Review of Sustainable: Living Walls

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Abstract

According to a United Nations forecast seventy percent of the world population will be living in cities by 2050 (UNFPA 2007).This is due to the huge transferring that continuing to profound from the vegetated and rural areas to the modern cities, which increased the pollution, noise, and crowdedness of cities bit by bit and shifting them into more concrete, solid and blocked jungle. In order to overcome such a major problem, new and innovative solutions are needed. The lack of the green is one of the main factors that can cause huge problems. So we must find better ways to integrate nature again into these expanding cities.

A new technology is now out to light, which uses the plant as a main solution to improving urban heat, achieving aesthetics, sound controlling and saving building energy. Using this new technology and using new systems allows plants to be part of a building where they are actually planted and growing in a wall system known as "Living Walls". With multiple benefits of plants in improving air quality, excellent aesthetics by the different colors and textures of foliage, reducing temperature and noise levels and reducing the energy costs through a process known as evapotranspiration. Living Wall naturally cools the air inside the building and on the outside it acts as an insulator which isolates the hot air and pollution which improve the building performance. All these benefits make living walls an excellent choice to be part of a sustainable solution of urban rehabilitation and adjusting the buildings to increase its performance.

The aim of this paper is to understand new systems and technologies involved for designing and installing living walls and understand the main differences between these systems in terms of composition and construction methods in order to achieve both aesthetic and functional elements.

To overcome many problems living wall with all its benefits and systems must evolve to become more sustainable solutions to achieve better performance in all building phases and not just technical solutions.

Key words: Living wall, bio-walls, living wall systems, Hanging Garden, sustainability, and evapotranspiration.

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Introduction

Living walls, also called bio-walls, have been successfully adding value and beauty to interiors and exteriors around the world for many years. Plants with different colors and textures of foliage can be woven into clever designs, so living walls are a perfect example of how plants can be featured as such works of art. *Fig(1)* However, the greening systems for buildings now a day are not just surfaces covered with vegetation, the technology involved in these systems can actually increase buildings performance through the benefits of plants.

In fact, covering buildings with vegetation, in urban scale, can clearly improve the urban environment by contributing to urban biodiversity, air quality, temperature reduction, storm water management and decreasing heat island. Beside that the environmental aspects, social and economic benefits that these greening system have.

Traditional living wall methods are historically known, since the Hanging Gardens of Babylon and the Roman and Greek Empires.

There are several systems can be used for living walls, and in order to understand these living wall systems and compare their features, an analysis of their composition must be made according to the following items: supporting elements, growing media, vegetation, drainage and irrigation. Additionally, given the importance of these subjects, two subsections were added to focus, first on the lifecycle of systems, and the different phases of their installation and maintenance, and second on the environmental performance and cost of living wall systems.

1. Modular Living Wall Systems

Modular systems are composed of pre-vegetated panels which can be square or rectangular panels with a specific dimension that hold the growing media where plants can grow and to support the plant material. These panels can be made of plastic, expanded polystyrene, synthetic fabric, clay, metal, and concrete, and support over 592 great diversity and density of plant species. Modular systems also can be composed of, vertical modules or planted blankets.

Living walls are emerged to allow integrating the green to high buildings and by uniform growth of plants among vertical surface, allow a rapid coverage of large surfaces in short time. Because of several systems it's easy to be designed to cover these blocks to convert them into a piece of art due to the wide variety of plant species that can be used, regardless to the height and kind of building as they adapting to all kinds of buildings.

1.1 Modular LWS forms

They are form of living wall system which consist of elements that are supported by a complementary structure or fixed directly on the vertical surface within modules where most

of the plant nutrient requirements can be found in the growing media. Modular LWS have various ways in their composition, weight and assembly. They can be in the form of:

1) Trays: They are rigid containers, attached to each other in sequence as beehive to hold plants and substrate weight. This system needed to be irrigated once a week to 10 days, where small amounts of water is added within the trays until the moisture can be fully absorbed. *Fig(2)*

Figure (2) Trays

2) Vessels: They consider the most common support for plants where they can be fastened directly to a vertical structure or be attached vertically to each other with a soft fabric string or ribbon, known as the wick, where part of it is buried in the vessel the other part hanging in a bucket or pot of water as this wick watering system will help to provide the correct amount of moisture to plants. *Fig(3)*

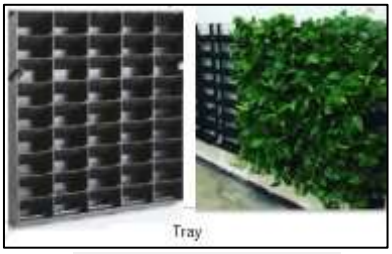

Figure (3) Vessels

3) Planter tiles: They are constructed by inserting pre-planted plants with a proprietary soil mix and filter fabric mesh where they can be planted in a random pattern, or to design specific patterns using the grid modules as bitmaps, allowing the understructure to disappear, *Fig(4)*

Figure (4) Planter

4) Flexible bags: They are microfiber material that includes a growing media and lightweight materials which allow the vegetation process to take place in surfaces with different forms, as curved or sloped surfaces. These microfibers allow even watering of all plant due to a wicking, water capillary movement, as the roots do the job in the felt. The felt pockets are attached to a channeled, rigid back board that allows air to flow behind the system where it prevents mold issues, or it can coupled with a pump system. *Fig(5)*

Figure (5) Flexible bags

1.2 Hydroponic LWS / Soil-Less Based

How Plants Grow In Soil

Naturally in horizontal sustainable landscapes, water carries nutrient solutes around and soil particles attract this nutrient and hold them through ionic bonding. The humus content of soil helps buffer pH, and breakdown compost into humic acids and humins.

The soil is also layered with micro-organisms and mycorrhizae where each have specific functions for the plants, which all ends up as a complex self-regulatory systems web, that create a stable environment for life. Gravity plays an essential role in this stability; holding it all together and ensuring the necessary inputs of rainwater and fresh material in the way of falling dead and decaying matter.

How Plants Grow In Hydroponics

All the complexity of soil and the problems of using compost as the growing medium are now can be avoided in hydroponic system, where plants don't have to expend to search for food as in soil. In fact, in hydroponic, all nutrients needed in a precise and controlled mode are delivered to them with zero-action exchange, so the plant doesn't have to expend 60% of its energy searching for food.

Normally soil simply provides mechanic root support for the plant and along with the minerals stored in, and it is only water that is required to absorb these minerals of course with the need of light and carbon dioxide from the air. But if all nutrients can be served directly to plants without all this effort, plants won't need soil to grow as well as the need of water as an input to a hydroponic system will decrease. This means hydroponic technique proves the fact that plants can grow without soil.

Hydroponic has two main systems; Active and Passive hydroponic systems. Active system needs a mechanical pump which passes chemical nutrients soaked in water directly to the roots and it is the common for living walls. While passive system works without a pump, instead water draws to the roots through a utilized wicking fabric or some type of inorganic media.

In Hydroponic living walls a waterproofing layer is needed to protect the structure behind the wall. There are many types of water proofing that can be proofing membranes, peel and stick applications as PVC sheets or in some cases layers of felt stapled directly to a concrete wall.

Medias / root support structures, clean water, temperatures, pH levels, lighting, nutrient solutions, and oxygen exchange (oxygen to nutrient ratios), are part of the synchronization of successful hydroponic walls.

1- <u>Rooting Media:</u> Felt fabrics, coco husk, porous sheets of scrub pads (mineral or rock wool) and porous foam are the most popular types of rooting media materials. *Fig(6)*

Figure (6)
Types of materials used for rooting media

N.B: Root rot can take place in hydroponic living walls system for many factors, mainly the improper water aeration, where roots get to be directly exposed to the water medium allowing zoospores to move freely causing the entire operations to be affected with root rot within two to four days due to the inherent nature. in which. There are also other factors causing root rot including: using unsterilized tools and equipment, leaving dead roots and leaves, other infected plant material and using unfiltered water. Fig (7)

To avoid root rot H2O2-treated water, nutrients and beneficial enzymes must be added. These enzymes displace any anaerobic bacteria and colonize the sterilized medium and system, hopefully. The best way to avoid any root rot and prevent it is to start with a clean system.

Hydroponics are very sensitive to salts, pH and changing variables including temperature. The water is the way how nutrient solution is delivered to the top of the wall via a pumping system and allows it to saturate the rooting media due to gravity from top to down while watering the roots.

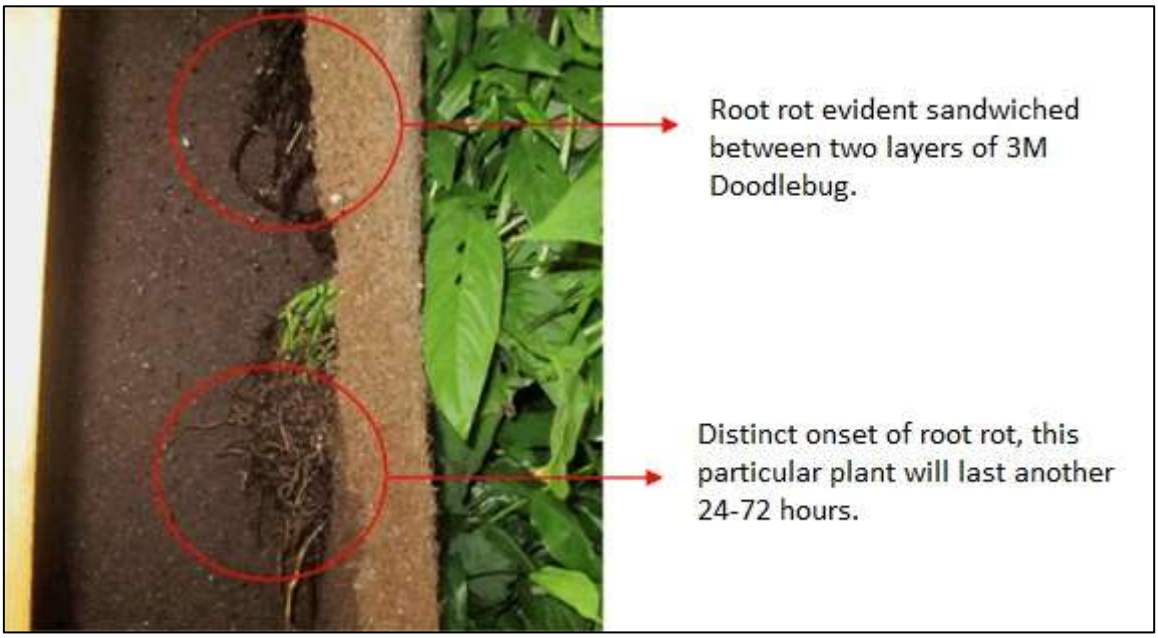

Figure (7) Root Rot

2- Water Temperatures: The temperature of the water is the main factor where the amount of oxygen dissolved in a nutrient solution depends on. Dissolved oxygen can be more held in cold water than warm water. A fully aerated solution at 20°C is 9 - 10ppm (part per million) and at 30°C it's 7ppm. This means that oxygen requirements for root system will double with every 10°C rise in temperature, while carrying oxygen in the capacity of solution will drop over by 25%. Therefore, oxygen dissolved in nutrient is not enough for the roots' oxygen need, leading to oxygen starvation, which will cause slow growth, mineral deficiencies and then the root dies.

3- pH level: pH is a scale from 1 to 14 that measures acid-to-alkaline balance: 1 being the most acidic, 7 is neutral and 14 is most alkaline. Every full point change in pH represents a 10-time increase or decrease in acidity or alkalinity. The best pH range level for most plants growth is between 6.5 -7, where plants can most efficiently absorb and process available nutrients. If the pH is too low (acidic), salts and nutrients bind chemically together leaving the roots incapable to absorb them and then plants won't be fed. On the other hand, a high pH level (alkaline), causes nutrients to become unavailable in soil. Toxic salt formed due to lack amount of water taken by roots can becomes another problem; so it's very important to measure the pH level in the water. The ideal pH range for hydroponics is from 5.8 - 6.8, which is slightly acidic. A weekly test should be part of the maintenance process; to increase pH level Potassium Hydroxide and Potassium Carbonate are added and to reduce pH level down Phosphoric acid is added. These products have to be taken in consideration of the maintenance coat of the hydroponic living walls.

4- Lighting: Plants, bacteria and algae are organisms absorb light and convert CO2 into organic material producing energy to fuel the biological activity in a process called "Photosynthesis. No light, no photosynthesis, no energy, simply no plant!

Unlike bacteria and algae, living walls with plants create energy through splitting water molecules by processing light to the form of O2 and glucose. In order for this to happen a quantum amount of light is needed and good as well and not just any light or any amount. Plants with chlorophyll grow better in light waves in the blue and red spectrum. Low light levels mean low levels of photosynthesis which means less energy.

5- Nutrient Solution: Nutrients used in hydroponic are differ from these that are used for soil growing plants. Soil nutrients don't contain all the micro-elements the plants need because they are plenty of them in the soil, so they are not added to nutrients designed for soil grown plants unlike the plants grown in hydroponic systems where all nutrient elements are needed. In order for plants to absorb the nutrients in hydroponic the pH level of that nutrient solution has to be in a range where plants can use. The composition of the nutrients is very important for plants to grow and there are more than twenty elements that are needed. Carbon, hydrogen and oxygen are absorbed from the air and water, while the rest of the elements, called mineral nutrients are dissolved in a correct ratios in the nutrient solution otherwise the plant won't grow healthy.

6- Supporting structure: Supporting structure is very important to provide mechanical support for the plants while growing attached to the felt. In order to attach the felt on the wall surface a PVC-board of a 10 mm is needed mounted on a stud work and sealed at joints,

leaving an air gap between the board and the wall behind to provide a double protection against moisture. A highly absorbent synthetic felt is attached on top of the board in many layers allowing the water to distribute evenly over the surface. The plants are inserted in-between a cut made in the outer felt layer which look like a pocket. Depending on type of species used the average surface depth increases with 200-500 mm, and the construction is very light about less than 25 kg/m2 including plants because of a soilless surface.

1.3 Substrate LWS / Soil Based

These systems typically use molded troughs or containers that are built on or attached to existing walls. Planting that is supported by soil-based substrates are utilizing a lightweight combination of recycled materials containing the right balance of nutrients with a free-draining medium.

The natural water retention properties of most substrates allow irrigation systems to be easily designed and constructed, therefore lowering the installation and maintenance costs. However, a disadvantage that is associated with substrate-based systems is their weight relative to other solutions. But using newer lightweight materials are becoming increasingly a new solution for this issue.

Growth Media for Loose substrate systems having sack based system:

In sack based systems, the growth medium needed has different requirements as it is exposed to environmental forces from all sides as a hanging basket. It is subjected to different factors like evaporative losses besides changing in temperature degrees that can affect these types of systems. Plants have to survive changing climate. The uniformity of growth medium is also required in the loose media as there is no control over water flow & sometimes water finds its own way to drain before it penetrates throughout media which could cause root rot in the sack.

2. Designing for Sustainability

The fundamental reason to provide living wall needs must be identified up front, as this will affect the design, construction and required level of maintenance for the system. Designing of living wall depends on many factors that determine the selection of plant species and the type of environment it will be built in, such as the location and climate, sun exposure and the surrounding area. The purpose of such construction is to create a one of a kind and unique wall that stands beautifully through all the seasons of the year. Knowing plant's growth habit, behavior and size on living wall is very important to make the right combination of plant to keep the competition between them at a healthy level. Well-performed design means less maintenance demand of the wall means less coast needed. Choosing the right plant for the right place and the right plant with another makes the right vertical garden that can last for long time.

2.1 Vegetation

Selecting plants depends on a number of related factors. The location of the living wall is the key driver regarding with temperature, light levels and exposure to the elements. The function of the wall will also determine the plants required. High impact feature walls require

plants with abundant foliage and brightly colored flowers. Living Walls are designed to improve air quality so they have to be planted with species that absorb dust and toxins.

Light levels (sun or shade) are another factor which will influence the selection of plants that able to cope with specific conditions. Indoor walls may require additional artificial light to support plant growth. Though it is important to select plants that require similar levels of irrigation to reduce the complexity required of irrigation system. The final aesthetics design, the speed of coverage and initial growth need to be considered. Some systems may require several months to grow or even years before achieving the desired visual impact.

2.2 Irrigation

In order for a living wall to be sustained it has to be irrigated. One of the common factors that cause plant failure is the interruptions to the water supply. Although with inbuilt irrigation systems that are designed to mitigate plant losses because of the inconsistent moisture management, still errors can occur. Most living walls have one of two types of irrigation systems regardless of the living wall system type. These types of irrigation systems are:

a- Recirculating irrigation system it recirculates water using an irrigation tank as a source of water which it can be either remote-controlled or directly fixed underneath the living wall. In order for this tank to provide an adequate supply of irrigation water, it has to be filled manually on a regular basis then the water is pumped from the tank and distributed to the plants in the wall. Then gravity plays the role of pulling excess water downward. The overflow drainage water is then been collected at the bottom of the wall and send back to the tank to be reused over and over again (recirculates).
Fig (8)

b- A direct irrigation system an external water source as the city water is the direct irrigation source of the living wall, so it doesn't have or need a water tank or pump because of the existing water pressure of the water lines. Sometimes by using injector this water is injected with fertilizer. Water is channeled to the living wall and distributed to the plants and the water is pulled down by gravity. The overflow irrigation water is collected then flushed away to a sewer drain (not recirculated).*Fig (9)*

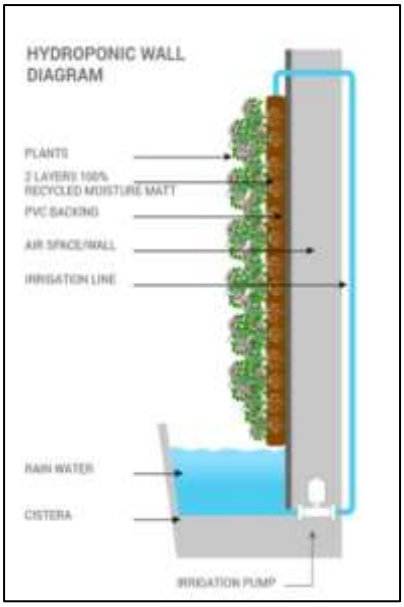

Figure (8)
Recirculating irrigation system

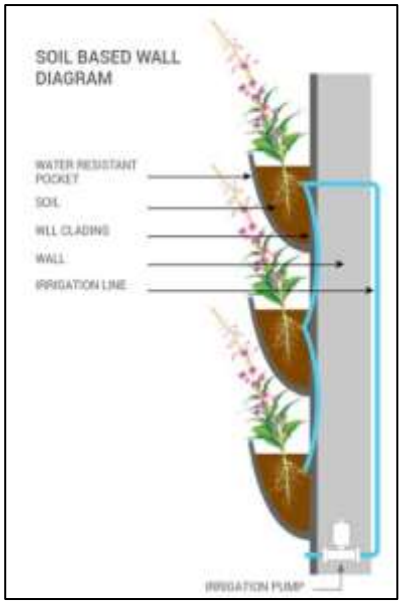

Figure (9)
Direct irrigation system

In high profile locations for living walls, automated and remotely controllable irrigation systems are used. The quality, design and costs of any living wall defer from system to another. For the maintenance supervisor it's easier for him to keep track of the automated performance of the system in sophisticated systems, including the irrigation delivered volume, its frequency, pH, substrate moisture content and nutrient levels in the water supply. The settings can be overridden if required; for example, the duration or frequency of irrigation cycles may increase on hot days.

In hydroponic systems, the nutrition of plant is preserved by a fertilizer injection system that releases the fertilizer in controlled doses into the irrigation system and this process called "Fertigation". Managing fertigation system and its delivering rates requires specialist knowledge, as it is more complex than fertilizing soil or growing media. A continual monitoring of pH, water hardness and total dissolved solids (TDS) are necessary in Hydroponic system as well as the adjustment of these parameters.

For hydroponic living wall systems, the fertigation system may apply 0.5-20 liters of irrigation solution per square meter per day. The requirements of indoor living walls are at the lower end of this range. In other hand, outdoor living walls at the higher end. Irrigation cycles last a few minutes typically and needed several times a day. Minimizing irrigation volumes reduces the waste and run-off, which are grabbed in a tank at the base of the wall and recycled back to the living wall.

Living walls that use a high quality, water-retentive growing medium and not exposed to hot location, may thrive on a weekly watering system. However, in soil-based systems fertigation system is not used, a controlled fertilizer is mixed in with the growing medium instead.

Irrigation must be available as soon as the plants are installed in the wall system. The irrigation system requires a water meter to monitor irrigation volume, and a pressure measurement to monitor the uniform water influence.

2.3 Drainage

The overflow fluid drainage takes place by gravity in living walls. In modular LWS, geotextiles are used which help drainage along the permeable membrane while preventing roots proliferation. Modular trays avail the modules overlapping and materials to improve drainage and the excess of water is reused to the modules below. For a better drainage the bottom of modular systems can be concave, perforated, inclined or absorbent material or it can be made in a porous. Vessels are another example using a filter material applied at the bottom of the module to fertilize the sand from any toxins or heavy metals, as well as purifying rainwater or a granular inert filler can be used such as expanded clay, gravel or expanded slate which promotes the drainage and development of roots. Other example in modular systems is inserting grooves or holes on the sides and the back face of modules, for better aeration and removing excess moisture contained in the substrate.

2.4 Installation and Maintenance

The design, installation and maintenance factors may defer from each other according to the type of the living wall, in addition of, building conditions and natural environment. These factors must be taken in consideration when designing, installing and maintaining living walls. During the constructing phase of the wall it is important that the designers, installers and manufacturers take the following consideration carefully:

- How will attach the living wall to the building surface? Either it will be fixed directly to the building's wall or it will be a free-standing system.
- For larger living wall types, careful load calculations must be made taking in consideration external factors like rain, plant and wind.
- Plant selection – putting in mind the locations climate, light exposure and humidity, as well as choosing the right soil and nutrition for plants and their lifetime as there are some plants take long time to fully grow and for the system to become 100% functional.
- Proper maintenance for irrigation system must be highly prioritized for fully functional and healthy living wall.
- Consultancy with specialists is essential for a successful project.

It's very important to have consultancy with experts for a proper and successful living walls installation, as there are many different ways to install living walls on different surfaces which need special tool or machinery that only known by experts.

All living walls defiantly require a degree of maintenance. It is important before installing living wall to know the amount of maintenance it needs and if it is easy to provide, as this can impact the selection of the living wall type as well as choosing the type of plants to install, as there are many types of living wall systems that each need a distinct maintenance measures that depend on the type of the system and the vegetation used. Plants from distant environments may need additional extra care and special maintenance than those native plants which are rich in nutrients with the contrasting climate, thus, less maintenance is needed. For a good living wall, there are some considerations need to be taken such as soil, irrigation, nutrients and long-term maintenance.

2.5 Environmental performance and costs

In order to know if living walls are a sustainable solution, several studies were conducted by researchers to compare the environmental performance of different living walls systems during their entire lifecycle. Some LWS may be questioned to be sustainable when analyzing their life cycle, due to different type of materials that are used and their durability, vegetation durability, water consumption and recycling potential which can have a significant load impact on the environment. As shown by Ottelé et al. the integration of stainless steel as supporting system can have an impact 10 times higher than using other recycled materials (e.g., HDPE, hard wood with FSC certificate or coated steel). Another important thing that has to be considered is the durability of materials used as there are several materials as PVC have a limited durability which means they need to be replaced more than once during buildings life expectancy. None the less, living wall systems use frequently materials with high environmental impact. However, recent studies proof that some systems can have less environmental burden through contributing to the wall thermal resistance which leads to a reduction on energy demand for cooling and heating. The cost of living wall systems can also have different significant impact on the selection process.

3. Design Suggestion

To better understand if living wall may be considered sustainable solutions, a suggested study was conducted to compare between the environmental performances in the presence and absence of living walls at "Madinaty Entrance Gate (1)" as a prototype of the research.

Table (1)

Before	Disadvantages	After	Description	Benefits
 *Madinaty Entrance Gate (1):* Cladding surface using limestone and sandstone materials and the colours chosen, give the appearance of a solid, boring and blocked surface. 	• The lack of vegetation in urban environments coupled with the heat reflected off hard surfaces of both high rise building and streets and paving contributes to higher temperature. • Living wall systems can be very expensive because of the panels and plant species, irrigation, installation and maintenance which depend on the type of the living wall system.	 *Madinaty Entrance Gate (1):* Adding the living wall on the gate offers more pleasant and healthier atmosphere due to the many benefits of living wall that improve urban environmemt and the verity of colours and texture of foliages that give the pleasant look. 	• Hydroponic (soil-less) technique is suggested to be used in this prototype as it soil free which means it's 10 times lighter than common modular box systems that make it easy to replace if the plants die or get a disease but in hydroponic systems they tend to thrive and don't have to be replaced very often. • **Technical Details:** 1- In order to hold the plants on the wall supporting elements are required to be attached to as vertical beams which could be	• **Reduction of Urban Heat;** through evapotranspiration process living walls can reduce and cool the surrounding air temperature levels in the urban environments. • **Lowering of Energy Consumption;** balancing the temperature of buildings in summer by cooling the air and insulate them in winter, help in lowering the energy usage, thus the energy coast of the building. • **Improvement of Air Quality;** though bio-filtration, living walls absorb carbon dioxide and volatile organic compounds which filters the air. • **Reduction of Noise Pollution;** the plants and their planting medium

			either aluminum, galvanized steel, stainless steel, or some other non-rusting metal. 2- Waterproof panels are then fastened to it, to protect the building from any moisture. 3-Two layers of material made of recycled synthetic fibers that are spun into a nonwoven matrix are stapled to the waterproof panels where the plants are placed between them in hand cut pockets. 4-A drip irrigation system is placed between the two layers of material allowing the water to slowly percolate downward.	considers effective sound barriers, so they absorb sound reflected from hard surfaces in the surrounding areas. • **Improvement of Health and Well-being;** naturally plants reduce stress, contribute the overall wellbeing and provide good mood which promote focused attention and lead more efficiency at work associated with increasing the productivity. • **Aesthetic Enhancement;** using the verity of colours, textures of foliage as a unique design elements converting boring, solid and blocked surfaces into a natural interesting beautiful piece of art surfaces.

Hypothesis

- How do Living Walls a sustainable solution?
- Can Living Walls be designed?
- Is there any relation between designers and other specialties?
- What is the link between Living Walls and Art?

Results

- Facing urban issues like changing climate, diminishing biodiversity, energy use, health problems due to water, air and noise pollution. Using the benefits of plants in living walls to improve the urban heat, achieving aesthetics, sound controlling and saving building energy, consider as a key component of sustainable development solution.
- By reviewing different types of living wall systems, it can be understood that innovation is centered mostly in improving their design to achieve a better performance, during the installation and maintenance process.
- The combination of skills required to design, install and maintain systems remain a challenge and requires input from a number of industry disciplines, e.g. architecture, horticulture, construction and designer.
- Living wall helps to soften the grey, hard and cold look of concrete especially in concrete urban and transform it into a piece of art work.

Recommendations

- In the field of living wall characteristics, the main concerns are to find new strategies for a better performance and durability through the integration of new water retention materials, simpler assembly, drainage and maintenance processes.

- Continuing to evaluate the contribution of living wall systems to improve buildings performance and comparing the environmental impact of these systems with other construction solutions to increase the buildings application.
- Living walls must evolve to become more sustainable solutions, through the usage of materials with less incorporated energy and CO2 emissions and using plant species that adapt with climate changes with less irrigation needed.

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