GREENERGY

# Resilient Vertical Forest Renovation of Reinforced Concrete Structures in Seismic Prone Areas

(H.F.R.I. Project Number 015376)

## Assessment of benefits resulting from VF buildings

Deliverable D1.2    Work package 1

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| | |
|---|---|
| **BREEAM** | Building Research Establishment Environmental Assessment Method |
| **CFD** | Computational Fluid Dynamics |
| **$CO_2$** | Carbon Dioxide |
| **ENVI-met** | High-resolution 3D microclimate model |
| **IAQ** | Indoor Air Quality |
| **LEED** | Leadership in Energy and Environmental Design |
| **$NO_2$,** | Nitrogen Dioxide |
| **$O_3$** | Ozone |
| **PM2.5** | Particulate Matter less than 2.5 micrometers |
| **PM10** | Particulate Matter less than 10 micrometers |
| **VOCs** | Volatile Organic Compounds |
| **$SO_2$** | Sulfur Dioxide |
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# ΠΕΡΙΛΗΨΗ

Το ερευνητικό έργο GREENERGY ακολουθεί τις πλέον πρόσφατες αντιλήψεις και εξελίξεις στον κατασκευαστικό τομέα, που αποσκοπούν σε ένα δομημένο περιβάλλον μηδενικής κατανάλωσης ενέργειας και ενός ουδέτερου αποτυπώματος άνθρακα, προκειμένου να προωθηθεί η «πράσινη συμφωνία» της ΕΕ.

Το ερευνητικό έργο GREENERGY έχει σκοπό να αναδείξει την χρηστικότητα και τη σημασία των κάθετων δασών για την άμβλυνση των επιπτώσεων των ακραίων καιρικών συνθηκών και την παροχή οικοσυστημικών υπηρεσίων από «πράσινα» ανακαινισμένα κτίρια, ακόμα και σε περιβάλλον υψηλής σεισμικότητας.

Το παρόν έγγραφο ( Παραδοτέο D1.2) υλοποιείται στο πλαίσιο του πρώτου πακέτου εργασίας (WP1) του έργου, δηλαδή «Τυπολογίες κτιρίων με κάθετα δάση, οφέλη, διακινδύνευση από κινδύνους και βασικές παράμετροι για την ανακαίνιση προς ένα αστικό περιβάλλον υψηλής πράσινης πυκνότητας».

Στο παρόν παραδοτέο γίνεται μια εκτενής αναφορά στα δυνητικά οφέλη που προκύπτουν από την ενσωμάτωση του πρασίνου στα κτίρια, με σκοπό τη γενική αξιολόγηση των κύριων πλεονεκτημάτων που προκύπτουν από τα κατακόρυφα δάση και τους πράσινους τοίχους και τη δυνητική συμβολή τους σε μια βιώσιμη στρατηγική χωροταξικού σχεδιασμού και αστικής ανάπτυξης. Τα πλεονεκτήματα αυτά διακρίνονται σε περιβαλλοντικά, κοινωνικά και οικονομικά και συμβάλλουν στη βιωσιμότητα και τη μείωση του αποτυπώματος του άνθρακα στα αστικά οικοσυστήματα.

Ως προς τα περιβαλλοντικά οφέλη, τα κάθετα δάση μπορούν να συμβάλλουν στη μείωση της ατμοσφαιρικής ρύπανσης φιλτράροντας τους ρύπους μέσω των φύλλων και του φλοιού των φυτών τους, απορροφώντας σωματίδια σκόνης και ατμοσφαιρικούς ρύπους. Η φυσική αυτή διαδικασία επεκτείνεται και στους εσωτερικούς χώρους δημιουργώντας ένα πιο υγιές περιβάλλον διαβίωσης και εργασίας για τους κατοίκους. Παράλληλα, η φυσική σκίαση που παρέχεται από τέτοιες υποδομές, βελτιώνει το μικροκλίμα και συμβάλει στη μείωση της θερμότητας που απορροφούν τα κτίρια έτσι ώστε να μειώνεται η επιφανειακή θερμοκρασία και να μετριάζεται το φαινόμενο της αστικής θερμικής νησίδας. Στα πλαίσια της ενεργειακής απόδοσης, οι πράσινοι τοίχοι μειώνουν την ενέργεια που απαιτείται για την ψύξη των κτιρίων ενώ επίσης λειτουργούν ως φυσική μόνωση και βελτιώνουν την φυσική πρόσβαση του φωτός στο χώρο.

Επίσης, τα κτίρια αυτά μπορούν να συμβάλλουν στην πρόληψη πλημμυρών και λειψυδρίας, καθώς σε αυτά συχνά ενσωματώνονται συστήματα διαχείρισης ομβρίων, για την αποτελεσματικότερη διαχείρισή τους. Η παρουσία φυτών λειτουργεί ως φίλτρο βελτιώνοντας την ποιότητα των υπόγειων υδάτων και μειώνει τα μολυσματικά φορτία στα αστικά υδάτινα σώματα. Προωθείται επίσης η επαναχρησιμοποίηση οικιακών λυμάτων, συμβάλλοντας στη μείωση της κατανάλωσης πόσιμου νερού και στη βιώσιμη διαχείριση των υδάτινων πόρων.

Μέσα από την ενσωμάτωση του πρασίνου στα αστικά τοπία, ενισχύονται σημαντικές οικοσυστημικές υπηρεσίες, όπως η επικονίαση, οι οποίες είναι ζωτικής σημασίας για τη διατήρηση της φυτικής ποικιλότητας στις πόλεις, αφού τα κτίρια αυτά αποτελούν καταφύγια άγριας ζωής και μπορούν να προάγουν τη βιοποικιλότητα. Τα κάθετα δάση και οι πράσινοι τοίχοι, αποτελούν την γέφυρα μεταξύ φυσικού και αστικού περιβάλλοντος προσφέροντας αισθητικές βελτιώσεις που μεταμορφώνουν τα αστικά τοπία. Ως εκ τούτου, συμβάλλουν θετικά στην ψυχολογία των κατοίκων

παρέχοντας συναισθηματική αποφόρτιση, μείωση του άγχους και αίσθημα ασφάλειας. Παράλληλα, λειτουργούν ως μονωτές των θορύβων της πόλης, αλλά και χώροι κοινωνικών συναναστροφών.

Ως προς το οικονομικό σκέλος, η ενσωμάτωση του πρασίνου δύναται να προστατέψει τα κτίρια από τις έντονες καιρικές συνθήκες και να βελτιώσει τις αντιστάσεις τους στις εναλλαγές της θερμοκρασίας ελαττώνοντας έτσι το βαθμό αλλοίωσης των υλικών και άρα την ανάγκη κοστοβόρων επισκευών. Τέλος, η υιοθέτηση τέτοιων πρακτικών ενισχύει το branding και τις πρωτοβουλίες μάρκετινγκ εμπλεκόμενων φορέων, όπως εργολάβων, επιχειρήσεων και δημοτικών αρχών. Αναδεικνύοντας στρατηγικά την περιβαλλοντική, κοινωνική και οικονομική τους αξία, τα κτίρια αυτά μπορούν να αποκτήσουν ανταγωνιστικό πλεονέκτημα, να ενισχύσουν την αφοσίωση των καταναλωτών και να συμβάλουν σε ένα πιο βιώσιμο μέλλον.

# SUMMARY

GREENERGY goes beyond the leading state of the art concepts in the area that aim mainly to produce nearly zero energy consumption and neutral carbon footprint within built environment in urban areas in order to promote the “green deal” while the real green nature itself is suppressed. Such an approach may satisfy merely mathematical indices and goals. However, it fails to revive natural growth in areas forests were once dominating, i.e. before urbanization. It holds down the decisive, that is natural mechanisms for sustainable environment of high air quality, controlled humidity, satisfaction and comfort for inhabitants.

GREENERGY envisions forest diffusion to alleviate extreme weather conditions impacts in coastal seismic urban regions and to optimize inclusive people-centric social engagement towards habitant comfort and satisfaction, through high-density urban forestation starting from green- renovated buildings. Based on the poor state of the art in the field of renovation towards vertical forests and the great necessity for their urgent development to really cope with detrimental climate change consequences and advance environmental resilience.

This document (Deliverable D1.2) is implemented within the framework of the first work package (WP1) of the project, namely " Vertical Forest buildings typologies, benefits, hazard-dependent risks and key parameters for renovation towards high-density urban greening".

This deliverable provides an extensive report on the potential benefits resulting from the integration of greenery into buildings, providing an overall assessment of the main benefits resulting from vertical forests and green walls and their potential contribution to a sustainable spatial planning and urban development strategy. These benefits can be divided into environmental, social and economic and contribute to sustainability and the reduction of the carbon footprint of urban ecosystems.

In terms of environmental benefits, vertical forests can help reduce air pollution by filtering pollutants through their leaves and bark, absorbing dust particles and air pollutants. This natural process is extended indoors, creating a healthier living and working environment for residents. At the same time, the natural shading provided by such infrastructure enhances the microclimatic conditions around the buildings and reduces the surface temperature, mitigating the urban heat island effect. In the context of energy efficiency, green walls reduce the energy needed to cool buildings and also act as natural insulation and improve the natural access of light into the building.

These buildings can also help prevent flooding and water scarcity, as they often incorporate stormwater management systems to manage stormwater more effectively. The presence of plants acts as a filter by improving groundwater quality and reducing contaminant loads in urban water bodies. The reuse of treated greywater is also promoted, contributing to the reduction of drinking water consumption and the sustainable management of water resources.

Through the integration of greenery into urban landscapes, important ecosystem services, such as pollination, are enhanced, which are vital for maintaining plant diversity in cities, as these buildings are wildlife refuges and can promote biodiversity. Vertical forests and green walls provide a bridge between natural and urban environments, offering aesthetic improvements that transform urban landscapes. As such, they contribute positively to the psychology of residents by providing emotional relief, reducing stress and a sense of security. At the same time, they act as insulators of urban noise and as places for social interaction.

From an economic point of view, the integration of greenery can protect buildings from harsh weather conditions and improve their resistance to temperature fluctuations, thus reducing the deterioration of materials and the need for costly repairs. Finally, the adoption of such practices enhances the branding and marketing initiatives of stakeholders such as contractors, businesses and municipalities. By strategically highlighting their environmental, social, and economic value, these buildings can gain a competitive edge, foster consumer loyalty, and contribute to a more sustainable future.

# 1 INTRODUCTION

Human beings are inherently linked to the natural environment, and as a result, they incessantly seek methodologies to create utilitarian green spaces within the urban infrastructure of metropolitan areas. The significance of these areas, in combination with free spaces, is extremely important, particularly within urban environments characterized by high-density development, as their existence offers many important ecological and social benefits. Therefore, the creation of urban green areas was not a priority during the period of city planning due to pollution and the poor integration of green areas into the urban environment. As urbanization continues to rise globally, cities face numerous challenges, such as increased pollution, heat island effects, and the loss of biodiversity and green spaces. Green roofs, Vertical Forest buildings and Living Walls have emerged as innovative solutions to some of these urban challenges (see e.g. Wang et al., 2022, Figure 1). Vertical Forest buildings and Living Walls (green walls or green facades) incorporate trees, shrubs, and plants into their design, bringing greenery and nature/biodiversity directly to urban settings. Vertical forests involve entire buildings covered in large trees and shrubs, while green walls typically feature smaller plants and climbers.


*Figure 1 Vertical greening system functions in the urban landscape (Wang et al., 2022).*

A vertical forest refers to a building, often a residential or commercial high-rise, that incorporates a large number of trees, shrubs, and plants directly into the structure's design. These plants are usually placed on balconies or integrated into facades, forming a green "forest" on the building's exterior. Hundreds or even thousands of trees, shrubs, and plants are planted across different floors of the building. By this, these structures support a wide range of plant species, which in turn can attract various birds and insects, promoting urban biodiversity. Simultaneously, they significantly contribute to reducing urban heat island effects, improve air quality by absorbing CO2 and pollutants, and provide natural insulation for the building. The most iconic example of vertical forests is the Bosco Verticale in Milan, Italy, designed by Stefano Boeri. It includes two residential towers covered with about 20,000 plants and trees (housing a total of 800 trees -480 first and second stage trees, 300 smaller ones-, 15,000 perennials and/or ground covering plants and 5,000 shrubs) (Boeri Studio, 2024).


*Figure 2 Bosco Verticale in Milan, Stefano Boeri.*

A living wall, or green wall, is a vertical structure that is partially or completely covered with vegetation. Unlike vertical forests, these green walls do not involve planting trees but focus on growing a variety of plants, including grasses, flowers, and small shrubs, directly on the wall's surface. Geen walls are often installed using special systems that include soil or substrate for the plants to grow in, as well as irrigation systems. They can be installed on both exterior and interior surfaces, making them a versatile solution for urban greening. Green walls significantly support pollutants' filtration, reduce $CO_2$, and improve the overall air quality in cities. Natural cooling for and soundproofing benefits are also a major contribution of green walls in the built environment. The CaixaForum in Madrid, Spain, features one of the most famous vertical green walls, designed by botanist Patrick Blanc.

The famous botanist Patrick Blanc has been recognized as a pioneer of modern vertical gardens. Patrick Blanc (1953, Paris) is a distinguished French botanist affiliated with the French National Centre for Scientific Research, where he concentrates his research on flora endemic to tropical forest ecosystems. He is recognized as the contemporary pioneer of the green wall concept; in particular, he invented the modern hydroponic vertical garden, which sets him apart from his predecessors. The original idea of Blanc was "to have nature coming back in towns" and to do so he took inspiration from both tropical rainforests and high mountain environments, where many plants grow without or with a minimal amount of soil. In 2009 he was awarded an Honorary Fellow of the Royal Institute of British Architects.

*Figure 3 CaixaForum in Madrid, Spain, Patrick Blanc.*

In the following chapters we present an overview assessment of the main benefits resulting from vertical forests and green walls infrastructure and their potential contribution in a sustainable spatial planning and urban development strategy.

# 2 ENVIRONMENTAL BENEFITS

## 2.1 AIR QUALITY REGULATION

Urban air pollution, predominantly caused by vehicular emissions and industrial activities, is a persistent health and environmental concern. Vertical Forest buildings have been shown to mitigate this issue by acting as natural air purifiers. These innovative structures incorporate plants and trees into building facades, effectively transforming the building itself into a tool for environmental enhancement. Vertical planting improves air quality both outdoors and indoors.

### 2.1.1 Outdoor air quality

Vertical forests can be described as buildings that will have a variety of plants along their building façades, on balconies, and at their terraces, contributing to reducing outdoors air pollution through cleansing by way of absorption from leaves and barks, fine particulate matter, and gaseous pollutants like Fine Particulate Matter PM2.5, $CO_2$, $SO_2$, $NO_2$, and $O_3$, alongside the volatile organic compounds VOCs, as cited by Perini & Roccotiello, 2018; Tiwary et al. 2016.

Fine particulate matter, often referred to as PM2.5, is composed of very small particles that remain suspended in the air. As these particles are inhaled, they can cause harmful effects on human health, including respiratory problems and other health issues. Leaves and surfaces of vertical forest structures provide a platform where PM2.5 particles can efficiently reduce their concentrations within surrounding air (Nash, 2005; Bellucci et al., 2012).

Greenery-covered buildings significantly contribute to the sequestration of carbon dioxide, a significant greenhouse gas responsible for global warming and climate change. Via the process of photosynthesis, plants absorb $CO_2$ and transform it into oxygen and glucose. This biochemical mechanism aids in diminishing atmospheric $CO_2$ concentrations while concurrently releasing oxygen into the environment, thereby improving air quality (Heidt &Neef, 2008; Hesslerová, 2022). Bosco Verticale in Milan hosts approximately 20,000 plants across 90+ species, including also full-sized trees, on all façades of both its towers, which collectively absorb an estimated 30 tons of $CO_2$ annually and significantly contribute to air filtration (Boeri Studio, 2024). As cities become denser and human activity and pollution sources increase, outdoor air quality declines. Vertical forests offer a sustainable solution for improving outdoor air quality as by sequestering $CO_2$ and PM2.5 the facades contribute to a cleaner and healthier urban environment (Abel, 2010).

Based on the data presented in Table 1 (Wang et al.,2022) green walls exhibit a greater efficacy in the mitigation of particulate matter (PM) compared to gaseous pollutants. Through the process of PM absorption and subsequent reduction of environmental concentrations, the foliage of plants has the capacity to enhance the quality of ambient air (Fukuzumi, 1996; Zhao et al., 2009; Lee et al.2010). Various factors such as plant species, dimensions, wind orientation, leaf area index, and humidity significantly influence the extent of pollution mitigation achieved by green walls. Empirical evidence indicates that green walls demonstrate superior efficacy in the collection of fine and ultra-fine particulate matter compared to coarser particles, and they exhibit enhanced effectiveness in the removal of particulate matter relative to gaseous pollutants. The impact of green walls, when assessed at varying heights and across different seasonal contexts, reveals no statistically significant differences in their decontamination efficacy; however, the topographical characteristics of living walls do influence the efficiency of pollutant capture (Wang et al., 2022).

*Table 1 Literature on vertical greening to improve outdoor air quality (Wang et al., 2022).*

| Region | Type | Plant | Conclusion | Method |
|---|---|---|---|---|
| Urban Toronto (Currie & Bass, 2008) | Green Roofs and Green Walls | Shrubs | The removal rate of PM10 is 1.37 mg/year. | Experiment |
| Road [Morakinyo, & Lam, 2016, Deutsch-Aboulmahassine, 2009) | Vegetation Barriers | -- | The reduction of pollutant concentration is due to the dispersion and deposition of green walls. | ENVI-met |
| New Street Railway Station (Weerakkody et al., 2017) | Living Wall | Buxus Sempervirens L., Hebe Albicans Cockayne, Thymus Vulgaris L. and Hebe X Youngii | Living wall plants have considerable potential in removing particulate pollutants from the atmosphere. | |
| Road (Weerakkody et al., 2018) | Living Wall | Twenty species of living wall plants | The average capture of PM1 particles by the living wall of 100 square centimeters is 122.08 ± 6.9 × 107, PM2.5 particles 8.24 ± 0.72 × 107, PM10 particles 4.45 ± 0.33 × 107. | |
| Road (Weerakkody et al., 2018) | Green Wall | Heuchera Villosa Michx, Helleborus × sternii Turrill, Bergenia cordifolia (Haw.) Sternb. and Hedera Helix L | The recovery of PM capture ability of four green wall species after rainfall was studied. Green wall has the potential to capture PM all year round. | Experiment |
| Road and Woodland (Ottel'e et. al., 2010) | Living Walls | Hedera Helix L | The number of particles collected on the front of leaves was more than that on the back, and there was no significant difference in height and season. | |
| Developing Countries (Joshi & Ghosh, 2014) | Green Facades | Vernonia Elaeagnifolia | For (SO2), the removal rates in dry and wet weather are 1.11 × 10-6 s-1 and 1.05 × 10-6 s-1 respectively | CFD |
| Road (Morakinyo et al., 2016) | | | At pedestrian height (1.4 m), green walls are an effective barrier to reduce exposure to pollutants and air quality deteriorates from 4 m. | ENVI-Met + Experiment |
| Street Canyons (Pugh et al., 2012) | Green Wall | | By planting vegetation in street canyons to increase sediment, street concentrations in these canyons can be reduced by 40% for NO2 and 60% for PM. | CFD |

### 2.1.2 Indoor air quality

Vertical planting, in addition to outdoor air quality, also affects indoor air quality. The natural process of filtering pollutants is extended indoors creating a healthier living and working environment for residents (Abel, 2010). Indoor air quality (IAQ) is a significant determinant of the comfort and health of occupants, and poor air quality can lead to a range of health issues, including respiratory problems, allergies, and in extreme cases, "sick building syndrome." (Mendez &Teiheira, 2014). Table 2 presents an overview of the pertinent scholarly works concerning the implementation of indoor vertical greening systems for the mitigation of indoor air pollutants.

*Table 2 The literature on indoor vertical greening to remove indoor pollutants (Wang et al.,2022).*

| **Inorganic Pollutant** | **Plant** | **Conclusion** |
|---|---|---|
| $NO_2$ (Petit et al., 2019) | Spathiphyllum Wallisii and Syngonium Podophyllum | Average NO2 clean air delivery rate of 661.32 and 550.8 $m^3 \cdot h^{-1} \cdot m^{-3}$ of biofilter substrate for the respective plant species. |
| $CO_2$ (Su & Lin, 2015) | – | The indoor plant wall of 5.72 m2 can reduce the $CO_2$ concentration of 38.88 m3 room from 2000 to 800 ppm in one hour. |
| PM (Su & lin, 2015; Petit et al., 2017) | Chlorophytum Comosum | The system recorded removal efficiencies were 53.35 9.73% for total suspend particles, 53.51 15.99% for PM10, and 48.21 14.71 % for PM2.5. |
| VOC (Wang & Zhang, 2011) | Different plant species | The significant single removal rates (spres) of toluene and formaldehyde were 91.7% and 98.7% respectively. |

## 2.2 URBAN HEAT ISLAND MITIGATION

The Urban Heat Island (UHI) phenomenon is increasingly being confronted by metropolitan regions. UHI can be defined as that phenomenon where urban areas show higher temperatures when compared to their rural surroundings, due to human functions, compact infrastructure, and the use of heat-absorbing materials such as concrete and asphalt (Yeang and Powell, 2007; Yang, 2008; Hopkins and Goodwin, 2011). Green facades and terraces allow for natural shading of high-rise buildings by blocking the direct sun from heating up the building surfaces. This is because the vegetation naturally causes shading, decreasing the heat that the edifice accumulates, thus lowering the surface temperature (Heidt, 2008; Hesslerova, 2008). Green walls, green roofs, and other forms of vertical greenery have been quite effective in mitigating UHI. It has been determined in studies that vertical greenery could significantly reduce both the demand for energy and CO2 emissions by providing a cooler urban surface. For instance, Campiotti et al. (2022) identified a maximum reduction in temperature by 13°C for some vegetated facades; thus, vertical greenery systems make a great contribution to building energy efficiency during summer.

Peng et al. (2019) gauged the effect of vertical greening on the indoor thermal environment and found it could reduce room temperatures by up to 2.2°C and wall surface temperatures by 13.9°C, emphasizing vertical greening's contribution to building energy efficiency and sustainable urban environments. Vertical forests consist of dense vertical gardens integrated into building structures that help in enhancing urban biodiversity and improving the local microclimate. Such infrastructures cool their surroundings through the processes of evapotranspiration and shading, which lower the surface and air temperatures. Vertical greenery is able to reduce UHI, according to a study released by Xiang and Tao (2023), up to a maximum of about 1.06°C, mainly at peak hours. The authors emphasize that maintenance deserves particular attention, along with the use of wind-driven rain as a natural source for irrigation.

Vertical forests are not only aesthetically appealing but also help to improve living conditions within cities by providing a natural cooling effect and air quality improvement. In Hong Kong, a case study demonstrated that vertical green walls could be practical and save energy in subtropical climate conditions. These vertical forests can also help in making urban living more sustainable (Wong and Baldwin, 2016). Vegetation inclusion, in urban planning, in the form of urban woodlands and trees, is important in the attenuation of the UHI effect. Bosch et al. (2021) developed a spatially explicit approach for evaluating urban greening options, which would contribute to developing the capabilities of urban planners in optimizing tree cover to protect climate resilience and public health. Indeed, optimal siting of trees can result in maximum cooling of up to 6.6°C hourly cooling on building exteriors for particular configurations (Zhao et al., 2018). These practices not only reduce UHI but also create generally more sustainable cities with cooler urban microclimates where less reliance on artificial cooling systems is fostered. Vertical forests mitigate the urban heat island effect. Therefore, while a vertical forest is implemented as a part of green infrastructure, there is a need to consider the financial and sustainability outcomes. Lower wind velocity due to a vertical forest is also responsible for negative consequences on air quality at ground level and therefore requires proper placement and design of the installation (Kang & Kim, 2023).

## 2.3 RAINWATER MANAGEMENT

It is evident that vertical green structures have become key approaches in managing stormwater through a process termed "green infrastructure" (Al-Kodmany, 2015; Chang & Chang, 2022; Li et al., 2019). Systems of this nature greatly enhance the management of runoff from storm water, consequently supporting the development of sustainable urban environments. Green infrastructures capture rainfall and discharge it gradually into the air. This process imitates natural water cycles and helps balance water and environmental resources. Vertical vegetation on buildings captures and retains rainwater in leaves, stems, and soil. This diminishes the quantity of stormwater runoff that would flow directly into the storm drains, potentially causing flooding (NYC, 2023). Plants take up rainwater from the soil through their roots via evapotranspiration and release it into the atmosphere. This process greatly reduces the total amount of rainwater runoff, helps control the amount of rainwater that reaches the drainage network, and is particularly beneficial in preventing flooding (Al-Kodmany, 2015). In the process of rainwater passing through vegetation and soil, natural filtration takes place. The roots of plants and grains of soil bind various pollutants and sediments, further improving the quality of the water that eventually enters underground aquifers, rivers, and streams (Al-Kodmany, 2023; Bortolini & Zanin, 2017). Innovations such as the rainwater-collecting and greening device delineate how even the facade can be harnessed in the effective management of rainwater while providing an aesthetically pleasing environment (Lin & Lin, 2015).

Furthermore, integration of rainwater collecting along with green walls helps meet the urban sustainability goals by reducing the use of potable water supplies. At the same time, it addresses the management of stormwater by natural filtration and storage processes (Xu, 2013). Utilizing such synergistic systems represents a holistic approach to managing water in urban areas, thereby enhancing ecological and aesthetic values of the urban environment (Guan et al., 2013). In order to optimize the advantages associated with these green systems, it is advisable to integrate them with additional sustainable methodologies, such as the implementation of blue roofs or hybrid systems, to improve water retention and flood management efficacy (Mai, 2022). Furthermore, it is essential to conduct site-specific assessments and modifications to customize these systems in accordance with local environmental circumstances and urban planning needs (Sysoeva & Gelmanova, 2020).

Vertical green buildings symbolize a critical advancement toward better management of urban rainfall. By incorporating concepts such as green roofs and vertical facades, these buildings help to minimize not only the ecological impacts from urban growth but also flood and water scarcity impacts in general, enhancing the urban resilience of growing cities. In the context of continuous development of urban cities, the strategic implementation of vertical greening approaches will be crucially essential in achieving a water-sensitive urban design that supports sustainability and enhances livability.

## 2.4 SEWAGE TREATMENT

Sewage treatment systems combined with vertical green buildings are one of the useful ways of fostering sustainable urban development. In this respect, the natural potential of flora for purification is combined with designed systems for processing wastewater, decreasing the usage of potable water, and enabling the development of an urban green environment. Related to the above, two major techniques have been studied: vertical green walls and green roofs, both with their advantages and challenges. Boano et al. (2019) introduce a type of sustainable sewage management using the method of vertical green walls on urban structures, focusing their efforts on treating and recycling domestic grey water. Such green walls, using modular panels to build vegetated containers, were also applied for grey water purification and were assessed against several parameters such as Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), nitrogen, and phosphorus. Results show that such a system, as depicted in Figure 4, increases the number of urban green spaces and encourages the reuse of treated greywater for non-potable purposes, thus reducing potable water usage and ensuring better management of this resource.

*Figure 4 Pilot system installed in the courtyard of the laboratory. (Boano et al., 2019)*

The potential of vertical greening systems regarding water conservation in an urban residential area is considerable. Besides, these systems reduce the burden on urban wastewater treatment plants and can supply water to gardening areas, recreational green spaces, golf courses, and sanitation facilities. These green walls can save water up to a rate ranging from 40% to 50% (Boano et al., 2020).

Vertical flow constructed wetlands that incorporate ornamental vegetation have exhibited significant efficacy in the removal of turbidity, Chemical Oxygen Demand (COD), and pathogens within greywater treatment systems. Specifically, sand-based configurations have illustrated enhanced performance (Stefanatou et al., 2023). The selection of plant species, including Trachelospermum jasminoides and Callistemon laevis, is pivotal in sustaining the operational efficiency of the system and in reducing water loss resulting from evapotranspiration (Stefanatou et al., 2023).


*Figure 5 Source Stefanatou et al., 2024*

It was also revealed that research has shown the potential of Vertical Greening Systems for pollutant removal in rain and sewage waters and is found capable in specially engineered substrates made of organic and inorganic elements in various proportions, the removal of nutrients, organic pollutants, and even heavy metals from wastewater streams. Principal floristic species used in such systems, like Canna lilies, Jasmine, and ivy, have very high efficiency for nutrient uptake-particularly nitrogen and phosphorus, both critical parameters of water pollution (Wang et al., 2024).

Recent advances have improved Vertical Greening Systems (VGS) performances in dealing with grey water-wastewater generated from nonsanitary sources like sinks and showers-and black water-wastewater that contains human excreta. Green walls with biochar-treated substrate, for instance, have been found capable of reducing Chemical Oxygen Demand (COD) and Total Nitrogen (TN) in effluents to ensure better quality water with minimized pollution load to aquatic systems in urban areas (Aicher et al., 2022). Biochar is a carbonaceous material obtained from organic waste and enhances remediation by providing a proper environment for the proliferation of microbes that degrade the contaminant.

Vertical green systems represent one of the potentially efficient sewage treatment integrations into an urban context. By combining the ecological benefits that come with urban greening and the functional aspects of wastewater management, this system offers a replicable approach toward solving urban water problems in a sustainable manner.

## 2.5 ENHANCEMENT OF URBAN BIODIVERSITY

Biodiversity fulfils various functions in the provision of ecosystem services: acting as a foundational support for other ecosystem services, serving as a distinct regulating ecosystem service, and embodying value through the existence of iconic species (Atkinson et al., 2012; Mace et al., 2012). Biodiversity conservation is essential for the sustained delivery of ecosystem services and the multifaceted advantages that fundamentally support human health and wellbeing (Bolund and Hunhammer, 1999; MEA, 2005; NEA, 2011). In light of escalating urbanization, the significance of urban biodiversity in facilitating ecosystem services has been extensively examined (Botzat et al., 2016); subsequently, ecosystem services are acknowledged to enhance the value of urban landscapes from economic, social, and environmental perspectives (Bolund and Hunhammer, 1999; Gómez-Baggethun and Barton, 2013; Natural England, 2013).

Urban biodiversity, the variety of living species within a city's landscape, is increasingly recognized as a critical factor in sustainable urban development. It is predominantly found within a constrained framework of green infrastructure (Finlay, 2010; Tzoulas et al., 2007). Traditionally, green infrastructure encompasses an amalgamation of parks, gardens, green corridors, and waterways, which are meticulously designed and interconnected to safeguard biodiversity (Tzoulas et al., 2007). If the current trend of urban expansion continues, the green infrastructure is not adequate to prevent the predicted losses in biodiversity at the urban scale (Mcdonald et al., 2008; Rosenzweig, 2003). In the future, green infrastructure will be particularly required in order to support the maintenance and enhancement of biodiversity and to ensure that certain ecosystem services continue to operate, such as air purification and temperature regulation. This will contribute to protecting the health of urban citizens (Francis and Lorimer, 2011; Tzoulas et al., 2007).

For instance, incorporating native plant species into parks and gardens can significantly increase local animal populations and meanwhile improve the living standards of residents with more recreation opportunities in natural settings. Furthermore, as urban precincts further expand onto peripurban areas, there is a proper need to understand the relationship between urban growth and biodiversity; hence, the development of good management practices will be needed to mitigate habitat fragmentation and promote ecological resilience. Furthermore, by empowering collaboration among all stakeholders-from city planners to community members-urban environments can be designed to celebrate and protect biological heritages that are often unique. Applying this holistic perspective does much more than merely enhance the aesthetic aspects of urban areas; it caters to the health and well-being of the populace as a whole, enabling biodiversity for the good of current and future generations (Barico and Castro, 2016).

*Figure 6 Bosco Verticale: The Milan High Rise that started a Green Revolution (Source: We Bulit Value).*

Vertical forest structures embody an impressive amalgamation of architectural principles and ecological considerations, aimed at seamlessly incorporating significant vegetation into metropolitan environments, thus converting conventional urban landscapes into dynamic, living ecosystems. A prominent illustration of this concept is Milan's Bosco Verticale (Figure 6), which integrates trees, shrubs, and various plant species within its architectural framework, predominantly utilizing balconies and facades. It not only enhances the aesthetic beauty of city scapes but also offers significant ecological benefits, enhancing urban biodiversity and creating habitat for a wide variety of species, from avian to insect and other wildlife species (Figure 7). By implication, these vertical forest structures are a realistic alternative to mitigate the impacts of urbanization, particularly in very densely populated cities where conventional green areas are often limited or shrinking in area altogether (Liu, 2023). Inclusion of plants in these structures creates ecosystems in between buildings so that nature and city life can go hand in hand.

The Bosco Verticale in Milan represents an innovative illustration of the potential for architecture to integrate with natural elements, thereby fostering a harmonious ecosystem. This structure sustains more than 1,600 varieties of plant life, playing a vital role in enhancing the city's biodiversity (Chen et al., 2020). Such a symbiotic relationship is essential in metropolitan settings, where the swift proliferation of concrete and steel frequently results in the loss of natural environments. Vertical forest buildings meet this challenge through the incorporation of green spaces that grow vertically, in a manner that best utilizes space in those urban centers where horizontal green spaces are often minimal. The use of greenery on skyscrapers also enables the creation of urban passageways, which help in the dispersal and connectivity of species through different parts of the city, enhancing general biodiversity and ensuring the resilience of urban ecosystems as a whole (Wang et al., 2020).

*Figure 7 Nesting site inside a living wall.*

Vertical forests provide not just aesthetic or symbolic functions, but more importantly deliver fundamental ecological functions and services in parallel. These green architectures are usually integrated into the urban structure by incorporating herbs, trees, and shrubs, which help mitigate a city's heat island, reduce air pollution, and maintain stormwater runoff. Trees and vegetation absorb carbon dioxide, produce oxygen, and filter out air pollutants, thereby improving air quality in urban areas (Stangl et al., 2022). Moreover, these green features cool the immediate surrounding environment through shading and evapotranspiration, which reduces the demand for artificial air conditioning and lower energy consumption. This dual role that vertical forests can play, ecological and infrastructural solutions or, in other words, providers of ecosystem services, makes them an important contribution to the development of sustainable urban design (Radomska, 2022). In Figure 8, a schematic representation depicts biodiversity benefits for climate, sound and air quality regulation.

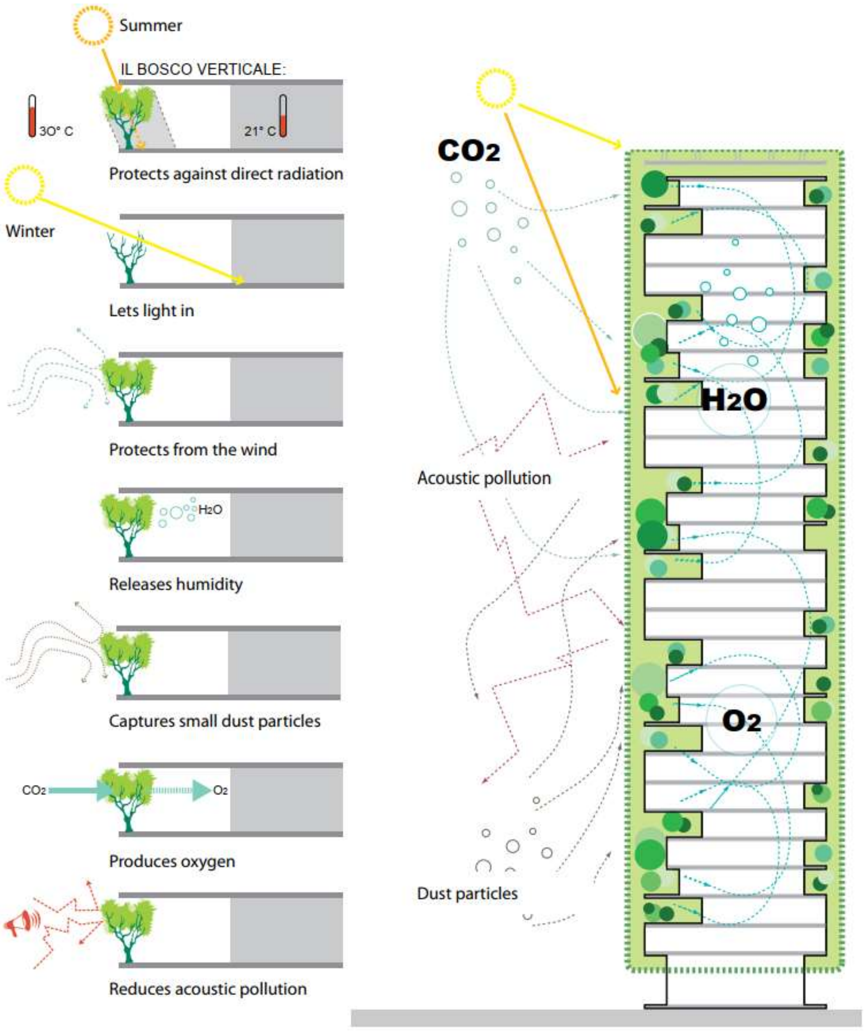


*Figure 8 The life cycle concept in Bosco Verticale © Stefano Boeri Architetti (Source: Giacomello 2015).*

In more specific terms, these structures indeed act as refuges for fauna in what would otherwise be an inhospitable urban environment. Avian species, insects, and small mammals find refuge among the flora, while the diversity of plant species attracts pollinators such as bees and butterflies. Overall, this phenomenon increases the local wildlife population and ecosystem services such as pollination and seed dispersal, crucial for maintaining plant diversity in cities (Chen et al., 2020). Besides, vertical greening contributes much to the restoration of fractured urban ecology by creating a green corridor for species migration in urban areas and, accordingly, enhancing urban biodiversity (Sevianu et al., 2021).

Another innovation related to space constraint issues of green areas in highly densely populated cities involves building vertical forest buildings. More green spaces are created by utilizing the vertical dimensions of a building without competing for land with other infrastructure in the city. This especially comes into play in those cities where, due to lack of space, conventional park and garden areas have been rendered very few and far between. The integration of vegetation within high-rise structures enables urban areas to optimize their spatial resources while simultaneously creating habitats for fauna and green environments for inhabitants (Osako et al., 2022). This strategy not only enhances the living conditions of city dwellers by increasing the availability of green areas but also bolsters the overall ecological functions of urban environments.

The contribution of urban forests in mitigating some effects of urbanization on biodiversity cannot be overemphasized. In an era when the expansion of cities and shrinkage of green spaces occur without end, these forests offer a haven for indigenous species while helping to maintain ecological balances. Vertical forests, an important constituent part of the greater urban forest typology, further this objective by providing habitats for species existing at different layers in the urban environment. It contributes not only to biodiversity but also provides pathways for citizens to get in touch with nature, raises environmental awareness among urban dwellers, and serves other purposes.

## 2.6 ENERGY EFFICIENCY

Vertical green buildings have gained great importance in architecture and town planning due to their contribution to energy efficiency. Green walls and green roofs make environmentally friendly features contributing to saving lots of energy and thus develop the area in an environmentally friendly way. These architectural advancements do not only play their role in decreasing the energy use but also help to alleviate urban heat island phenomena and improve the quality of the indoor environment.

The integration of green walls in various buildings is one of the key factors in energy efficiency. For example, in high-rise residential buildings within hot climatic zones, the various green walls provide an effective insulation system that reduces energy consumption in general cooling (Wong & Baldwin, 2016). By employing processes such as shadowing and evapotranspiration, vertical green systems establish microclimates that reduce building temperatures and regulate humidity levels, thereby contributing to energy conservation (Pérez et al., 2011; Sheweka & Mohamed, 2012). Research has documented the relative effectiveness of green walls in comparison to green roofs, revealing that green walls typically yield higher annual energy savings (Azis et al., 2019). For example, green walls can provide improved energy consumption reduction due to the effect of increased thermal insulation and improved access to natural lighting, thereby enhancing energy efficiency improvements (Djedjig et al., 2016).

The integration of these technologies into architectural design further satisfies broader ecological functions. The green building structures reduce heat island effect, enhance biodiversity, and stormwater control while supporting energy efficiency through thermally improved performance of the building structures (Shishegar, 2015; Jaffal et al., 2012). In addition, with reduced energy use emanating from the energy-efficient building design features, the resultant emissions associated with the production of energy are reduced proportionately. This development helps to enhance overall sustainability and a minimal carbon footprint (Osseweijer et al., 2017).

According to green design principles, green covered skyscrapers can include solar panels, wind turbines or any other installed system. These systems leverage natural resources for energy generation, thereby lessening reliance on traditional energy sources (Halava et al., 2018). Although there are significant energy savings associated with vertical greenery, several challenges hinder its implementation, chiefly concerning costs, maintenance, and operation of these systems. The incorporation of advanced technologies, such as solar photovoltaic panels in conjunction with green walls, has the potential to mitigate certain energy requirements and enhance the practicality of these systems (Ghaffarianhoseini et al., 2013). The deliberate integration of both passive and active energy-conservation strategies, customized to specific regional climates, can optimize the energy advantages associated with vertical greening systems (Xu & Chang, 2018).

Vertical green structures signify a transformative change in urban architectural practices, promoting energy efficiency and sustainable design methodologies. Through the utilization of green wall systems, these edifices minimize dependence on finite resources, improve indoor air quality, and contribute to larger environmental goals. With ongoing technological progress in the realm of sustainable architecture, it is probable that vertical green systems will assume a critical position in mitigating global energy challenges and cultivating resilient urban environments.

## 2.7 ENHANCING AESTHETICS

Vertical green buildings are a revolutionary force in urban architectural design. They provide visual amenities that reshape the outlook of a metropolitan city and bind built spaces with natural features (figure 6). These buildings, featuring living walls and green roofs among others, address not only ecological concerns but also become an integral part of visual improvement and urban renewal processes.

Probably one of the most valuable features of a contribution that green vertical buildings can offer relates to an opportunity to insert natural beauty into city architectural ensembles. The vertical gardens on the skyscraper surfaces integrate flora into the views dominated by concrete and glass, releasing some breathtaking views for the public and softening the lack of natural sceneries in overpopulated cities (Golasz-Szołomicka & Szołomicki, 2019). Green facades augment the aesthetic attractiveness of structures through the incorporation of living vegetation into their exteriors, transforming these buildings into dynamic natural tapestries that enhance both visual appeal and biodiversity (Rakhshandehroo et al., 2015). The integration of such green components within densely populated urban architecture reorients the conventional urban discourse from a narrative characterized by sterility to one filled with vibrancy, thereby enriching a city's overall aesthetic value and ecological well-being (Al-Kodmany, 2014).

Vertical green structures act as a conduit between natural ecosystems and urban environments, amalgamating the visual attractiveness of natural topographies with the practical aspects of city architecture. Such an amalgamation improves the urban landscape, prompting both residents and visitors to interact more profoundly with their environment. Through the incorporation of green features in architectural design, urban areas can create settings that are not merely efficient in function but also aesthetically stimulating (Bösehans & Walker, 2020).

Vertical green buildings represent a pivotal evolution in the face of urban design, bringing together man-made structures and natural beauty. These buildings are quite crucial in rejuvenation processes of the urban setting, making life more viable with a set of aesthetic and ecological improvements. With the present rate of growth in metropolitan areas, incorporation of vertical green projects can be seen as a fundamental strategy to progress the aesthetic approach of our cities, allowing them to be lively, sustainable, and exciting for both current and future generations

# 3 SOCIAL BENEFITS

## 3.1 PSYCHOLOGICAL EFFECTS AND HUMAN HAPPINESS

With increased urbanization and population density within the city, green open areas start collapsing rapidly. But in turn, this has brought about architectural innovation for integrating greenery into urban environments: vertical green buildings and vertical forests. These structures offer a variety of environmental benefits, including air cleansing and temperature modulation, yet greatly contribute to the psychological well-being of those in cities: emotional refreshment, improved cognitive functioning, and social functioning, along with perceived safety and security. While feelings around urban vegetation can be complex, the restoration effects from vertical green buildings are unequivocal. Even while cities continue to grow, a more promising strategy for reducing the challenges of urban living might be the incorporation of vertical forests in an urban context, with the aim of improving the psychological and emotional wellbeing of citizens. The following sections represent the most important psychological effects of vertical green structures and vertical forests, explaining the ways such new developments influence emotional wellbeing, social interaction, and cognitive functioning.

The placement of vegetation into the built environment has been shown to be invariably associated with improved emotional health and lowered levels of stress. For vertical green structures and forests, their incorporation of flora into the structural framework allows city inhabitants to experience nature-an element that can elicit positive emotional responses. For example, Wei et al. (2022) established that great green spaces around cities, which include vertical forests, are associated with increased emotional positivity categorized by smiling and happiness. In relation to this, sad mood levels decreased as a result of greenery exposure, thereby increasing the emotional wellbeing of an individual (Wei et al., 2022). Similarly, Rakhshandehroo et al. (2015) support the therapeutic values of the vertical greenery. The authors are of the opinion that green façades of buildings can restore stress among urban populations as much as a significant percent. Vegetation on building façades creates relief, enhances mood, and develops mental calmness. The beneficial psychological impact is ascribed to the biophilic relationship that exists between individuals and their natural environment, which is fundamental in alleviating the mental stress caused by life in urban areas (Rakhshandehroo et al., 2015).

Beyond the individual mental benefits, this process of vertical greening then develops a better social interaction and builds community bonds further. Reeves-Latour (2017) researched greening in the urban setting for its psychosocial benefits, in particular how green alleys were put into place in Montreal. Green areas in cities reduce anxiety in people and create social cohesion or harmony; this translates to improved living among citizens. While the focus is on green spaces being horizontal, the findings reveal that vertical forests can have some psychological benefits as well in transforming previously neglected space in the urban setting into a welcoming, community-centered environment (Reeves-Latour, 2017). Whether horizontal or vertical, green spaces serve as gathering points for residents who can interact, make friends, and form social networks. Equally, the integration of vertical forests into residential communities can act as means of social interaction, improving overall well-being and residents' satisfaction with their place of residence. The effect of such open spaces on social interaction is especially high in very densely populated cities, where a deficiency of open spaces adds up to the development of growing rates of loneliness (Golasz-Szołomicka and Szołomicki, 2019).

Beyond the facilitation of emotional well-being and social engagement, vertical green buildings are able to showcase an improvement in cognitive functioning and productivity. The presence of natural elements within built environments has long been associated with heightened focus, creativity, and overall cognitive efficiency. Kuo et al. (1998) demonstrated that urban green spaces such as tree-lined streets and well-maintained lawns significantly enhanced feelings among residents of safety and security, with a resultant improvement in cognitive functioning and decision-making capabilities. These findings can be related to the architectural design of vertical green buildings where such access to natural elements might likewise improve mental acuity and reduce cognitive weariness. Further research on the psychological effect of environmental certification of buildings, with special focus on vertical green structures, was conducted by Holmgren et al. (2017). They established that occupants of green-certified buildings evidenced greater satisfaction and higher cognitive performance, especially when their indoor environment was cooler. This study further establishes the potential of vertical green buildings in terms of maintaining a creative atmosphere that is conducive to productivity and mental growth, especially in workplaces and schools.

Although wide recognition exists for the psychological benefits associated with both forms of vertical green structures and vertical forests, some studies point out the complex nature of human reactions to vegetation in cities. Sonti (2020) discusses ambivalence from residents towards urban forests: even while greenery of this type can be restorative, it could just as well evoke negative feelings, such as fear or apprehension, in instances where the green space is also seen as unkempt or overgrown. This ambivalence may also relate to vertical green structures, whereby design and maintenance of the vegetation themselves play a crucial role in determining residents' psychological views (Sonti, 2020). However, the recovering potential of vertical green buildings is still significant. Knecht (2011) demonstrated how urban greenery, including its vertical format, is successfully reducing physiological levels of stress and restoring cognitive ability. Where vertical forests create a natural environment that is beautifully appealing, their effect is one of a mental refuge for those living within urban milieu and stresses. Benefits of restoration are particularly important in areas when population density is great and contact with nature is often limited (Knecht, 2011).

Other research has shown that there may indeed be gendered differences in psychological responses to vertical green buildings. Nevárez-Favela et al. (2023) observed that, in general, women exhibited higher levels of perceived tranquility and emotionally activated states than men after being exposed to living walls and rooftop gardens as features of green infrastructure. Men, on the other hand, tend to report more neutral or suppressed emotional responses. The obtained difference in gender scores suggests that vertical green buildings may have a stronger psychological impact on women, particularly concerning stress reduction and emotional well-being (Nevárez-Favela et al., 2023). These different psychological responses to vertical green buildings point out the importance of considering diverse user experiences in designing green buildings. This could be furthered in psychological benefits if architects and urban planners would reassess different emotional and cognitive needs of its residents.

A more specific psychological issue of inner-city areas pertains to issues of perceived safety and security. Incorporating plants into built environments can have positive and negative influences on such perceptions. Kuo et al. (1998) found a significant effect of trees and other vegetation on inner city residents' perceived safety. The findings concluded that well-maintained green spaces, including vertical green features, make an important contribution to an enhanced perception of safety, which is vital for the mental well-being of those living in cities (Kuo et al., 1998). The perception of safety becomes especially relevant in the context of vertical green architecture since the careful placement of vegetation can enhance not only the visual aesthetic of a place but also the perceived safety of the environment. Malys et al. (2016) showed that green walls and green roofs would be able to provide a positive impact both on the thermal comfort of the buildings and on the psychological aspects, keeping the feelings of safety and satisfaction among the residents while in their home environment.

## 3.2 NOISE REDUCTION

Urban settings frequently experience elevated levels of noise pollution, which adversely affects the quality of life and health of their residents. As urban areas expand, vertically designed green buildings have the potential to mitigate noise pollution by functioning as natural sound barriers and absorbing sound waves (Yeang & Powell, 2007; Yeang, 2008; Al-Kodmany, 2015; Chang & Chang, 2022). Vertical greenery systems function by absorbing sound via the plant structures and substrate layers, thereby mitigating the transmission of external noise into buildings (Azkorra et al., 2015). When sound waves encounter these surfaces, they are partially absorbed rather than reflected. This process of absorption contributes to a reduction in noise intensity, leading to a quieter environment (Al-Kodmany, 2015). The strategic placement and diversity of vegetation on facades contribute to their acoustic effectiveness, with different plant species and structural configurations enhancing noise attenuation (Radosavljević et al., 2015). This aspect of green architecture aligns with findings that demonstrate significant noise reduction capabilities for urban spaces, especially in areas with substantial traffic noise (Kang et al., 2014).

In addition to its sound absorption characteristics, sprouting acts to scatter sound waves in different directions, thus preventing their concentration in any single direction. This reduces the direct impact of noise on building occupants. Simultaneously, natural sounds such as the rustling of leaves and chirping of the birds contribute to creating a more peaceful acoustic environment (Yeang & Powell, 2007). Despite evident advantages, the application of green facades for noise mitigation should be considered with due care regarding design aspects and physical limitations: optimum substrate thickness, vegetation type, and construction parameters have to be fixed in order to grant an adequate noise reduction performance (Pittaluga et al., 2011). The effectiveness of vertical green components in mitigating noise is significantly augmented when integrated with urban planning approaches that take into account the spatial configuration and density of green zones. Densely arranged and interconnected green spaces can serve as more efficient barriers against noise, thus providing holistic strategies to address urban noise pollution (Sakieh et al., 2017). As green roofs and facades become more integrated into increasingly urban areas, they represent one potentially effective strategy to reduce noise pollution and improve the quality of the environment. Combining aesthetic appeal with functional design, such green infrastructure contributes toward not only reducing noise annoyance and improving acoustic environments but also stimulating sustainable urban development (Ryherd, 2010). Further studies and practical installations will most probably be refined towards optimizing the design of such systems, in order to increase the noise-reducing capability while maintaining their environmental and aesthetic advantages.

## 3.3 AWARENESS RAISING FOR VERTICAL GREEN BUILDINGS

The implementation of vertical green technology not only mediates the harsh and inflexible appearance of steel and concrete typical of urban areas but also mediates incongruous factors such as the fast pace and high levels of stress that characterize cities. At the same time, it promotes interaction with nature that stimulates the interests of individuals, develops a more optimistic attitude, and improves physical and mental health (Theodoridou et al., 2012; Boc V., 2015; Gattringer et al., 2016). Vertical gardens and green facades are very important methods in cases where space for green areas is limited in an urban environment. Such systems contribute greatly to the urban environment both ecologically and socially. Other than beautifying the urban scenery, green façades help improve air quality, reduce the urban heat island effect, and increase biodiversity, thus fostering a healthier urban environment (Rakhshandehroo et al., 2015). These benefits go hand in hand with the rising global emphasis on sustainability because they are in line with broader approaches to solving current ecological problems (Peng, 2013).

Public interest and awareness in green architecture is also reflected in market dynamics, where properties featuring these systems tend to sell faster, even if consumers remain hesitant to pay premium prices for green enhancements. This trend showcases the growing cultural and economic value associated with green buildings, highlighting their role as catalysts in promoting sustainable urban development (Grewal, 2023). Educational programs developed to highlight the economic and environmental benefits of green roofs and facades have the potential to capture a wider audience and increase interest in these practices. By investing in civic education projects and promoting open communication, cities can encourage more residents and businesses to implement green technologies into their buildings (Knuth, 2016).

Looking ahead, the application of more advanced sustainable technologies will continue both to enhance the appeal and functional potential of vertical greens. Innovations in the design of green roofs, including integrated photovoltaic systems and smart irrigation systems, hold the potential to further enhance their ecological performance (Luchkina, 2020). The environmental viability of the structures can be enhanced with the inclusion of various plant species and the use of recycled or sustainable materials in vertical gardens, thus appealing to the increasing number of ecologically conscious customers. To really "grow" widespread interest, vertical green buildings must go beyond being simple architectural elements and become integral components of the ecosystem in urban areas. This progression necessitates joint initiatives among architects, urban planners, policymakers, and the general public to guarantee that these advancements fulfill the requirements of contemporary cities and their residents (Modirrousta & Mohammadi, 2015).

# 4 ECONOMIC BENEFITS AND IMPORTANCE

## 4.1 PROTECTION OF BUILDING STRUCTURE

Vertical greeneries involving green walls and roofs serve an important dual function of ecological viability and structural safety. The development of such architecture reinforces the durability and survivability of the building structure because of its thermal insulation, reduction of rainfall, and temperature differentials, which greatly contribute to the whole in stability and functional effectiveness of the building structure accordingly (Yeang and Powell, 2007; Yeang and Richards, 2007). The leaves and branches of vegetation provide a natural screen to harmful ultraviolet (UV) radiation from the Sun. Thus, they contribute to the structural integrity of buildings by providing a protective cover that can absorb UV radiation, which may cause material breakdown, discoloration, and decomposition of construction materials (Yeang & Powell, 2007). Vegetation not only diminishes thermal load but also serves as a protective barrier against precipitation (Rakhshandehroo et al., 2015). This layer of vegetation aids in safeguarding the building envelope from severe weather conditions, consequently mitigating the deterioration of materials over time (Erçin and Usluer, 2022).

Green facades also have the potential to improve the heat resistance properties of building exterior. With an attempt to add thermal mass, these systems can dramatically improve thermal efficiency in brick façades, hence improving energy efficiency and structural durability especially during colder seasons (Tudiwer and Korjenic, 2017). Moreover, these systems are designed to be sustainable and adaptable to various architectural forms, thereby facilitating the production of healthier built environments (Halaszova and Kozlovská, 2021). Vertical green systems not only protect building structures but also enhance their environmental value. By mitigating the urban heat island effect, increasing urban biodiversity, and improving air quality, these green systems contribute to ecological sustainability and building functionality (Abdullahi and Alibaba, 2016). All these put together result in an integrated building system: robust, durable, very sensitive to the environment, and pleasing to the eye.

Notwithstanding the evident benefits, the implementation of vertical green systems presents difficulties related to maintenance, expenses, and design intricacy. To tackle these issues, comprehensive research and development initiatives are essential to devise systems that are economically viable and manageable (Du et al., 2010). Furthermore, streamlined installation procedures and enhanced availability of resources may promote wider acceptance of these technologies within urban environments. The general importance of green structures therefore lies in protection and enhancement of the integrity of building components by thoughtfully implementing green walls, facades, and roofing systems, improving the durability of materials used to construct buildings, increasing thermal comfort, and ecological sustainability. With continuous evolution toward more sustainable frameworks in architectural methodologies, it would be said that the capability of vertical green systems to shield the building infrastructure while maintaining ecological balance will always be intrinsically a part of urban development strategies.

## 4.2 BRANDING AND MARKETING

Vertical greening can increase branding and marketing opportunities for developers, businesses, and local governments taking part in such projects. In urban settings that continuously raise the sustainability bar, branding for vertical greens becomes vital to differentiate products and reach those consumers giving value to such environmental responsibility. The development and identity of the green brand are considered key to gaining more visibility and marketability of such buildings. A green brand is constructed on the foundations of sustainability, bolstered by strategic marketing methods and external certifications such as Leadership in Energy and Environmental Design (LEED) in the United States and Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, which serve to authenticate environmental performance (Burnett, 2007). Clarity in brand strategy, preservation of unique trade mark, and traceability of products are all very important in effectively positioning brands in a competitive market place, according to Xiao (2014). Marketing of vertical green building must also be promoted in terms of the environmental benefits and economic and social value that these buildings bring to the marketplace. As noted by Yudelson (2006) the green building marketing strategies differ from the traditional ones, in that such strategies mainly depend on sustainability attributes for creative branding and the development of customer involvement.

Promotional efforts for environmentally sustainable structures frequently present an overarching view of the advantages without adequately detailing distinct green characteristics, even though there is a significant cost differential for eco-friendly real estate. This implies a demand for more focused marketing initiatives that underline the distinctive features of vertical green architecture and the enhancements they contribute to one's lifestyle (Chen et al., 2017). The tactical placement of vertical green buildings is essential to their effectiveness in the commercial sector. Such structures are generally situated in prominent commercial locations, where they convey robust branding messages that correspond with corporate commitments to environmental stewardship (Braun and Bienert, 2015). Nonetheless, an increasing occurrence of these sustainable edifices emerging in less desirable regions suggests a maturation of the market and a transition towards broader accessibility and societal acceptance. Eco-friendly building construction encompasses social and cultural dimensions, positioning these structures as centers of community interaction and local engagement. According to Kang and Kim (2014), this holistic approach to sustainability can improve the market positioning of green buildings by relating them to comprehensive lifestyle benefits rather than purely ecological attributes.

Although the market opportunities for vertical green buildings are expanding, there are issues related to consumer education and market comprehension. Regarding sustainability, the features of the building need to be comprehensively communicated in order to demystify the benefits and justify the cost investment (Akhani and Pitroda, 2018). Branding and marketing vertical green buildings are pivotal in establishing them as the norm for city structures. These buildings could become competitively advantageous, ensure consumer loyalty, and thereby help in contributing to a more sustainable future if the environmental, social, and economic value is underlined with intention.

# 5 CONCLUSIONS

While rapid urbanization presents an avenue for change that could be leveraged with efficient urban planning, it also presents numerous risks. Such risks call for assessments of the institutional frameworks in acting more appropriately against such contemporary challenges as climate change and natural hazards. This is since urban centres remain among the greatest contributors of greenhouse gases, hence being the epicentre of climate change causes and solutions. This indicates that municipal governments move to the center in designing and implementing action programs site-specifically for the needs of the residents with respect to climate-associated problems. The programs further focus on low-carbon, resilient urban growth, underlining the critical role of sustainable urban planning for long-term environmental goals.

Vertical forests and green walls serve as groundbreaking responses to various environmental, social, and economic issues within urban ecosystems. Given that numerous cities globally are deficient in green spaces, these green infrastructures offer a sustainable approach to incorporating natural elements into urban settings, thereby improving urban resilience, environmental quality, and the well-being of residents. Therefore, this analysis outlines that, with appropriate configuration of the plants and trees around buildings, green walls and vertical forests can help bring in multidimensional benefits in terms of air quality, urban heat, water management, biodiversity, energy efficiency, economy, and general urban wellbeing.

Building-integrated greenery creates an array of environmental benefits that include improving air quality and eliminating the phenomena of the urban heat island. There were, from 1950 until 1970, about 300-320 ppm of CO2 in the atmosphere. It reached 400 ppm in 1970-2010, though there is an estimation of 700 ppm in the year 2100 (Jozay et al, 2024). Vegetation on buildings helps in filtering, acting like a barrier between indoors and outdoors. The vegetation absorbs indoor and outdoor $CO_2$ through photosynthesis and captures air pollutants (Q. Wang et al., 2019). Air passing through the foliage results in fine particulate matter being intercepted on leaf surfaces, which decreases the levels of injurious particles, thereby protecting the atmospheric air quality and air health. The importance of this is particularly pronounced in metropolitan regions where air contamination presents considerable health hazards. Furthermore, vegetation plays a crucial role in the sequestration of carbon dioxide, which is a primary greenhouse gas influencing global warming and climate change. Studies indicate that environmentally friendly structures release between 3% to 39% less CO2 when compared to conventional construction techniques for sustainable architecture (Jozay et al, 2024). A quintessential illustration is the instance of Bosco Verticale in Milan, which captures 30 tons of carbon dioxide annually (Boeri Studio, 2024).

Vegetation is especially important in dissipating the urban heat island effect, or locally higher temperatures of the built-up city compared to its rural surroundings. This diversification of green features in fact creates the possibility for buildings to benefit from a cooling process related to evapotranspiration, in which surrounding air temperatures would be reduced and heat released from construction materials minimized. The inherent cooling phenomenon contributes to reducing the need for air conditioning, hence reducing thermal discharge from air-conditioning systems (Pan & Chu, 2016; Thomsit-Ireland, 2018). This in turn reduces energy use, saving between 24% and 50%, according to Jozay et al. in 2024, which further results in reduced energy generation emissions and better urban air quality. Various studies have estimated that indoor temperature can be reduced through vertical greening by 2.2°C and wall surface temperature by 13.9°C (Peng et al. 2019).

Projections done indicate that 153 cities will experience increased temperatures ranging from 1.4–3.1 °C up until 2050. Global warming is an issue that already significantly prevails in cities today. Temperature regulation in green buildings is achieved both directly, through a reduction in heating and cooling energy needs, and indirectly, through mediation of water runoff patterns (Silva et al., 2016). Vegetation can absorb and filter rainwater, mitigating water drainage issues commonly exacerbated by heavy rainfall, while providing an additional layer of bioprotection for older buildings (Thomsit-Ireland, 2018), by shielding it from harsh weather conditions, corrosion, and erosion (Kaposztasova et al., 2024).

Additionally, the quality of surface and underground water is improved, while flooding and water scarcity risks are mitigated. Adoption of such green infrastructure can save 40–50% of water (Boano et al., 2020).

Greenery-covered buildings are reshaping urban design to landscape the urban area in an aesthetically pleasing yet ecologically beneficial way. These innovative structures meet environmental challenges while contributing a great deal to improving the visual appearance of urban areas, thus beautifying and renovating the cityscape perspectives. The incorporation of greenery systems, including green facades, into retrofitted residential buildings facilitates the engagement of older structures in the sustainable advancement of urban environments, contributing to decreased cooling loads, enhanced shading, and diminished solar and conductive heat gains (Mostafa Khalil, 2022). In addition to the environmental advantages, green facades enhance the aesthetic and social worth of urban locales by fostering visually diverse and welcoming spaces.

Such environments encourage community interaction, well-being, and a high quality of life in the urban area, as Kaposztasova et al. 2024 noted, for both inhabitants and wildlife. Many greenery buildings remain standing as a refuge for the wild animals, incorporating various species of plants and animals like birds and insects-allowing biodiversity, hence allowing human and nature co-existence. These benefits align with the growing international concern for sustainable living, as they align with broader efforts toward solving contemporary environmental problems (Peng, 2013). Public interest and awareness about green spaces and architecture can also be seen in the property market, where sales that involve such systems are usually faster. This phenomenon illustrates the increasing cultural and economic significance linked to green buildings, emphasizing their function as facilitators in advancing sustainable urban development (Grewal, 2023).

The increasing acknowledgment of the ecological advantages associated with greenery has prompted urban areas to resist the development of glass skyscrapers, given their detrimental environmental effects, as demonstrated in the instances of New York and Toronto. In contrast, governments may provide financial incentives or mandate the incorporation of green elements into these structures (Al-Kodmany, 2023).

This development necessitates cooperative endeavors among architects, urban planners, policymakers, and the general public to guarantee that these advancements correspond with the requirements of modern urban environments and their inhabitants (Modirrousta & Mohammadi, 2015). Through collaboration, these parties can devise urban green strategies that are both ecologically sustainable and socially inclusive, promoting cities that are resilient, inhabitable, and effectively harmonized with natural components.

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