E3S Web of Conferences **546**, 01004 (2024) https://doi.org/10.1051/e3sconf/202454601004
ICoGB 2024

A comprehensive framework for living wall design: bridging standards, current approaches, and unexplored frontiers in architectural and structural practices

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Abstract. In recent years, policymakers worldwide have emphasized innovative solutions for urban challenges, guided by initiatives like the UN's Sustainable Development Goals and the European Green Deal. Nature-based solutions (NBS) play a crucial role in addressing climate issues and improving urban well-being. With urban areas witnessing a surge in NBS demand due to their dense populations, initiatives like green wall technologies, such as Living Walls (LW), are becoming more prevalent. However, integrating vegetation onto buildings presents complexities requiring structured support. This research aims to establish a robust foundation for LW design by combining existing standards, exploring current approaches, and pushing architectural and structural practices. It seeks to provide comprehensive guidelines for LW design to enhance efficacy, durability, and safety while preventing errors. Notably, existing global guidance lacks uniformity, necessitating a detailed European guide for LW design and maintenance. The methodology involves consolidating global guidelines and analysing current LW solutions to identify guidance gaps. Anticipated outcomes include foundational guidelines for architects and structural designers to improve LW processes, guiding further research and testing for advanced LW practices.

1 Introduction

The Sustainable Development Goals (SDGs) established by the United Nations in 2015 1 and the European Green Deal (EGD) 2 introduced by the European Commission in 2019 provide overarching frameworks to tackle global challenges, with a strong focus on sustainability and environmental conservation. The EGD, closely aligned with the SDGs, prioritizes mitigating pollution, biodiversity loss, and climate change impacts while promoting sustainable resource management. Urban environments are witnessing a growing emphasis on sustainability, with Nature-Based Solutions (NBS) gaining traction to address environmental issues 3. Vertical green systems (VGS), a significant component of NBS, are increasingly integrated into urban landscapes, contributing to SDG and EGD objectives by enhancing infrastructure sustainability, mitigating climate issues, and fostering biodiversity. Collaboration among experts is crucial for effective VGS design and implementation to maximize their benefits.

1.1 Terminology and parameters

There are several typologies of vertical green systems, each with its unique design and installation characteristics. They can typically be divided into two groups: green façades (GF) where climbing plants are trained to grow on the exterior of a building or structure with or without a support, covering the surface with vegetation, and living walls (LWs) which consist of vertical structures filled with soil or another growing medium, where plants are directly planted or inserted into pockets or modules attached to the wall (Fig. 1). This paper focuses on the second type which includes continuous LWs, pocket systems, planter box systems and panel systems.

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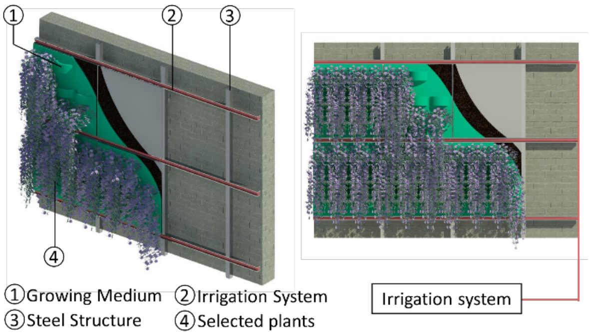

Fig. 1. Modular living wall (MLW) structure.

Designing LWs involves a comprehensive consideration of various parameters to ensure the successful integration of green infrastructure into the built environment. These parameters include both aesthetic and functional aspects, as well as factors related to plant health and system sustainability. Fig. **2** illustrates the parameters that have been determined essential for the design of LWs. Each of those parameters includes several considerations which will be explained in section 3.

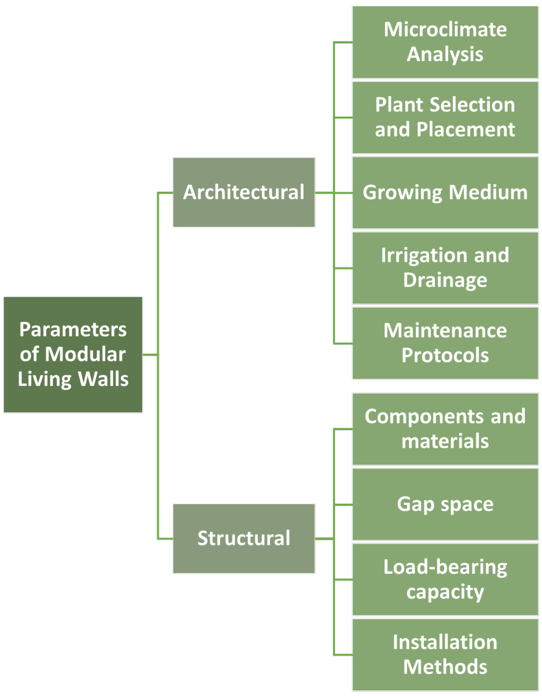

Fig. 2. Parameters of Modular Living walls.

1.2 Living walls benefits

LWs offer numerous benefits, enhancing their value and sustainability when combined with optimized designs 4. These benefits are categorized into private, building-scale benefits, and public, urban-scale benefits. Building-scale benefits include facade protection, thermal comfort, energy consumption, and acoustic comfort. LWs protect building facades from degradation caused by temperature variation and solar radiation while regulating microclimates to reduce temperature fluctuations. Additionally, LWs contribute to thermal comfort by neutralizing solar radiation effects and providing insulation. Acoustic comfort is enhanced as LWs filter outside noises and reduce sound levels, influenced by factors like the depth of the growing media and vegetation coverage 5. On the urban scale, LWs contribute to urban temperature mitigation, air quality improvement, stormwater management, increased space for urban wildlife, noise reduction, and therapeutic effects. These benefits align with SDGs related to health, well-being, and sustainable cities, making LWs an important solution for creating healthier and more sustainable urban environments.

1.3 Methodology and scope of the paper

This paper focuses on examining the architectural and structural design parameters of LWs. The research aims to address several research questions regarding existing guidelines and research needs in the field of VGS including inquiries about the comprehensiveness of existing guidelines, current design practices and challenges faced by designers, and the importance of architectural and structural parameters in the performance and safety of VGS with steel support. The methodology involves analysing international guidelines, identifying lacking parameters, and proposing refined criteria to advance living wall design principles, aiming to fill gaps in guidance and standardize testing protocols.

2 State of the art

The European Union Construction Products Regulations (CPR) establish essential requirements for marketing construction products in EU member states. European standardization organizations create European Standards and European Technical Assessments (ETA) based on the CPR, leading to CE marking for compliance 6. For LWs, there are no specific EN Standards or ETAs 7. To address this, the research explores guidelines for similar technologies, including Green Roofs (GR), Ventilated Façades (VF), and Curtain Walls (CW), comparing their similarities and differences with LWs. While GR and VF have ETAs and national standards, CW is covered by a harmonized product standard, EN 13830. The following table 1 lists the guidelines analyzed in the research.

2.1 Extra European guidelines

In the context of extra-European guidelines such as those from North America, Australia and Singapore, the research emphasizes the abundance of information on GR compared to limited coverage for VGS, particularly LWs. North American guidelines, provide insights into GR and VGS policies, with a focus on construction standards. Australian guidelines from Victoria and New South Wales offer comprehensive coverage, including construction details and maintenance considerations. Singapore's guidelines emphasize structural integrity, work safety, and lightning protection for VGS projects. However, a critical analysis reveals that existing guidelines often lack clear calculation methods, specific design parameters for LWs, and uniformity across expert recommendations.

Table 1. Extra EU and EU guidelines regarding the design of VGS, GR, VF and CW systems.

Country	Guidelines
North America	- Green Walls in High-Rise Buildings: An output of the CTBUH Sustainability Working Group.8 - Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West. 9 - Les murs végétalisés 2022 + 2023. 10 11
Australia	- Urban Green Cover in NSW - Technical Guidelines. 12 - Green Roofs and Walls Design Guide & Waterproofing Guide. 13
Singapore	- Concise Guides to Safe Practices on Rooftop Greenery and Vertical Greenery. [14] - CS E10:2014 – Guidelines on Design Loads for Skyrise Greenery. [16] - CS E11:2014 – Guidelines on Design for Safety of Skyrise Greenery [16]
Europe	- EN 13830:2015+A1:2020 – Curtain walling - Product standard. [17] - ÖNORM L 1136 – Outdoor vertical greening - Directives for planning, building, maintenance, and control. [18] - Guide for facade greening MA 22 - City Council of Vienna, program for environmentally friendly services. [19] - UNI 11018 – Cladding and anchoring systems for mechanically mounted ventilated façades – Instructions for design, execution, and maintenance – Stone and ceramic covering [20] - UNI 11235 – Criteria for design, execution, testing and maintenance of roof garden [21] - Green Roof Guidelines – Guidelines for the Planning, Construction and Maintenance of Green Roofs[22] - UK Guide to Green Walls [23]

2.2 European guidelines

The analysis of European standards and guidelines on VGS reveals a nuanced landscape, with notable contributions from various countries such as Austria, Italy, Germany, and the United Kingdom.

European standard EN 13830:2005, focused on curtain walling, serves as a foundational reference, emphasizing performance characteristics such as fire resistance, watertightness, acoustic performance, thermal properties, and durability. While EN 13830 primarily targets curtain walls, its parameters are relevant to VGS, necessitating adaptations for specific considerations.

Austria, through the issuance of ÖNORM L 1136 in 2021[18], provides comprehensive guidelines for outdoor vertical greenery. Categorizing vertical greening into distinct types, this standard covers planning, execution, maintenance, and control aspects, considering factors like seasons, climate, and sustainability. Reference to various ÖNORM standards underscores a holistic approach to vertical greenery. The city of Vienna contributes to this domain with the Façade Greening Guideline Vienna MA 22, emphasizing the multifaceted benefits of greening urban structures. The guideline delves into plant selection, greenery types, and factors influencing the choice of plants for vertical greening. Structural considerations, material selection, fire safety, and care actions are meticulously outlined, aligning with the broader objective of promoting green architecture.

In Italy, the absence of specific VGS guidelines is compensated by relevant standards on VF and GR. Analyzing UNI 11018:2003 (VF) and UNI 11235:2015 (GR) reveals valuable insights applicable to VGS. These Italian standards provide product requirements and prescriptive guidelines for VF and GR, offering a basis for crafting guidelines for living walls.

Germany stands out with its comprehensive Green Roof Guidelines, a seminal document since 1982. Although primarily focused on GR, its extensive details encompass factors like construction, material requirements, structural considerations, drainage, and maintenance. While certain aspects are less applicable to VGS, key parameters related to vegetation areas and stratum design remain pertinent. The United Kingdom contributes to the discourse with its succinct Guide to Green Walls, offering insights into plant selection, irrigation, maintenance, and relevant policies. Despite its brevity, the guide emphasizes practical considerations for implementing VGS.

A comparative analysis highlights the strengths and gaps in existing standards. The need for performance indicators tailored to VGS, structural considerations, and specific parameters for living walls is evident. Integrating elements from CW, VF, and GR standards can contribute to the development of more comprehensive and tailored guidelines for vertical greenery systems

https://doi.org/10.1051/e3sconf/202454601004

3 Exploring unaddressed design variables

3.1 Architectural

3.1.1 Microclimate and site analysis

The microclimate analysis serves as a cornerstone in the selection of an appropriate LW type, adapted plant species, and the ideal location around the building.

It considers various factors including sunlight availability, air temperature, precipitation, wind patterns, and microclimate variations, all of which heavily influence design decisions. For instance, variations in sunlight across the LW area necessitate meticulous plant selection, while understanding air temperature fluctuations, influenced by factors like elevation and local climate conditions, is crucial for determining plant resilience. Identifying the plant hardiness zone within the project area further refines plant selection criteria. Additionally, rainfall patterns and relative humidity play a significant role in shaping irrigation strategies, impacting the sustainability of the vegetation. Wind characteristics guide LW positioning to prevent potential plant damage. Microclimatic variations, particularly notable in urban canyons, require tailored analysis to ensure accurate design adjustments. Although a comprehensive quantitative guide is yet to be established, seeking guidance from local horticulturists can provide valuable insights. Moreover, site and building-specific factors such as existing structure, accessibility, neighboring vegetation, water collection options, and potential harmful emissions must be carefully considered to optimize LW performance and longevity [24] [18].

3.1.2 Plant selection and placement

The process of selecting plant species for a living wall (LW) involves considering project goals and constraints, favoring native, non-invasive species for ecological balance (Fig. 3). Plant characteristics such as density, root system, and height should align with project objectives like comfort, noise reduction, air quality improvement, and aesthetics. Denser plant coverage benefits the building and surroundings, while higher plant diversity enhances LW resilience and environmental impact. Smaller plants at densities of 25 to 30 per square meter optimize growth and coverage [24].

Plant layout considerations include elevation and location differences, with adapted species needed for varying conditions such as temperature fluctuations, drafts, wind exposure, and sunlight variations across the LW. Larger plants can provide shade and stability, and interactions between species should be carefully considered to create a balanced environment.

During plant establishment in LWs projects, pre-grown plants from nurseries require acclimation to outdoor conditions, which can take several months to over a year depending on maturity at installation 8. Adequate irrigation, fertilization, and invasive species control are crucial during this period to ensure plant health and resilience.

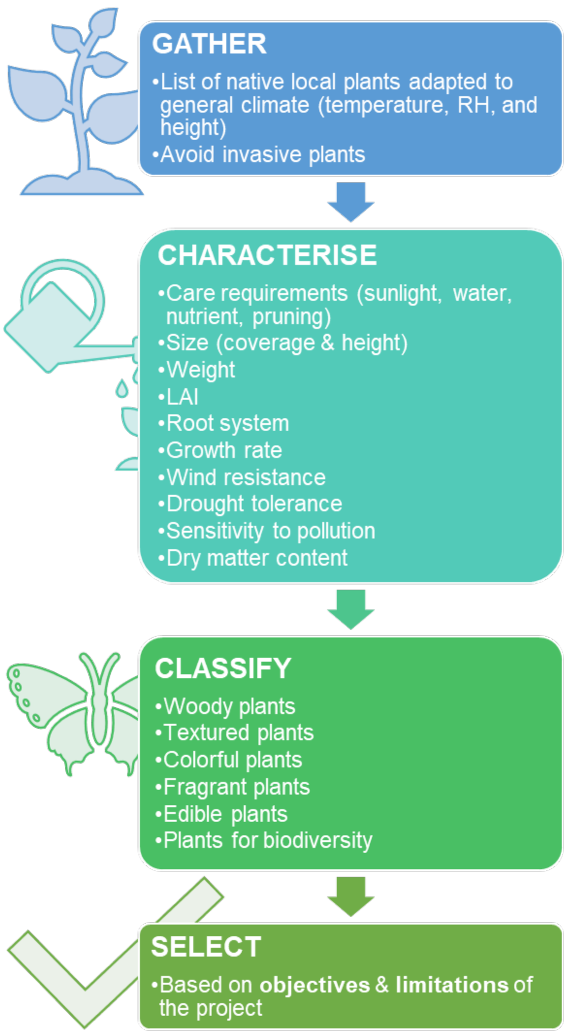

Fig. 3. Plants selection process.

3.1.3 Growing medium

The growing medium (GM) is crucial for supporting vegetation and consists of organic and inorganic matter, air, and water. Hydroponic systems rely solely on fertilizers for nutrients, while soil-based substrates contain a mix of organic and inorganic materials. Hydroponic substrates, lightweight and stable, require frequent irrigation and precise nutrient intake but may struggle in hot, dry environments. Soil-based substrates, engineered for vertical applications, contain less organic matter to resist compaction and require less maintenance. A mixed substrate combining organic and inorganic materials is also an option. Essential GM characteristics include good drainage, water-holding capacity, durability, nutrient cycling, weight, and filtration. Physical and chemical properties should be analyzed and controlled based on plant species, with consultation from specialists recommended for determining acceptable ranges (Figure 4). Standardized methods exist for assessing GM properties, ensuring suitable substrate quality for LWs projects.

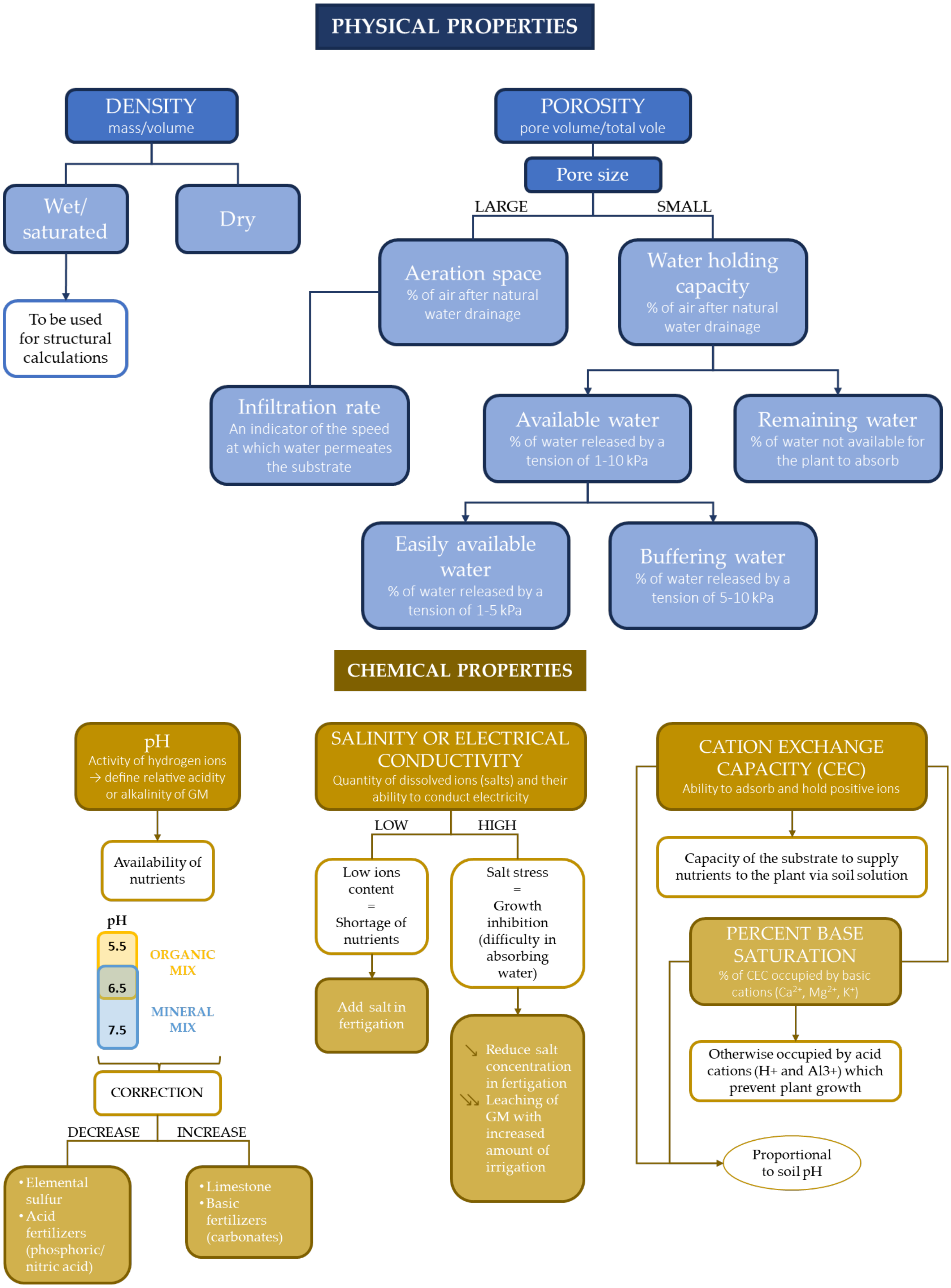

Fig. 4. Physical and chemical properties of substrate.

3.1.4 Irrigation system and drainage

The irrigation needs of LW vary based on the type of system used, which can be either closed circuit or open circuit. In closed circuit systems, water is recirculated within a closed loop, minimizing water wastage, and making it suitable for water conservation efforts. Open circuit systems, on the other hand, do not recirculate water, potentially leading to higher water usage. The main components of an irrigation system for LW include tanks, pumps, piping, collectors, timers, conductivity meters, pH meters, and fertilizers[25]. Designing the irrigation network involves considering factors like operational pressure, emitter flow rates, number and spacing of emitters/drip lines, and water management strategies. Effective irrigation operation requires securing an appropriate water supply, minimizing water losses, and considering factors like temperature, humidity, and sunlight exposure. Graywater utilization can also help reduce water consumption[26] Fig. 5 [26]. Water quality is essential for plant growth, with considerations for total dissolved solids (TDS), sodium adsorption ratio (SAR), and salinity levels[27]. Drainage is crucial in LW to prevent waterlogging and ensure proper substrate oxygenation, with design considerations including drainage capacity, gradient, filtering elements, and material selection to avoid corrosion. Proper drainage systems help manage excess water, with filtering elements and waterproof materials ensuring efficient water flow and system durability.

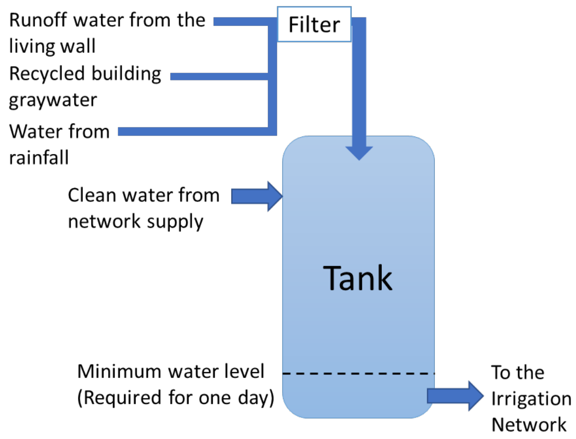

Fig. 5. Water recirculation system integrated with reuse of resource.

3.1.5 Maintenance protocols

Ensuring the long-term success of Living Walls (LW) involves a comprehensive approach to maintenance and monitoring. Maintenance tasks encompass structural integrity checks, irrigation system performance monitoring, plant health assessments, fertilization management, pruning, pest and disease control, weed management, and regular inspections. These tasks aim to uphold the LW's functionality, aesthetics, and plant health.

Structural integrity maintenance involves identifying potential degradation processes, addressing causes, and proposing interventions to prevent issues. Monitoring the irrigation system ensures proper water distribution and drainage, while plant health assessments include disease and pest checks, pruning, and soil testing. Fertilization management involves continuous monitoring, alternating between liquid and organic fertilizers, and periodic foliar and water analyses to maintain nutrient balance [26].

Implementing a living wall maintenance monitoring system involves using sensors to measure soil moisture, temperature, pH, and nutrient levels [28]. Data loggers collect and store data from these sensors, enabling real-time monitoring and analysis to identify trends and make informed maintenance decisions.

A maintenance schedule should be developed early in the project, including establishment, routine, cyclic, reactive, and renovation stages [29]. Each stage addresses specific maintenance tasks to ensure the LW's long-term success, functionality, and aesthetic appeal.

3.2 Structural

3.2.1 Components and material selection

The LW structural integrity relies on its three main components: the primary support, which encompasses the building structure or load-bearing wall; the secondary structure, consisting of an anchoring system, brackets, load-bearing profiles, and fasteners; and the vegetation support system, which can be either pockets, containers, or panels. The secondary structure can also accommodate a layer of insulation and a ventilated cavity for thermal properties improvement and moisture control.

The primary support dictates various aspects of the design. Specifically, the structural type determines the positioning of anchors, the choice of material dictates the type of anchors required and sets the waterproofing standards, while the geometry determines anchor distribution, vegetation support dimensions, and the effectiveness of thermal insulation and ventilated cavity.

Depending on the primary support and vegetation support configuration, the secondary structure may comprise uprights, crosspieces, or a combination of both. Typically, corrosion-resistant steel and aluminum serve as the primary materials for the substructure. To mitigate thermal transmittance, incorporating thermal breaks where brackets or profiles meet the primary support can be advantageous.

Regarding the vegetation support system, the materials used vary depending on the chosen type. Pocket systems often utilize recycled plastic, felt, fabric, and geotextile, while planter boxes and panels are commonly constructed from metal, plastic, or fiberglass. The inclusion of a backboard within the assembly of vegetation support serves to provide rigidity to modular living wall elements, prevent water from reaching the air cavity between the building façade and the living wall and can function as a root barrier to safeguard the building's external façade, with materials ranging from cement particle board to PVC or polypropylene panels or sheets, while in absence of a solid backboard, polyolefin or PVC membranes may be utilized as a root barrier and waterproofing layer.

3.2.2 Positioning of the vegetation support system

LW assemblies are installed via a substructure which creates a gap between the primary support and the vegetation support system. For VF, it is recommended to leave at least 20 mm for the evacuation of rainwater and condensation and to use open joints between cladding panels for pressure equalization between the outside environment and the cavity avoiding the suction of rain inside the gap space [30]. In the case of LW, the vegetation will create its microclimate and the air gap required for proper ventilation might increase based on the local climate as indicated in Table 2.

Table 2. Gap spacing recommendation for different climates.

Climate	Gap range [mm]
Hot & dry	20 – 100
Temperate & slightly humid	50 – 100
Hot & humid	100 – 200

If a sufficient gap can be reached, the ventilated cavity will act as a waterproofing layer for the building façade's material. Otherwise, it might be necessary to add a waterproofing layer to protect the wall material or the insulation layer.

3.2.3 Loads-bearing capacity

The first step in the evaluation of the load-bearing capacity is the determination of acting loads. Similarly to other building components, the Eurocodes can be followed to determine self-weights, wind, seismic, accidental, and fire loads acting on the LW. For self-weights, it is important to consider a fully saturated substrate and mature plants. As for the snow load, considering the texture of the plants, it is possible of having snow accumulation even if the plants are applied on a vertical surface [19]. A method for assessing the maximum amount of snow that can be retained by different types of plants still needs to be defined. Regarding wind load, LW present some particularities compared to a traditional façade as illustrated in **Fig. 6**. They are influenced mainly by two factors: the presence of a ventilated cavity, inside which the pressure is mainly affected by gap spacing and vegetation permeability [31], impacting stress on the substructure, and the texture of vegetation, affecting external pressure coefficients. Studies show that plants modify wind effects, with flexible and permeable characteristics leading to decreased drag coefficients at higher wind speeds [32] and potential reductions in external pressure on buildings with vegetation on facades [33]. These factors suggest a reduction of wind action on both primary and secondary structures, but current standards on GR and VF consider those particularities only as a safety factor and recommend evaluating wind action as per standards practices.

The second step is the evaluation of the supporting structure resistance. This includes primary support load-bearing capacity assessment, secondary structure configuration and sizing, and vegetation support system selection. Before installing the LW system on the primary support, various verifications beyond structural and material integrity are necessary, including assessments of static and dynamic resistance to loads, reactions to fastener application and thermal insulation, as well as controls for differential settlements and tolerances of verticality, horizontality, and planarity. The secondary structure load-bearing profiles must be sized for the maximum deflection and stress resistance based on Eurocodes. The maximum admissible deflections should be as follows: for horizontal profiles, the vertical deflection should not exceed L/300 and horizontal deflection is limited to L/100, while for vertical profiles, the horizontal deflection limit is L/200 [20].

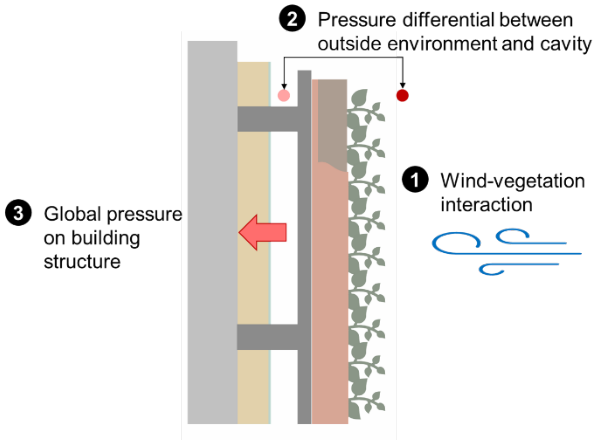

Fig. 6. Wind load considerations for a building covered with a LW.

Additionally, thermal expansion must be accounted for by fixing the profiles only at one point while the other fixing should be flexible and allow sliding along the profile's length. Brackets and fasteners must be carefully selected to facilitate compensation for primary support irregularities, adjustment of planarity, verticality, and horizontality, ensure compatibility between vegetation and primary support, and allow for insulation layer and ventilated cavity space creation, while also meeting requirements for bearing capacity in service, which assesses resistance to tensile and shear stresses under serviceability loading conditions, and considering failure mode at ULS, which determines whether the tensile resistance of the anchor or that of the support material (concrete, masonry, etc.) is reached first. Finally, the vegetation support system must be designed to resist the full weight of the plants and growing medium but also to resist environmental factors such as UV, pollution, and rainwater as it might be directly exposed at least partially before the plants reach their maturity. The resistance of the vegetation support must be tested to evaluate its overall performance, including its ability to withstand flexion from wind pressure, resist extraction of fixings, endure seismic action, and withstand impacts.

Moreover, the overall LW assembly must resist corrosion and fire hazards. Corrosion resistance can be achieved by the selection of appropriate materials and protective layers, with a particular attention to metal combinations leading to galvanic corrosion. The fire assessment of living wall (LW) assemblies, expected to fall under class B to D due to vegetation presence, necessitates two tests: EN ISO 19925-2 for ignitability and EN 13823 for final fire reaction class, smoke production, and flaming droplets/particles class. To address fire hazards, regular maintenance to remove dead vegetation is crucial, while enhancing fire resistance can be achieved through vegetation breaks, using non-combustible materials in critical locations, selecting plants with minimal biomass, or implementing specific protective measures to ensure building safety in case of fire

3.2.4 Construction and installation method

The installation phase has four important aspects to be considered: the installation program, the management of the construction site, the quality control, and the health and safety considerations.

The installation program is planned by the project manager based on various factors such as the construction site's condition, the optimal installation sequence, workers' skills, manufacturers' production time, plants' maturity at installation, and the appropriate outdoor planting season. The installation sequence usually follows three phases: the primary support preparation including the waterproofing installation and testing if required, the secondary structure and insulation installation, and the irrigation system, vegetation support system, and growing media and plants installation and testing. Control and necessary adjustments should be realized after each phase.

The management of the construction site includes the survey of the existing building, the proper selection of equipment for the installation, the correct management of the components before their installation, i.e. packaging, transport, and storage, and the introduction of measures to minimize the disruption of users.

Quality controls need to be performed by qualified individuals before, during and after the installation and include tasks such as evaluation of the environmental and building conditions, control of the anchoring system installation quality for performance achievement, and control of the vegetation layer coverage, rooting, and pests 12 months after installation. Proper tolerances on deviations of the structural system must also be controlled during and after the installation.

Finally, health and safety factors must be considered for both the installation and maintenance teams. First, strategic planning must be conducted during the initial design phase considering safety measures in the definition of work procedures and schedules. Second, a qualified supervisor must be hired and must effectively relay all necessary information to the workers under their supervision. Third, a risk assessment must be conducted, and a periodical review of hazard identification and risk assessments should be performed to confirm their efficacy and accuracy. Last, appropriate countermeasures must be defined for the identified risks including ensuring safe access to and from the work areas, providing a fall prevention plan, and developing a robust permit-to-work system.

4 Conclusion

Many countries promote VGS in cities through policies and incentives, yet designer guidance is limited, leading to uncertainty about performance. Some countries offer specific directives; for example, Melbourne's Growing Green Guide offers exhaustive insights on architectural considerations, Austria's ÖNORM L 1136 stands out in Europe, prioritizing plant selection, irrigation, and maintenance, but structural guidance is lacking. Integration of VGS guidelines with CW, VF, and GR standards could improve structural guidance, but a comprehensive approach remains elusive, requiring leveraging existing knowledge and ongoing research.

Although this research focuses on LW design parameters which include quantitative or qualitative factors that influence the design process and outcomes, design criteria are also an essential part of complete guidelines. Those refer to qualitative standards or requirements that a design solution must meet and focus on the qualities or attributes of the design solution. European product standards like EN 13830 cover design criteria by providing lists of characteristics to be fulfilled by the product and methods to assess the performances in order to certify the product's quality before its marketing. For LW systems, the essential assessments include wind load resistance, snow load resistance, impact resistance, seismic resistance, resistance to ageing by UV radiation, thermal resistance, hygrothermal and freeze-thaw behavior, and resistance of metallic elements to corrosion.

Additional aspects that could be the focus of future research include cost and environmental impact analyses. Indeed, green technologies are meant to increase the environmental and economic benefits with respect to traditional solutions. Therefore, the whole life cycle of the product must be analysed and the benefits in terms of environmental and economic impacts should overcome the costs to be able to say that this technology is green. Guidance on Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) should also be available to LW designers.

Acknowledgements: The project leading to this application has received funding from the European Union's RFCS2022 research and innovation program under grant agreement No 101112158.

References

1. United Nations, "Transforming our world: the 2030 Agenda for Sustainable Development," [Online]. Available: https://sdgs.un.org/2030agenda. [Accessed 13 December 2023].
2. European Commission, "The European Green Deal," 2023. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. [Accessed 13 December 2023].
3. International Union for Conservation of Nature (IUCN), "Nature-based Solutions," 2023. [Online]. Available: https://iucn.org/our-work/nature-based-solutions. [Accessed 12 December 2023].
4. B. Riley, "The state of the art of living walls: Lesson learned," Building and Environment, vol. 114, pp. 219-232, 2017.

5. S. M. Sheweka and N. M. Mohamed, "Green Facades as a New Sustainable Approach Towards Climate Change," Energy Procedia, vol. 18, pp. 507-520, 2012.
6. EOTA - European Organisation for Technical Assessment, "What is an EAD?," EOTA, 2024. [Online]. Available: https://www.eota.eu/what-ead. [Accessed 24 January 2024].
7. EOTA - European Organisation for Technical Assessment, "ETA database," EOTA, 2024. [Online]. Available: https://www.eota.eu/etassessments. [Accessed 24 January 2024].
8. A. Wood, P. Bahrami and D. Safarik, Green Walls in High-Rise Buildings: An output of the CTBUH Sustainability, Chicago: Council on Tall Buildings and Urban Habitat, 2014.
9. L. Tolderlund, Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West, Denver, 2010.
10. J. Champagne-Caron, L. Hénault-Éthier and G. Grégoire, Les murs végétalisés, Saint-Hyacinthe: Société québécoise de phytotechnologie, 2022. (in french)
11. C. Frédette and M. Trickey-Massé, Murs végétalisés, Saint-Hyacinthe: Québec Vert, 2023. (in french)
12. State of NSW and Office of Environment and Heritage, Urban Green Cover in NSW Technical Guidelines, Sydney: Office of Environment and Heritage, 2015.
13. City of Sydney, "Green roofs and walls," 2020. [Online]. Available: https://www.cityofsydney.nsw.gov.au/environmental-support-funding/green-roofs-and-walls. [Accessed 7 December 2023].
14. National Parks Board, A Concise Guide to Safe Practices for Vertical Greenery, Singapore, 2013.
15. Building and Construction Authority (BCA), Housing and Development Board (HDB), Ministry of Manpower (MOM), National Environment Agency (NEA), National Parks Board (NParks), Public Utilities Board (PUB) and Singapore Civil Defence Force (SCDF), A handbook on developing sustainable highrise garden: Bringing Greenery Skywards, Singapore: National Parks Board, 2017.
16. CUGE Centre for Urban Greenery and Ecology, "CUGE Standards," 2014. [Online]. Available: https://www.nparks.gov.sg/Cuge/Resources/Publications/CUGE%20Standards. [Accessed 8 December 2023].
17. European Committee for Standardization, EN 13830:2015+A1:2020 - Curtain walling - Product standard, CEN, 2020.
18. Austrian Standards International, ÖNORM L 1136: Vertikalbegrünung im Außenraum - Anforderungen an Planung, Ausführung, Pflege und Kontrolle [ÖNORM L 1136: Outdoor vertical greening - Directives for planning, building, maintenance and control], Vienna: Austrian Standards plus GmbH, 2021.
19. Florian Kraus, et al., LEITFADEN FASSADENBEGRÜNUNG [Guide for facade greening], Vienna, 2019. (in german)
20. UNI - Ente Nazionale Italiano di Unificazione, UNI 11018:2003 - Rivestimenti e sistemi di ancoraggio per facciate ventilate a montaggio meccanico - Istruzioni per la progettazione, l'esecuzione e la manutenzione - Rivestimenti lapidei e ceramici, Milano: UNI - Ente Nazionale Italiano di Unificazione, 2003. (in italian)
21. UNI - Ente Nazionale Italiano di Unificazione, UNI 11235:2015 - Istruzioni per la progettazione, l'esecuzione, il controllo e la manutenzione di coperture a verde, UNI - Ente Nazionale Italiano di Unificazione, 2015. (in italian)
22. FLL - Landscape Development and Landscaping Research Society e.V., Green Roof Guidelines – Guidelines for the planning, construction and maintenance of green roofs, Bonn: Landscape Development and Landscaping Research Society e. V. (FLL), 2018.
23. M. Laurence, et al., UK Guide to Green Walls - An introductory guide to designing and constructing green walls in the UK, Urban Greening, 2013.
24. State of Victoria through the Department of Environment and Primary Industries, Growing Green Guide: A guide to green roofs, walls and facades in Melbourne and Victoria, Australia, 2014.
25. J. Champagne-Caron, L. Hénault-Éthier and G. Grégoire, Les murs végétalisés, Saint-Hyacinthe: Société québécoise de phytotechnologie, 2022. (in french)
26. L. Pe´ rez-Urrestarazu and M. Urrestarazu, "Vertical Greening Systems: Irrigation and Maintenance," in Nature Based Strategies for Urban and Building Sustainability, 2018, pp. 55-63.
27. T. F.scherer, D. Franzen and L. Cihaceck, Soil, Water and Plant Charactristics Important to Irregation, North Dakota State University, Fargo, North Dakota, 2013.
28. H. Yin, Y. Cao, B. Marelli, X. Zeng, A. J. Mason and C. Cao, Soil Sensors and Plant Wearables for Smart and Precision, 2021.
29. S. S. T. N. U. P. B. P. K.A. Hofmann, Vertical Green 2.0 – The Good, the Bad and the Science, Berlin: Deutsche Nationalbibliothek, 2023.
30. Angelo Lucchini, Facciate ventilate - Manuale facciate ventilate. [Online]. Available: https://www.rockwool.com/it/prodotti-applicazioni/isolamento-pareti-esterne/facciate-rivestite/facciate-ventilate/. [Accessed: November 11, 2023]. (in italian)
31. K. Perini, M. Ottelé, A. Fraaij, E. Haas and R. Raiteri, "Vertical greening systems and the effect on air flow and temperature on the building

envelope," Building and Environment, vol. 46, pp. 2287-2294, 2011.

32. L. Manickathana, T. Defraeyea, J. Allegrini, D. Derome and J. Carmelieta, "Comparative study of flow field and drag coe cient of model and small natural trees in a wind tunnel," Urban Forestry & Urban Greening, vol. 35, pp. 230-239, 2018.
33. H. Li, Y. Zhao, B. Sützl, A. Kubilay and J. Carmeliet, "Impact of green walls on ventilation and heat removal from street canyons: Coupling of thermal and aerodynamic resistance," Building and Environment, vol. 214, 2022.
34. K. Koch, R. Samson and S. Denys, "Aerodynamic characterisation of green wall vegetation based on plant morphology: An experimental and computational fluid dynamics approach," Biosystems Engineering, vol. 178, pp. 34-51, 2019.