A sustainability evaluation of vertical greenery systems based on emergy

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Abstract

Vertical Greenery Systems (VGS), also known as vertical gardens, are innovative constructive elements conceived to be anchored on building facades. Besides their surprising aesthetic effect, they are supposed to improve the environmental performance of buildings.

A research project, namely GREENED, is aimed at investigating potential environmental costs and benefits. A 90m^2 VGS, composed of plants fixed on felt layers, which allow for a hydroponic culture (without any substrate), has been studied as a case study.

In a preliminary step, an eMergy evaluation was performed in order to assess the environmental costs of VGS manufacturing and maintenance. This analysis, based on HT Odum's energy systems theory, accounts for the environmental resource use intensity (specific emergy – sej m^{-2}), that can be interpreted as an indicator of the investment needed to obtain benefits during the operational time of VGS, such as energy saving for indoor cooling and heating.

In particular, the direct and indirect environmental resource use was estimated, associated to the following phases: A) manufacturing of structural elements and the production chain, including materials, components, and plants; B) maintenance, including the use of water, fertilizers and electricity.

An analysis of the thermal performance (a VGS prototype has been assembled and monitored in time) is then expected to assess the saved quantity of electricity for cooling and natural gas for heating (to be next elaborated in emergy terms) and thus to provide an appraisal of the environmental benefits. A comprehensive environmental costs-benefits balance is among the scopes of the GREENED project.
Keywords: building facade, emergy evaluation, life cycle, living wall, vertical greenery system.

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1 Introduction

A research project, namely GREENED, conducted by researchers of the University of Siena, Ecodynamics group – in partnership with the University of Florence and the University IUAV of Venice – is currently in progress, aimed at investigating the environmental performances of vertical greenery systems (hereafter VGS). VGS are structural systems, fixed on building facades that support and allow a number of embedded plants to grow, fed by a watering and nurturing automatic system. A simplified classification of different types of VGS is available in literature [1]. Types of VGS exploit a hydroponic culture, without any substrate, namely *living walls*. A few examples of existing VGS, living walls type, are shown in Figure 1.

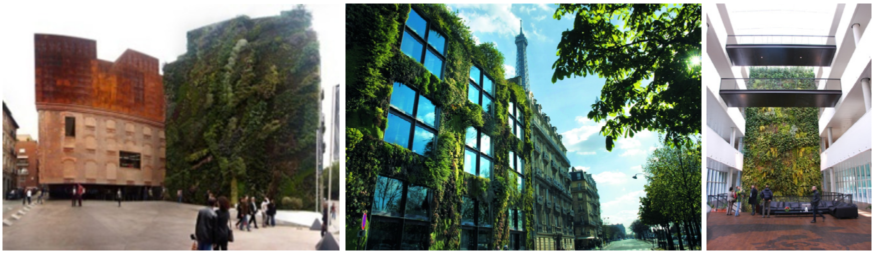

Figure 1: a) Patrik Blanc, Caixa Forum, Madrid, Spain; b) Patrik Blanc, Musee du Quai Branly, Paris, France; c) SUNDAR Italia, Diesel S.p.A. headquarter, Breganze (VI), Italy.

Recent studies were conducted worldwide in order to evaluate VGS environmental effects, mainly focussing on their thermal performances, both indoor [2–10], and outdoor (e.g. decreasing of the urban heat island effect) [11], but also relating to the effects on hydrodynamics in urban areas [12], air pollution [13] and acoustics [14]. A life cycle assessment of different VGS types has also been performed [15] in order to evaluate environmental potential impacts associated to the productive chain.

GREENED intends to provide an additional contribution to the research on VGS with a special focus on their application in Italy and other Mediterranean countries. In particular, the aim is to evaluate the *environmental costs*, in terms of resource depletion or CO_2 emissions (among other indicators), in the phases of VGS manufacturing and maintenance, and *benefits* (energy saving), in the operational phase, respectively.

As a case study, a VGS was hypothesized installed on a 90m^2 building facade, composed of 1x1.5m panels. This VGS is made of the following elements: 1) aluminium frame to be anchored on the facade (5cm air cavity between the wall and the VGS); 2) supporting PVC layer (1x1.5m panels – 1cm depth); 3) overlay of three felt layers maintained in a constantly wet state; 4) plants embedded in the felt layers, without any substrate, with an average density of

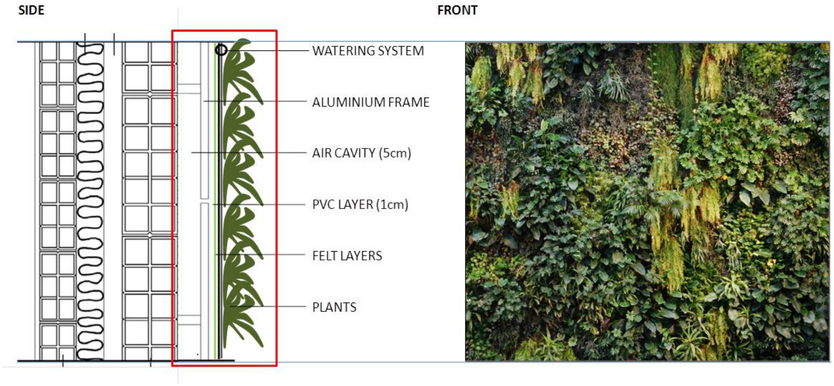

Figure 2: Side scheme of a VGS prototype.

20kg m^{-2}; 5) automatic system for nurturing plants (water and fertilizers) made of PVC pipes, an electric pump, and a tin box including a dedicated hardware.

2 Energy system diagram of a vertical greenery system

This paper presents outcomes from an emergy evaluation of a VGS. The eMergy evaluation (spelled with an ‘‘m’’) is an environmental accounting method that accounts for the direct and indirect appropriation of environmental resources by a given process, based on the thermodynamics of open systems [16, 17]. The emergy evaluation assigns a value to products and services by converting them into equivalents of one form of primary energy, the solar energy. The outcoming amount of primary energy is an indicator of the quality of different inputs (for instance, 1 Joule of petrol and electricity are equivalent in terms of energy but, in emergy terms, electricity is much higher because many Joules of petrol are needed to provide 1 Joule of electricity). The unit for emergy is the solar emergy joule (sej).

In Figure 3 an energy system diagram is shown as a schematic representation of a VGS including manufacturing, maintenance, and its operational phase. In particular: (1) Building manufacturing is the process of gathering and assembling materials to generate a built stock (i.e. the VGS structure represented by the symbol of ‘stock’, a triangle on a semicircle) that persists during an estimated 20 yrs lifetime as a permanent reservoir or memory of primary solar energy. (2) Building maintenance refers to energy and materials inflows needed periodically in order to maintain the built stock constant in time, resisting its physical entropic degradation. (3) Building use includes interactions with users that need constant energy inflows especially for cooling and heating; the main inputs to this phase are given by the consumption of electricity, natural gas and water.

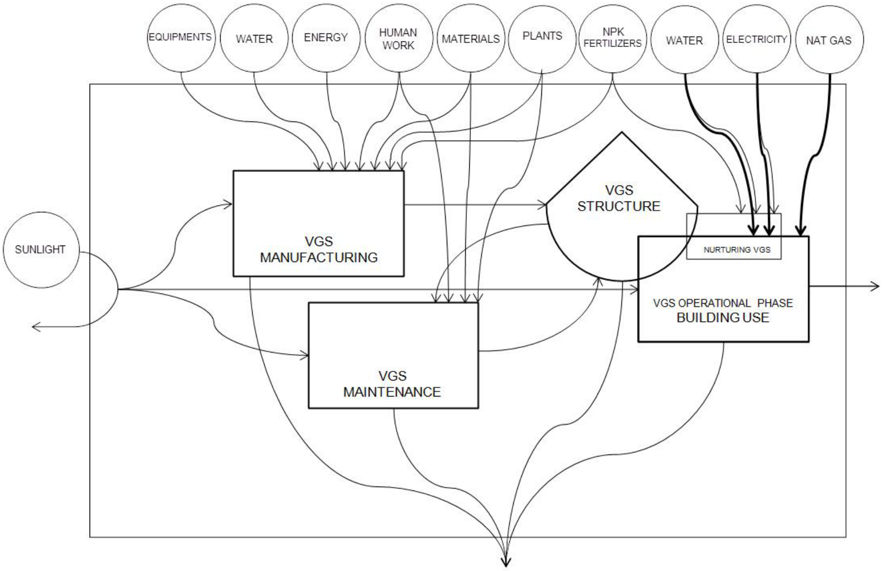

Figure 3: The energy system diagram of a VGS manufacturing, maintenance and use.

The installation of a VGS (that needs to be nurtured by water, fertilizers and uses electricity) on a building facade is supposed to influence the thermal performances of the building envelop and thus to condition the use of energy by the dwellers (represented by the dark arrows in the diagram). GREENED aims to quantify the total emergy inflow for manufacturing and maintaining a VGS as a proxy for environmental costs, and to estimate the energy saving, in emergy terms, due to the augmented thermal performances of the envelope by the VGS, as a proxy for environmental benefits.

3 Emergy evaluation of VGS manufacturing and maintenance

An emergy evaluation is commonly performed based on the inventory of energy and material inputs to a given process. In the following tables, energy and mass quantities for each item, considering the main inputs to the processes investigated, were reported and transformed into equivalent amounts of emergy. This can be done through specific coefficients, namely unit emergy values (UEV), that represent the equivalent solar energy needed to provide a unit of a specific item. The UEV used in this study were available in literature as shown in the corresponding references. All the values in this study refer to the 9.26E+24 sej yr^{-1} baseline [18]. The emergy evaluation has the ability of accounting for the solar energy equivalent to a given quantity and thus to make items comparable to each other from a sustainability viewpoint. In general, the higher the emergy amount, the higher the environmental impact given by direct and indirect environmental resource withdrawing and use.

Table 1 shows the emergy assessment of a VGS manufacturing process. This includes the emergy embedded in the production of structural elements, plants treatment, transport of VGS panels to the building site and their assembling on the facade, the latter including human work as a main input.

Table 1: Emergy evaluation of the manufacturing of a 90m^2 VGS (20 yrs lifetime).

ITEM	QUANTITY	UNIT	UEV	REF.	EMERGY	%
VGS elements					**5,14E+15**	**51,5**
Aluminium	201,64	kg	1,27E+13	[19]	2,56E+15	25,7
PVC layer	478,98	kg	4,13E+12	[20]	1,98E+15	19,8
Felt layers	102,38	kg	5,17E+12	[20]	5,29E+14	5,3
PVC pipe	1,89	kg	4,13E+12	[20]	7,79E+12	0,1
PVC pump	3,33	kg	4,13E+12	[20]	1,38E+13	0,1
Tin sheet (cabinet)	12,00	kg	4,02E+12	[20, 21]	4,82E+13	0,5
VGS plants					**4,62E+15**	**46,3**
Plants	2000,00	kg	2,31E+12	prj GREENED	4,62E+15	46,3
VGS transport					**4,46E+13**	**0,4**
Transport to the site	828.863	kmkg	5,38E+07	[22]	4,46E+13	0,4
VGS assemblying					**1,82E+14**	**1,8**
Electricity in site	17.820.000	J	1,49E+05	[23]	2,66E+12	0,0
Human work in site	33.488.000	J	5,35E+06	[24]	1,79E+14	1,8
TOTAL EMERGY 90m^2 VGS MANUFACTURING (20yrs lifetime)					**9,98E+15**	**100**

Energy and mass quantities in the inventory refer to a VGS whole life time of 20 yrs. Most of the elements were thus estimated to have a 20 yrs lifetime except for felt layers (16 yrs), pipes (12 yrs), and plants (12 yrs). This assumption allowed for considering wearing effects and some repair and replacement operation occasionally executed.

The UEV of plants was calculated as an outcome from the GREENED project. This considered: a) the production of plants in a greenhouse in the Netherlands (the emergy of plants production corresponds to 5,35E+11 sej kg^{-1}); b) the transport of plants from the Netherlands to Italy (1250km); c) plants treatment in a greenhouse in Italy. Table 2 shows the emergy assessment of VGS maintenance, spread on a period of 20 yrs.

Table 2: Emergy evaluation of the maintenance of a 90m^2 VGS (20 yrs lifetime).

ITEM	QUANTITY	UNIT	UEV	REF.	EMERGY	%
Solar irradiation	27.216.000.000	J	1,00E+00	[25]	2,72E+10	0,0
Water use (tap water)	1.262.900	kg	1,84E+09	[26]	2,32E+15	91,9
Fertilizers N	4,05	kg	3,73E+12	[17]	1,51E+13	0,6
Fertilizers P	4,71	kg	3,83E+12	[17]	1,80E+13	0,7
Fertilizers K	3,92	kg	1,08E+12	[17]	4,23E+12	0,2
Pesticides	1,98	kg	1,45E+13	[27]	2,87E+13	1,1
Electricity use	320.112.000	J	1,49E+05	[23]	4,77E+13	1,9
Human work	16.744.000	J	5,35E+06	[24]	8,96E+13	3,5
TOTAL EMERGY 90m^2 VGS MAINTENANCE (20yrs lifetime)					**2,53E+15**	**100**

The diagram in Figure 4 shows the results of the emergy evaluation. Inputs, measured in terms of solar emergy joules (sej), were thus compared to each other in order to evaluate their relevance throughout the production chain.

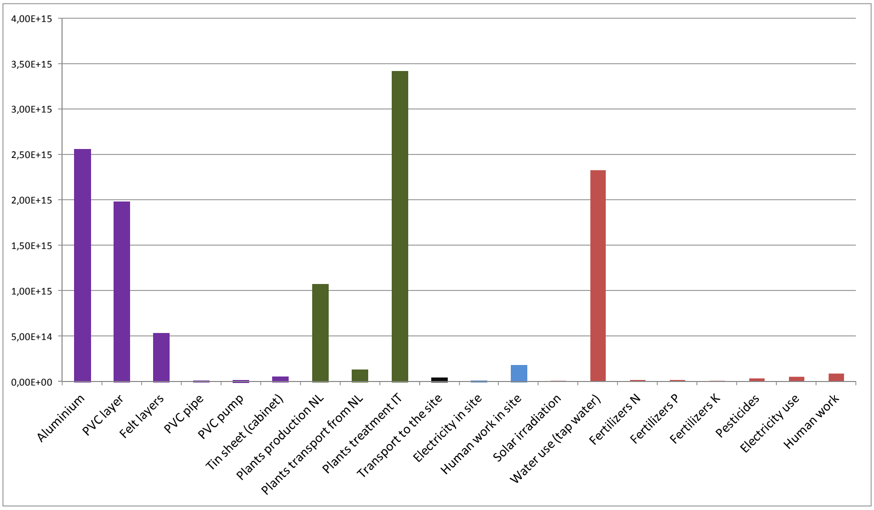

Figure 4: Emergy inflows for VGS manufacturing and maintenance. Colors refer to: a) production of structural elements; b) plants treatment; c) transport; d) assembling; and e) maintenance.

In the diagram, inputs were gathered into five processes or steps: a) production of structural elements; b) plants treatment; c) transport; d) assembling; and e) maintenance.

Results from the emergy evaluation highlighted that the manufacturing and maintenance of a 90m^2 VGS, considering a 20 yrs lifetime, correspond to 9.98E+15 sej and 2.53E+15 sej, respectively. Therefore, the VGS manufacturing corresponds to the 80% of the total emergy investment of 1.25E+16 sej, and includes the production of structural elements (41%), plants treatment (37%), transport to the building site (0.4%), assembling (1.5%). The maintenance, even spread on 20 yrs, accounts for the 20% of the total emergy.

From these results (even preliminary) we observed that the choice of materials and constructive elements that constitute the supporting structure (41%) can easily influence the entity and amount of impacts, as well as the plans treatment (37%).

From an eco-design perspective, on one hand, the choice of more eco-friendly materials should take into account their production chain as well as their resistance, durability (e.g. PVC layers has a higher resistance to humidity with respect to wood) and end of life (e.g. aluminum has a high impact in terms of emergy but also allows for recycling), and therefore would need a deeper investigation on alternative technologies to be compared based on life cycle.

On the other hand, the production and treatment of plants would take into account the location (e.g. being plants production located in the Netherlands, transport was found to have an environmental impact more than 1% that can be easily avoided through a local production) and the efficiency of production systems (e.g. plans production in the Netherlands – 9% – has a higher efficiency in energy and material use with respect to plants treatment in Italy – 27%).

Maintenance is a critical aspect in the management of VGS but almost all the impacts (90% of the maintenance emergy) are associated to the use of tap water (13% renewable, 87% non renewable [26]) and the use of energy is almost negligible. This aspect could be easily managed through the provisions of systems for collecting rain water or grey water from buildings watering systems. This is expected to highly decrease the impact of maintenance in terms of resource depletion. Same consideration for the electricity use (even less than 1%), that could be powered by installing photovoltaic or micro-windpowers, integrated in the facade. Both these scenarios would need a new assessment of impacts in the manufacturing phase, depending on the addition of new structural elements.

4 Conclusion

The emergy evaluation allowed for the assessment of both direct and indirect environmental resource appropriation by VGS. Results highlighted the impacts of different processes within the two phases of manufacturing and maintenance. The total emergy investment, 1.25E+16 sej, mainly depends on manufacturing (80%), including structural elements (41%) and plants treatment (37%), and maintenance (20%) including the use of tap water (18.6%) and electricity (0.4%). A few actions towards an eco-design perspective were introduced and briefly discussed. These would easily allow for making scenarios and decreasing impacts.

However, the emergy evaluation highlighted that VGS have a comprehensively low environmental impact. Considering that the emergy of a traditional building construction was estimated 6.26E+14 sej m^{-3} [28], and assuming that the analyzed case study refers to a $90m^2$ VGS anchored on the facade of an average $1000m^3$ building, the manufacturing of the entire building would correspond to 6.26E+17 seJ. Just based on this general and approximate estimation, the emergy investment for VGS manufacturing (9.98E+15 seJ) would be an added investment of less than 2% with respect to a traditional building construction, in terms of emergy.

This paper presented preliminary results from an emergy evaluation developed within the GREENED project. Results would represent a proxy for environmental costs due to the manufacturing and maintenance of the VGS. The scope of the project (to be developed next) is to compare costs with benefits, the latter deriving from the energy saving in the operational phase. This analysis has been undertaken in collaboration with the University IUAV of Venice and concerns with the monitoring of the thermal performance of a VGS prototype.

Moreover, other evaluations based on Life Cycle Assessment, Carbon Footprint and Ecological Footprint has been developed within the GREENED project in order to augment the accuracy of the information provided, based on complementary indicators, and achieve a more general comprehensive evaluation of VGS environmental sustainability.

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