A Life Cycle Assessment and Comparison **Sustainability Impacts of Five Vertical Greening Systems**

Text, photography, and diagrams by Marc Ottelé

1. An example of direct façade greening in Delft, The Netherlands (see Fig. 2b for illustration).

The integration of vegetation with green roofs and vertical greening systems is a constantly evolving research field. However, green envelopes (especially the most innovative vertical greening systems) are not yet fully accepted as an environmental quality restoration and energy-saving method for the built environment, mainly due to the lack of data needed to quantify their effects and evaluate their real sustainability value (environmental and economic). The many greening systems available on the market allow combining nature and the built environment to improve the environmental quality of urban areas; for example, green façades and living wall systems offer more surfaces with vegetation and, at the same time, contribute to the improvement of the thermal performance of buildings.

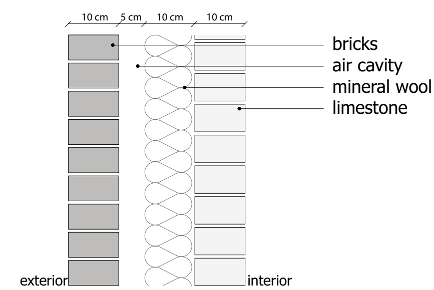
From a functional point of view, vertical greening systems, as compared to green roofs, demand a more complex design, which includes consideration of a major number of variables. In the case of vertical greened surfaces, there are a number of systems to green façades, with or without windows, starting from a simple disposition of climbing plants at the base of the façade. The characteristics and materials involved in vertical greening systems can either positively or negatively influence their performances, with respect to improvements in the building's envelope efficiency, microclimatic conditions (cooling potential and insulation properties), and environmental burden produced during their life spans (installation, maintenance, disposal, etc.).

Green façades and living wall systems have a number of functions, as also previously mentioned, that are beneficial to the built environment. They include for example: increasing its biodiversity and ecological value; mitigating the urban heat island effect; providing indoor and outdoor comfort; providing insulating properties; improving the air quality; and enhancing the social and psychological well-being of city dwellers. Vertical greening systems are a growing field of study that has developed rapidly, especially in the last three to four years, such that various living wall systems and greening systems with different materials and characteristics are available at the moment (Corrado 2010; Ottelé 2011). The usage of these (extra) materials, in combination with the necessary equipment for these systems (nutrients, water pumps, etc.), influences either positively or negatively the environmental burden, as will be discussed in this article. According to Henry and Frascaria-Lacoste (2012), the presented study has identified new scientific directions to reduce the environmental costs of green constructions.

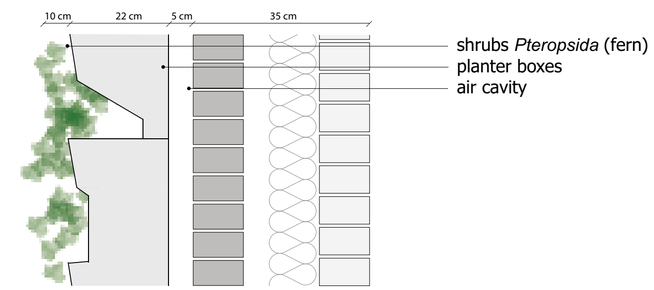
A life cycle assessment (LCA) was performed (Ottelé et al. 2013) for five different vertical greening systems, based on the principal differences in the characteristics of the green systems analysed. Such a life cycle analysis is an effective way to evaluate the sustainability of a building, by considering the balance between the environmental load and possible benefits, but also from the point of view of material optimisation. The goal of the assessment was to evaluate the actual and potential environmental aspects associated with constructing, maintaining, and disposing one square metre of greened façade and to determine the impacts of raw material depletion, fabrication, transportation, installation, operation, maintenance, and waste.

Five vertical greening systems were studied in comparison to a conventional insulated bare European masonry façade (Fig. 2a). The first system studied is direct façade greening, consisting of a well-grown evergreen climber *Hedera helix*, of foliage thickness +/- 20 centimetres, attached directly to the building surface and planted at the base of the greened façade (Fig. 2b). The second system analysed uses indirect façade greenery, constituted by steel frames as support for evergreen climbing plants, in this case *Hedera helix*, planted to thickness of +/- 10 centimetres (Fig. 2c). The remaining three systems are living wall systems, working with systems for water and nutrients, and planted with ferns (*Pteropsida*). While the third greened façade investigated has been based on planter boxes, or plastic modules (HDPE) filled with soil as its substrate (Fig. 2d), the fourth system has been based on several felt layers, supported by a PVC sheet (Fig. 2e), and the final and fifth system has been based on mineral wool, supported through a frame (Fig. 2f).

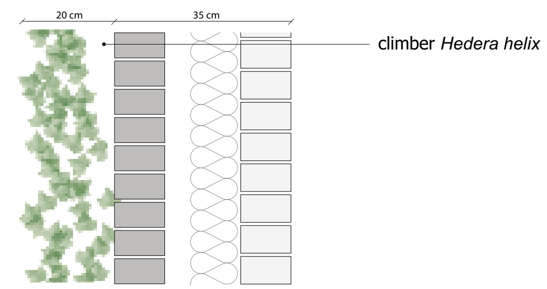
For a sustainable approach, the microclimatic and environmental benefits that can be obtained have to be related to the environmental burden produced during the whole life span of a vertical greening system. Therefore, the analysis takes into account the balance between the environmental load and possible benefits of a life span of 50 years. Characteristics, components, and materi-



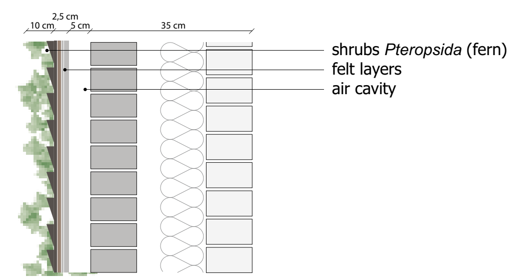
a. Conventional Insulated Bare European Masonry Façade



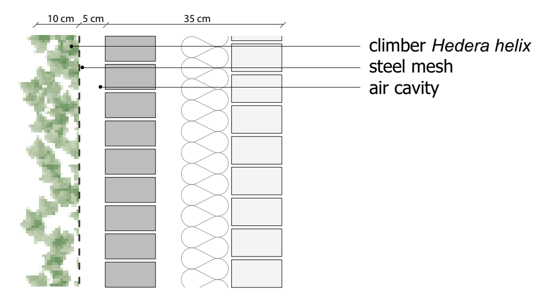
b. Living Wall System Based on Planter Boxes



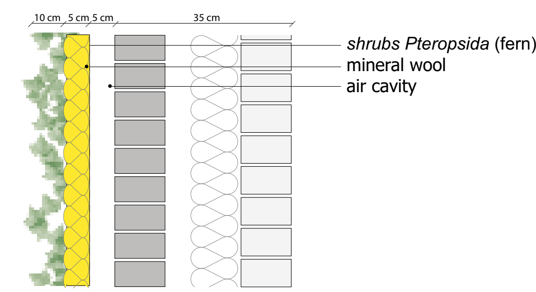
c. Direct Façade Greenery



d. Living Wall System Based on Felt Layers

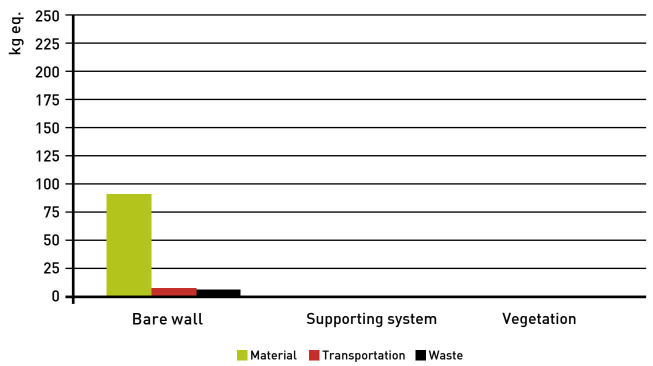


e. Indirect Façade Greenery Based on Stainless Steel Mesh

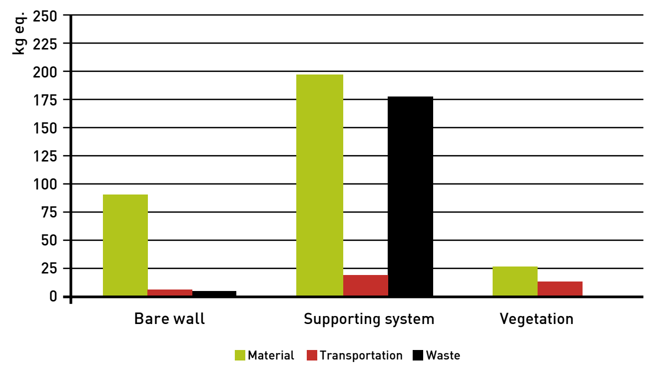


f. Living Wall System Based on Mineral Wool

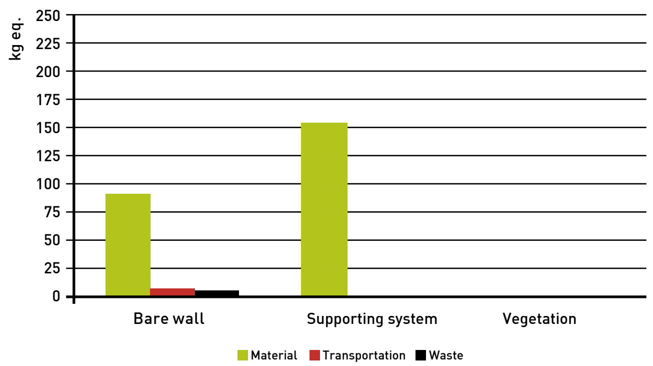
2. Illustration of Different Types of Vertical Greening Systems Studied



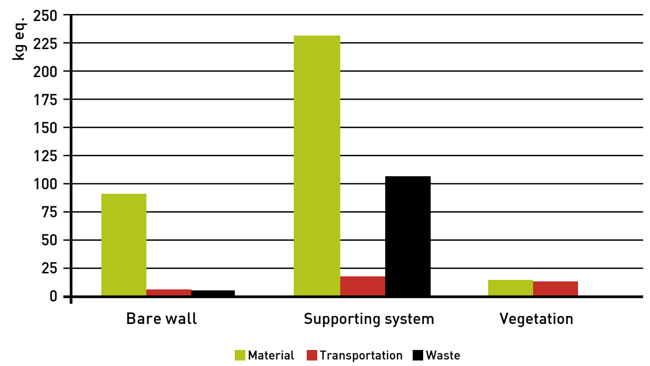
3. Total environmental burden profile for classes material, transportation, and waste for direct greening system



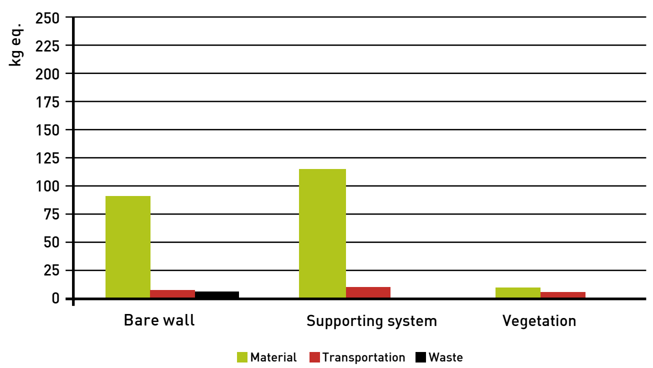
4. Total environmental burden profile for classes material, transportation, and waste for living wall systems based on felt layers



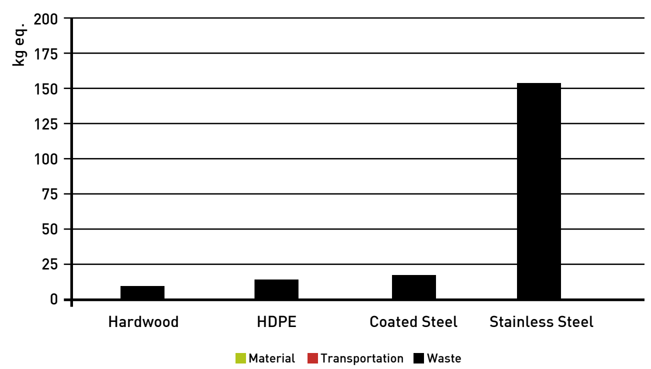
5. Total environmental burden profile for classes material, transportation, and waste for indirect greening system based on stainless steel mesh



6. Total environmental burden profile for classes material, transportation, and waste for living wall systems based on mineral wool



7. Total environmental burden profile for classes material, transportation, and waste for living wall systems based on planter boxes



8. The environmental burden calculated for different supporting materials. One has to take into account the material impact on the environmental profile for each greening system.

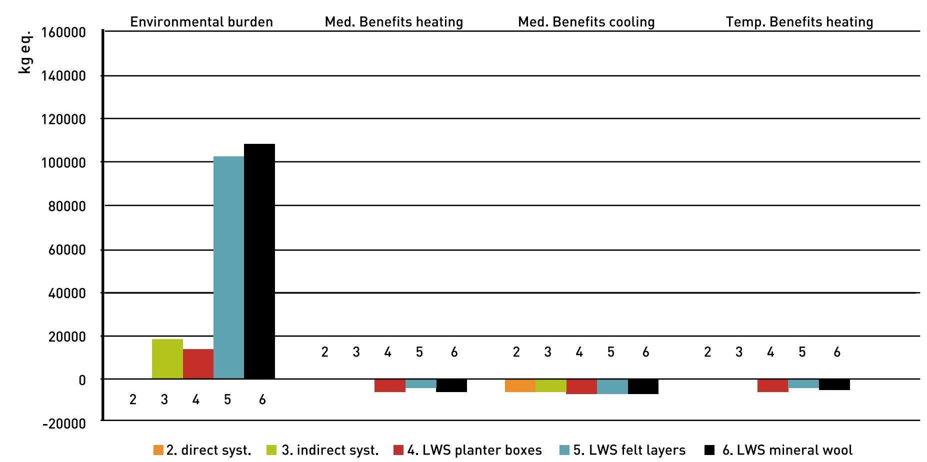
als of vertical greening systems can influence not only the environmental benefits, as above described, but also the environmental burden produced by a system during its life span (Perini and Ottelé 2012), as has been demonstrated by Ottelé et al. (2011). The environmental load, measured by the standard global warming potential in kg eq., was further broken down to factors identified: material (amount of each material used in kilograms); transport (distance from factory to building in kilometres); and waste (everything that will not be recycled after demolishment in kilograms).

Depicted by Figures 3 to 7, total environmental burden profiles were built up for each system, with the environmental load measured in kg eq., showing the burden produced by each of its components of supporting systems, vegetation, and a bare wall, broken down into their attributes of material, transport, and waste. The results show a significant difference in total environmental burden between the greening systems and the bare wall, with the exception of the direct greening system. The most significant factor found in the analysis is the material of the supporting systems. As such, the direct greening system that uses no additional materials has the lowest environmental burden. For the direct and indirect greening systems, the vegetation component also has a very small impact, since it is only related to transportation (no watering and nutrients system and replacement of plants is needed). In the case of the living wall system based on felt layers, waste has a major impact, due to the impossibility of recycling the entire module involved. All the systems studied in this analysis reveal similar dominating impact categories, including the overwhelming effect of material of the supporting system, though their magnitudes differ considerably. The differences are mainly caused by the differences in supporting material and estimated durability of both plants and material. Due to this, the living wall systems based on felt layers and mineral wool have the highest environmental burden, since panels would have to be replaced five times in a service life of 50 years and because of materials used such as aluminium that contribute significantly to the burden profile.

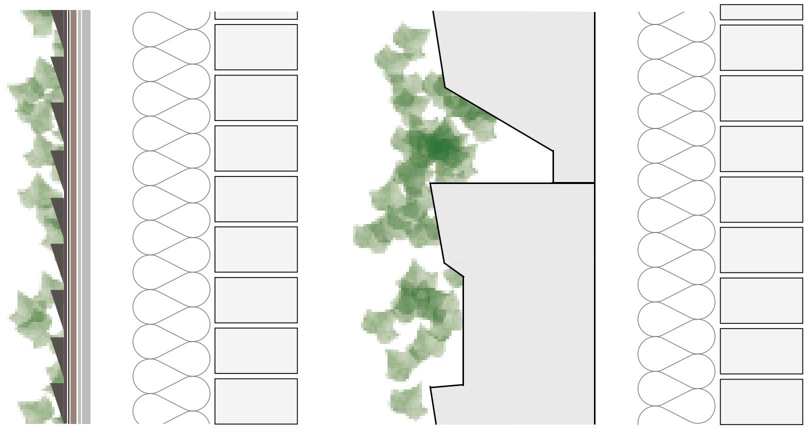
Many types of materials used to build indirect greening systems, such as different types of wood, plastic, aluminium, and steel, can be a support for climbing plants instead of stainless steel mesh, the latter which positively or negatively influences the environmental burden of the greening system (Fig. 8). These materials can produce an environmental burden roughly 10 times lower than for example a stainless steel mesh. Each of the materials enumerated changes the aesthetical and functional properties of the system due to the different weights, profile thicknesses, durabilities, and costs. 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 (Ottelé et al. 2011).

The environmental burden profile shown is in relation to the energy savings that can be obtained for air conditioning and heating. An estimation of the micro-scale benefits of greening systems in a Mediterranean and a temperate climate was made. To calculate the energy savings for heating, due to the increase of the insulating properties caused by greening systems, the additional thermal resistance is calculated to be up to 0.09 m^2K/W. This assumption is used for all of the direct and indirect greening systems analysed due to the layer of stagnant air in and behind the foliage, as found by Perini et al. (2011). For the living wall systems, the thermal transmittance of the substrate and the used materials are added. The energy savings estimated for a Mediterranean climate with respect to vertical greening systems is roughly two times higher than for a temperate climate, mainly caused by the role of air-conditioning systems, even after considering that less annual energy consumption for heating is needed. A study conducted by Alexandri and Jones (2008) reports a temperature decrease of 4.5 degrees Celsius for the Mediterranean climate, resulting in 43 percent of energy savings in air conditioning. The energy savings calculated for heating have a lower impact on the environmental burden calculation—1.2 percent for direct and indirect greening systems, 6.3 percent for living wall systems based on planter boxes, and 4.0 percent for living wall systems based on felt layers, according to Perini et al. (2011).

Figure 9 shows the relation between the environmental burden and benefits of the systems analysed. Analysing the environmental burden profiles of the indirect greening system and the living wall systems, they show a major impact (due to the materials used and life span), even if, as described, the environmental profile may be reduced by a more sustainable material choice and an integrated envelope design (Fig. 10). For a temperate climate, the environmental burden profile is higher than the energy savings for heating for all of the greening systems (supporting system and vegetation), except for the direct greening system that is sustainable (when the environmental burden is



9. Total environmental burden for four greening systems (supporting systems and vegetation), benefits for heating and cooling for Mediterranean climate, and benefits for heating for temperate climate, according to Ottelé et al. (2011 and 2013)



10. Illustration of higher integration into the building envelope in a living wall system-based concept. In this case, for a newly designed building, the traditional cladding system can be omitted. This results in a less expensive solution, faster building time, decrease of the environmental profile, and so forth.

lower than the environmental benefit profile). For the Mediterranean climate, thanks to the energy savings related to air conditioning, the direct greening system is sustainable, while the living wall system based on planter boxes is almost sustainable. In both climate types, the living wall system based on felt layers reveals an environmental burden profile higher than the benefits gained for heating and cooling. The environmental burden and the benefits for both heating and cooling are calculated for the service life of the greening systems studied (Ottelé et al. 2011).

Main conclusions:

- Direct greening systems have a very small influence on the total environmental burden. Thus this type of greening, without any additional material involved, is always a sustainable choice for the examined cases.
- Indirect greening systems analysed based on stainless steel supporting systems have a high influence on the total environmental burden.
- Living wall systems based on planter boxes do not have major environmental footprints due to the types of materials involved, since those materials used also positively affect the thermal resistance of the system. However, the environmental burden profile could be further improved with higher integration within the building envelope (combining functionalities).
- Living wall systems based on felt layers have a high environmental burden due to their relatively low durability and the types of materials used.
- Living wall systems based on mineral wool have a high environmental burden due to the types of materials used, although higher energy savings could be achieved through better insulating properties.
- Greening the building envelope is a sustainable option, considering the materials involved, which as shown can have a high influence on the environmental profile, and taking into account all the (unquantifiable) benefits.

Despite their need for additional resources initially, the direct greening system, the indirect greening system with a supporting system based on hard wood, coated steel or HDPE, and the living wall system based on planter boxes are still the environmentally preferable choice when constructing and retrofitting a building, due to the reduction in energy demand for heating and cooling (this study can be easily applied to other construction types). However, it should be noted that this case study is limited to the façade type, climate, and location of the study, as well as depends on the assumptions that are made inside the assessment.

As suggested by Henry and Frascaria-Lacoste (2012), the adoption of LCA analysis for the labelling of green products could increase their use, since green labels have the potential to boost the confidence of consumers. At the same time, they could lead to particular focus being placed on specific green elements, which could potentially further homogenise natural features within cities, with possible negative impacts on other benefits of green, such as biodiversity (Henry and Frascaria-Lacoste 2012). However LCA analyses could lead to deeper consideration by manufacturers of the environmental burden produced by their systems to improve the balance between benefits and burden for a more sustainable built environment. Such a responsibility does not stop with the manufacturer, but also includes building owners, policy makers, and architects, who should think of more sustainable uses of the built environment.

Practical issues to increase the sustainability impact of vertical greening systems (keep in mind that in *grosso modo* these aspects can also be used for horizontal greening systems) have to be found in material choices and increased thermal properties of the system, either by evapotranspiration (cooling) or insulation (less energy needed for heating and/or cooling). With these aspects one can calculate the environmental impact. Other benefits related to urban greening, such as social impact, biodiversity, air pollution reduction, and so on, may be too difficult to take into account at the moment, but still contribute to a sustainable building approach and therefore cannot be disconnected from one another.

Material choices are often underestimated by designers, manufacturers of greening systems, and architects. An optimal balance has to be found between: durability aspects; materials really needed (also by mass—in this case less is more!); service life; and life span. In the case of a new design, try to integrate a greening concept into the building envelope instead so as to add an "extra" green layer to a conventional solution. Greening concepts (vertical and horizontal) should be seen as a "building material" with multifunctional properties (ecological, social, mitigation, urban heat, and so on) alongside our traditional cladding and roofing materials (masonry, concrete, marble, glass, bitumen, and so on).

Besides, one has to be aware of the cooling and insulation potential of green structures related to energy savings. Green structures may contribute to a lower energy demand at the building level and must not be underestimated. The total awareness will lead to a more eco-friendly and sustainable design of cities.

References:

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11. An example of a living wall system based on felt layers in Amsterdam, The Netherlands (see Fig. 2e for illustration).

12. An example of a living wall system based on mineral wool in Utrecht, The Netherlands (see Fig. 2f for illustration).

13. An example of a living wall system based on planter boxes in Delft, The Netherlands (see Fig. 2d for illustration).