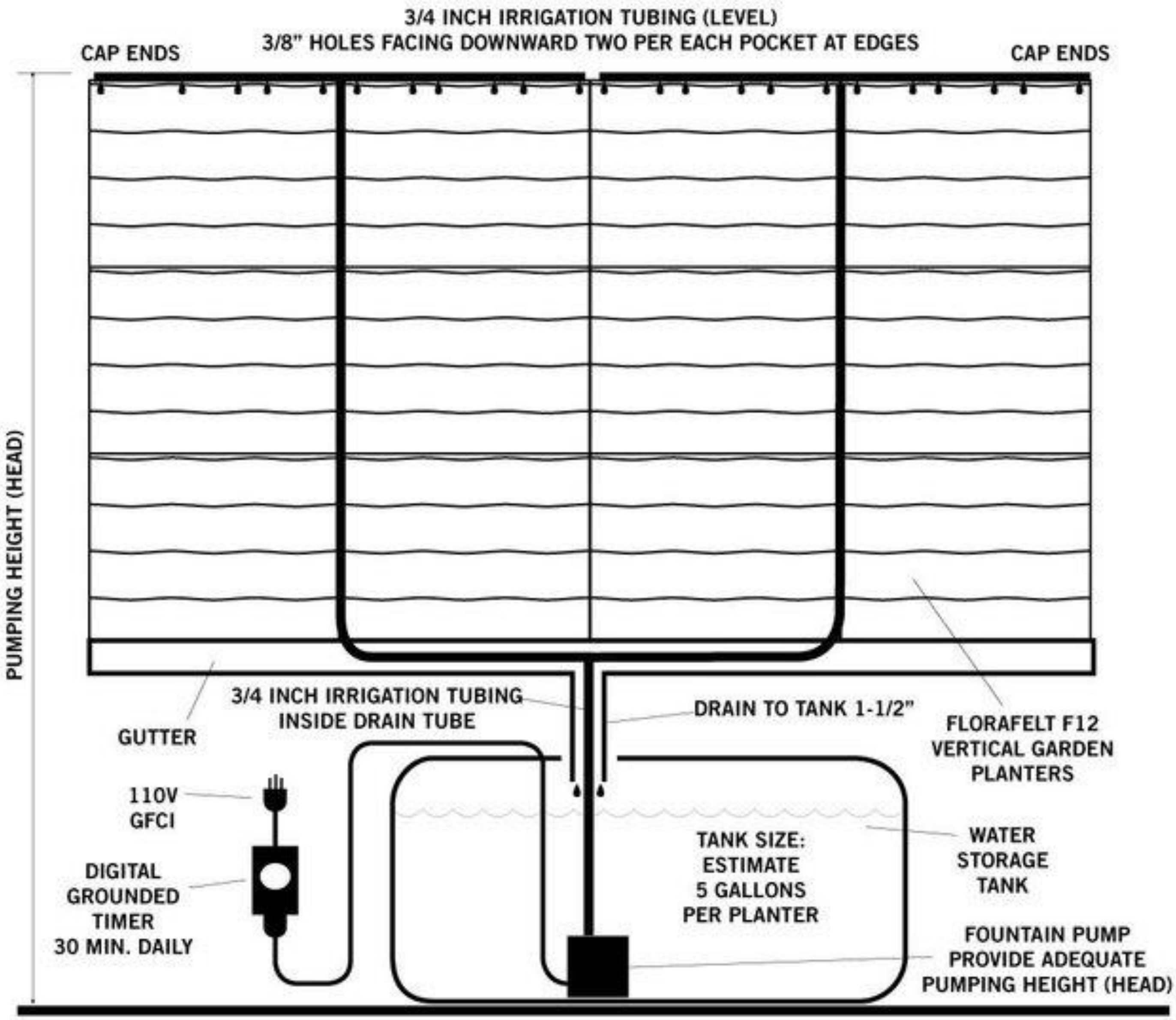


Figure 3.34: Florafelt Custom Recirculating System. Florafelt Pocket Panels Custom Recirc Installation. (n.d.). Retrieved May 25, 2020, from https://florafelt.com/florafelt-pocket-panels-custom-recirc-installation

The concept of the Florafelt Pocket Living Wall Planter was applied in the design of a home in Culver City, Los Angeles (figure 3.36). It included the installation of the Florafect Compact Living Wall Kit, which can fit eight plants. The project was completed in October 17th, 2017, by a collaboration between Tucker Warner Design and Florafelt (Florafelt). The living wall is highly efficient in optimizing indoor space by bringing benefits to a limited area. The living wall was placed in the dining room, which is organically integrated into the indoor environment.

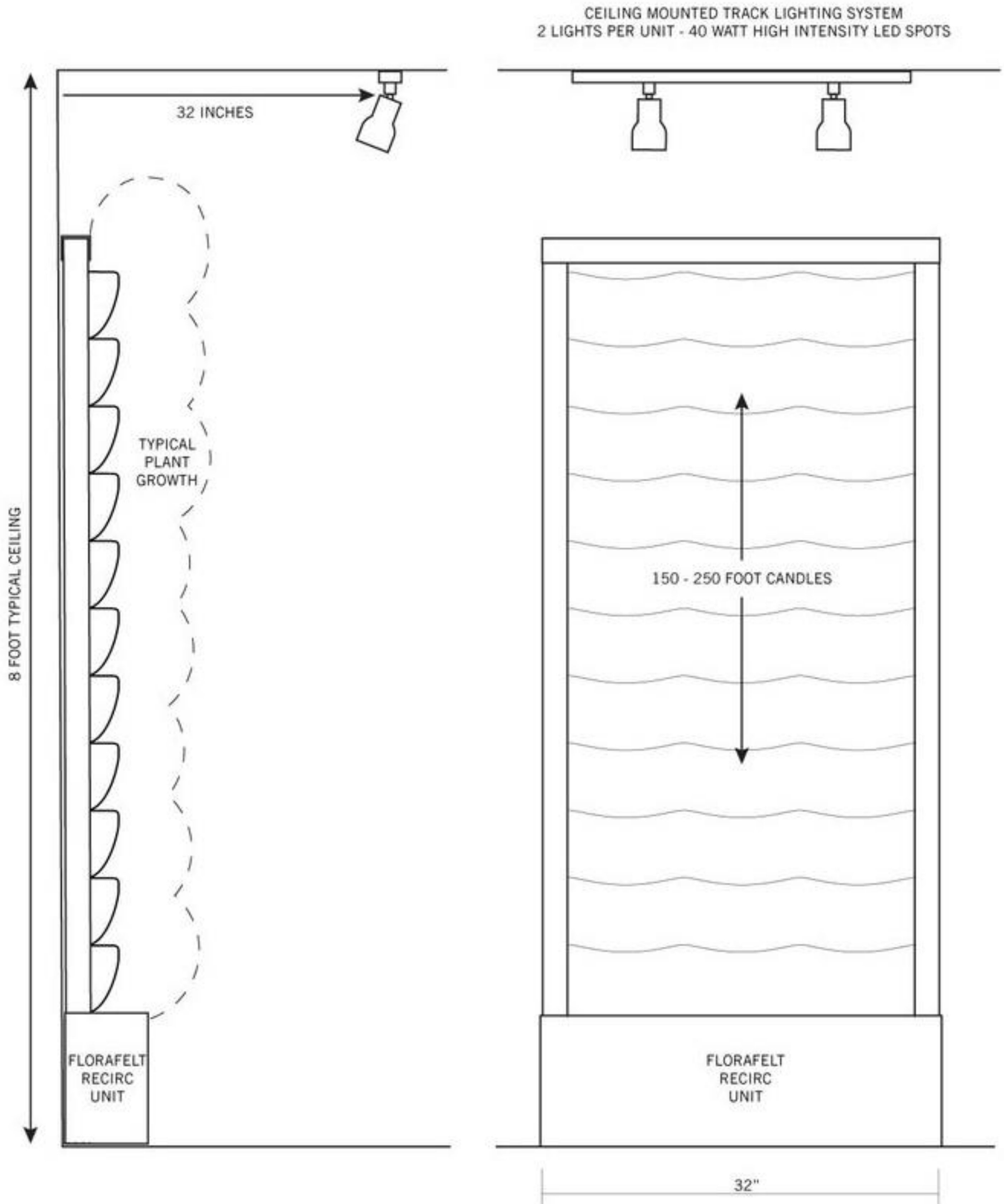


Figure 3.35: Recirc Interior Lighting. Florafelt: Guides: Lighting Guide. (n.d.). Retrieved May 25, 2020, from https://florafelt.com/lighting-guide

The Florafelt Compact Living Wall Kit is an affordable solution yet brings many benefits to users. According to Florafelt, the Florafelt Compact Living Wall Kit costs $289.00 and also includes a 3-gallon water bin, water pump & tubing, digital timer, full size pockets, root wrappers, and other necessary components for installation (Florafelt).

For this type of living wall, Florafelt recommends using lighting of 250-foot candles with a temperature around 70 degrees which is enough for indoor tropical plants (Florafelt). The fertilization options of plants will be dictated by the choice of plants and the average feeding cycle. Based on Florafelt, the balance of fertilization should be checked and maintained every six months in order to provide healthy plant growth. Typically, there are two main options of fertilization: manual and automatic. Manual fertilization includes the use of a spray to deliver an even distribution throughout the system, whereas automatic fertilization includes the use of pump with a dosimeter, which will automatically add nutrients into the irrigation system (Florafelt).

Conclusion

The Florafelt Compact Kit as well as other Florafelt Products represent an affordable method for creating an indoor living wall. One of the biggest advantages is not only its affordability, but also its easy installation process. Florafelt Living Wall can be installed by a user with agricultural or construction knowledge simply by following all the instructions presented on the Florafelt website. The flexibility of the system allows to multiply the existing number of pockets by adding extra felt, if needed. The system does not require high expenses, but will demand manual maintenance and watering.

Another important advantage is the lightness of the system. It does not require heavy structural support and can be simply fixed to a plastic board, which is also used for waterproofing. The lightness allows to move the living wall without additional expenses and services. Cradle-to-Cradle model, which Chris Bribach followed, allows the reuse of recyclable materials without leaving any impact on the environment. In sum, the installation of Florafelt Living Wall whether 4,12 or 24-Planter is an affordable solution to hydroponic gardening and improves indoor air quality.

Figure 3.36: Florafelt Compact Kit Indoor Living Wall at Culver City Home, Los Angeles. Bribach, C. (2017, October 17). Elegant and Simple Vertical Garden. Retrieved May 25, 2020, from https://florafelt.com/blog/elegant-and-simple-vertical-garden

3.3.5. NAAVA

NAAVA is an innovative company that makes smart indoor living walls for air purification purposes. It is a biological purifier, which was originally established based on NASA's indoor plants purifying power research (NAAVA). The NAAVA system combines the flexibility, affordability and innovativeness of indoor living walls. NAAVA is currently based in Finland, Sweden and the United States (NAAVA). The story of NAAVA begins from a personal experience of a co-founder Aki Soudunsaari. The idea was born from recalling his childhood moments when he spent most of the time outdoors by crystal clear lakes, forests, and rivers in Lapland, Posio (NAAVA). Aki realized that not everyone has the ability to enjoy and breathe clean air due to global air contamination problems which then affects indoor air quality (NAAVA). The central mission of NAAVA is to allow people to experience nature and clean air in urban settings and in places where people spend the most time such as offices, public spaces, commercial, and residential areas (NAAVA).

NAAVA provides five types of smart indoor living walls (NAAVA):

1) **Naava One;**
2) **Naava One Slim;**
3) **Naava Duo;**
4) **Naava Flow;**
5) **Naava Flow Duo.**

This paper will analyze the application of NAAVA One Indoor Living Wall, which serves as an air purifier bringing nature back into our homes.

NAAVA One Indoor Living Wall

Naava One combines the innovative technologies and uniqueness of natural Scandinavian designs. The team of NAAVA conducted a study identifying the positive aspects of Naava One use. The installation of Naava One includes a variety of benefits, such as a reduction of harmful chemicals, optimization of air humidity, prevention of indoor air diseases, increase of productivity, and overall improvement of cognitive performance.

As can be seen on figure 3.37, Naava One absorbs the air through the plant's roots and the soil-less media. Contaminated air is purified through the roots and then returned back fully clean. To accelerate air circulation, fans are installed inside the system that naturalize clean air back into the room. A smart automated system with sensors helps to analyze the level and need for nutrients, irrigation, or lighting requirements. For user's convenience, NAAVA has developed an application that tracks how a living wall works, what the system needs, and how successful the living wall is at air purification.

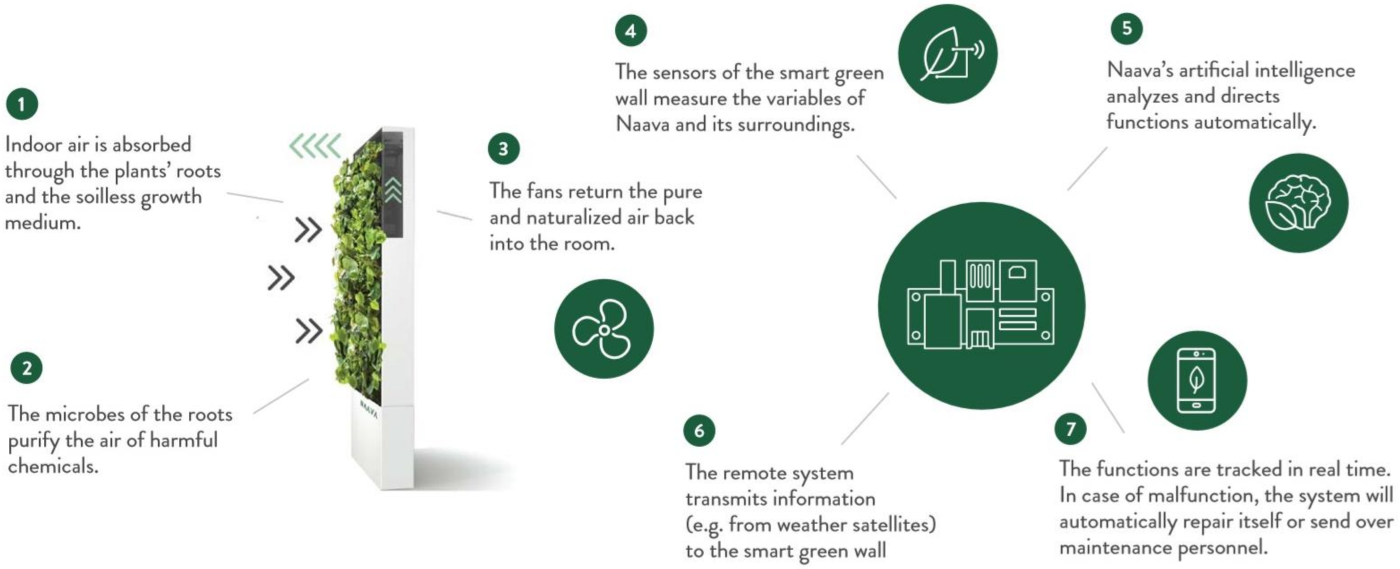


Figure 3.37: The Concept of NAAVA Living Wall. NAAVA. NAAVA Product Brochure. Retrieved from Naava. (n.d.). Download Materials. Retrieved May 25, 2020, from https://www.naava.io/en/download-materials

One of the greatest advantages of Naava One is the soil-free growth. It grows plants inorganically avoiding the growth of mold, smell, and allergens (NAAVA). The flexibility of the system allows living walls to be placed in any available indoor space or be used as a space divider, improving space efficiency. An apartment or home can include the combination of living walls placed in several rooms or zones creating a healthy living environment.

The entire delivery process consists of three stages: the analysis of indoor space and projection of Naava One into the space, delivery and installation including assembly and examination, final installation, and launch of applications (NAAVA).

Naava One is made of light aluminum and can be easily moved to another indoor location if needed. It comes in two colours: black and white with a maximum weight of 660 lbs. The standard size on Naava One is the following (NAAVA):

Width: 40";

Heights: 83", 91";

Depth: 14".

In the case of H 83”, Naava One can grow up to 63 plants, whereas the H 91” can grow up to 72 different plants species (NAAVA). Naava One includes a built-in lighting source located on the top of the living wall system.

Figure 3.38: NAAVA ONE Living Wall. NAAVA. NAAVA Product Brochure. Retrieved from Naava. (n.d.). Download Materials. Retrieved May 25, 2020, from https://www.naava.io/en/download-materials

Naava One should be placed in an indoor space with a temperature of at least 60°F in order to provide successful air purification and healthy plant growth (NAAVA). The system does not require natural light and is not recommended to be placed near an air vent.

For safety measures, Naava One is attached to the main structure from the top edges with minimal bracketing. According to NAAVA, Naava One does not restrict the choice of material onto which the LWS will be attached. For maintenance purposes, 4” extra should be left above Naava and 0.6” of space on both sides (NAAVA).

The lighting system is attached to the frame itself or can be fixed separately on the ceiling above Naava One. Typically, lighting duration is from 7am to 10pm (NAAVA). During the night lights are off, which is required for photoperiodism by the plants. There are three colour options of spotlights: white, silver, and black (NAAVA).

Naava One system needs to be constantly plugged into a source of electricity in order for it to work properly and deliver the necessary amount of nutrients and water to the plants. According to NAAVA, LWS consumes about 15 kWh per month, which is less than the energy consumption of a microwave.

Naava One represents a free-standing innovative living wall, which can be used as an interior design feature as well. The backside of Naava One can also be used as a magnetic whiteboard. The purification power of Naava One can cover up to 645 sq. ft. (NAAVA). Smart technologies of Naava One optimizes its performance 24/7. It includes various sensors, connection to the cloud for identification of indoor environmental changes, real time feedback, air circulation system, and automated irrigation.

The concept of Naava One was applied in a private studio in downtown Helsinki (figure 3.41). The main goal of the client was to fill the indoor environment with nature and provide clean and fresh air. Naava One was placed in the middle of the living room. It was necessary to place the living wall to allow constant visual contact of nature and expand the air purification power of the living wall to all areas of the apartment. Living wall organically fits into an indoor space, creating a design accent and enhancing the efficiency of the space itself.

Naava One is compatible with 12 different plants species including seasonal plants that allows for the broad choice and combination of patterns (NAAVA). During the design stage, the NAAVA team identifies the most compatible plant combinations and creates individual settings for watering, irrigation, and lighting. Compatible plant selections can be found on figure 3.40.

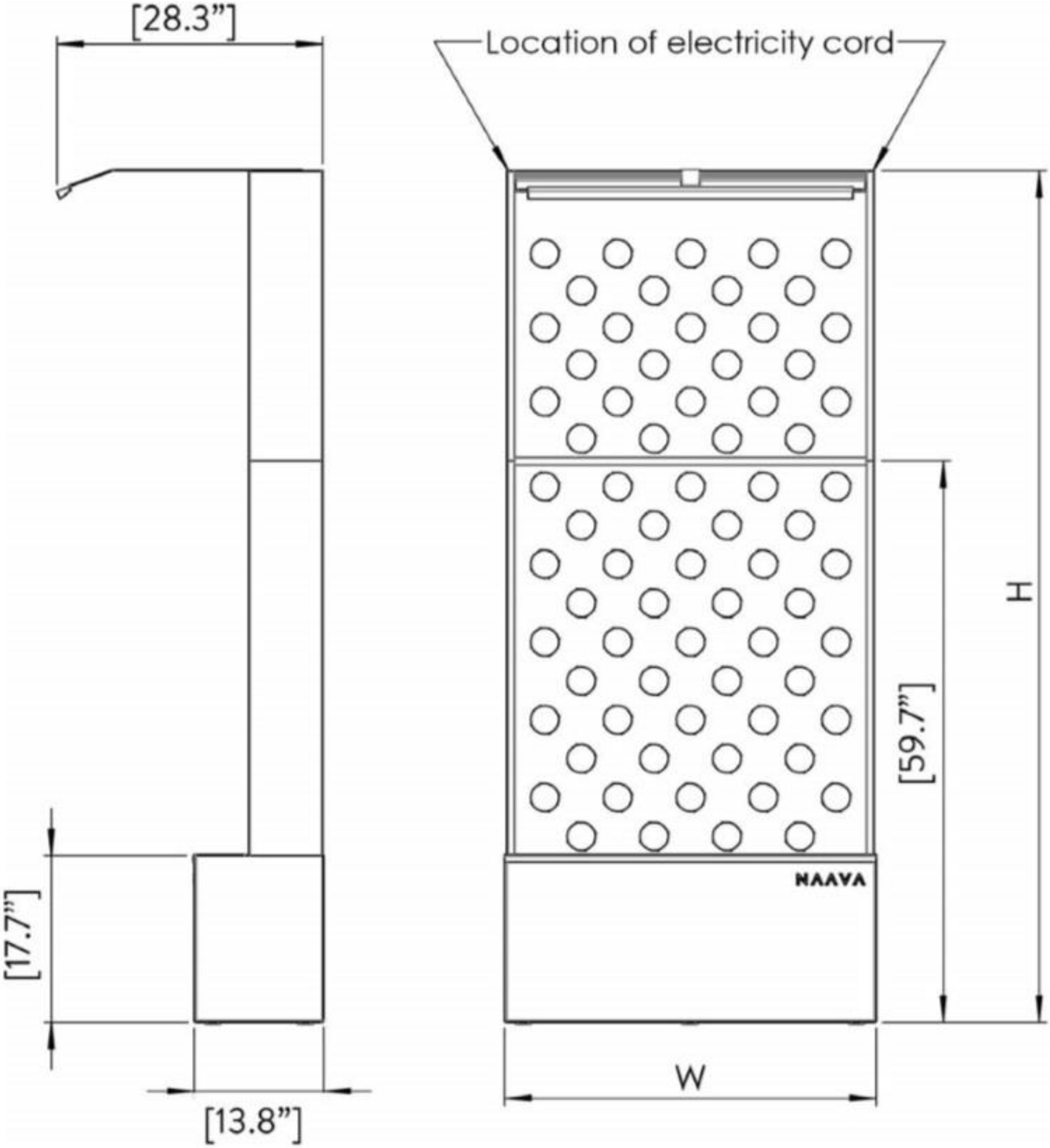


Figure 3.39: NAAVA ONE Living Wall Dimensions. NAAVA. NAAVA Design Guide. Retrieved from Naava. (n.d.). Download Materials. Retrieved May 25, 2020, from https://www.naava.io/en/download-materials

Figure 3.40: Plants Selection. NAAVA. NAAVA Product Brochure. Retrieved from Naava. (n.d.). Download Materials. Retrieved May 25, 2020, from https://www.naava.io/en/download-materials

Conclusion

Naava One living wall is the representation of how smart technologies make our life more efficient and healthier. One of the greatest advantages is the flexibility of the system as it can be placed anywhere in the indoor space without any lighting regulations. Additionally, it does not require much maintenance and irrigation as the system is fully automated and can be controlled from the phone. The information related to costs is not provided online, but can be obtained by directly contacting the team through their website. Naava One is a great example of how such a compact system is efficient in purifying a big area covering up to 645 sq. ft yet minimizing the "heaviness" of the space.

Figure 3.41: NAAVA ONE Indoor Living Wall in Private Residence, Helsinki. Niemelä, E. (2018, January 29). Smart Green Wall Brings Nature into Urban Home. Retrieved May 25, 2020, from https://www.naava.io/editorial/smart-green-wall-brings-nature-into-urban-home

Naava One can be successfully used in small apartments where area is limited in order to optimize space efficiency. This living wall is designed only for air purification and humidification purposes and does not provide an opportunity for food growing. Despite that, Naava One is the new generation of living walls. They will improve not only the quality of indoor air but enhance the well-being and cognitive performance of a person.

3.3.6. Biotecture

Biotecture is based in the United Kingdom and has become one of the leading Living Wall companies. Biotecture's mission is to transform the lifestyle of people by connecting them with nature and enhancing the well-being of people and the planet. The team at Biotecture consists of various qualified specialists such as a plant manager, maintenance technician, directors, managers, and supervisors, who help to install a living wall and assist throughout its journey (Biotecture). The work done by Biotecture ranges from outdoor to indoor living walls as well as its space location such as commercial, cultural, educational, residential, public spaces, and transport hubs. According to the direction of this research report, this case study will concentrate on providing details about residential indoor living walls.

Besides hydroponic indoor and outdoor living walls, Biotecture offers complimentary green products and services (Biotecture):

1. **Bespoke Projects:** includes Integrated Biophilic Design (living walls, sustainable urban planters, climbers with its full installation and lighting design), Value Engineering (the application of techniques and biophilic design methods to achieve cost-effectiveness), Grand Ideas (long term partnerships including design stages, planning, implementation and maintenance);
2. **Green Screens:** design, installation, and maintenance are being provided for green screens. It additionally requires the insertion of irrigation system, which is done by Biotecture specialists;
3. **Plant Box:** simple, flexible, and adaptable system, which can be installed indoors and outdoors. It does not require an irrigation system. The structure can be free-standing or wall-mounted, offered in diverse range of dimensions, which suits any requirements. Plant Box is a lightweight and easily installed system, adaptable to any configurations.

Biotecture Living Wall

Biotecture offers a living wall, which was invented by the founders of the company. It represents a modular system (figure 3.42) that provides the best flexibility for insertion into existing design conditions. One of its biggest advantages is that the system minimizes water use and stays resilient throughout the use.

Biotecture Living Wall consists of panels that come in the standard sizing of 600mm wide and 450mm high (Biotecture). Panels are fixed onto T section recycled aluminum rails (Biotecture). The rails are mounted to a backing board, which serves as waterproofing material, separating the rest of fabric from the main wall (Biotecture). Biotecture states that during the design process, the panels can be adjusted by cutting and trimming the edges in order to suit existing conditions.

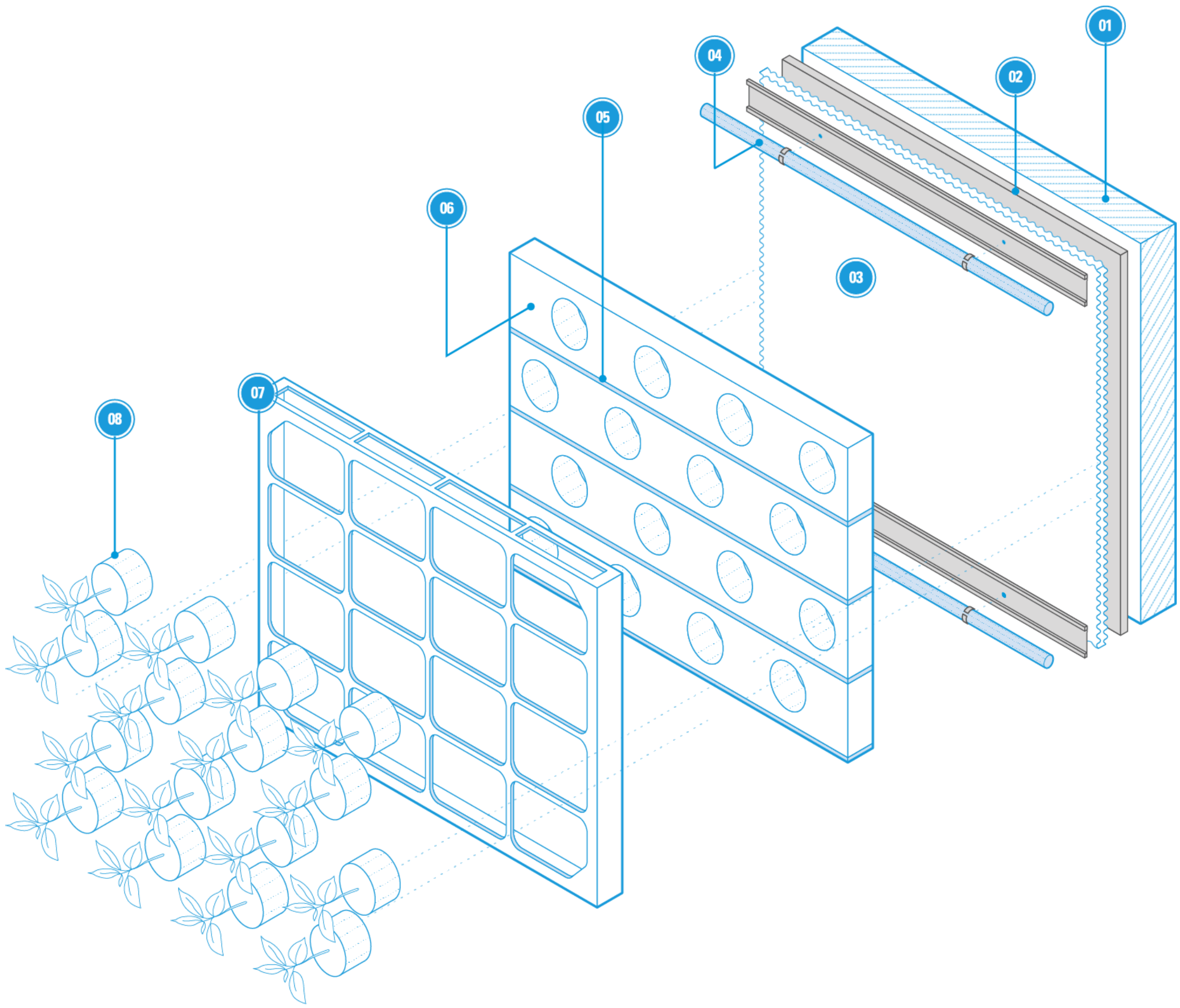


Figure 3.42: Biotecture Living Wall Specification. Green Wall Specification and Drawings. (n.d.). Retrieved June 03, 2020, from https://www.biotecture.uk.com/design-and-specify/specifications-and-compliance/specifications-and-drawings/

Biotecture Living Wall includes (Biotecture):

1) Supporting structure;
2) Waterproofing material;
3) Rear drainage;

4) Aluminum rails and dripline;
5) Growing material;
6) Panels;
7) Plants.

Biotecture recommends ensuring an even amount of water at any location of the living wall, including various plant demands according to species and their location. The most important factor is to avoid the overuse of water through controlling the required amount for proper plants flourishment.

Biotecture uses a hydroponic method developed for living walls that predicts the behavior of plants and gets the full efficiency from the living wall installation (Biotecture). It helps to avoid vertically stacked soil and therefore, achieve durable and healthy indoor living walls. Biotecture created an innovative hydroponic method “Grodan” (Biotecture). It represents long-lasting, water resistant and efficient method of planting (Biotecture).

According to the author, the use of regular soil requires more nutrients, water, and energy. However, the “Grodan” method allows plants to receive necessary components in precision without extra expenses and effort (Biotecture).

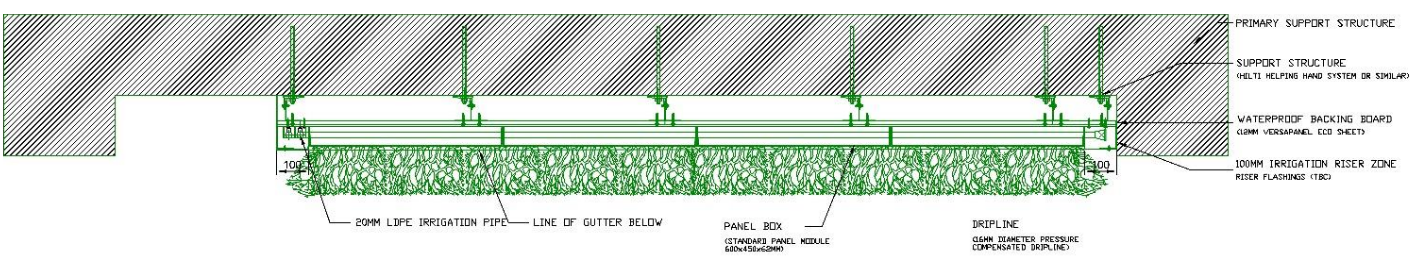


Figure 3.43: Plan of Biotecture Living Wall. Green Wall Specification and Drawings. (n.d.). Retrieved June 03, 2020, from https://www.biotecture.uk.com/design-and-specify/specifications-and-compliance/specifications-and-drawings/

“Grodan” hydroponic method differs from other systems by its absence of ionic bonding inside nutrients, which has a zero-cation exchange (Biotecture). It works as a sponge by accumulating 95% of the air and 80% of moisture inside before the system begins to drain (Biotecture). The system allows to hold 15% of volume for air in order to prevent plants from overwatering. “Grodan” requires far less water compared to regular soil and can easily help to predict water demand for plants (Biotecture).

Prior to the installation process, Biotecture offers consultation, including existing design drawings and living wall specification (CAD and PDF). The Biotecture website offers various samples of specifications, drawings, engineering assessment, and operational testing.

Living wall is fully artificially irrigated and organized by cladding panels that are made of inorganic growing material (Biotecture). It is mounted with a void former and waterproof protector and fixed to the rails (figure 3.43, 3.44) (Biotecture). According to Biotecture, the approximate weight of panels, including growing material and plants, is 65kgs per m^2 (Biotecture).

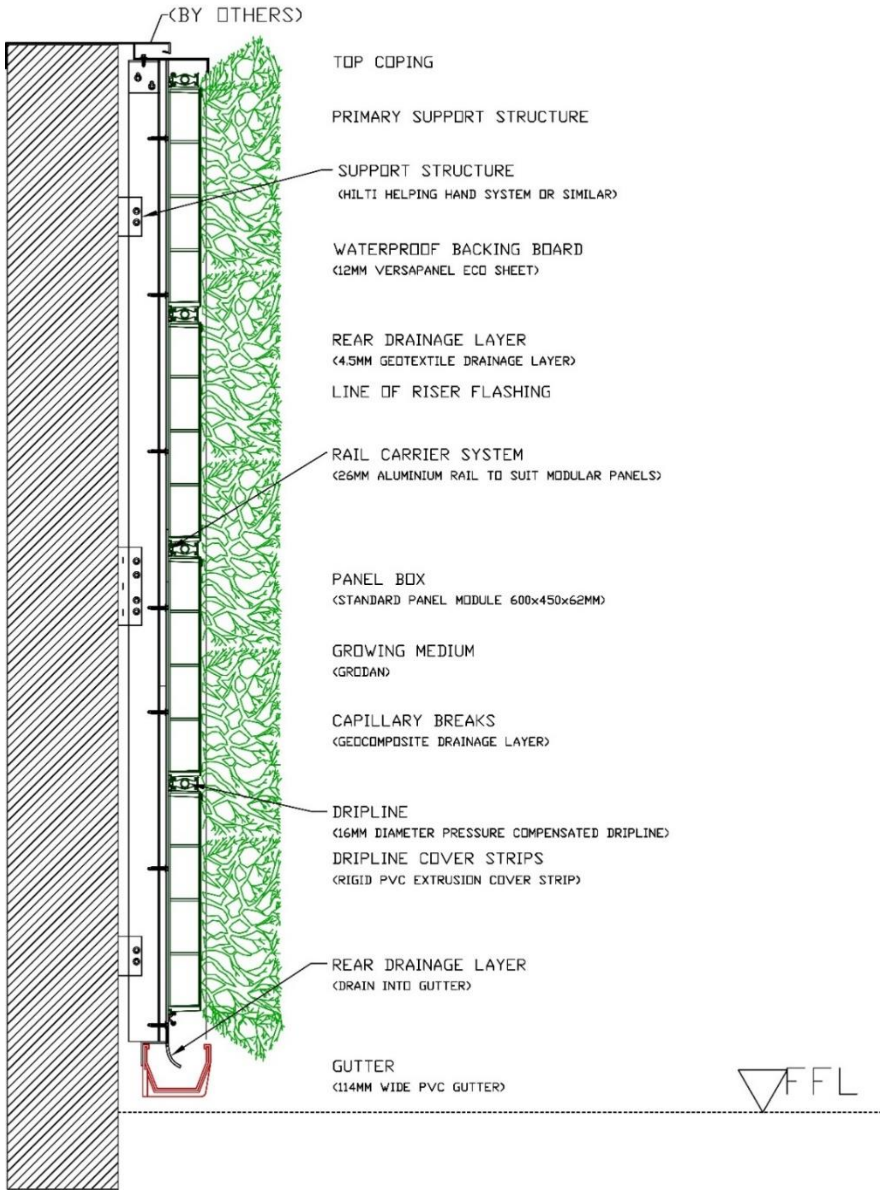


Figure 3.44: Biotecture Living Wall Section. Green Wall Specification and Drawings. (n.d.). Retrieved June 03, 2020, from https://www.biotecture.uk.com/design-and-specify/specifications-and-compliance/specifications-and-drawings/

Biotecture uses the standard dimension of supporting structure, providing 600mm coverage horizontally, 300mm vertically and 150mm for exposed perimeter locations (Biotecture). Typically, Biotecture applies galvanized steel box sections or timber battens as the main material for support (Biotecture). Waterproofing material consists of 12mm resistant board "Versapanel Eco sheet" or a similar material fixed to support (Biotecture). Modular panels are also attached to "T" profile rails that carry the system together. Cladding panels are organized by applying the black polypropylene component, which is produced from recycled polymer (Biotecture).

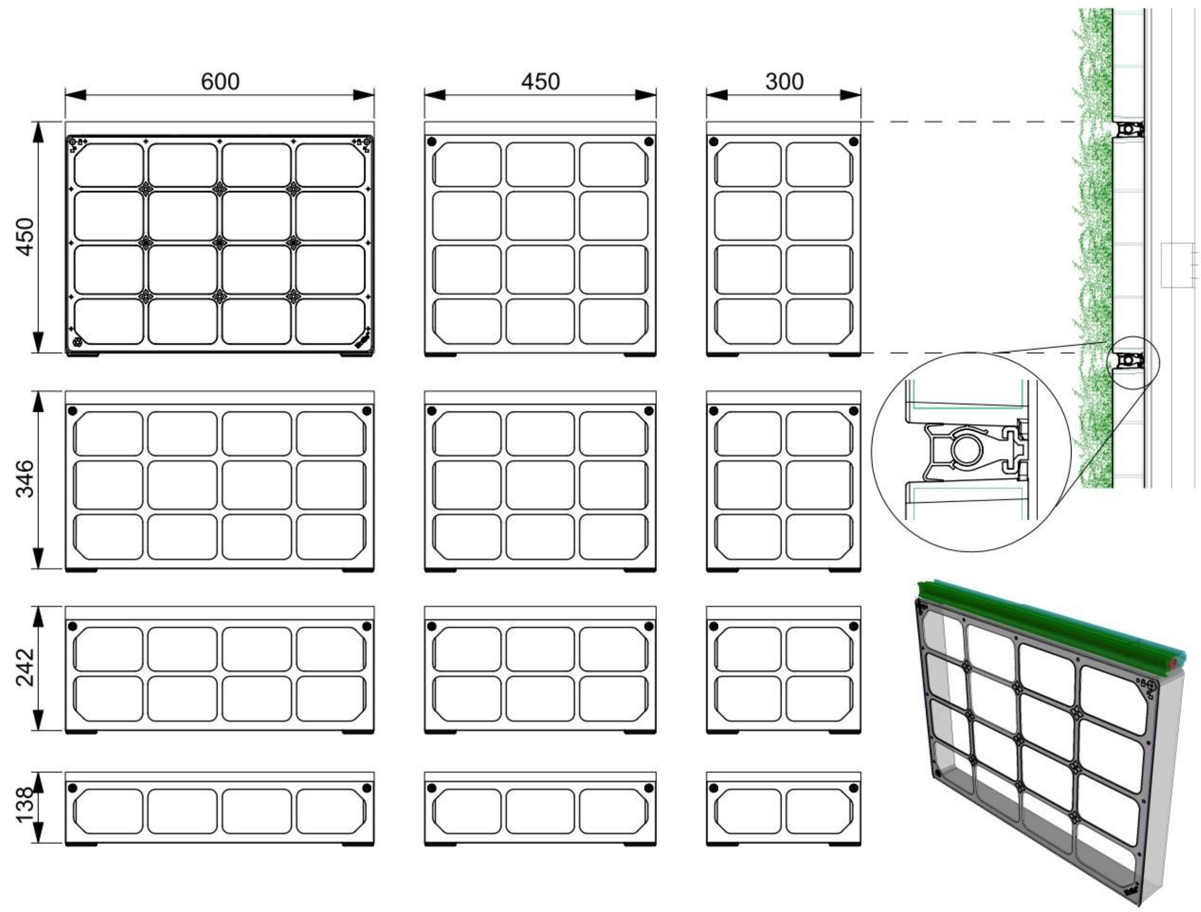


Figure 3.45: Standard Biotecture Living Wall Panels. Biotecture (2015). Technical Report. Retrieved from https://www.biotecture.uk.com/design-and-specify/specifications-and-compliance/specifications-and-drawings/

Standard panel sizes come in 600mm wide, 450mm high and 62mm depth (figure 3.45). The material of growing media consists of 'stonewool' with a nominal density of 16.8 kg/m^3 (Biotecture; figure 3.46). Rear drainage consists of high-density polyethylene including geotextile filter at one side, which acts as waterproofing material and a drainage layer at the other side (Biotecture).

Figure 3.46: Sample of Hydroponically Grown Plants. Hydroponic Living Wall for Plants That Thrive. (n.d.). Retrieved June 04, 2020, from https://www.biotecture.uk.com/design-and-specify/why-hydroponics/

Biotecture states that plants can be grown according to 60 plants per sq. m. The selection process of plants is done by specialists and the client, which helps to identify compatibility with indoor climatic conditions. Plants are planted into the BioTile panels and usually take a minimum of twelve weeks to be produced (Biotecture).

Water is applied by using irrigation driplines (not less than 16mm in diameter) (Biotecture). The water tank holds a sufficient amount of water to supply plants throughout the 24 hours cycle. It is delivered by pumps and equally distributed to all drip points (Biotecture). Additionally, the irrigation system is connected with a remote sensing controller, which helps to assure safety and sufficiency of necessary elements. The controller is connected to maintain the flow rate of each section of the living wall by applying interval screening (Biotecture).

Fertigation is managed by the addition of nutrients into the water supply by using Dosatron, which controls the dosage (Biotecture). According to specialists, it should vary between 0,2% and 0,5% depending on the volume of plants and the size of a living wall. Drainage is organized by 114mm wide plastic gutter, which is then mounted at the foundation of a living wall (Biotecture). It allows to collect extra water supply with 32mm outlet. Alternatively, pressed aluminum gutter 90x60x120mm can be used (Biotecture).

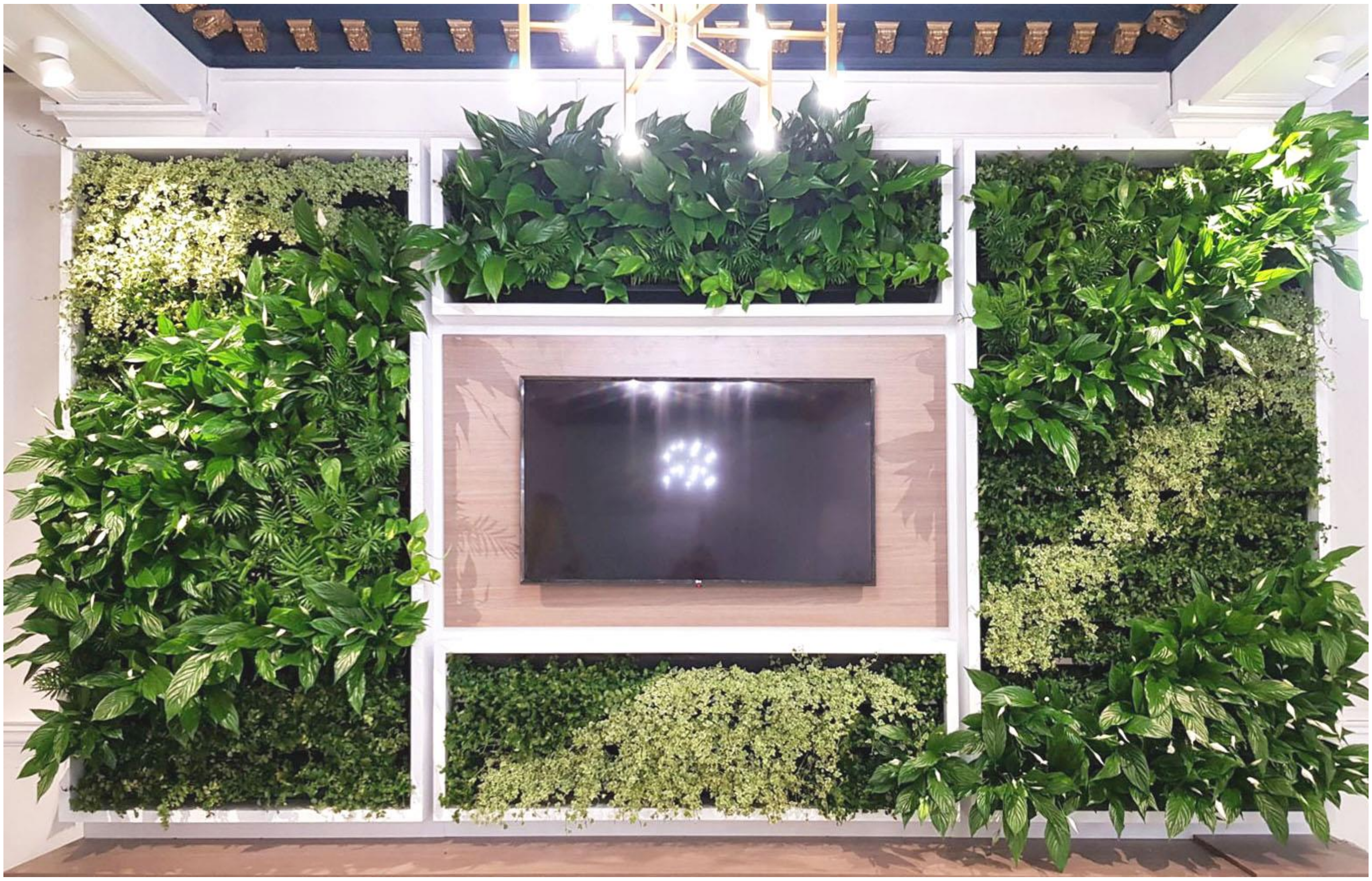


Figure 3.47: Bonham Carter House Indoor Living Wall. Hospital Reception Area Living Wall: Bonham Carter House. (n.d.). Retrieved June 16, 2020, from https://www.biotecture.uk.com/portfolio/bonham-carter-house/

Following the above requirements and instructions, Biotecture designed an indoor living wall in Bonham Carter House (figure 3.47) (Biotecture). The living wall was designed in 2018 in London, United Kingdom (Biotecture). It covers approximately 13 m^2 and is used as a full design feature (Biotecture). The living wall structure was integrated in the downstairs space surrounding a TV screen. The integration of a living wall in this case helps to absorb the heat from the TV and lifts the look of a space by saturating it with plants. According to Biotecture, minimal natural lighting with the combination of a living wall provides a lighter feeling to a space. This living wall demonstrates how living walls can be integrated in design settings according to the client's preferences or requests. It demonstrates the possibility to create flexibility of indoor living wall systems that can be adapted by creating innovative designs. Biotecture used hydroponically-grown plants in conjunction with a plant mix to create a unique interior design of the downstairs space. The example reveals that there will be no conflict between electronic appliances and an integrated living wall in terms of moisture and humidity levels, if the system was installed correctly. In this scenario, Biotecture provided its full support in creating a unique natural experience for the indoor space.

Conclusion

Biotecture living walls represent the efficiency and affordability of the system provided by the combination of modules, prefabricated structures, and hydroponically grown plants. As shown in the above example, Biotecture LWS can be easily integrated into design settings of indoor spaces without creating moisture and humidity conflicts. One of the biggest advantages of the Biotecture system underlines in the precision of nutrients and water supply, which allows to reduce or completely avoid waste of water and extra expenses. Irrigation sensors installed into the system provide full 24-hour management of living wall working processes. This makes it easier for clients to manage necessary requirements. The modularity of the system allows for an adaptive living wall in indoor settings and if needed, one can replace partitions without any issues. Biotecture LWS highlights the simplicity of its implementation and maintenance that will help a client maintain good plants and structure conditions. For the potential client's convenience, Biotecture provides a full spectrum of information including detailed drawings, benefits, and the maintenance process on their website, allowing one to choose a better indoor living wall option.

3.3.7. Sagegreenlife

Sagegreenlife was founded in 2010 by the founder of Equity Office CEO, Richard Kincaid (Sagegreenlife). The office is based in Chicago, Illinois, and provides services in North America and other countries (Sagegreenlife). Sagegreenlife is composed of various specialists and is subdivided into sales & horticulture, operations, finance, product development, and marketing & brand departments. The diversity of team specialists permits the creation of innovative products and delivers living walls according to specific preferences and requirements. The main mission of Sagegreenlife is to create a better quality of life by integrating biophilic designs. It connects nature with outdoor and indoor environments including real estate, healthcare, educational, commercial, and corporate spaces. According to Sagegreenlife, over 300 biophilic products were installed around the globe with their patented unique hydroponic technology, resource-efficient installation, and management approach (Sagegreenlife). Establishing the company, Richard Kincaid was driven to help people and companies connect with nature and to acquire the full potential of plants including aesthetic, biological, and psychological means (Sagegreenlife).

Besides outdoor and indoor living walls, Sagegreenlife provides two main products:

1) **Flourish:** a living wall with a custom design and the use of a self-contained water system. It represents a modular LWS, which can be flexible and relocated to the desired space (Sagegreenlife);
2) **Duet:** demonstrates two-sided, self-contained living wall system, used as a mobile partition. It can be applied as a room or space divider and as a sound barrier. This free-standing living wall on wheels can be moved around and adapted for special needs (Sagegreenlife).

The research report will analyze the use and technical aspects of the Flourish living wall system. It will include elevations and top views of prototypes along with a table comparison of Sagegreenlife wall with other traditional living wall systems. Additionally, irrigation, its main components, and smart technological aspects will be included to describe how LWS is connected and can be controlled remotely. The end of this section will concentrate on an indoor living wall implemented project done by Sagegreenlife according to their patented technology and parameters.

Verdanta Flourish Living Wall

Flourish represents a modular living wall (figure 3.48), which allows to adapt to any indoor size availability to fulfill the space with nature and beauty. It is organized as a snap where each of them includes self-contained irrigation system, making it easy to install and maintain .

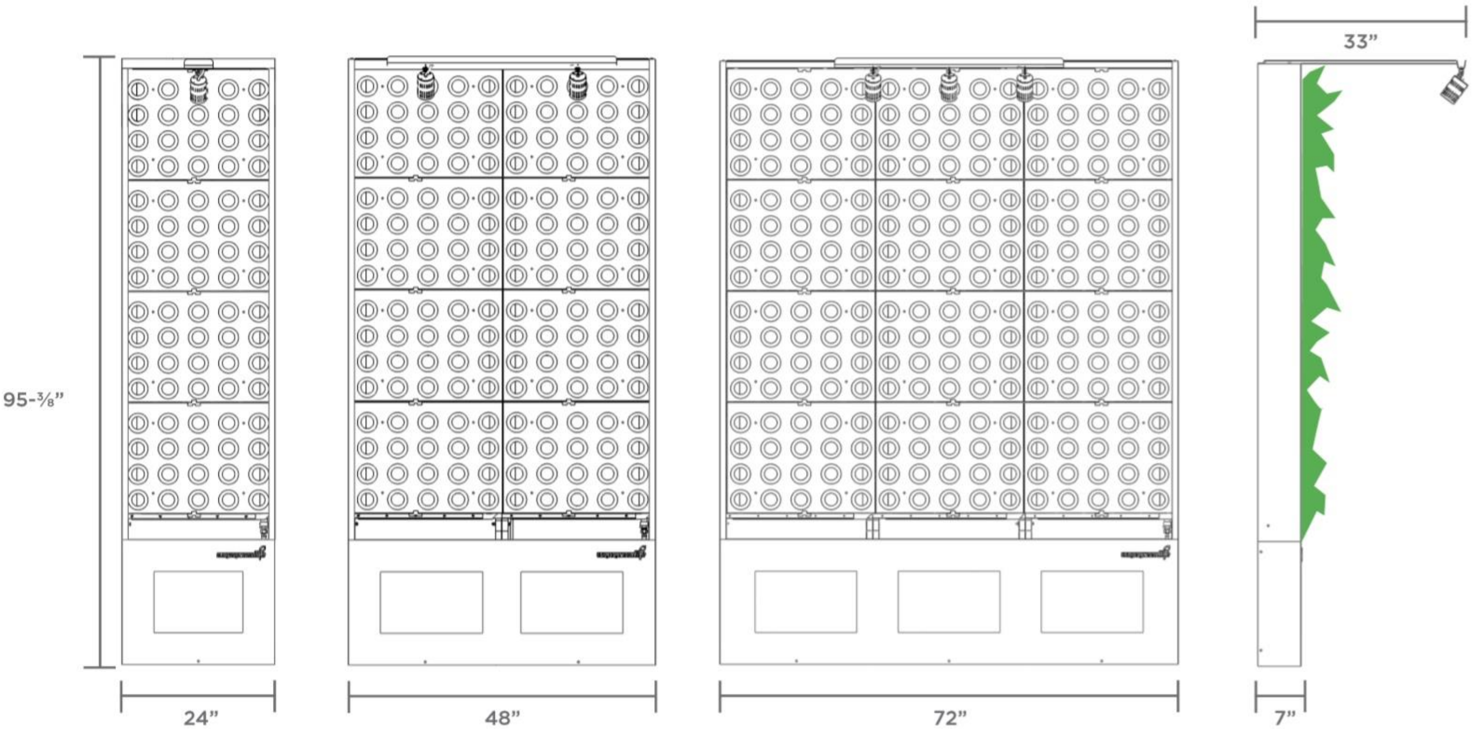


Figure 3.48: Basic Dimensions of Verdanta Flourish Living Wall. Sagegreenlife. Verdanta Flourish Product Sheet. Retrieved from https://www.sagegreenlife.com/product/flourish/

Dimensions 2’	95-⅜”H x 24”W x 7”D
Dimensions 4’	95-⅜”H x 48”W x 7”D
Dimensions 6’	95-⅜”H x 72”W x 7”D
Plants	80 (24”), 160 (48”), 240 (72”)
Plant Palette	Tropical foliage
Lighting	One (24”), Two (48”), or Three (72”) LED grow lights
Growth Medium	Soil free rock wool
Irrigation	Self-contained recirculating system
Tank Capacity	Two weeks
Weight (per 24”w Module)	85lbs (empty), Approx 275lbs (plants + water)
Power	120v AC, Single three-prong grounded outlet
Delivery	12 weeks
Colors	Polar white, Medium gray, Charcoal

Figure 3.49: Dimensions and Characteristics of Verdanta Flourish Living Wall. Sagegreenlife. Verdanta Flourish Product Sheet. Retrieved from https://www.sagegreenlife.com/product/flourish/

The main component of Sagegreenlife living wall is a Biotile. Biotile represents a cornerstore organized as a layer of tiles (figure 3.50) (Sagegreenlife). It is used as a rock fiber and Rockwool, which allows an easy and even distribution of water and nutrients to the system (Sagegreenlife). The advantage of the system can be explained by its absence of potential mold or decay, which brings sustainability to the rooting system and plants environment.

Figure 3.50: Biotile Components Overview. Vertical Garden Watering System & Technology. (2020, March 03). Retrieved June 20, 2020, from https://www.sagegreenlife.com/process/technology/

Biotile is a biodegradable material as it can be recycled or reused later. Another big advantage is the stability of Rockwool material, since the material does not expand or change in size whether it is in dry or wet, cold or hot conditions (Sagegreenlife).

The irrigation system of Sagegreenlife (figure 3.51) is fully integrated into the system and concealed inside in order to keep plant material visible. One of the features of such irrigation system is the full control of the amount of water. It delivers only the necessary amount of water that the plants need and avoids any waste.

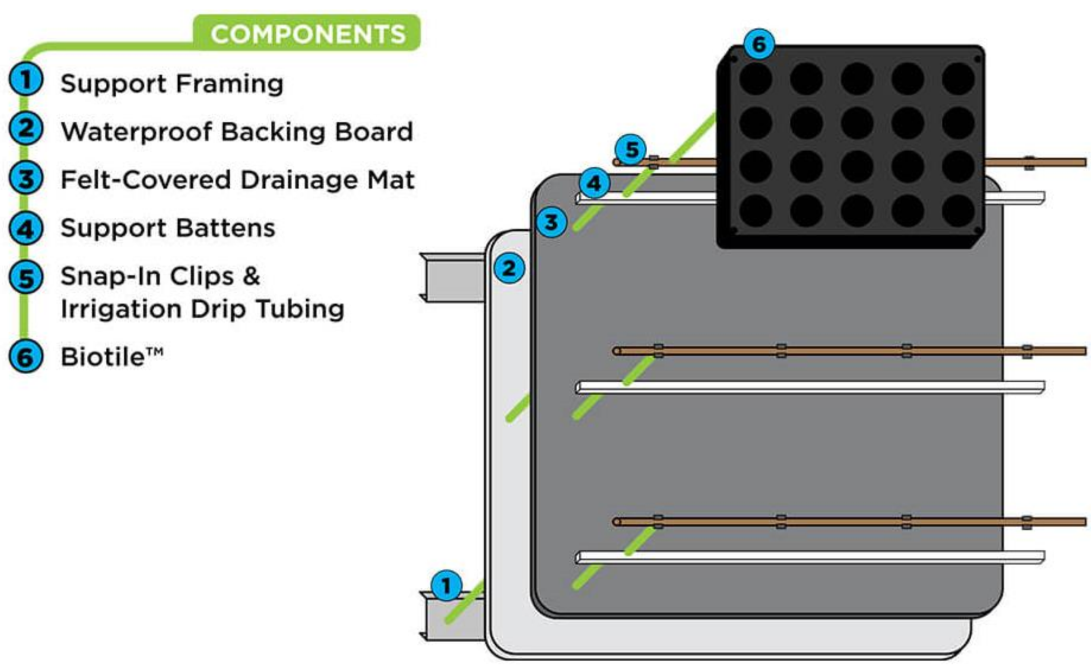


Figure 3.51: Irrigation System Components. Vertical Garden Watering System & Technology. (2020, March 03). Retrieved June 20, 2020, from https://www.sagegreenlife.com/process/technology/

Sagegreenlife living walls are monitored by Internet of Things Technology (figure 3.52), which provides real-time information, alerts, and maintenance requests to protect plants' health (Sagegreenlife). The system is connected to the living wall over 4G cellular data network including attached sensors and irrigation controllers that ensure the best living wall performance (Sagegreenlife).

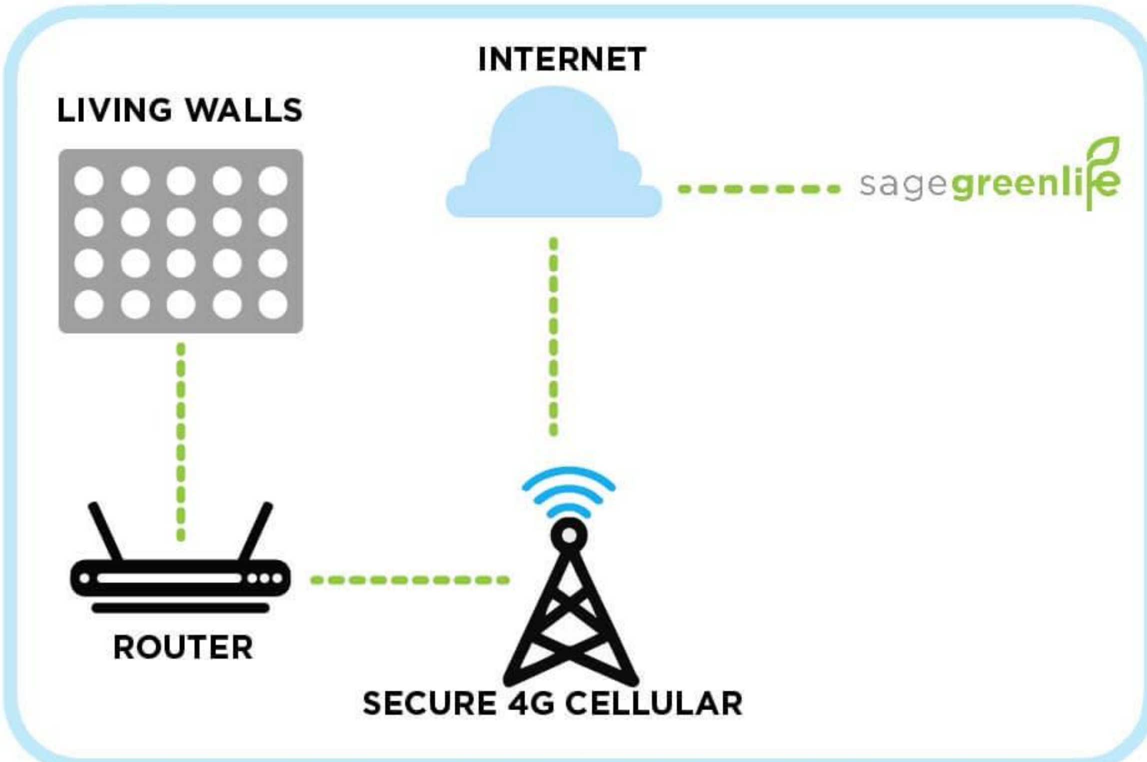


Figure 3.52: IoT Sagegreenlife Technology. Vertical Garden Watering System & Technology. (2020, March 03). Retrieved June 20, 2020, from https://www.sagegreenlife.com/process/technology/

Sagegreenlife offers a plant palette, where clients can choose plants that will be suitable for specific indoor conditions. It includes tropical plants that were designed by horticultural specialists. According to Sagegreenlife, Dracaena compacta, Ficus Repens, Philodendron "Brasil", and Arboricola "Mini Green" are the most suitable plants for indoor environments as they can be grown in low light areas.

Sagegreenlife provides a detailed maintenance guide, including: (Sagegreenlife):

1) **Pinching:** the removal of tips to permit new growth. It provides an opportunity to spread and become bushier. It is necessary to remove a small section of the stem for young growth. According to Sagegreenlife, a client should pinch above a node (the point of leaf attachment to the stem);

2) **Pruning:** the removal of dead stems and brown or yellow leaves in order to avoid decay. Based on Sagegreenlife, pruning is usually done in late spring and summer months using sharp pruners or scissors to shape the form of plants and the composition itself;
3) **Shearing:** used to shape large areas of plants to allow for fast growing, more denser environments and branching. It encourages repeat blooming and is used to protect the distinction between diverse plant masses. Sagegreenlife's advice is not to remove more than one-third of the plant;
4) **Deadheading:** the removal of faded flowers with pruners and scissors. Deadheading in the interior wall should be done as soon as noticed by removing flowers and developed seeds in order to redirect plant's energy into root growth and re-blooming;
5) **Cleaning**: The foliage can be cleaned by light spray or mist to remove dust and provide moisture when indoor air is dry. Wiping leaves clean with a cloth or a wet sponge will allow plants to absorb more light. Hairy leaves can be cleaned with a feather duster by brushing. Fine-foliage plants such as ferns can be cleaned with a spray of water or a pressurized watering tank;
6) **Plant replacement:** plants can be replaced by a compatible plant type that has similar characteristics to the original plant. For indoor wall plant replacement, 3''-4'' finished plant material should be used;
7) **Nutrients:** Distributed water should contain fertilizers that can be added into the tank every three months. Sagegreenlife recommends adding a ¼ teaspoon of dilution per gallon of water.
8) **Irrigation inspection:** includes the inspection of moisture levels (two times a month), the addition of fertilizers (two times a month), the inspection of components such as heads, valves, emitters, filters, timers, sensors and control system, replacement of irrigation line emitters when necessary, and cleaning of hard surfaces;

Patented Sagegreenlife living wall technology was implemented in an indoor area of South Loop's Eleven 40 residential building in Chicago (figure 3.54) (Sagegreenlife). The living wall is located in the common area and designed to reach the full height of the ceiling. The area combines chairs, sofa, and a table, with the living wall which brings up a sense of nature and enhances indoor environment. The living wall was fully customized to the existing indoor settings and climate conditions. It included a combination of various tropical plants, representing a unique design and diversity of plants.

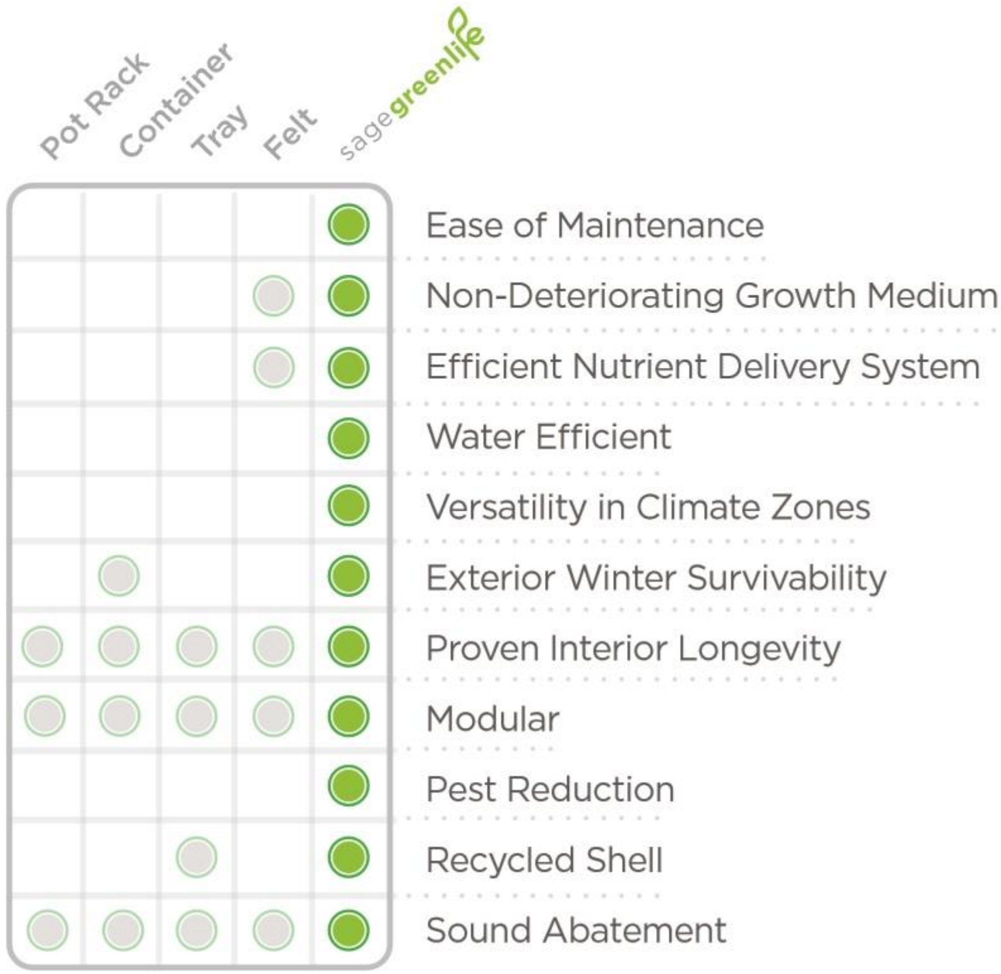


Figure 3.53: Sagegreenlife Technology Comparative Analysis. Sagegreenlife. Comparative Analysis. Retrieved from Vertical Garden Watering System & Technology. (2020, March 03). Retrieved June 20, 2020, from https://www.sagegreenlife.com/process/technology/

As can be seen in the photo (figure 3,54), living wall lighting was installed on the ceiling to provide necessary lighting levels and uses LED bulbs to reduce energy consumption. The drainage system is installed at the bottom of the living wall and is fully concealed to not distract an observer from the magnificent living wall design. The living wall is well integrated in the existing design including its colour palette, furniture, floor, and wall material.

Conclusion

Sagegreenlife living wall is considered to be an affordable and easily installed LWS. Installed sensors and IoT technology showcases its full potential from living wall installation to its design. The layered tile structure provides an opportunity to adapt the design of living walls into existing indoor conditions. Flourish living wall demonstrates the simplicity of living wall structures, providing an opportunity to install a living wall without additional installation services.

The integrated smart system is another advantage as it minimizes wastage and follows the precise living wall requirements. Partitional organization of modules replaces damaged plants or structures without strenuous effort. Besides that, as can be seen on figure 3.53, Flourish living wall can be used as an acoustic insulator, which brings comfort to an indoor space.

Figure 3.54: Indoor Sagegreenlife Living Wall South Loop's Eleven 40 Residential Building in Chicago. West Loop Firm Sagegreenlife Channels the Outdoors to Stunning Effect. (n.d.). Retrieved June 20, 2020, from https://michiganavemag.com/living-wall-trend-sagegreenlife-nathan-beckner

3.3.8. Novintiss Vertiss

Novintiss is a company specializing in supplying landscaping, construction, and building products. It was formed by Serge Pelsy and Boris Pelsy in August 2003 (Vertiss). It supplies a variety of products from geosynthetics such as geotextiles, geocomposites, and geomembranes, as well as green/living walls and green roofs (Vertiss) . Vertiss represents a brand, which was created as a part of the Novintiss company. Vertiss provides innovative design solutions for indoor and outdoor living walls. Vertiss was founded in 2009 in France and since then, has become a top leading company on the living wall market (Vertiss). The brand focuses on sustainable living wall performance, which includes low water consumption, thermal and acoustic insulation, and carbon sequestration potential. Vertiss offers services around the globe but mainly in Europe, Middle East, North Africa, and Canada (Vertiss).

Vertiss Plus Living Wall

Vertiss Plus is a module used for indoor and outdoor living walls (figure 3.55). The high-quality materials integrate living walls in extreme climatic conditions, adapting and optimizing plant selection. Vertiss living walls are composed of high density expanded polypropylene, which brings following **number of benefits (Vertiss)**:

1) Easy installation and maintenance process;
2) Provides thermal and air quality benefits such as air purification and evapotranspiration;
3) Corrosion resistant;
4) Great sound and acoustic insulation;
5) Protection of walls from UV rays;
6) East adaptation of design into existing design settings.

Each HD-EPP Module is composed of 16 planting cells, which makes replanting and replacement simple (Vertiss). Vertiss modules can be easily combined to create a composition. Vertiss offers only one **module size option** (Vertiss):

Height: 760 mm;

Width: 590mm;

Depth: 190mm;

Volume of growing media 32 L;

Dimensions of fixed module: 800 x 600 mm.

According to Vertiss, a module has no partitions but a uniform module, which provides water and nutrients to all 16 plants without fail.

Figure 3.55: High Density Expanded Polypropylene Module. Modular Green Wall: Vertiss Plus. The Vertical Garden. (n.d.). Retrieved June 21, 2020, from https://www.vertiss.net/vertiss-plus-le-module-vegetalise?lang=en

The growing media of Vertiss Living Walls (figure 3.56) consist of pozzolan and clay balls, which positively affects water retention, aeration, and drainage (Vertiss). Another growing media component is a garden peat, an organic material that allows quick plant recovery after watering (Vertiss). Growing media absorbs up to 300 times its weight in water, leading to effective water savings (Vertiss). Water consumption of growing media can be adjusted by an automated drip system fixed into the living wall. **Benefits** of Vertis growing media are the following (Vertiss):

1) Efficient root growth;
2) Absence of root asphyxiation;
3) Water capacity;
4) Excellent drainage system;
5) Porosity, which allows micro biotic penetration;
6) No growing media disease;
7) Good nutrients absorption;

8) Minimization of leakage.

Figure 3.56: Vertiss Growing Media. Modular Green Wall: Vertiss Plus. The Vertical Garden. (n.d.). Retrieved June 21, 2020, from https://www.vertiss.net/vertiss-plus-le-module-vegetalise?lang=en

Partitions of the watering system can be supplied as an option from another supplier. According to Vertiss, the automated system can only be installed in big living walls, not the ones that are composed of a few modules only. Automated irrigation allows homogeneous and efficient water supply with nutrients to plants avoiding overuse of water and omissions.

Vertiss irrigation system is subdivided into two options (Vertiss; figure 3.57):

1) **Primary network (technical area):** controls necessary frequencies and durations for watering and nutrient amount;
2) **Secondary network (localized watering):** an automated system, allowing reduction in water consumption. Modules are evenly watered by a drip line and connected to the irrigation system.

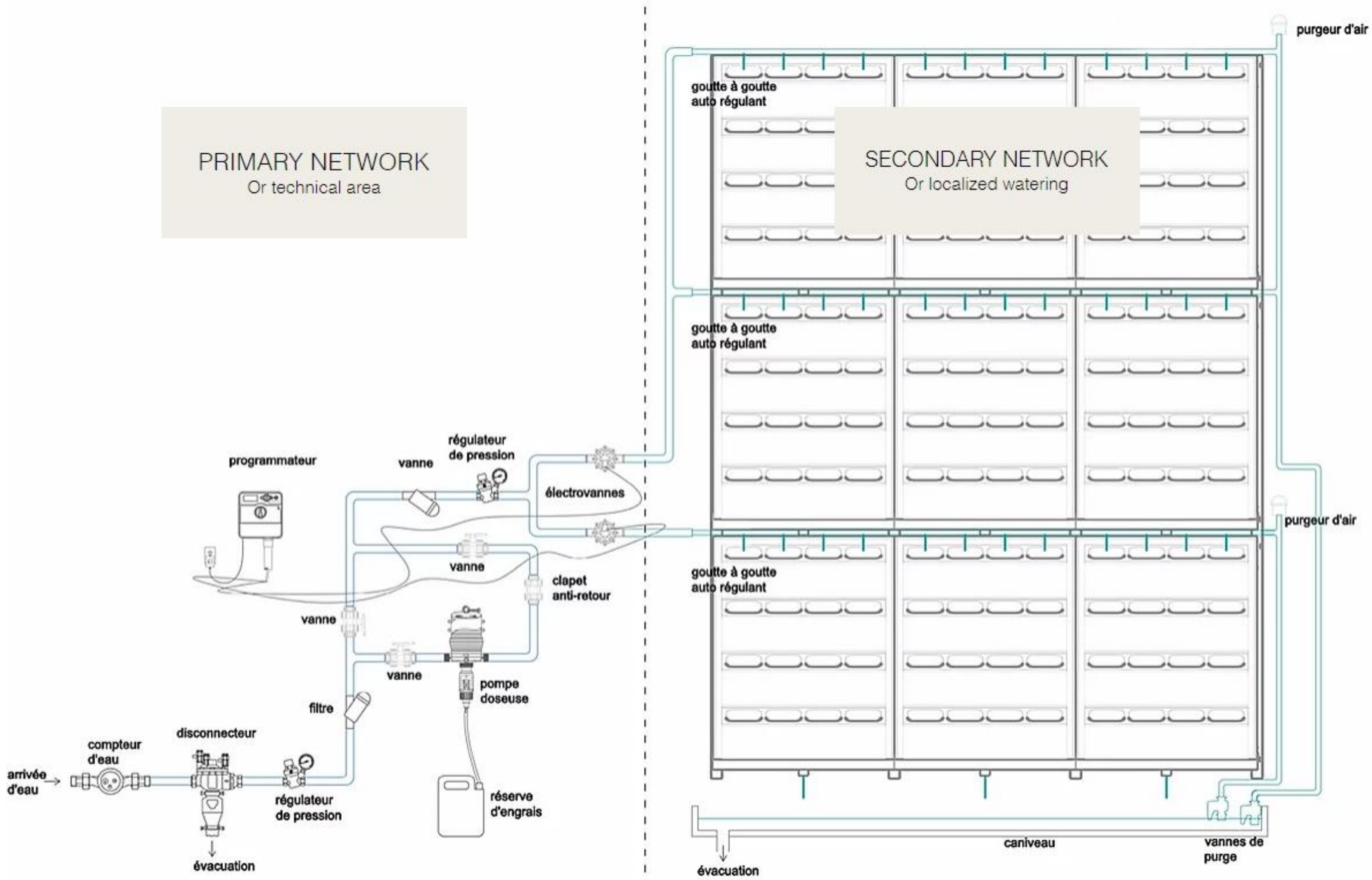


Figure 3.57: Vertiss Irrigation System Options. Modular Green Wall: Vertiss Plus. The Vertical Garden. (n.d.). Retrieved June 21, 2020, from https://www.vertiss.net/vertiss-plus-le-module-vegetalise?lang=en

Vertiss modules can be pre-grown in advance for a fast installation process. Typically, an average Vertiss living wall takes up 10 m^2 per day with two people working on the living walls (Vertiss). According to Vertiss, the installation of an irrigation system takes half a day and only a few minutes for the installation of drip lines.

Vertiss recommends following next maintenance guidelines (Vertiss):

1) Inspection of the structure;
2) Inspection of plants health;
3) Check of irrigation system and its components;
4) Check of moisture levels, system operation and growing media;
5) Trimming and cleaning of plants;

Vertiss irrigation system (figure 3.58) provides local watering to be evenly distributed throughout the wall. It is connected to a main fertigation point, which automatically injects and launches the water supply (Vertiss). Drip lines are fixed into the upper part of each section with

80 cm spacing (Vertiss). Vertiss recommends to water living walls frequently, approximately 2 to 5 minutes per cycle and 1 to 5 times a day depending on indoor climate conditions (Vertiss).

Figure 3.58: Vertiss Irrigation System. Living Wall: Maintenance and Set-Up: Vertiss. The Green Wall. (n.d.). Retrieved June 21, 2020, from https://www.vertiss.net/mur-vegetal-entretien-mise-en-oeuvr?lang=en

According to Vertiss, the use of a minimum 1500 lux lighting source is suitable for most indoor plants. The relevant colour temperature should approximately be 4000K where metal halide light bulbs can be used (Vertiss).

EPP modules and the metal structure of a living wall are mounted onto a supporting structure (Vertiss). Modules are mounted on and next to each other to create density and composition. If required, modules can be cut in size to adapt to specific indoor settings. Vertiss company offers all the necessary services including the supply and installation, dimensions studies such as metal frame, free standing metal structure, the irrigation system, lighting, and finishing components such as water recovery, lateral frame, and maintenance support. Planting modules should be organized of plant containers with an incline of -35 with respect to plants' phototropism (Vertiss). 16 modules create a density of 32 plants/ m^2 (Vertiss). The backing system should be waterproofed with an air gap for ventilation.

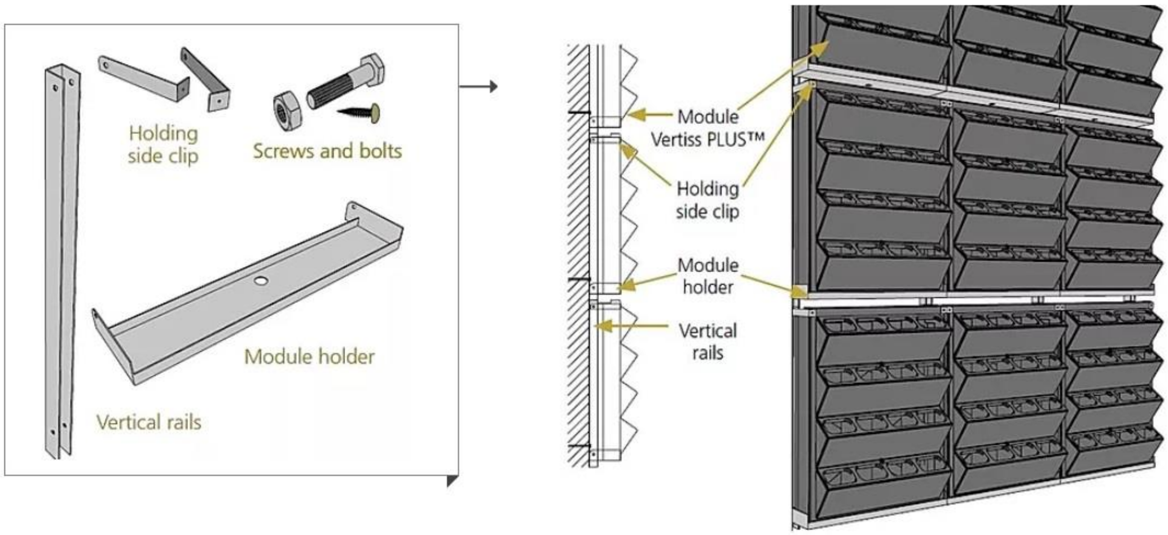


Figure 3.59: Living Wall Components and Assembly. Modular Green Wall: Vertiss Plus. The Vertical Garden. (n.d.). Retrieved June 21, 2020, from https://www.vertiss.net/vertiss-plus-le-module-vegetalise?lang=en

A drip tray is installed at the bottom of the living wall to hold and catch excess water. Plants are planted by hand in containers with a maximum of 9 cm pots in order to not break the roots (Vertiss). The choice of plants and living wall components will be determined according to environmental factors such as light, temperature, and plant requirements.

The indoor Vertiss Living Wall system was installed at the private villa in Moyen Orient region (figure 3.60) (Vertiss). The living wall is located in an indoor veranda, which covers approximately 40 m^2 (Vertiss). Living wall modules were integrated within existing window structures. The lighting source was mainly accented from natural light, which efficiently decreases energy consumption. Such integration of a living wall demonstrates the flexibility and adaptability of the Vertiss system, showing that it can be used as a powerful tool to enhance the indoor environment without requiring additional space. As can be seen on figure 3.60 modules are placed on top of each other with a drip drainage at the bottom of living walls. As it is located in the veranda, additional floor drainage was installed in case of leakage or excess water. Each module contains a different tropical plant, which gives it diverse and unique design look.

Figure 3.60: Indoor Vertiss Living Wall at Private Villa in Moyen Orient. Mur Végétal: Galerie D'images: Vertiss Le Jardin Vertical. (n.d.). Retrieved June 21, 2020, from https://www.vertiss.net/galerie-d-images?lang=en

Conclusion

The Vertiss Living Wall is a good option for those who are looking for a fast and affordable implementation. The modularity of the system enables it to be installed in a few days. The option of pre-grown plants provides an opportunity to shorten the installation process as well. Modules create the composition, which will not only be attractive as a design tool, but adaptable to be well integrated into existing design settings. The simplicity of the installation process and modular organization allows for a living wall to be installed without requiring additional services, reducing extra expenses. As can be seen, indoor living walls can be well integrated into existing designs and framed around windows or any other structure. Two options of irrigation network provide an opportunity to choose a more affordable living wall version, as well as an automated network, which fully controls the components and living wall requirements.

3.3.9. NextGen Living Walls

NextGen Living Walls is a joined company of Nature's Green Europe and Architectural Supplements North America (NextGen Living Walls). Both companies are specialists in the landscape industry, providing services around the globe. All products are being created by the corporation of both firms, which delivers products and services in Europe, Middle East, South America, and North America (NextGen Living Walls). The main office of NextGen Living Wall is based in Netherlands with other branches spread all over the world (NextGen Living Walls). NextGen Living Wall's team includes specialists who successfully finished programs to become a member of the group, aiming to provide the best service to clients. All experts are well-qualified, have product knowledge, and have skills in calculating design and plants specifications.

According to the company, NextGen Living Walls are the best solution in creating a healthy living environment as indoor and outdoor space. NextGen Living Walls come as a standard customized LWS, as a room divider, and double or a single sided living wall. In this section, a customized living wall will be evaluated, which will include the observation of two irrigation systems, lighting requirements, plans and elevations of a prototype, assembly instruction, a table of suitable plants, and a few examples of indoor living wall installation in the residential sector.

The NextGen Living Wall is organized in a way where water flows from top to bottom, which can be done manually or automatically. The company provides a variety of irrigation options including manual, semi manual, semi-automatic, and complete automatic. In this case, both manual and automatic systems will be described. According to NextGen Living Walls, a regular watering cycle takes up to four weeks. NextGen Living Walls recommends to manually water small indoor living walls. For medium and large living walls, a water reservoir with a pump including fittings, hoses, and water disposal, can be installed. NextGen Living Walls stated that due to the simplicity of a living system, manual watering can be done in all cases from small to large living walls.

The living wall is easy to install by yourself with an assistance of the **following tools** (NextGen Living Walls):

- Electric Drill;
- Extension Cord;
- Tape Measure;
- Marking Pencil;
- Screwdriver.

NextGen Living Wall components (figure 3.61) are composed of standard elements such as a grid, tray with or without drainage, leaf screen, drain hose, and optional components such as side panels, hydroscreens, water meter, and track lighting (NextGen Living Walls).

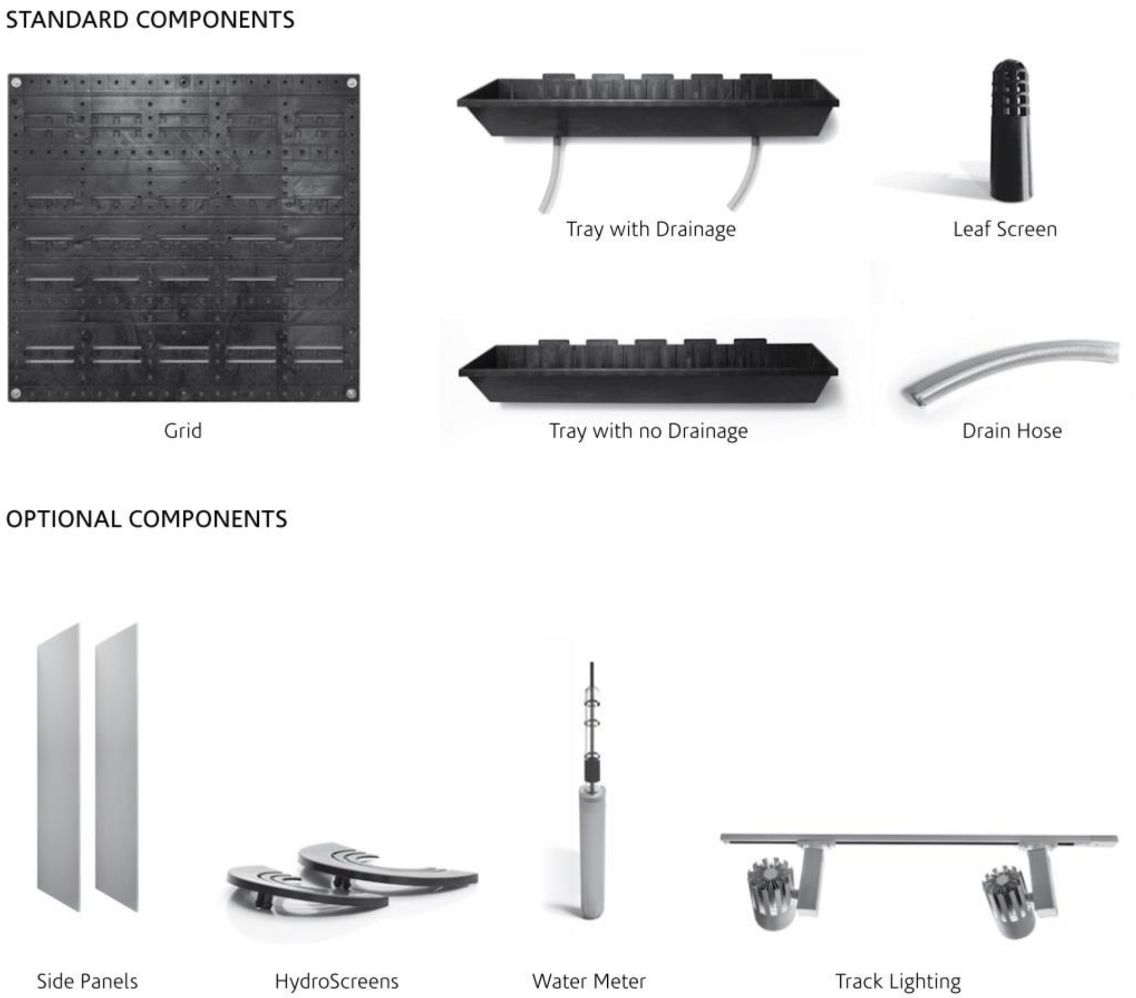


Figure 3.61: NextGen Living Wall Components. NextGen Living Walls. Instruction Manual. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

NextGen Living Walls recommends two people to install a living wall in order to do so with ease. A detailed drawing of living walls' measurements, information on proper integration, and other details can be obtained through website by contacting specialists. First of all, a client should determine what material the studs are made of. Fasteners for the supporting structure can also be obtained from NextGen Living Wall services.

Basically, there are two living wall grid options supplied by the company (NextGen Living Walls):

GRID-5075: 50 cm long by 75 cm high, which holds trays 50 cm long;

GRID-8075: 80 cm long by 75 cm high, which holds trays 100 cm long including hydro grow pots or large soil grow pots.

Both options are supplied with holes in order to provide good ventilation for the system and the plants. For the first option, no spacing between each grid is required. On the other hand, for second option, 20 cm is a mandate between the grids (NextGen Living Walls).

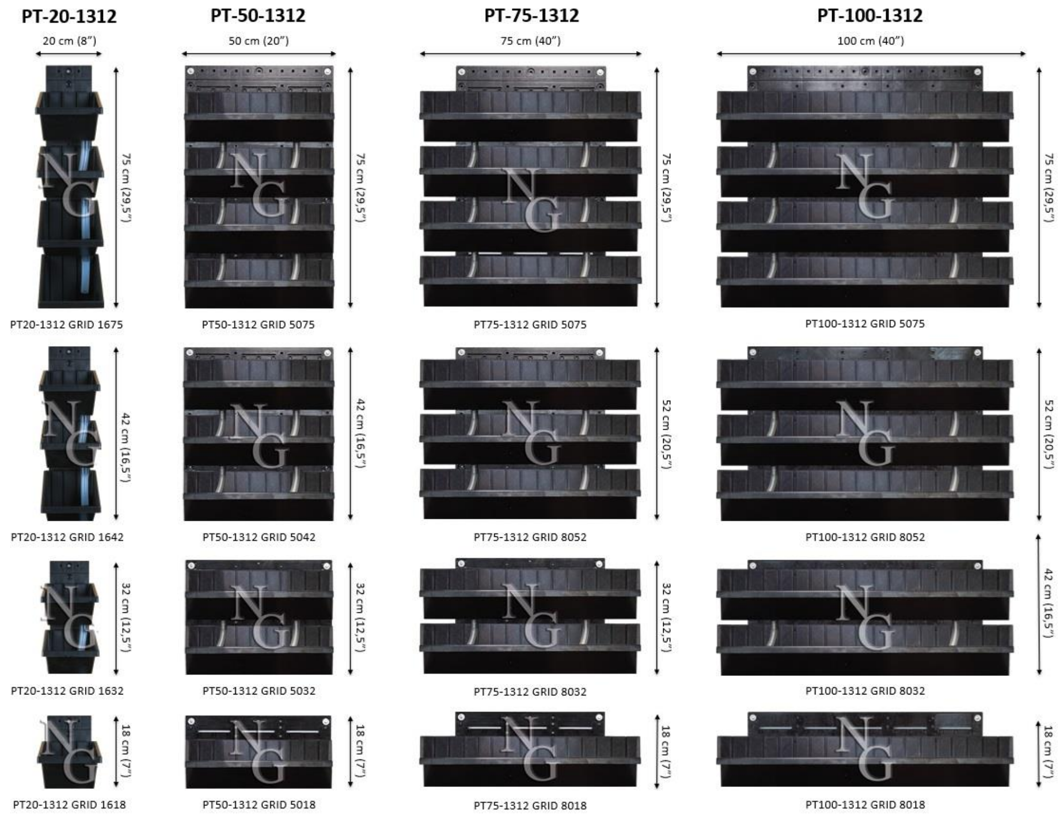


Figure 3.62: NextGen Grids and Trays Options. NextGen Living Walls. NextGen Living Wall Design Tool. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

NextGen Living Walls recommend beginning installation with the bottom left grid, identifying the location of the left and bottom sides of the living wall. For the first step, level and a marking pencil can be used to draw vertical lines. The next step is to determine how far off the floor the bottom of the living wall will be and to mark it the same way. The first grid can be installed after identifying of all the sides of the potential living wall space. After this, one person can mount the first grid while another one is marking four mounting holes (in four grid corners) . NextGen Living Walls do not recommend using light duty fasteners in any situation. The second grid can be installed the same way as the first one by repeating tasks (figure 3.63).

50 cm L x 75 cm H GRID SPACING

80 cm L x 75 cm H GRID SPACING

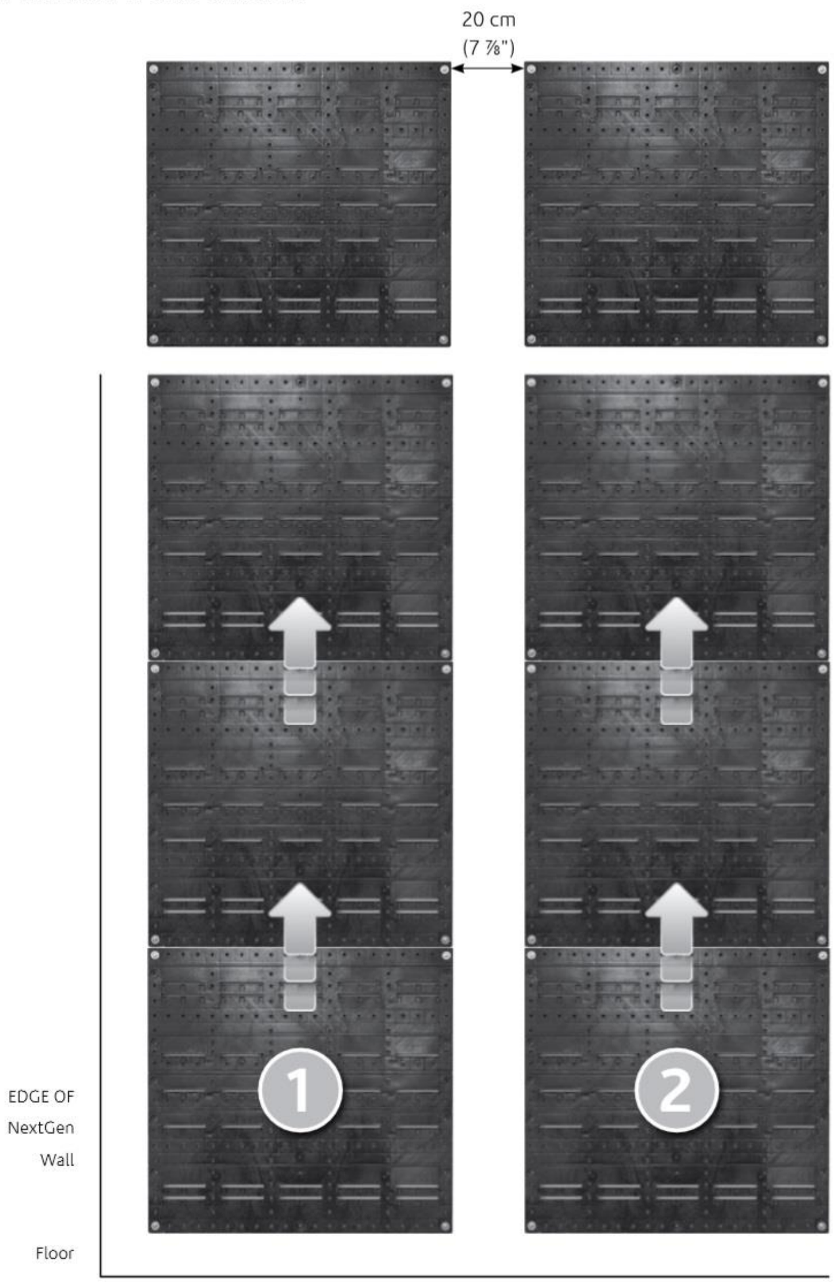


Figure 3.63: Horizontal and Vertical NextGen Living Wall Composition. NextGen Living Walls. Instruction Manual. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

For vertical grid combination (figure 3.63), one person lines up the grid, while another one marks the holes. The holes and the grid are drilled the same way as horizontal composition. In the case that a living wall exceeds the provided space, the top of the grid can be cut to a desired height by a table saw and a jig saw (NextGen Living Walls).

When all desired grids are installed, trays can be inserted. Trays with drains are attached to leaf screens and hoses (NextGen Living Walls). For 100 cm trays, NextGen Living Walls recommends using three or four trays per grid, whereas for 50 cm trays, there is an extra option of five plants per grid since the plants planted are usually smaller in size. Firstly, a bottom tray with no holes should be inserted at the bottom of the living wall (NextGen Living Walls). When all the trays are installed step by step from the bottom to the top, side panels can be connected with a main structure. When trays are installed, grow pots can be added. There are three main grow pots that can be used and are found in North America.

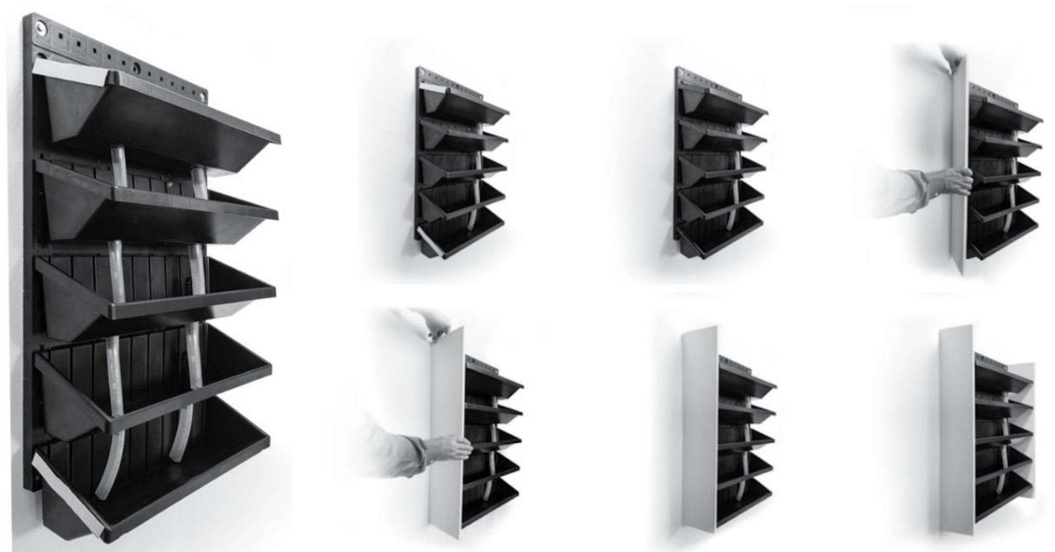


Figure 3.64: Side Panels Installation. NextGen Living Walls. Instruction Manual. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

Figure 3.65: Grow Pots Types. NextGen Living Walls. Instruction Manual. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

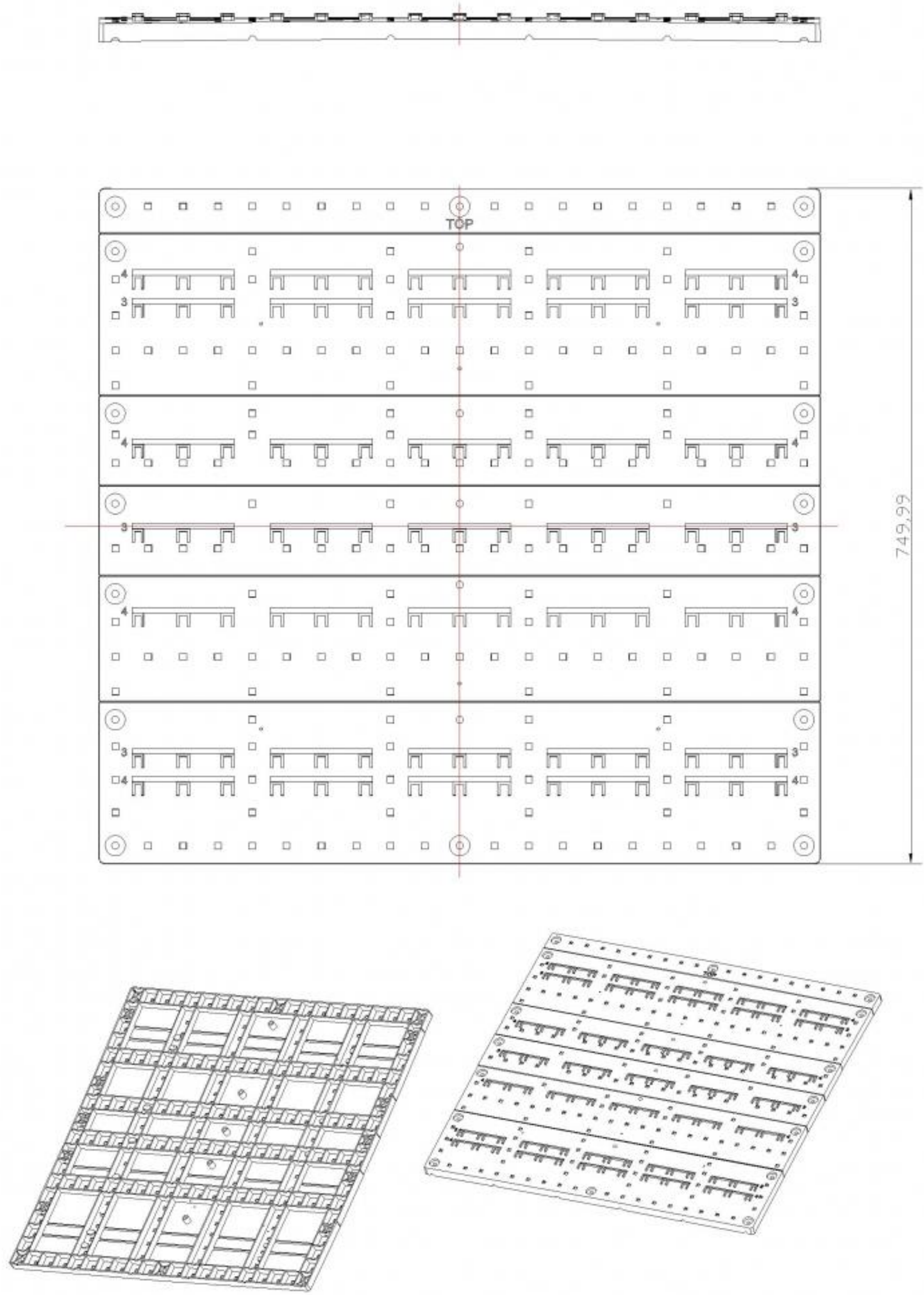


Figure 3.66: GRID-8075 Model. Welcome to NextGen Image Download Center. (n.d.). Retrieved June 22, 2020, from https://imagedatabase.nextgenlivingwalls.com/product-color.php?groep=82

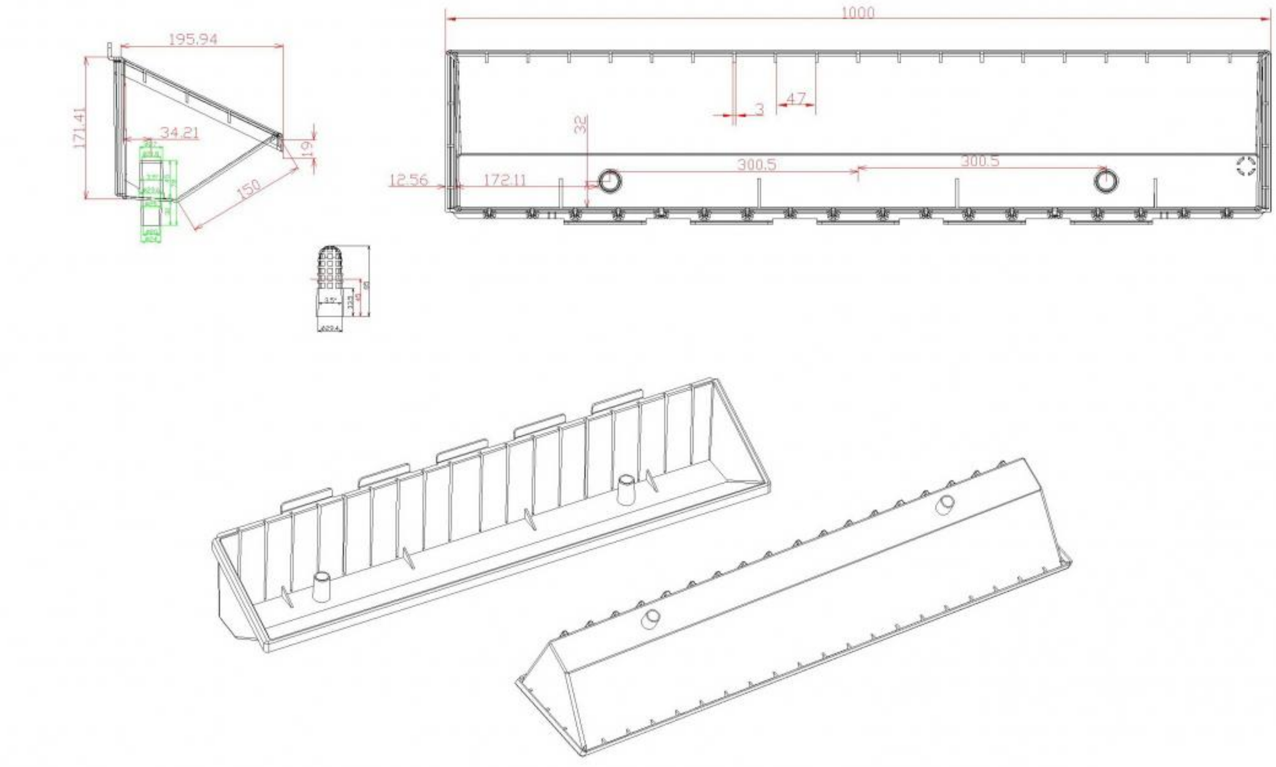


Figure 3.67: PT-100-1312-Model (100cm tray option). Welcome to NextGen Image Download Center. (n.d.). Retrieved June 22, 2020, from https://imagedatabase.nextgenlivingwalls.com/product-color.php?groep=82

NextGen Living Wall includes a water reservoir installed on the wall itself. This differs from other living types, where reservoirs are installed at the bottom (NextGen Living Walls). The bottom tray holds excess water that was collected from the top trays. To water a living wall, a Watering machine can be used. Top trays are watered first, where excess water drains down to the next tray and therefore, to the bottom tray. NextGen Living Walls recommends paying attention to the bottom tray in order to not overfill the tray with water. Usually, it takes up to 15-20 minutes for grow pots to be saturated with water (NextGen Living Walls). As an option, automated irrigation systems can be installed, but it might require additional expenses.

Figure 3.68: Plants Suitable for NextGen Living Wall. NextGen Living Walls. NextGen Living Wall Design Tool. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

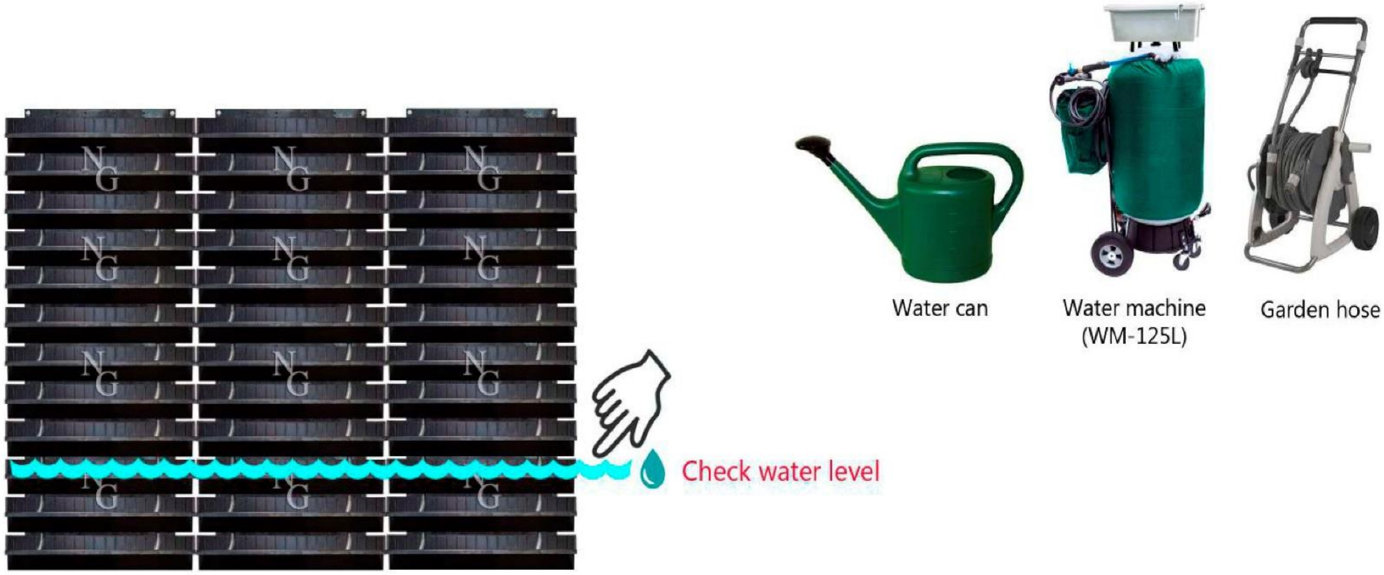


Figure 3.69: Hand Watering Option. NextGen Living Walls. Irrigation Options. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

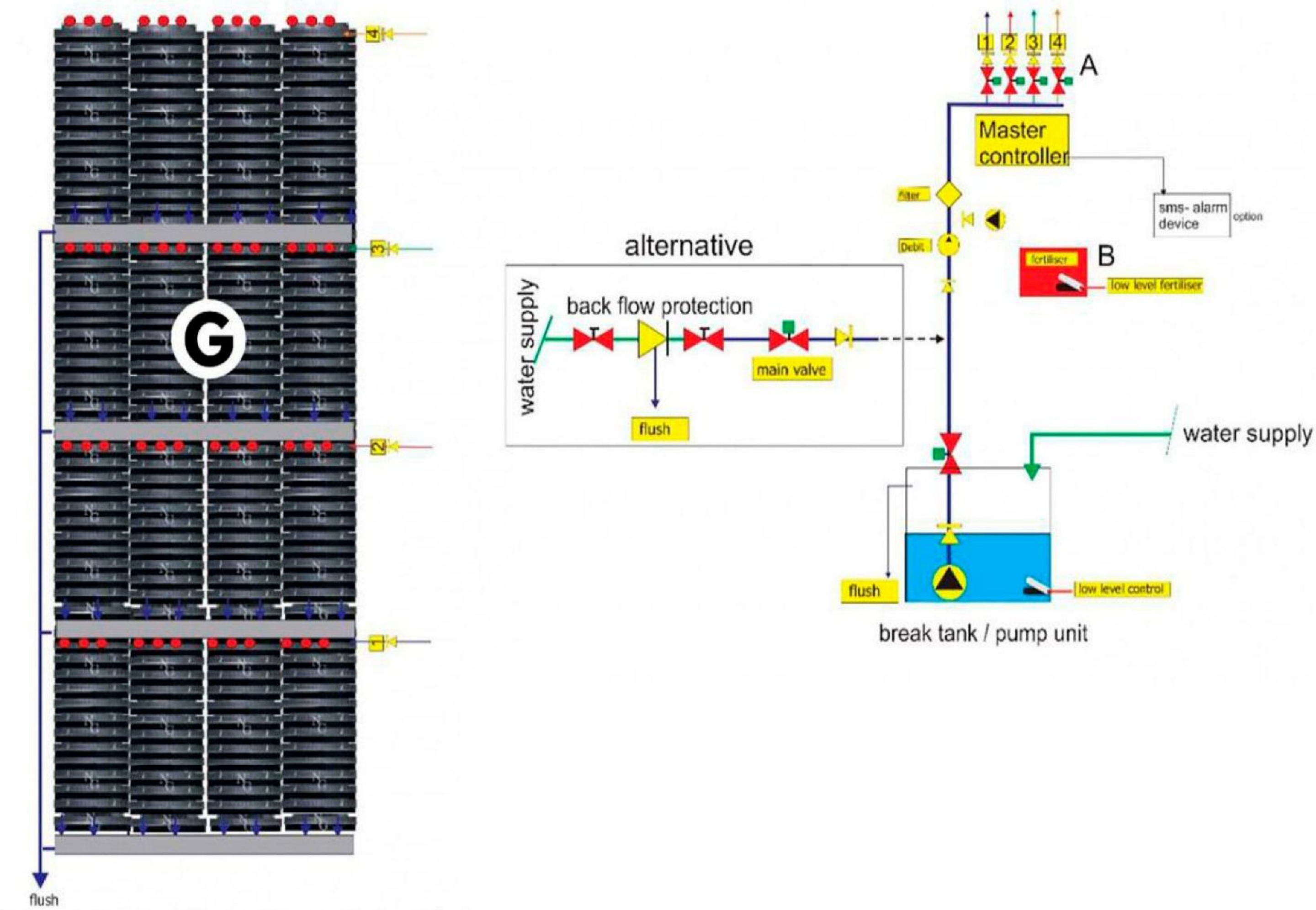


Figure 3.70: Automated Watering Option. NextGen Living Walls. Irrigation Options. Retrieved from https://imagedatabase.nextgenlivingwalls.com/brochure.php

NextGen Living Walls advises to provide light in the range of 1600 to 3200 Lux (150 to 300 Footcandles) (NextGen Living Walls). To provide the best lighting source, NextGen Living Walls have created an LED Track Light that follows the necessary lighting requirements. The source is 40w in wattage, 5000k in colour temperature with a beam angle of 60 (figure 3.71) (NextGen Living Walls). According to the author, one light bulb can cover an area of 1.5 to 2 square meters (NextGen Living Walls).

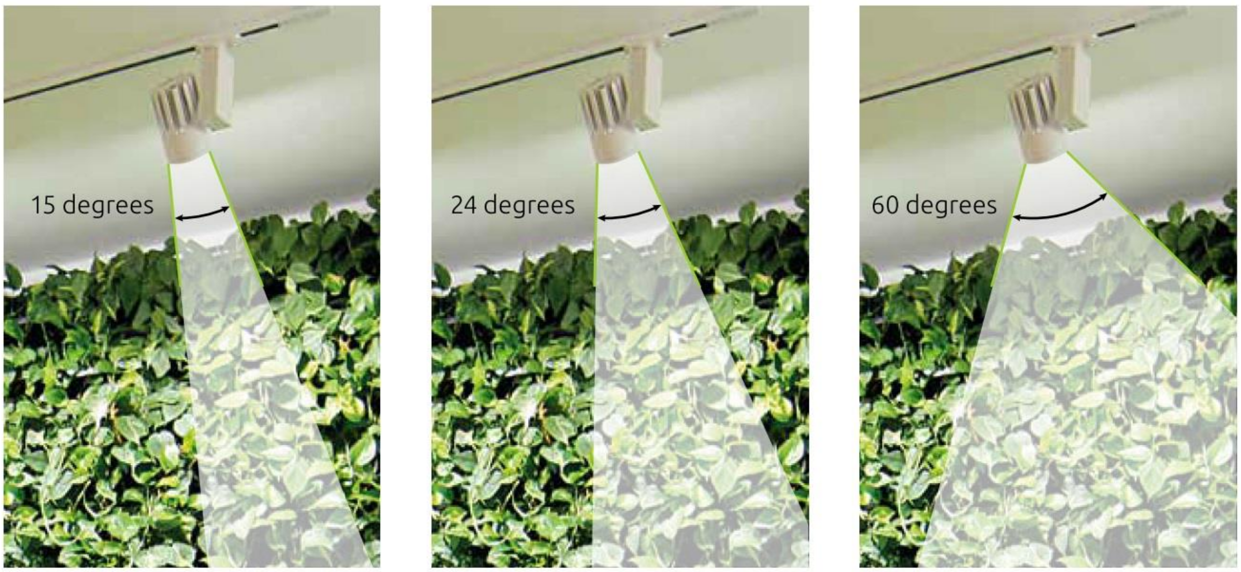


Figure 3.71: Lighting Angle Conditions. Lighting System. (2017, July 19). Retrieved June 22, 2020, from https://www.nextgenlivingwalls.com/lighting-system-2/

NextGen Living Wall technology was used in the installation of an indoor living wall at a residential place. The system was installed in conjunction with a Flower Company in Czech Republic (NextGen Living Walls). It is located in a living area, which includes a TV, chairs, and a table. The living wall structure was integrated and framed around the TV and existing furniture. As can be seen on figure 3.72, LED NextGen Living Wall system was installed on the ceiling, which provides a great lighting source and meets all the criteria. LWS was subdivided by modules/grids and inserted in two places, framing a TV and a separate LWS by the dining table. It can be noticed that a single grid size was used, but adapted in different ways following installation guidelines. The living wall is well-integrated into existing indoor conditions, which brings a sense of nature and enhances the atmosphere into an eco-friendly interior.

Conclusion

NextGen Living Wall represents a modular grid system, which provides an opportunity of a full adaptation into indoor settings. As can be seen on figure 3.72, living walls can be used as an effective design tool that does not require additional space. It can be successfully integrated into small available spaces by going over existing design elements. Provided irrigation drawings explain how systems work and what is necessary to reach the best design result. An innovative lighting system created by NextGen Living Walls helps to provide necessary light in order for plants to thrive. Additional lighting guidelines presented on the website identifies proper lighting settings. One of the biggest advantages of NextGen Living Wall is the simplicity of installation and detailed installation instructions. The system can be easily installed by two people, which will help to avoid extra expenses on services. Another important advantage is that the system does not require heavy structural support, as the grids and rails provide necessary staidness to the system.

Figure 3.72: Interior NextGen Living Wall in Residential Place in Czech Republic. Projects. (2018, May 26). Retrieved June 22, 2020, from https://www.nextgenlivingwalls.com/projects/

3.3.10. Scotscape

Scotscape company specializes in design, installation, and maintenance of living walls in Europe and the United Kingdom (Scotscape). Their mission is to offer "The Complete Green Solution" to clients by designing outdoor and indoor living walls to enhance the use of an environment (Scotscape). The head office is located in London, United Kingdom with a few other offices in Europe (Scotscape). Angus Cunningham, a managing director of Scotscape, stated that the driving factor in launching the company and encourage green environment was the global warming, pollution, and urbanization problem (Scotscape). Since then, Scotscape patented a Smart Greening System, which faces these issues around the globe (Scotscape).

To provide the best service to clients, the work of Scotscape involves a multiple of team actors such as designers, operationists, site managers, estimators, technical managers, directors, and others. Besides that, in over 35 years, Scotscape has accumulated diverse relationships with landscaping, installation, horticultural teams, and various building companies (Scotscape).

Scotscape Living Wall

The Scotscape Living Wall represents a lightweight, semi-hydroponic modular panel system. The main components of LWS is a patented Fytotextille fabric (Scotscape). Each square meter can contain up to 49 plants that is organized in individual pockets (Scotscape). A dripline is integrated into each panel in order to provide proper irrigation for plants (Scotscape). One of the advantages is the flexibility of the panels, which fits a structure to flat and curved surfaces. The living wall can be designed by a team of specialists with a minimization of on-site disruption. In this case, Scotscape living walls are planted on site and does not require pre-growing of plants.

Scotscape offers full design services for commercial and residential sectors. The living wall comes in nine standard panels and can be broken down into modules to adapt to interior settings (Scotscape). According to Scotscape, interior living walls improves indoor air quality, environmental humidity, removes VOC's compounds such as benzene, formaldehydes, and acts as a bio-filter. It allows to enhance the health and well-being of residents by enhancing overall productivity and concentration. The installation of Scotscape Living Wall connects people with nature within interior spaces and built environment (Scotscape).

To prove the efficiency of Fytotextile fabric, a study at the University of Seville was undertaken (Scotscape). The fabric provides great aeration for roots and encourages healthy growing with high resistance to pests and diseases (Scotscape). The Scotscape living wall is composed of three main layers: a waterproof layer, irrigation layer and breathable layer. The water is distributed evenly throughout the system into the root zone (Scotscape).

Figure 3.73: Fytotextile Multilayer System. 1- Auxiliary Substructure; 2-Water Harvesting Gutter; 3-Carril Profile FYTVOL; 4-Multilayer Modules Fytotextile; 5- Irrigation System; 6-Auxiliary Engineering; 7-Plants. Scotscape. Breathing Life into Cities. Retrieved from https://konferencaverticalplantlifebcnaklo.files.wordpress.com/2017/10/niall-mcevoy_scotscape-living-wall-systems.pdf

Fytotextile Living Wall panels can be manufactured into any shape and size to adapt to the existing interior criteria. The regular installation process consists of four major steps: sub-frame, modules, irrigation and planting.

Scotscape Living Wall has an automated irrigation system, which suits large and small living walls. The run-off water is collected at the foundation of the living wall. Excess water is being recirculated through the system for the next watering cycle.

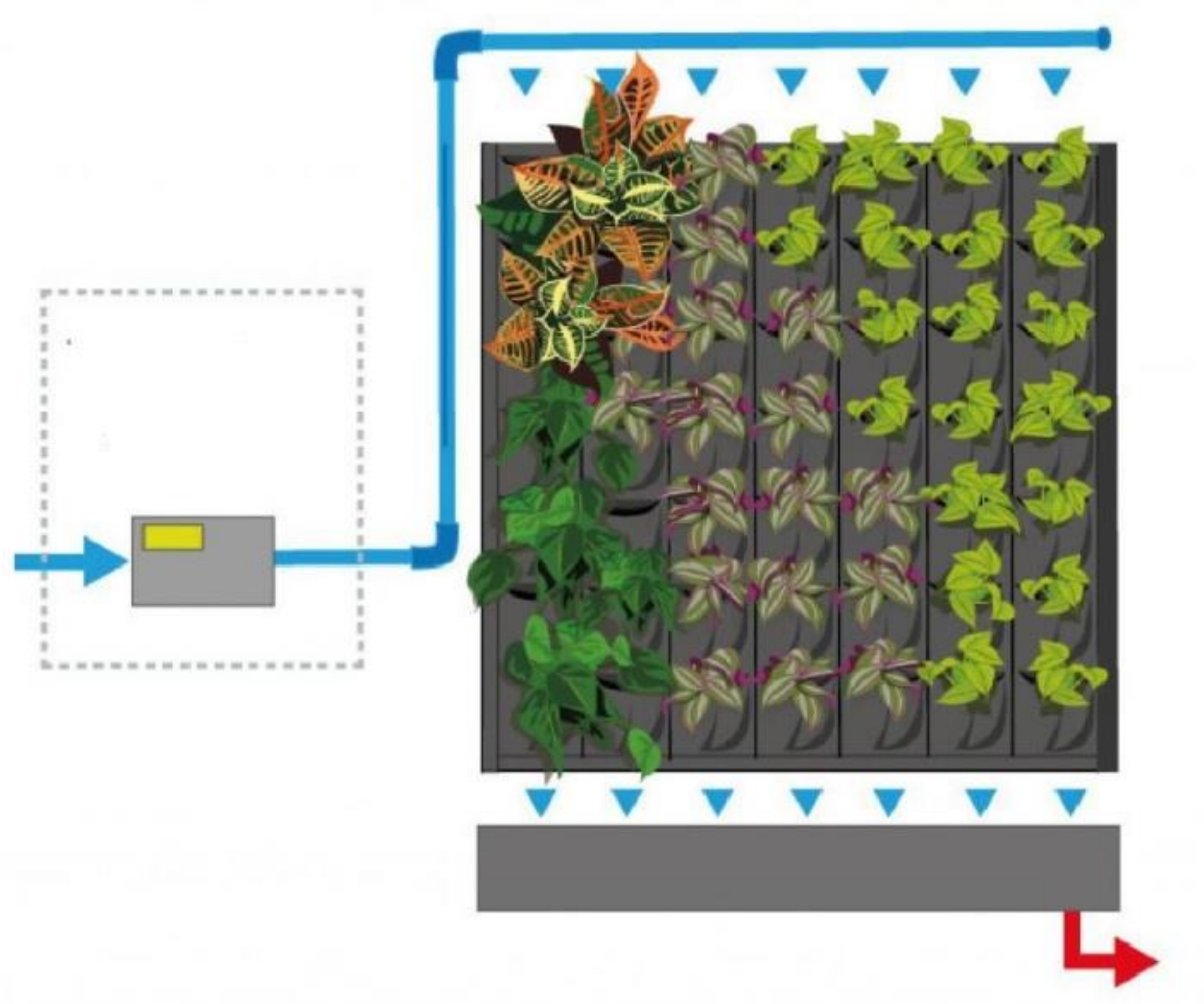


Figure 3.74: Irrigation System. FYTOTEXTILE® LIVING WALL - Preserved Green Wall by Terapia Urbana: ArchiExpo. (n.d.). Retrieved June 22, 2020, from https://www.archiexpo.com/prod/terapia-urbana/product-85848-1921833.html

The weight of one square meter, including full equipment and planting, is less than 40kg (Scotscape). For proper living wall use, a fresh and unsoftened water is required for irrigation. The system is connected with 240v electrical supply for irrigation system working process (Scotscape). For an automated irrigation system, 1200mm x 900mm floorspace should be left (Scotscape).

The first design stage includes the development of a concept and planting design. Afterwards, Scotscape specialists work on the design of the structural support and irrigation system. All necessary elements are being supplied by the company and delivered to the site.

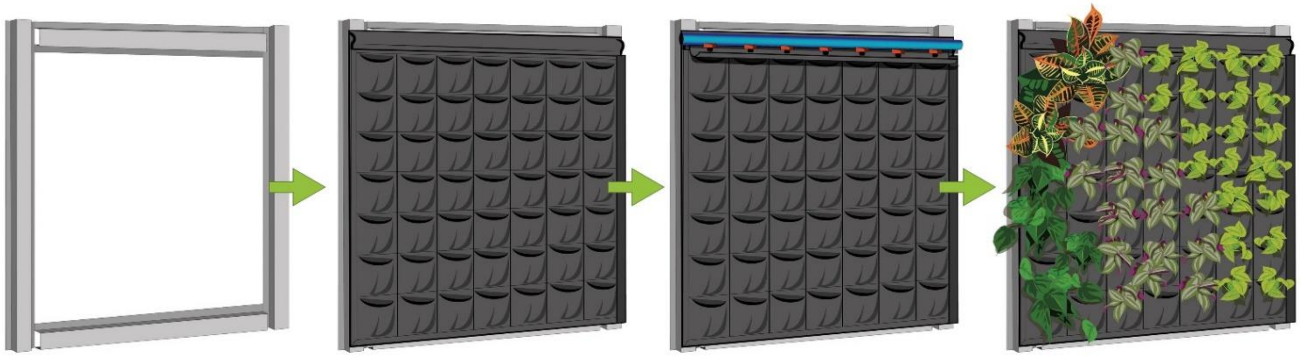


Figure 3.75: Living Wall Installation Process. Living Walls. (n.d.). Retrieved June 22, 2020, from https://www.scotscape.co.uk/services/living-walls

Living Wall fabric is fast and easy to install. It is fixed to a steel or timber supporting structure and hung from a steel fixing rail (Scotscape). Maintenance services are provided for every living wall including regular inspection of irrigation, planting system, and trimming.

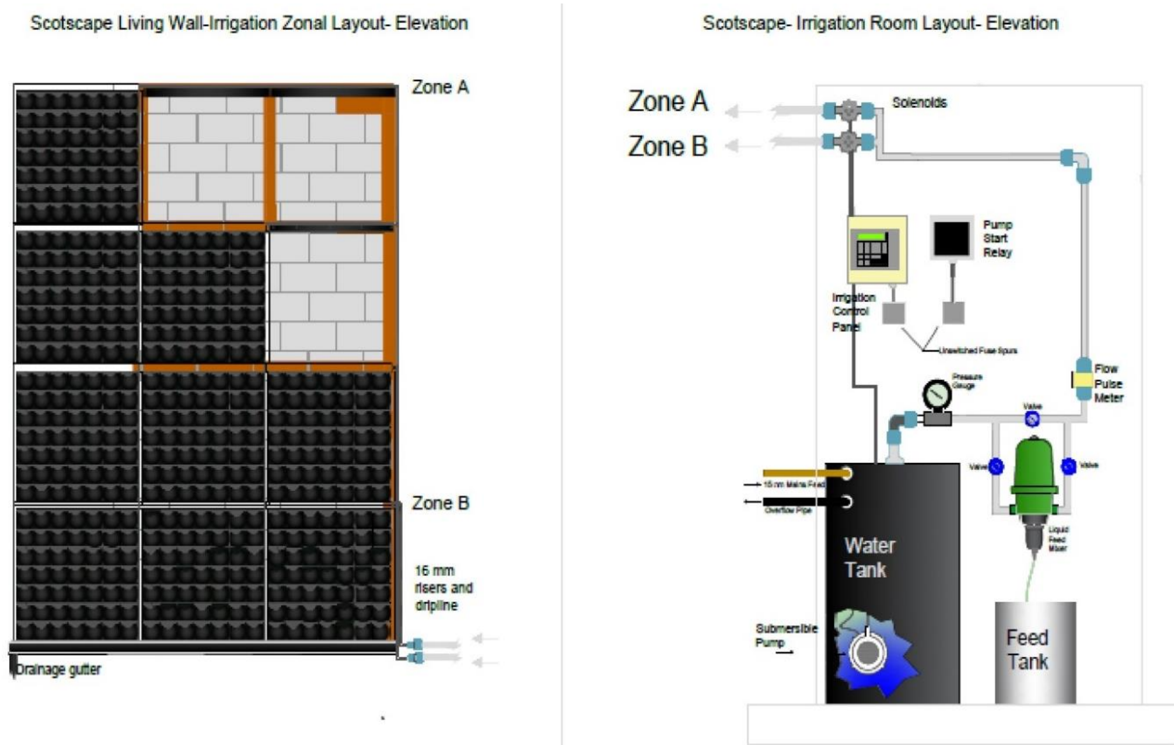


Figure 3.76: Scotscape Living Wall Irrigation System. Scotscape. Breathing Life into Cities. Retrieved from https://konferencaverticalplantlifebcnaklo.files.wordpress.com/2017/10/niall-mcevoy_scotscape-living-wall-systems.pdf

Scotscape technology was used in realization of a Living Wall at Golden Square in London (figure 3.77) (Scotscape). The indoor living wall is located in the reception area, which was designed in conjunction with Lusted Greeneho company and the Scotscape team (Scotscape). It covers approximately 18.5 m^2 and represents a diverse and sophisticated design filled with a variety of different plants.

Figure 3.77: Golden Square Indoor Living Wall. Living Wall at Golden Square. (n.d.). Retrieved June 23, 2020, from https://www.scotscape.co.uk/projects/living-wall-at-golden-square

The client's main request was to create a plant matrix composed of different colours that can flow organically in the indoor environment. To create the density of the composition, Scotscape decided not to use live planting modules but saturate each of them with different plant species. According to Scotscape, the designed living wall is highly tolerant to pests and diseases. It also provides great environmental value by purifying the air of a public space and brings health benefits to the residents.

Conclusion

Scotscape Living Wall is a great example of a pocket living wall system. It is characterized by its simplicity of implementation and affordability of installation and design. Fytotextile fabric allows plants to thrive and obtain great aeration for the roots, which encourages healthy growing. The simplicity of the system is framed by three main elements such as waterproofing, irrigation, and the breathing layer. It allows client to install a living wall without problems and in a short period of time. One of the biggest advantages is that the Scotscape Living Wall does not require that the plants are pre-grown, which sufficiently shortens the waiting time. Without a doubt, it shortens the time from the concept to the implementation process. The flexibility of the pocket system makes it adaptable not only to straight surfaces but curved as well. If needed, clients can cut the fabric to a specific size in order to insert it into the existing indoor situation. As a result, Scotscape is a living wall, for someone who is looking for fast and easy implementation with basic maintenance requirements and low design expenses.

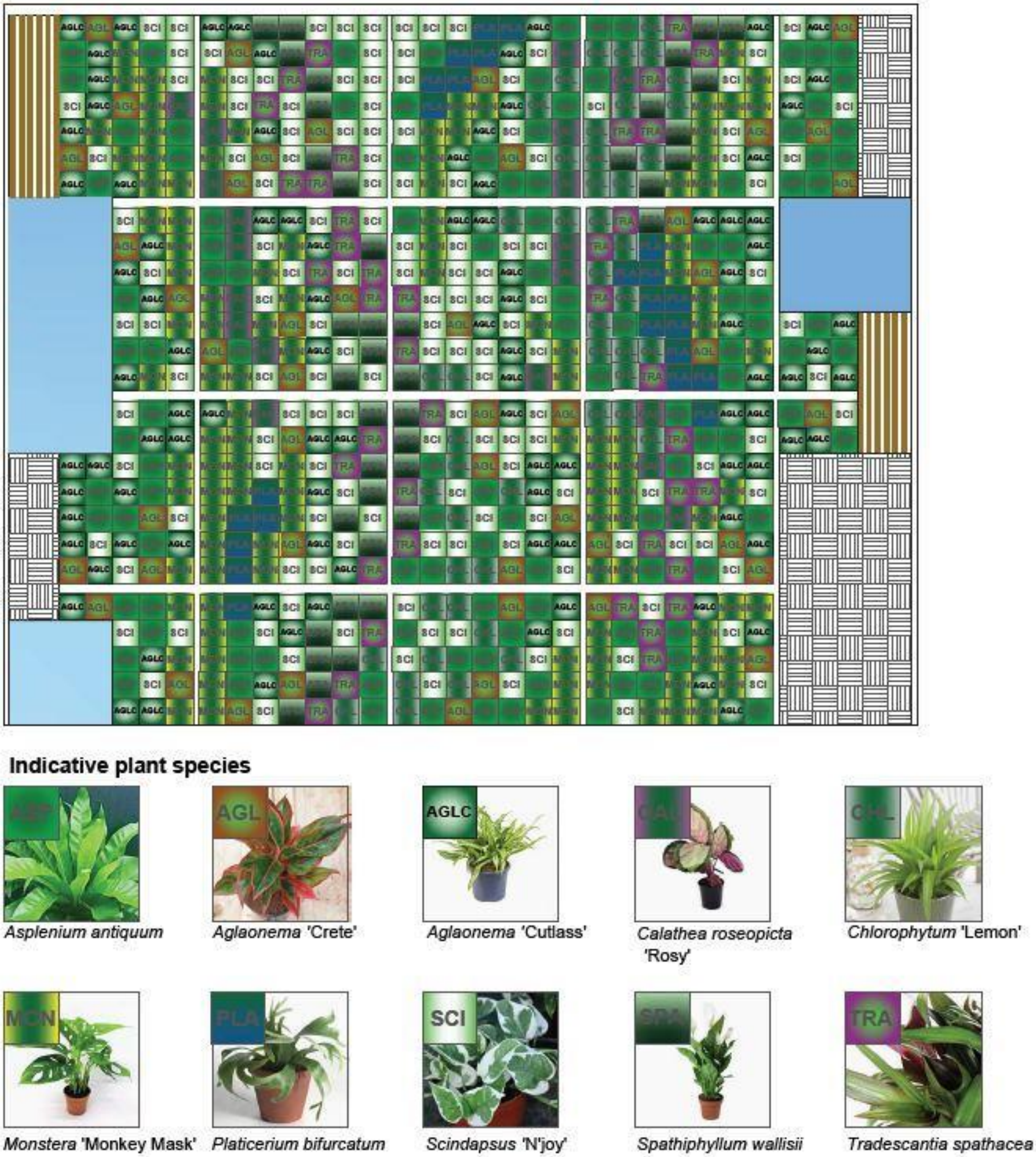


Figure 3.78: Golden Square Living Wall Plant Composition. (n.d.). Retrieved June 23, 2020, from https://www.scotscape.co.uk/projects/living-wall-at-golden-square

3.4. CONCLUSION

The analysis of case studies of ten major living wall companies helped to reveal distinctions between a diverse variety of installation and design options. Evaluated case studies indicate that the major concentration of living wall companies is located in the United States of America and Europe with the primary function of aesthetics, design, and air purification purposes. The main aim of the chapter was to identify common ground elements of living walls and its components. As can be understood now, a living wall, which has two or more functions, might have a variety of options including irrigation system, drainage, LWS type, lighting, and growing media. In fact, a client will be able to choose the best suitable and affordable option for the indoor space. Distinctions of living walls varies from chosen structural support, irrigation systems, which can be automated or manual, drainage types, waterproofing materials and growing media. A common goal throughout, for the use of indoor living walls, is to functionalize the structure for air purification and aesthetics purposes. Despite the fact that the aim of the chapter was to investigate living walls for both air purification benefits and for food production, during the case study analysis, edible living walls were not found. This can be mean that the current prime function of living walls is framed around air purification and aesthetics principles. The absence of edible living walls in the global market helped to identify a niche for further research.

The next chapter will begin by an identification of ten potential decision-making aspects that start the initial stage of indoor living wall designs. The chapter will rely on the table comparison made after an analysis of ten case studies, which will help to explain the dependence between the main reason of living wall implementation and the best suitable components and materials needed. The main focus of the fourth chapter is to guide designers and future occupants through the decision making process, which will help to determine necessary requirements and materials and therefore, find the best suitable solution to meet the target.

CHAPTER FOUR: DECISION MAKING PROCESS

4.1. INTRODUCTION

When thinking of indoor living wall design, the process should begin with a concrete idea of the functions of the living wall and how it will enhance the occupants' life. Chapter Two was based on technical aspects of indoor living walls. Chapter Three indicated how different living wall systems and its components including drainage, irrigation, and lighting, are currently being implemented throughout the world in indoor residential spaces. It is now important to understand the reason behind indoor living wall implementation. The Living Wall System combines a variety of elements that create a uniform system, which can be used in various ways. The chosen content of a living wall will be reflected on a primary goal, which has to be set long before the design process begins. This chapter will explain how to select a living wall based on the particular situation and its needs.

The first question that one should ask when making the decision to implement a living wall is "why". "Why" will help users determine the main reason for an indoor living wall presence inside the residential space. The explanation of the variety of implementation decisions will be described later in this chapter and will include ten potential incentives such as affordability, maintenance, air purification, food production, economic benefits, aesthetics and design, well-being and stress reduction, accessibility and climate independence, energy consumption, noise level reduction, and smartness and technology. The chapter will explain how an indoor living wall will help to achieve a goal and how the choice of components will vary according to the primary setting.

The second important question during the indoor living wall decision process is "how". "How" should be considered at the second stage right after the main goal is set. It concentrates on the essential ingredients of the living wall that will vary following the choice of a living wall and its function. The choice of function will determine the components of the living wall and therefore, the price and its result. This stage will also determine the process of installation including the cost and timing, and the future maintenance process from least to highest time-consuming living wall choice to expenses that the maintenance process will require.

The third essential question during the indoor living wall decision making process is "where". "Where" defines the setting of the planned indoor living wall placement. First, it is important to understand whether a living wall is planned to be placed in an existing house or an apartment or a completely new setting that can simultaneously integrate a living wall with the design of the entire space. The existing indoor environment will require one to pay special attention to the placement of a living wall, since it can only be located where the space allows it. In the case of a new planning apartment or a house, simultaneous design of the space will bring more opportunities to a living wall location and its function. The significance of indoor living wall location and its details will be explained later in this chapter providing guidelines and instructions on where it is ideal to place a wall and what one should pay attention to.

The primary idea of the chapter is to advise architects and designers about the indoor living wall decision process, to help them to project the future and success of living wall installations. The chapter will include ten main decision aspects, where each will be explained in detail, providing advice to future indoor living wall owners. It will also include the reflection of decision onto a living wall system and its components such as drainage, irrigation system, and lighting requirements.

4.2. DECISION MAKING ASPECTS

The decision making process is by far the most important stage, as it determines how an indoor living wall will correspond to the needs of occupants and what value it will bring to an indoor space and its owner. The chosen function will identify what living wall components are needed, what structural support should be used, and what irrigation and maintenance system needs to be applied. The combination of elements will vary according to the primary chosen function and living wall location inside an indoor space.

To analyze how indoor living walls are currently used and what variety of components it consists of, a comparison table (figure 4.1) was created after review of the third chapter according to the ten case studies. It summarizes each case study comparing the most important information including their function, LWS type, structural support, irrigation, drainage, waterproofing, growth media, vegetation, and lighting. The reference to case study’s comparison table is essential in order to understand the choice of a living wall system’s components, its variety, and combination. The guidelines that will be given in each section of the indoor living wall decision process in this chapter will be based on acquired knowledge and accumulated materials from the second and the third chapter as well as the comparison table, which will identify the most suitable criteria and components according to the choice of function.

Name	Location	Year	Company	Function	LWS type	Structural support	Irrigation	Drainage	Waterproofing	Growth media	Vegetation	Lighting	Cost
Versa Wall	Brooklyn, NY	2012	GSky (product) BAXT INGUI ARCHITECTS (architect) DEBBIE KOTALIC (plant designer)	Air purification, aesthetics	Modular (tray system)	Plywood backing	Automated (pumps, drip lines, tanks)	Automated Recirculation	Boards	Nursery growth	Philodendron, Peace Lilies, Pothos, Schefflera, Ficus	LED/ Metal Halide lights (10-12 hours/day, 4000-5000K)	—
Live Wall	Chicago	—	Live Wall	Air purification, aesthetics	Modular (planters)	Furring Strips (Verti Rail) + Slot Rail + Rain Rail	Side Feed or Rear Irrigation	Rear Drain/ Bottom Drain	20 mil polypropylene or EPDM	Pre-grown	Tropical plants	NORB Botanic LED (12-15 hours per day, typically 7 AM to 8-9 PM)	—
ANS Living Wall	United Kingdom	2014	ANS Global	Air purification, aesthetics	Modular	Fixing Rails	Irrigation Pipework	Osma Squaraline Gutter	Waterproof membrane	ANS modules	Tropical plants	Minimum 3000K and 250 FC	—
Florafelt Living Wall	Culiver City, Los Angeles	2017	Florafelt	Air purification, aesthetics	Pocket System	Plywood support	Irrigation tubing	Drainage at the base of LWS	Plastic boards	Hydroponic	Tropical plants	250-foot candles, 70 degrees, 40 WATT LED	$289.00
NAAVA ONE	Helsinki	—	NAAVA	Air purification, aesthetics	Free-stand LWS	—	Automated	Automated	—	Hydroponic	Tropical (figure 3.42)	Built-in LED lighting	—
BIOTECTURE	London, United Kingdom	2018	BIOTECTURE	Air purification, aesthetics	Modular	Galvanized steel box sections or timber battens	Driplines, water tank	Rear drainage (4.5 Geotextile Drainage Layer, drain into gutter)	Backing board (12mm Versapanel ECO Sheet)	Hydroponic Stonewool (16.8 kg/m3)	Tropical plants	—	—
SAGEGREENLIFE	Chicago	—	SAGE-GREENLIFE	Air purification, aesthetics	Modular	Support framing	Self-contained recirculating system	Felt-Covered Drainage Mat	Waterproof backing board	Soil free rock wool	Tropical plants	LED grow lights	—
NOVINTISS VERTISS	Moyen Orient	—	VERTISS	Air purification, aesthetics	Modular	Vertical rails	Primary or secondary network (automated, localized)	Drip tray at the base	—	Pozzolan and clay balls	Tropical plants	Metal halide light bulbs (1500 lux, 4000K)	—
NEXTGEN LIVING WALLS	Czech Republic		NEXTGEN LIVING WALLS	Air purification, aesthetics	Modular grid (tray system)	Grid panels	Both manual and automated	Water reservoir at the base	—	Hydro or soil plants	Tropical plants (figure 3.70)	LED Track Light (1600 to 3200 lux, 5000K)	—
SCOTSCAPE	London, United Kingdom	—	Fytotextille living wall	Air purification, aesthetics	Pocket System	Steel or timber supporting structure	Automated	Water harvesting gutter	Waterproof membrane	Fytotextile fabric	Tropical plants (figure 3.80)	LED	—

Figure 4.1: The Comparison Table of Living Wall Case Studies.

4.2.1. Affordability

One of the main challenges of indoor living wall design is affordability. It is important to identify the best living wall components combination that will be affordable in design, implementation and maintenance as well. Nowadays, technological advancements and innovative design approaches strive to find the best solution, which will meet the target cost. The author tends to believe that the current design and technological market, with its abundancy of diverse products, provides an opportunity to be affordable, durable, and creative simultaneously.

An affordable factor is determined by the cost of the living wall design, implementation, and maintenance process. This research report, as well as materials that can be found online, might help design a living wall without the need for a design specialist, which will reduce design expenses. The simplicity of a living wall structure and its elements will be reflected on its affordability factor. The most affordable irrigation options are manual, side feed, and tubing systems, while the most expensive is a system with automated or self-contained recirculation. Without a doubt, when considering affordability, everything that can be done manually will be more affordable than an automated system. However, it will be more time-consuming. Options such as the bottom drainage, reservoir, gutter, or drip tray are considered to be the most affordable drainage options, but they require special attention to overfilling, which need to be inspected regularly.

When considering the choice of growth media, both hydroponic and soil plants have their own advantages of affordability. Hydroponic growth media itself costs more, but requires less maintenance expenses. On the other hand, regular soil will cost less initially, but will demand for more thorough care, which might result in acquiring additional maintenance products.

Structural support should be placed with a gap in between the existing wall and the living wall itself. According to the author, the use of wooden support such as plywood backing is more affordable than the use of metal such as fixing rails, furring strips, grid panels, or galvanized steel.

The placement of an indoor living wall in a well-lit area will result in the reduction of artificial lighting needs. This means that less lighting sources, and in turn less energy, will be needed to support the growth of plants. Despite the fact that there is a full variety of lighting sources such as LED, Metal Halide lights, and NORB Botanic LED, Metal Halide lights might be the most affordable option, but will require more frequent lightbulb replacement than LED lights.

The abundance of living wall classifications and necessary components that were examined during research and that are currently available on the market allows for more choices in order to meet the target of affordability. Case studies indicated a variety of living walls from small, medium, to big sizes, which can be installed suiting the residential indoor space requirements. The author states that the most affordable applications out of all examined case studies are the Florafelt Living Wall System (section 3.3.4.) and NextGen Living Walls (section 3.3.9.). The affordability factor can be explained by the simplicity of the installation process and manual maintenance process. Both examples illustrate that the model of their indoor living walls can implemented without extra assistance. This means that occupants can easily follow the installation instructions presented here and on the companies' websites. The process for these two options can simply begin by ordering necessary materials online and installing and maintaining them later. The maintenance process can easily be done by occupants without the need of a specialist. However, it might require them to have the basic knowledge, which can be gathered from this report.

The cost regarding indoor living wall implementation in the presented case studies have only been found in the Florafelt Living Wall System. The information can be obtained on their website or by calling them directly. The price range of Florafelt Living Wall Systems begin from $89 for 4-Pocket Panel Living Wall System, to $159 for 12-Pocket Panel Living Wall System and up to $400 and $2,955 for bigger living walls with a recirculating system.

The variety of currently available living wall components will allow one to choose the most affordable design option, which means that a living wall can be installed in small houses as in bigger homes. The affordability factor will depend on the choice of chosen materials. Preferably, it will be a completely manual system, including wooden support structure, hydroponic or soil growing media, bottom tray drainage, and LED or Metal Halide lights. The most important part is to calculate how much each of these components will cost separately in order to find a better solution from presented options of chapter 2 and 3. The information regarding average installation and maintenance costs can be found in chapter 2 (section 2.7.2.)

4.2.2. Maintenance

The research of indoor living walls helped identify how technology can change our lives. Nowadays, technology allow us to save time, money, and bring more opportunities into a design. Maintenance factor can be defined as the time spent to provide a living wall with the necessary nutrients, which also includes an inspection of the current living wall conditions of soil, water, and nutrients level, as well as it's structural support, drainage, and irrigation systems. Living wall plants require regular inspection of leaves, replacements if needed, and an overall growth progression analysis.

The analysis of case studies helped to explore how maintenance is done in different types of indoor living wall systems. Technology reduces the time spent on maintenance by acquiring a fully automated system. For example, a fully automated living wall system minimizes the need for regular inspections due to the fact that the system is being checked through a computer, where major changes are made and sent back to the living wall for self-maintenance. This type of living wall is an innovative idea, as it partly replaces the need for manual maintenance. Fully automated living walls are a good solution for those who do not have time for regular maintenance and for those who do not have a basic knowledge about living wall systems and its components. Besides that, an automated system will be advantageous for elderly population and people with disabilities. One should take into account that although there are benefits, an automated system will cost more and may require replacement of partitions or equipment in the future. Full automation is a big advantage in reducing overuse and over fill of water and nutrients. The analysis, which is being made by computer or sensors, identifies the specific volume of compounds. Therefore, it decreases expenses of fertilization and water consumption. The implementation of an automated system will surely reduce the time spent on maintaining the living wall, but will still require weekly and monthly inspections and work on plants' condition.

On the other hand, manual maintenance demands for more time, and therefore requires more knowledge about LWS and planting. The inspections should be done more frequently with special attention to plant condition, water clog, and overuse and overfilling of water, resulting in unsuccessful use of living walls and death of plants.

The size of a living wall is an important factor to consider when thinking about future maintenance. Small indoor living walls will not require heavy equipment, However, high or hardly accessible living walls will demand for specialists or more advanced maintenance facilities.

In order to be able to maintain a living wall independently, an occupant should consider the complexity of the living wall system. The installation of a living wall with a manual irrigation and drainage system and small to medium in size will allow for easier maintenance of the structure without the need for a designer or a specialist. In this case, an occupant needs to have basic knowledge of living walls' main components including lighting, maintenance, irrigation, and growing media. This information of which can be found in chapter 2. In the case of bigger living walls, with a complex system including an automated irrigation and drainage, there may be a need for an inspection by a specialist who can check how the automated system and mechanisms work. When comparing an automated and manual living wall system, the maintenance of a manual living wall can be fully done by yourself, but will require more frequent inspections. In the case of an automated system, living walls will require checks less often, but inspections made by specialists are made every few months.

4.2.3. Air Purification

It is well known fact that the air that occupants breathe indoors is the air from the outside atmosphere. Therefore, the air indoors consists not only of air pollution, but indoor contaminants as well. Indoor air is composed of contaminants that come from chemical emission sources such as adhesive materials, biologic substances, carpets and fabrics, interior coating, cosmetic products, and furniture. Some of the most common indoor contaminants are volatile organic, formaldehyde, and toluene pollutants. A more detailed study on indoor contamination and indoor living wall air purification was provided in the second chapter (section 2.9.).

Designing an indoor living wall for air purification purposes is a good solution for those who suffer from lung dysfunction, asthma disorders, and other breathing problems. In this case, the installation of an indoor living wall will help rid indoor air of contaminants and air borne pollutants such as toluene, ethyl benzene, xylene, and other volatile organic particles. Living walls moisturize and oxygenate indoor air by collecting contaminants and dust particles. It is important to take into account the fact that different plant species vary in which specific pollutant they remove. Therefore, such specificities need to be studied in advance during plant selection. The choice of plants will determine how effectively the living wall will purify indoor air and how it will affect one's health condition. Another important factor to consider when making plant selections for air purification purposes are allergies and reagents. Prior to living wall installations, one needs to ensure that they are not allergic to the selected plants. The presence of allergens in indoor air might result in the deterioration health conditions or worsening of existing respiratory diseases.

4.2.4. Food Production and Economic Benefits

An analysis of current living wall designs around the globe helped to identify a lack of information about edible living walls in indoor spaces. Currently, indoor living walls are primarily used for air purification and aesthesis purposes, which is caused by the lack of materials on how edible plants can be integrated into an indoor living wall. Actual environmental challenges, including the effect of the traditional agricultural food production processes such as aggregation, food processing, marketing, preparation, and consumption, result in environmental burdening, an increase of emissions, and resource and waste generation. Besides that, the most affordable vegetables and fruits on the market largely consists of genetically modified crops that negatively affect one's health. Meanwhile, organic produce is not be affordable for everyone, especially those who experience food insecurity. A more detailed study about global problems of food production can be found in the first chapter (section 1.1.2.).

The author tends to believe that the variety of suitable edible plants including vegetables and fruits can integrate food production into homes following the same indoor living wall system concept. Nowadays, technology allows us to bring nature back into our homes and fulfill the gap of nature connectiveness, which was once lost and diminished.

The insertion of edible plants into the indoor environment will not only provide an air purification effect but will also produce fresh vegetables and fruits. The production of edible plants will reduce the need for store bought produce and will create a source of fresh edible plants within your home space. This innovative design integration will provide an opportunity to reduce monthly expenses and produce plants that were naturally grown without being genetically modified. The idea of edible living walls is a good solution for people who are looking for an affordable and accessible source of fresh produce and for those who value naturally grown plants.

When making the decision to install an indoor edible living wall, one needs to consider whether the plant species are suitable (figure 2.15-2.17) and what the necessary planting and maintenance requirements are in order to achieve proper growth and harvest. The most important factors to focus on when selecting plants for an edible living wall are the nutrients, spacing, compatibility of plants, and lighting. To maintain an edible living wall and to succeed in harvesting, planting skills such as knowledge on selected plants' behavior, its soil, water, and nutrient needs are required. Detailed plants selection can be studied in the second chapter (section 2.4.1.).

4.2.5. Aesthetics and Design

Besides air purification and food production, an indoor living wall can be used as a design tool. The tendency to design indoor spaces with plants is now developing rapidly, combining innovative technology and creative design techniques. A space filled with plants positively affects psychological conditions and brings great value to the interior environment.

Throughout the report, various indoor living wall types were studied including free stand, wall to wall, modular, mobile, room divider, and pocket system. The abundance of different systems enables the integration of a living wall to any interior setting whilst considering adaptability to existing furniture placement, available area, size, and vertical or horizontal surfaces. One of the most important factors to consider is where the location of the future indoor living wall will be and how it will affect current design settings. The choice of a living wall system will be determined according to its future location. The implementation of a living wall into a built home or apartment will require special attention to the location of a wall that would be most successful. Some of the criteria underlines in the lighting, moisture condition, and temperature condition that the chosen place can provide. The integration of an indoor living wall into a new home or apartment may create more flexibility and opportunities for the design of a living wall due to the fact that the design of the space is being evaluated uniformly.

For the placement of an indoor living wall into a space with existing furniture settings, more flexible systems are preferable such as modular or a pocket fabric. The modularity of living wall components allows a living wall to adapt easily or create a variety of patterns onto the walls themselves. The use of a room divider concept or a double-sided mobile living wall will provide an opportunity to divide indoor spaces according to their different functions. This means that big indoor ineffective spaces can be divided into rooms or spaces to bring more efficiency and functionality to the existing indoor environment. Mobile living walls allows an indoor living wall to move from one place to another when needed or when the function has changed. On the other hand, wall to wall systems do not provide such opportunity and is mounted and fixed onto the main support wall. This type of living wall, however, can be a good solution to when more area is available, bringing a huge contribution to air purification and the design of the space itself. The more area that is available for indoor living wall installation, the more species it can grow, and the more density of plants it can create. As a result, the number of growing plants directly affects the potential for a positive air purification impact and affects the volume of food that can be produced.

4.2.6. Well-being and Stress Reduction

The author tends to believe that presence of plants in homes can reduce blood pressure and heart rate problems while offering a variety of other psychological and environmental benefits. It is common practice for designers to pay special attention to greening in indoor spaces of hospitals and clinics. First, air purification directly affects health conditions and therefore, the overall well-being of a person. Second, the better the health conditions become, the less stress that the person experiences.

Psychological benefits of plants have been recognized in a variety of places such as hospitals, schools, and offices. According to Vertical Oxygen, studies show that living walls help increase productivity of college students up to 12%. The feeling of nature that living walls provide is obtained endlessly without dependence on the season. This means that during cold and rainy seasons, living walls still provide health benefits and reconnects the person with nature, reminding them of warmer climates.

The installation of a living wall is a good solution for those who experiences a psychological imbalance and struggles with feeling overwhelmed which brings stress and health problems. Besides, it is a good choice for people who are passionate about gardening. Nowadays, technology allows us to create green environments despite the season, which means that the benefits of living walls will be provided despite outdoor weather conditions. The process of plant maintenance itself and gardening is a self-relieving process, which will bring happiness to the lives of users.

4.2.7. Accessibility and Climate Independence

The installation of indoor living walls is an innovative way to create an accessible, climate-independent source of natural and fresh produce within the home space. Whether an occupant chooses to install a living wall for air purification, design, or food growing purposes, a living wall will be accessible throughout the year. This means that compared to outdoor living wall installations, indoor living wall will bring more impact whether to serve food or to purify air. During the winter season, especially in colder regions of Canada, the presence of a living wall inside home will create a sense of nature and allows one to grow herbs and vegetables, suitable species of which can be found in chapter 2 (section 2.4.).

The implementation of indoor living wall for food growing is a good solution for those who aim to obtain harvest throughout the year or for spaces that lack free space for big outdoor gardens. Hence, a living wall as a vertical structure will help save area in indoor spaces. Despite the fact that a living room might be the best location for living walls, occupants and designers needs to take into consideration the lighting, temperature, and moisture levels of indoor spaces where a living wall is planned to be located. The more natural light space there is, the less need there will be for artificial lighting, meaning that it will help to save money for additional lighting sources. Using a living wall in the living room will create a more natural connectiveness between nature and occupants, which can be characterized by more frequent interactions and movement flow throughout the living room. The best placement for an edible living wall is a well-lit living room with good ventilation and adjustable temperature settings. Prior to installation, occupants need to consider the additional extra space needed in front of the living wall, which is necessary for convenient maintenance. Living walls for air purification and design purposes can be easily installed in bedrooms as well. This will provide occupants with clean air and better sleep.

4.2.8. Energy Consumption

During the hot and dry seasons, people struggle with indoor heat, lack of moisture, or over humidification. During the summer, energy consumption in homes and apartments raise rapidly due to the use of air conditioning and humidifiers. In fact, the use of air conditioning might lead to a cold or another sickness, especially in countries where people are not well accustomed to fast temperature fluctuations. For example, in the United States and Canada, the presence of indoor air conditioning is common in indoor residential spaces. However, in Russia, where the most common construction material is stone, providing cooling during hot seasons, air conditioning may not be needed and therefore if installed, might affect health conditions because people are not accustomed to it. In North America, where one of the most common construction materials is wood, air conditioning is essential.

According to Tirelli, the sunlight absorbed by plants (50%) is being reflected in a lower capacity (30%). This means that a living wall can be used as a tool to create a cooler and more pleasant indoor environment (figure 4.2). As a result, installation of living walls will reduce or fully replace the need for indoor air conditioning and consequently, lower energy consumption and expenses spent to cool indoor spaces.

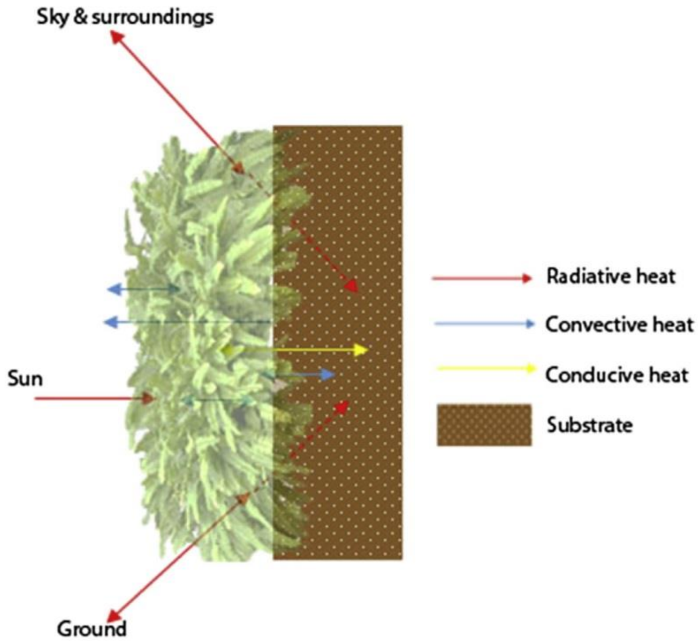


Figure 4.2: Heat Flux of LWs. Susorova, I., Angulo, M., Bahrami, P., & Stephens, B. (2013). A Model of Vegetated Exterior Facades for Evaluation of Wall Thermal Performance. Building and Environment, 67, 1-13. Sailor, D. J. (2008). A Green Roof Model for Building Energy Simulation Programs. Energy and Buildings, 40(8), 1466-1478.

4.2.9. Noise Level Reduction

One of the most important, but unfamiliar, benefits of an indoor living wall installation is a noise level reduction (figure 4.3). Currently, green walls and green barriers are commonly used on roads, highways, public places, and exterior building surfaces. However, the design of a living wall in indoor spaces will help to reduce unwanted noise as well. Wall-to-wall living wall systems installed between rooms or apartments decreases adjacent noise by blocking high frequency sounds. Indoor living walls act as an insulation layer between spaces reflecting, refracting, and absorbing acoustic energy (Ambius).

The success of noise level reduction will require correct living wall location and an air gap left between the existing wall. It also depends on the plants that were selected, the supporting structure and the density of plants. It is important to notice that small living walls will provide less noise protection than bigger ones. The bigger the wall, the more plants can be grown, offering more effective noise reduction benefits.

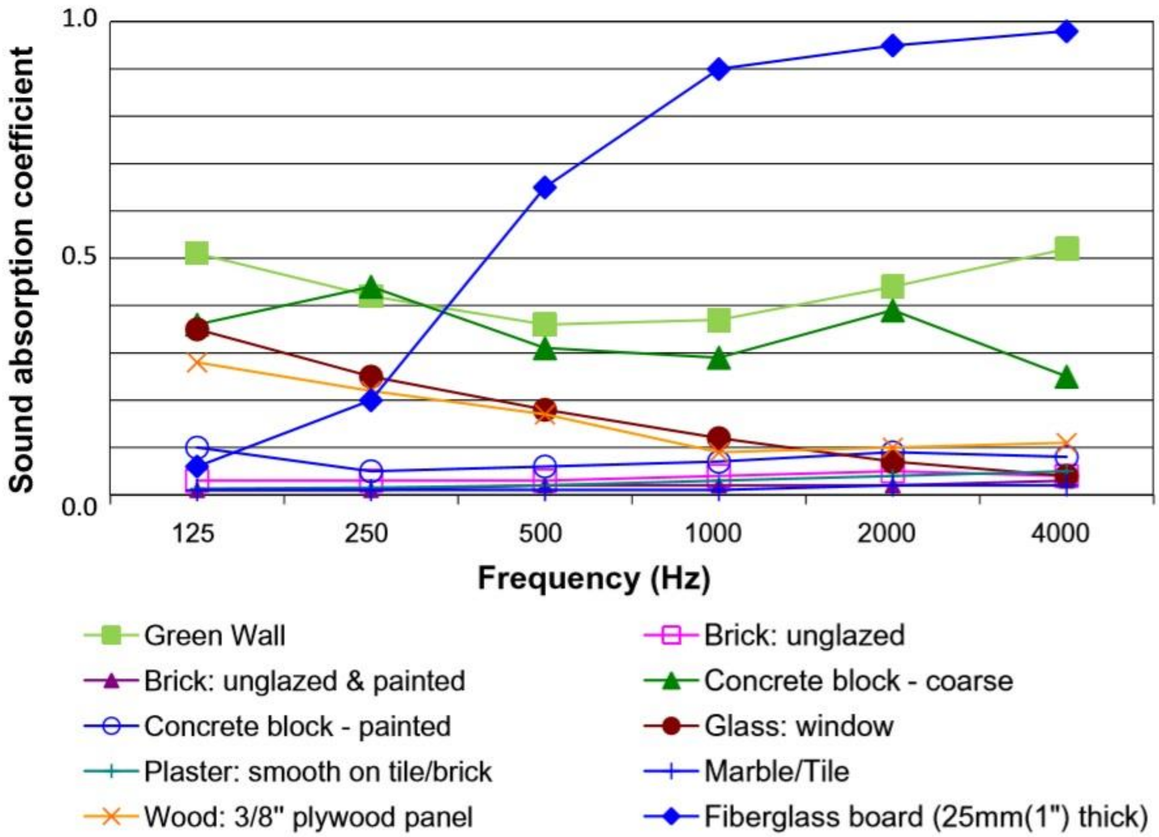


Figure 4.3: Sound Absorption Coefficient Value Comparison Between the Green Wall and Common Building Materials. Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Burés, S., Álvaro, J. E., ... & Urrestarazu, M. (2015). Evaluation of Green Walls as a Passive Acoustic Insulation System for Buildings. Applied Acoustics, 89, 46-56.

4.2.10. Smartness and Technology

The rapid development of technology brings up more opportunities in designing our homes. Nowadays, the abundance of technological products provides us with an opportunity to find the best solution for design varying from most affordable to expensive choices. With time, technology became more affordable and can be successfully integrated into interior spaces. Indoor living wall research identifies the new generation of smart living walls that facilitates and enhances the efficiency of an indoor environment. Installation of smart living wall systems or a fully automated system, which is wirelessly connected to the phone or computer, allows users to acquire the full potential from a living wall design. Smart living walls are a good solution for those who want to be kept updated with the help of technology in order to maximize efficiency of an interior space. Smart living wall systems can be compared to a smart home concept, where a uniform space represents a self-sustaining organism. Smart living walls are based on computerizing processes such as irrigation, maintenance, lighting, fertilization, and watering. The processes of a living wall can be evaluated through the phone and computer, where a user can monitor the current condition of living wall. The system notifies users when a LW lacks water, nutrients, or when it needs a change of lighting sources. Irrigation, watering, and drainage happens automatically, and the results of each cycle are sent to users and to the company for the system's work evaluation.

The integration of smart indoor living walls is the best solution for people who lack free time for maintenance, the elderly, or people with disabilities. One of the best illustrating examples of a smart living wall is NAAVA One Indoor Living Wall, which was described in Chapter Three (section 3.3.5).

4.3. CONCLUSION

Acquired knowledge and accumulated materials during the work on this research helped analyze the significance and potential of indoor living wall designs. The main incentive to living wall development should begin by rethinking the significance of nature connectiveness in the world. With the advent of technology, the integration of green infrastructures into urban fabric became an essential design strategy in order to preserve the connection between nature and the built environment. Continuous population expansion and city densification have isolated cities from nature and human beings. Nature connectiveness and its importance should be one of the primary focuses in our daily life and education. In order to combat global, environmental, and societal issues, the importance of nature, its proximity, its presence, and human behavior should be studied in reference to the historical value of nature. Nature connectiveness needs to be readdressed and reflected in the educational system and the architectural and construction industries. The author believes that indoor living walls should become a part of the design process in each home, whether it be a house or an apartment. Current living wall options offer a diverse variety of functions and elements to choose from that can suit all types of preferences. The main challenge is to motivate society and to create an interest focusing on all groups of population.

The research report helped to identify a lack of materials surrounding edible indoor living walls. It needs to be addressed in the future to bring more interest and opportunities to homes. The drive towards the development of indoor edible living walls derives from social necessity in having a qualified source of fresh produce, its potential user accessibility and affordability, as well as air purification benefits and environmental urban improvement.

The materials presented in this research report can become an incentive to normalize indoor living wall designs. The existing indoor living wall concept is fundamental in order to bring food production into homes. This can be done by combining the knowledge of gardening including plant species selection, plant mix, and plants compatibility, along with current living wall systems and components including drainage, irrigation, and lighting, which can be completed in the same way as for living walls designed specifically for purification and aesthetic purposes.

The research shows that mostly all existing design companies do not offer edible indoor living walls. From the author’s point of view, design and architecture firms should incorporate such opportunities in order to serve occupants’ needs and improve the global environmental situation.

Living wall design is a great investment not only to overall health improvement, noise reduction, air purification, but an ability to profoundly increase the value of homes. The author believes that indoor living walls provide a gateway to a green and eco-friendly world, which can change the way we think, the way we behave in nature, and change the future that we will live in.

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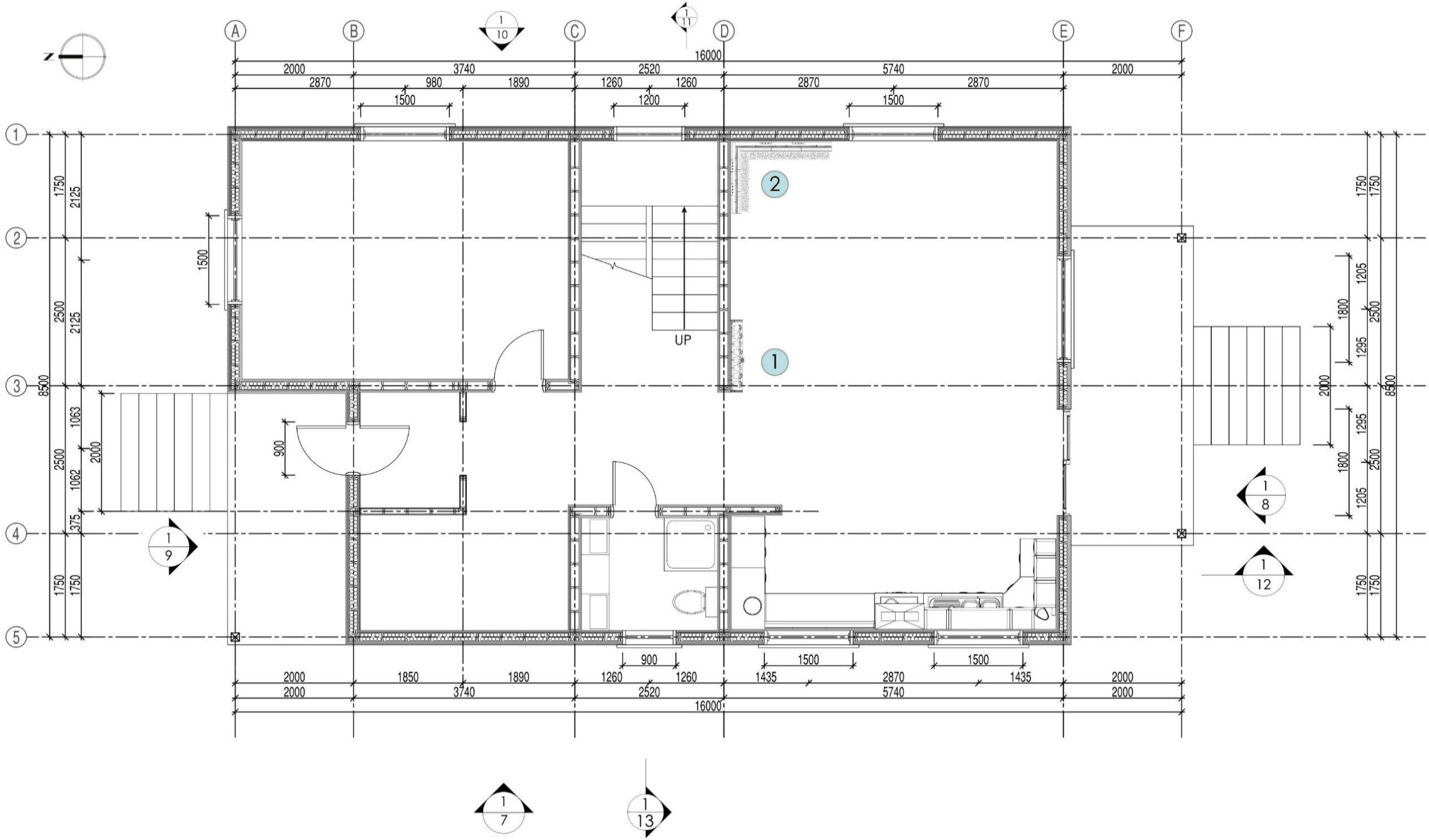
APPENDIX

In order to enhance the knowledge about indoor living wall design and to understand how the system can be integrated into an interior environment, the project of a house including two living walls was designed. This project was done as a part of the Master's program in the course of Selected Topics in Housing 1 instructed by Professor Avi Friedman.

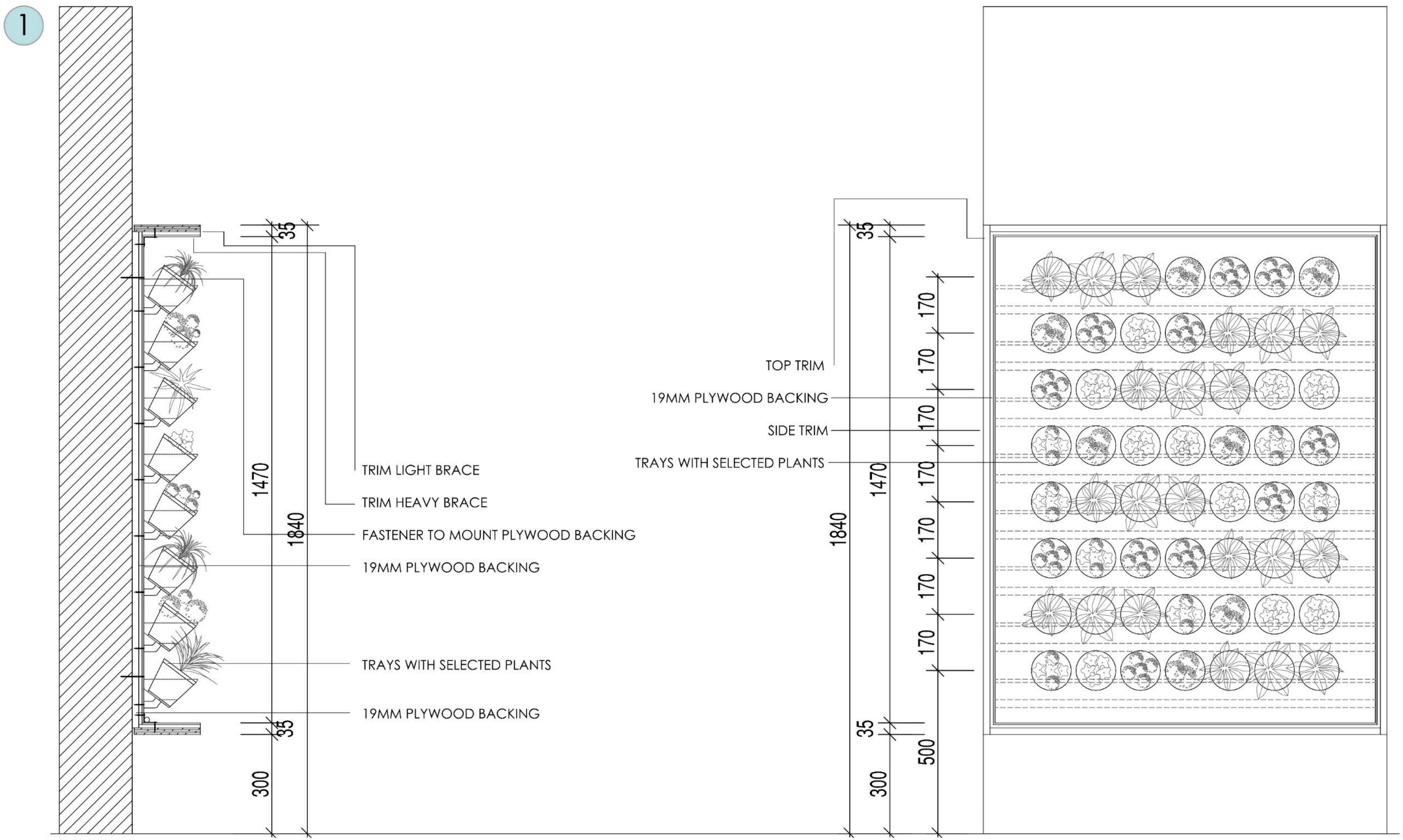
The house includes the integration of two living walls located in the living room area. The findings from the case studies of GSky Versa Wall (section 3.3.1.) and Biotecture Living Wall (section 3.3.6.) were used as a concept to draw the living wall details. The project has two types of living walls including the tray and panel box systems. Each living wall includes plans, sections, and elevations with their main living wall components. Living wall Number 1 represents a modular system fastened onto a 19mm plywood backing for waterproofing and better support. The system is composed of trays where selected plants are grown. The trays are fixed to the system with fasteners to provide stability and immobility of pots.

Living wall Number 2 represents a panel box system composed of a waterproof backing board, rear drainage 4.5 mm geotextile drainage layer, and an 18 mm dripline, which allows consistent water and nutrient distribution throughout the living wall. The water is collected at the bottom of a LWS in a 150 mm wide PVC gutter.

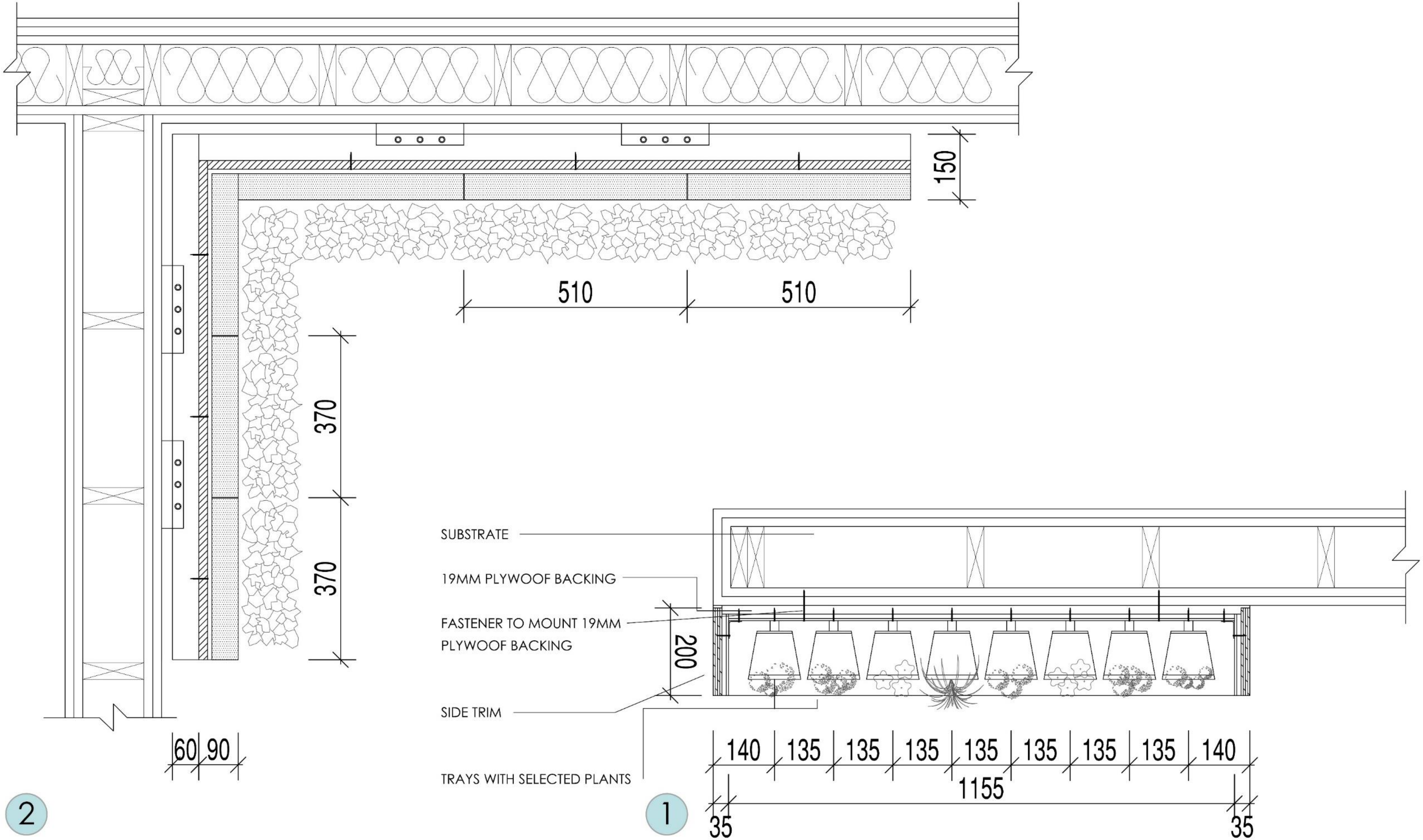
The modular living wall concept provides an opportunity to create flexible patterns and designs that can be used for growing herbs and other suitable species of vegetables. The panel box system, on the other hand, brings more efficiency in noise absorption from outdoor noise and enhances air purification benefits. This house project shows how indoor living walls can be integrated and used differently, and demonstrates how a system's components vary according to the choice of function.



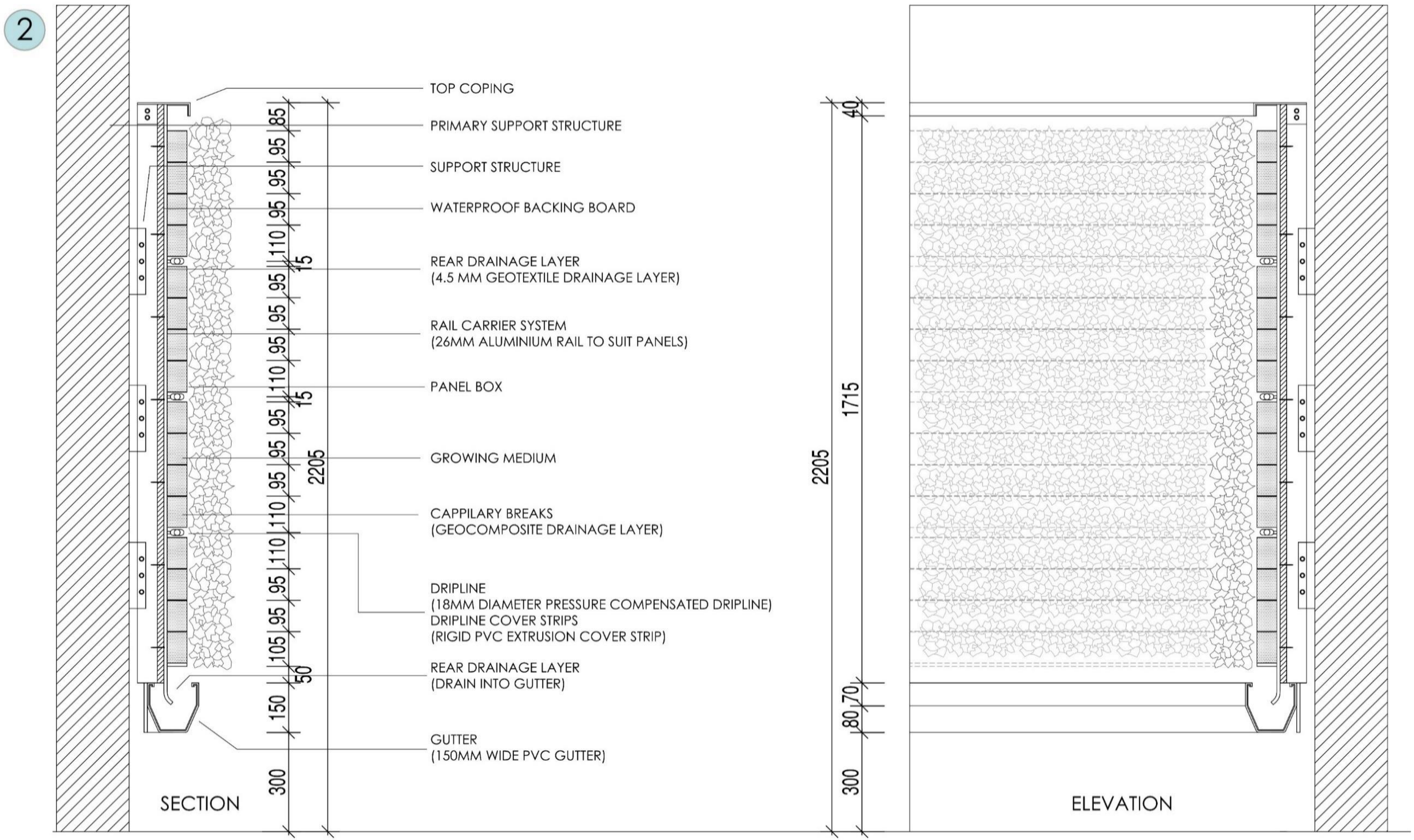
Ground Floor Plan and Identification of Two Living Walls Placement.



The Concept of Modular Living Wall № 1 with Section on the Left and Elevation on the Right.



Living Wall Plans with Type № 2 on the left and Type № 1 on the Right.



Living Wall Type № 2 for Air Purification Purposes with Section on the Left and Elevation on the Right.

Living Room Interior Rendering Including Two Living Wall Types.