Greening Building Enclosure for Improved Footprint: Reducing the Environmental Impact of Green Facades and Living-Wall Systems LWS

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Abstract

Several concepts are used in greening the building enclosure, for example green roofs, green façades with climbing plants, and living wall systems (modular pre-vegetated panels). Greening the building enclosure allows to obtain a tangible improvement of its energy efficiency, ecological and environmental benefits, as well as an increase of air quality. Since the interest in restoring the environmental integrity of urban areas continues to increase, new developments in construction practices integrating such vertical greening systems. The integration of vegetation is not a new concept and can offer several benefits as a component of the current building enclosure. It enhances the relation between environmental benefits, air quality, energy saving, and the vertical greening systems. This represents a sustainable approach for the enclosure of new and existing buildings

This study investigates the ecology and typology of green facades and living wall systems LWS and its significance in improving indoor air quality. LWS has been defined as an air purification method. The potential for reducing inorganic gaseous indoor pollutants, volatile organic compounds (VOC's), and CO2 concentrations have already been proved. Moreover, LWS have also been investigated for the reduction of indoor particulate matters, especially for PM_{10} and $PM_{2.5}$, where many studies concluded with significant removal efficiency. Assessment in real indoor environment demonstrated temperature reduction capacity of vertical green systems, which ultimately can be beneficial to lower down the energy requirement for cooling purposes in the buildings.

Since construction of these systems consumes a lot of metals, the study also proposes a circular economy approach through redesigning the industrial metal waste stream used to construct these living walls skeleton. This ecological understanding of materials will reduce environmental impact and serve as a basis to create new value streams for recyclable materials. This concept of ecological material advances the environmental awareness of the benefits of available sources and applications of living walls materials, especially those metals used to construct the skeleton of these walls.

KEY WORDS: Building Enclosure, Living Wall Systems; Green Facades, Environmental Impact.

1. Introduction

The built environment is responsible of almost 40% of global emissions. A definition of sustainable or eco-architecture represents an attempt to respond to global environmental problems and to reduce environmental impacts due to the building industry, which include the exhaustion of natural resources, emission of CO2, and other greenhouse gases (Pulselli, 2007).

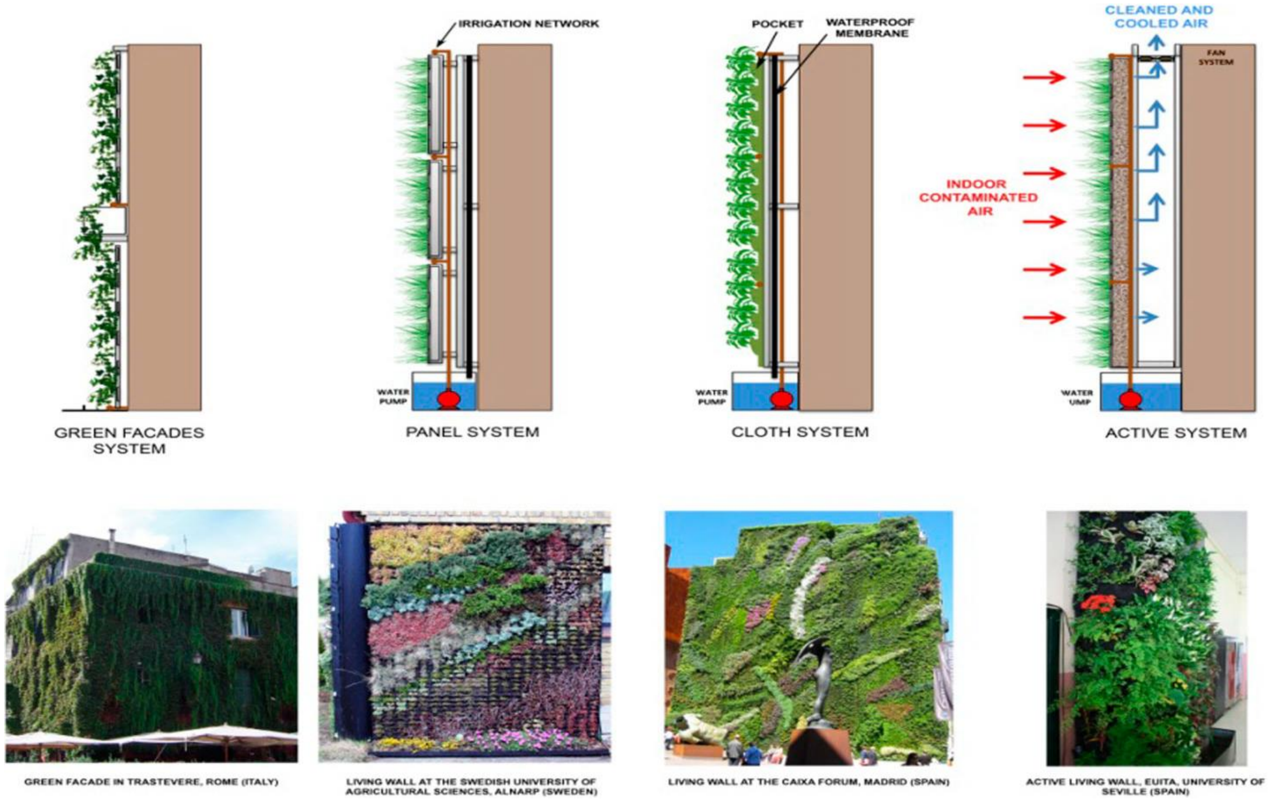
The integration of vegetation on buildings, through vertical greening, allows obtaining a relevant improvement of the building's efficiency, ecological and environmental benefits, and it can be an opportunity to obtain more "urban forestry". The benefits gained due to the use of vegetation are the subject of studies and research started from 1970s.

Vertical gardens offer the potential to learn from traditional architecture. The earliest form of vertical gardens dates back 2000 years in the Mediterranean region. It incorporated advanced materials and other technology to promote sustainable building solutions (Köhler, 2008). It is a good example of combining nature and buildings by linking different functionalities in order to address environmental concerns in dense urban surroundings (Bohemen, 2005). Since urban centers nowadays are searching for areas to plant vegetation due to the lack of space in order to transform the carbon dioxide produced by traffic and heating into carbon hydrates and oxygen.

The application of vegetation as a vertical building skin can drastically change its aesthetics and have a positive influence on comfort and wellbeing in and around the building. The ecological and environmental benefits for green facades are: the reduction of air pollution mainly related to reduction of fine dust levels (Ottelé et al, 2010); increase of biodiversity; reduction of the heat island effect in urban areas due to the lower amount of heat reradiated by green façades; the humidity affected by the evapo-transpiration caused by plants; and indirect benefits of energy savings for the building. In fact, both the growing medium and the plants themselves provide insulation and shade which can reduce energy for cooling and improve the indoor and outdoor comfort (Wong et al, 2009). Besides these benefits, social and economic values are also involved, with respect to the real estate market, the improvement of durability and better psychological feelings of citizens.

2. Vertical Greening Systems Typology

Vertical Greening Systems VGS are also known as green-wall technologies, vertical gardens, or bio walls.



GREEN FACADES SYSTEM

PANEL SYSTEM

CLOTH SYSTEM

ACTIVE SYSTEM

GREEN FACADE IN TRASTEVERE, ROME (ITALY)

LIVING WALL AT THE SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES, ALNARP (SWEDEN)

LIVING WALL AT THE CAIXA FORUM, MADRID (SPAIN)

ACTIVE LIVING WALL, EUITA, UNIVERSITY OF SEVILLE (SPAIN)

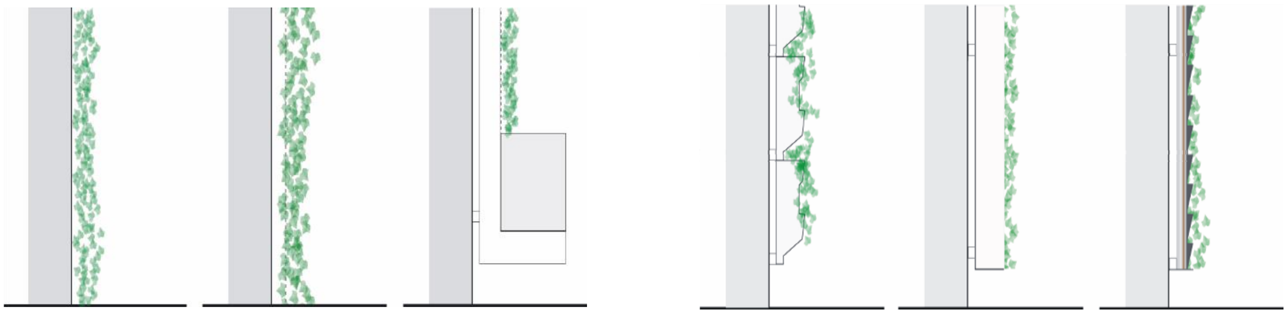
Figure 1: Vertical greening systems: categories and examples (Perez et al, 2015)

They consist of vertical structures that spread vegetation that may or may not be attached to a building facade or to an interior wall. Attending to the level of complexity, there are several green-wall typologies that range from the simplest configuration to the most complex and high-tech design. Based on the type of vegetation and support structures used, these systems can be divided into two major groups: green facades and living walls (Kontoleon, 2010; Manso, 2015).

In Green Facade GF systems, or green screens, the vegetation cover is formed by climbing plants or cascading groundcover (Figure 1). Specially designed structures can be used to force the plant development through the building's wall, which can serve as support for the climbing vegetation. Normally, green facades are rooted at the base in the ground or in plant boxes, but intermediate planters, fixed to the wall at a certain height or even on rooftops as a falling green cascade can also be used. Due to the lower diversity and density of plants, green facades normally require less intensive maintenance and protection than living walls (Ottele´ et al., 2010).

Living Wall Systems LWS are generally more complex infrastructures that involve a supporting structure with different attachment methods. A waterproof backing is required to isolate the living wall from the building in order to avoid problems associated with dampness. An irrigation network is also necessary while fertigation, monitoring, and lighting systems are optional. Cloth (or felt) and panels (or boxes) are the most commonly used vegetation attachment methods to the supporting structure (Figure1). Within the panels system there exists the possibility of planting in situ once the structure is attached to the wall or using pre-vegetated panels that are prepared before planting in specially designed structures. In each of these cases, the growing medium is allocated inside the pocket (if cloth system is used) or the panel. The systems that use either organic or inorganic growing media along with mineral nutrients to grow plants outside the soil are also known as soilless or hydroponic systems

VGSs are usually located outdoors and fixed to the exterior wall of the building. Nonetheless, they can also be built in the interior of the building envelope (termed as indoor living walls) though, in that case, some considerations regarding indoor humidity, lighting, and plant species must be taken into account (Fernandez-Canero et al., 2012). Traditionally, the green wall has acted as a "passive" bio filter, but new approaches and technologies are moving towards the integration of living walls (both indoors and outdoors) within the building's air conditioning and ventilation systems. The result is called "active living wall," in which an air current is forced to pass through the green wall and collected afterwards so that the recycled fresh air can be supplied to the building's interior as the air has been cooled, filtered, and humidified by the plants and growing media.



(a) Direct greening sys b) Indirect greening sys (c) Indirect + planter boxes (d) LWS Planter boxes (e) LWS foam substrate (f) LWS felt layers

Figure 2: Prototypes of vertical greening systems evaluated by LCA study (Otelle et al, 2011)

3. Environmental Impact of Green Façades GFs and Living Wall Systems LWS

Besides the environmental benefits that greening systems allow to obtain, it is eventually not clear if these systems are sustainable, due to the materials used, maintenance, nutrients and water needed. Sustainability can be defined as a general property of a material or a product that indicates whether and to what extent the prevailing requirements are met in specific application. These requirements, which relate to air, water and soil loading, have influences on wellbeing and health of living creatures, the use of raw materials and energy, and also consequences for the landscape, the creation of waste and the occurrence of nuisance to surrounding environment.

Greening system	Benefit	Mediterranean climate	Temperate climate
Direct green	energy saving for heating	1.2%	1.2%
	temperature decrease	4.5°C	2.6°C
	energy saving for cooling	43%	---
Indirect green	energy saving for heating	1.2%	1,2%
	temperature decrease	4.5°C	2.6°C
	energy saving for cooling	43%	---
LWS planter boxes	energy saving for heating	6.3%	6,3%
	temperature decrease	4.5°C	2.6°C
	energy saving for cooling	43%	---
LWS felt layers	energy saving for heating	4%	4%
	temperature decrease	4.5°C	2.6°C
	energy saving for cooling	43%	---

Table 1. Energy saving for heating, energy saving for cooling and temperature decrease for Mediterranean and temperate climate based on Alexandri and Jones, 2008.

The life cycle assessment LCA is an effective tool for evaluating the sustainability of a building element, with respect to the integral balance between the environmental load and the possible benefits. A study conducted by Ottelé et al., 2011, regarding a life cycle assessment of four greening systems, shows the environmental burden profile in relation with the energy savings for air conditioning and heating achievable (according to Table 1), since only an estimation of the microscale benefits is taken into account in research, for a Mediterranean climate situation and for a temperate climate one. The four greening systems analyzed in this LCA are: a direct greening system (a), an indirect greening system (b), a LWS based on planter boxes (d) and a LWS based on felt layers (f), shown in (Figure 2).

The energy benefits provided by the greening options make a noteworthy impact in the LCA and are calculated for temperate climate; for the Mediterranean climate the benefits calculated are roughly two times higher thanks to the energy savings related to the cooling potential. From this LCA research it can be concluded that: 1) The direct greening system has a very small influence on the total environmental burden, for this rea- son this type of greening, without any additional ma- terial involved, is always a sustainable choice for the examined cases; 2) The indirect greening system analyzed based on a stainless-steel supporting system has an high influence on the total environmental burden; 3) The LWS based on planter boxes has no major footprint due to the materials involved, since the materials affect positively the thermal resistance of the system; 4) The LWS based on felt layers has a high environmental burden due to the durability aspect and the materials used.

Since the development in this field is growing rapidly, especially in the last few years, many systems with different materials and characteristics are available. The different systems and materials can have an influence on the environmental burden either positively or negatively. For example, for the indirect greening system, other materials can be used as support for climbing plants, such as different types of wood, plastic, aluminum and steel, instead of a stainless-steel mesh, and can have an influence on the environmental burden of the system roughly 10 times lower than the stainless-steel mesh

(Hendriks et al, 2000). Besides this for living wall systems, a sustainable approach can involve a higher integration within the building envelope by combining functionalities, since the protection against the environmental parameter can be absolved by the layers involved.

Greening the building envelope, considering the materials involved, that have a high influence on the environmental profile, and taking into account all the benefits is a sustainable option for new constructions and retrofitting.

4. Metals as High Impact Materials in LWS

The widespread production scheme for stainless steel manufacture includes; smelting, decarburizing alloyed product, final steel finishing and steel casting (Gudim, 2015). The global stainless-steel production was forecasted to grow by about 4% to 52.1 million tons in 2018 according to metals market research company SMR. China was the largest producer of stainless steel in 2017 with 27.0 million tons, consuming more than 20 million tons of stainless steel flat and long products in the same period. China is followed by Europe, India and Indonesia consecutively as the highest producers of stainless steel. Urbanization is one the factors causing the increase of stainless steel demand (Shah 2018). Galvanized sheet metal is a resilient material consisting of steel sheet and zinc coating. It is galvanized to preserve steel in a process known as hot-dipped galvanization or electro-galvanization. After coating in zinc, the steel sheet undergoes spangling, alloying for uniformity and chemical treatment for anti-corrosion and printability to become a product mostly used in metal walls systems. According to American Institute of Steel Construction AISC, the recycled content of domestically produced structural steel is between 90% and 100%.

Aluminum are made from the Hall-Heroult process (Davis 1993). Caustic soda is used to dissolve the aluminum compounds found in bauxite to separate them from impurities. The slurry is heated under pressure, allowed to settle, filtered and fed to precipitate. Smelting is continuous with constant electric power; this process makes aluminum the metal with the highest consumption of energy. However, according to the US Aluminum Association, the current recycled content of aluminum is 43% in 2023 which significantly reduce its manufacturing energy.

5. Reducing Environmental Impact through Circular Economy Approach

A circular economy (CE) approach proposes the change of linear cycle of production from open loop to a closed loop process. The CE concept began in the 1970's and 1980's and focuses on ideas of industrial ecology and metabolism (Frosch et al, 1989). CE became more popular in the 1990's with a focus on the industrial activities on environment, framing CE in opposition to linear economy. CE proposes a redesign of the life-cycle of products with the aim to have a minimal input and minimal production of system waste streams (D'Amato et al., 2017). A system to achieve net reductions at organizational supply chains and industrial levels (Murray, 2017; MacArthur, 2013). This study highlights the ecology of the LWS to propose a circular ecology through redesigning the industrial metal waste stream to reduce environmental impact of LWS assembly.

With an increasing demand for natural resources to produce metals, negative effects on the environment are expected to rise. There is a need for innovation in product design, production methods and technologies, policies, business models, financing, and consumer behaviors. An important topic in Circular Economy is material flow. This was put forward initially in 1985 (Chen, 2009). It is said to be the outcome of globalization as products circulate in the world to realize their optimal allocation. As stated earlier, living walls made from metals modules are regarded as expensive and above most project budgets.

The ecology of the metals used shows that the process of production of metals contributes to the high cost of living wall systems. Material and energy transfers between industries and/or companies create interactions and structures analogous to predator−prey interactions in an ecological food web. An Ecological Network Analysis can inform a sustainable organization of material and energy flows among industries that was not previously in the network design space (Layton, 2016). A suggested link between the automobile industry and the construction industry can be established through design solutions with a focus on sustainability. Industrial symbioses, also known as eco-industrial parks, occur when multiple firms or facilities in a bounded geographic area achieve higher system efficiency through the exchange of "waste" energy and materials (Reap, 2014). The value of waste from industrial production can be improved with designated treatment. Circular Economy performance is revealed in processes that design out waste. A collaborative network in real time can aid designers in the production of LWS that utilize scrap metals in the production of their modules. Reverse logistics and waste management flow can operate with information on industrial output. This information will assist in the creation and improvement of value in the production of living wall systems.

Literature available on LWS focuses on their thermal properties on the effectiveness of their foliage. In the use of LWS, lightness is an important characteristic of the module and support materials. Aluminum is the lightest metal to be used. Because aluminum uses the highest amount of energy in its production as electricity is required to electrolyze alumina, there is a need for other metals. Tracing the source and use of metals for LWS is necessary to have a framework for materials used to construct them (Fig.3). Applying the values of circular economy in sourcing metal materials for modules will add value to the waste materials and reduce the amount of loss in the industry.

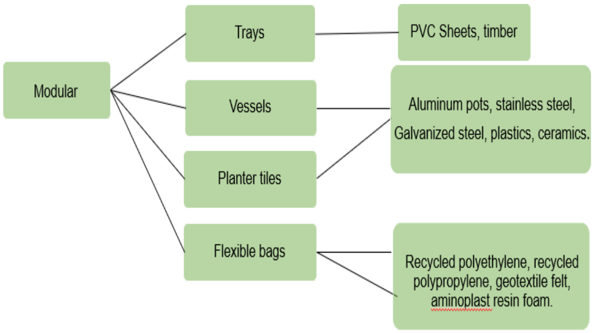


Figure 3: Existing materials of modules in living wall systems. Source: (LiveWall®, 2022)

6. Conclusion

Vertical greening systems and their environmental benefits are the subject of studies and research starting from the seventies; however, it has not been approved as an energy saving method for the built environment. Most of the studies have been conducted about green façades (based on climbing plants), but still those concepts are not fully investigated. Much research can be deepened for quantifying the environmental benefits especially for the macroscale. Recent technical solutions are under development for vertical greening systems, as defined living wall systems LWS. This is a new field to investigate, regarding the insulation properties, durability aspects, maintenance, plants choice related to the climate conditions, materials involved, etc. The systems design can consider many aspects, such as the integration with the building enclosure, a sustainable material choice considering the environmental impact but also the symbiosis between the growing medium and the vegetation, which is a key element for the success of the greening system. Also, the economic aspects, related to cost savings due to possible reduction of energy needed for heating and cooling, have to be considered to avoid a larger use of green enclosure in the urban area. A process tree can be developed for urban design, new constructions and retrofitting projects, to afford the right choice of greening system, considering the main parameters, such as the climate type and building characteristics, to avoid damage and maintenance problems caused by an inappropriate design. The multiple benefits of vertical greening systems could allow for more sustainable urban design and compensate for the lack of green spaces inside dense cities.

Metals exist in different forms of LWS in buildings. The living wall is an effective metal façade aim to reduce energy consumption. The ecology of materials used for modules in existing living walls shows that metals, plastics, and ceramics are used to make LWS modules. Metals are the most durable and expensive module material. Research suggests creating networks for a supply chain between the construction industry and specifically the automobile industry in the design and construction of living walls with automobile by-products. Future research can be carried out in the study of the accruable benefits of reusing automobile scraps as planter materials in living walls. Research can also focus on the properties of metal scraps from the automobile industry and their suitability as modules. Circular economy values will be used to assess the existing instances of their design and use to integrate circular economy principles at the early stages of LWS design to significantly reduce its overall environmental impact resulted from using virgin metals as substrate. Utilizing the high recyclability of both steel and aluminum (90% and 43% respectively) will significantly help reduce these impact if properly traced through circular economy.

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