REVIEW ARTICLE

Living walls enhancing the urban realm: a review

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Abstract

In the current Anthropocene epoch, globalization and urbanization have adversely affected our environment causing global warming. To counter the adverse effects of global warming, research is being conducted into many innovative technologies to identify viable solutions. This paper will focus on one such solution, Living walls and how the built form is enriched by the environmental and psychological benefits provided by Living walls. Buildings with Living walls have lively surroundings which enhance the urban fabric. This review paper shall elaborate on the effects of Living walls on the built environment in the urban realm and analyze how Living walls improve the urban fabric in terms of activity and behavior pattern, streetscape and building frontage.

Introduction

The human tendency to alter their physical environment has transformed the ways in which they live while in close contact with vegetation. The Neolithic era is an example of that, and proofs are available that there has been a relationship between greenery and humankind (Zeybek 2020). In the twenty-first century, an increasing number of people are moving to densely populated cities and living in a compact man-made physical environment (Muahram et al. 2019), as the result of rapid urbanization and globalization. This impact has affected city climate (Ghazalli et al. 2018), pollution levels (Ghazalli et al. 2018), per capita green space (Xia et al. 2021), mental health (Elsadek et al. 2019), and much more. Apart from the environmental impact, the impact on the social environment is also noticeable (Anguluri and Narayanan 2017). Recognizing such an impact on

the environment, people are putting in efforts to make cities future-ready and livable. Governments and citizens have started stressing the need for greenery in cities. Greenery contributes to active surroundings and encourages outdoor activities (Wu et al. 2020; Xia et al. 2021).

According to A Pattern Language book (1977), the streets do not offer much reassurance for outdoor activities as most of the space is tied down by cars and a lot of spaces within the right of way are underutilized due to poor street design. To provide the opportunity for social interaction, we require space for sheltered walks, arcades and paths which are dedicated to pedestrian movement as well as provide physical comfort while walking or resting. Such places invite visitors locally as well as globally. Places which offer such opportunities in the urban streetscape are relatively limited. Social interaction has the characteristic that it only takes place when conditions are optimal with a minimum chance of hindrances, inconveniences, and disadvantages (Gehl 1989). Time spent in social interactions is a trigger for memories and the comfortable physical environment is a catalyst to the same (Stoltz and Grahn 2021).

However, all these venues, which encourage social interaction take up space and in the competitive world of real estate economics, there is rarely a leeway provided for green spaces in urban centers without incurring drastic costs (Boulton et al. 2018; Wang et al. 2021). Vertical surfaces in the form of bare walls remain the only space that can be utilized for providing greenery economically (Collins et al.

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2017). By installing Living walls on bare walls, we can make cities green, sidestepping the issue of scarcity of spaces (Charoenkit and Yiemwattana 2017). Like urban level street greenery and parks, Living walls provide multiple benefits (Charoenkit and Yiemwattana 2017).

What are Living walls?

A Living wall represents a type of vertical greenery system (Sa et al. 2014) where a vertical surface is covered in greenery with plants of uniform growth, instead of scattered or unplanned development (Manso and Castro-Gomes 2015; Riley 2017). Living walls offer freedom of plant selection as well as reduce the limitations of application on higher floors of the building (Charoenkit and Yiemwattana 2016). A vertical irrigation system is attached to the walls providing the required nutrients and water to the plants growing on a substrate (Giordano et al. 2017). The substrate can be soil or an artificial growing medium like rockwool (Stav 2016), cock-coir (Stav 2016), perlite (Ottelé et al. 2011), felts (Ottelé et al. 2011), peat chunks (Gunawardena and Steemers 2020), peat moss (Gunawardena and Steemers 2020), coconut fibers (Gunawardena and Steemers 2020) and foam (Rakhshandehroo et al. 2015).

Living walls can be implemented using soil-based systems or hydroponic systems (Ottelé et al. 2011; Rakhshandehroo et al. 2015). Generally, small herbaceous species, grasses, perpetual flowers, ferns and low shrubs are used in Living walls (Charoenkit and Yiemwattana 2017). Living walls are divided into two categories—continuous and modular systems (Charoenkit and Yiemwattana 2016; Cortês et al. 2021; Manso and Castro-Gomes 2015). The continuous system consists of a lightweight screen (Manso and Castro-Gomes 2015; Riley 2017) and felts (Weerakkody 2018). It is termed as Mat system, invented by Patrick Blanc (Weerakkody 2018). The installation is done on-site, where plants are plugged into the support skin (screen or felt) (Gunawardena and Steemers 2020). The modular system has trays, vessels, planter tiles, and flexible bags. This equipment allows the plants to grow uniformly (Manso and Castro-Gomes 2015; Riley 2017). Modular systems can be prepared in-situ and attached to the structural frames (Weerakkody 2018). It consists of separate units, so it can be prepared off-site and transported to the site for assembly (Gunawardena and Steemers 2020).

Living walls act as bio-filters and ecological air conditioning systems (Rakhshandehroo et al. 2015). They improve mental health (Muahram et al. 2019) while providing environmental (Charoenkit and Yiemwattana 2016), social (Rakhshandehroo et al. 2015) and economic benefits (Sheweka and Magdy 2011) as well as reduce energy (Riley 2017) and water (Cortês et al. 2021) consumption. Along with that, they provide opportunities for social interaction (Stav 2016) and help overcome the loss of collective memory (Felasari and Peng 2012), image and identity (Okesli and Gurcinar 2012). These benefits are discussed in detail in Section 3.

This review paper will focus on the following listed objectives:

- To explore the benefits that Living walls provide in urban spaces.
- To discuss the benefits that Living walls provide to improve the urban fabric in terms of activity and behavior pattern, streetscape and building frontage.
- To analyze Living walls as a system to improve the urban fabric.

Methodology

An online search through Web of Science, Science Direct, and Google Scholar was conducted to access papers for literature review. Keywords used to search papers were "Greenery system," "Vertical Greenery system," "Living wall," "Green wall," "Green facade," "Vertical gardens" and "Urban Living wall," "Urban Realm," "Image and Identity" and "Quality of Life." Research papers, conference papers, and theses with theoretical and practical approaches were considered to frame this paper. A total of one hundred seventy papers were assessed, out of which sixty were shortlisted to understand the benefits. Among these sixty papers, forty-one were related to energy consumption, forty to environmental benefits, eighteen to water consumption, fifteen to economic benefits, eleven to health benefits, eight to social benefits and only seven to urban context. Table 1 elaborates the distribution of themes across these papers. In this exploratory study, it was found that most researchers have focused on formulating empirical evidences on energy consumption and environmental benefits. But only few who focused on the same for social benefits in the urban context (Virtudes & Manso 2016). Hence, empirical results on social benefits in the urban context is identified as a research gap.

Books like The Image of the City (Lynch 1960), The Death and Life of Great American Cities (Jacob 1961), A Pattern Language (Alexander 1977), A Theory of Good City Form (Lynch 1981) and Life Between Buildings: Using Public Space (Gehl 1989) become the base to understand the social benefits at the urban level. These theorists elaborate on how building frontage and streetscape are one of the aspects which help in enhancing social interaction. To study how they enhance a space, it is important to understand the activity and behavioral pattern of people. These becomes the groundwork for the "Social benefit" section.

The paper has been divided into two parts. First part explores on the different benefits and how Living walls

Table 1 Papers for each theme and their methods

S.No	Theme	Title	Author	Year	Location	Methods
1	E	The perception of green integrated into architecture: installation of a green facade in Genoa, Italy	Adriano Magliocco*, Katia Perini	2015	Genoa, Italy	Experimental test
2	E	More than just a Green Facade: The sound absorption properties of a vertical garden with and without plants	M.J.M. Davis*, M.J. Tenpierik, F.R. Ramírez, M.E. Perez	2017	Ecuador, South America	Experimental test
3	E	Evaluation of green walls as a passive acoustic insulation system for buildings	Z. Azkorra, G.Perez, J. Coma, L.F. Cabeza, S. Bures, J.E.Alvaro, A. Erkoreka, M. Urrestarazu	2015	Spain	Experimental test
4	E	Thermal Behavior of the Extensive Green Roofs in Riyadh City	Ashraf Muharam, Nasser Al-Hemiddi, El Sayed Amer	2019	Riyadh	Test on real case
5	E, U	Application of Green Walls in Sustainable Urban is the Remedy to the Global Problems	Dr. G. Sudhakar, Swarnalath.G, Vijayakumar. G, Dr. V.venkatarathnamma	2017	-	Perception study
6	E	Green wall impacts inside and outside buildings: experimental study	Rabah Djedjiga*, Rafik Belarbi, Emmanuel Bozonnet	2017	France	Experimental test
7	E	An application of a parametric transducer to measure acoustic absorption of a living green wall	Anna Romanova*, Kirill V. Horoshenkov, Alistair Hurrell	2019	United Kingdom	Experimental test
8	E, H	Alterations in use of space, air quality, temperature and humidity by the presence of vertical greenery system in a building corridor	Aini Jasmin Ghazallia*, Cris Brack, Xuemei Bai, Ismail Said	2018	Canberra	Test on real case
9	H	Vertical greenery buffers against stress: Evidence from psychophysiological responses in virtual reality	Sarah Hian May Chan, Lin Qiu*, Gianluca Esposito, Ky Phong Mai	2021	Singapore	Experimental test
10	H	Green façades: Their contribution to stress recovery and well-being in high- density cities	Mohamed Elsadek, Binyi Liu*, Zefeng Lian	2019	Shanghai, China	Experimental test
11	H	Psychological and physiological effects of a green wall on occupants: A cross-over study in virtual reality	Seungkeun Yeom, Hakpyeong Kim, Taehoon Hong	2021	Seoul, South Korea	Experimental test
12	W	Green walls for greywater treatment and recycling in dense urban areas: a case-study in Pune	F. Masi, R. Bresciani, A. Rizzo, A. Edathoot, N. Patwardhan, D. Panse, G. Langergraber	2016	Pune, India	Experimental test
13	W	Water consumption of felt-based solutions for grey-ing walls in warm climates	Luis P'erez-Urrestarazu	2021	Spain	Test on real case
14	W	A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits	Fulvio Boano*, Alice Caruso, Elisa Costamagna, Luca Ridolfi, Silvia Fiore, Francesca Demichelis, Ana Galvão, Joana Pisoeiro, Anacleto Rizzo, Fabio Masi	2020	-	Perception study

Table 1 (continued)

S.No	Theme	Title	Author	Year	Location	Methods
15	W	Urban living walls: reporting on maintenance challenges from a review of European installations Kanchane	Kanchane Gunawardena* Koen Steemers	2020	-	Perception study
16	EN	Knowledge mapping of research progress in vertical greenery systems (VGS) from 2000 to 2021 using CiteSpace based scientometric analysis	Muhammad Mubashir Ahsan, Wei Cheng*, Aqsa Bilal Hussain, Xuefeng Chen, Basit Ali Wajid	2021	-	Perception study
17	EN	Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades	Julia Coma, Gabriel Perez*, Alvaro de Gracia, Silvia Bures, Miguel Urrestarazu, Luisa F. Cabeza	2017	Spain	Experimental test
18	EN	Energy simulation of vertical greenery systems	Nyuk Hien Wong, Alex Yong Kwang Tan*, Puay Yok Tan, Ngian Chung Wong	2009	Singapore	Simulation
19	EN	Vertical Greenery System as the Passive Design Strategy for Mitigating Urban Heat Island in Tropical Area: A Comparative Field Measurement Between Green Facade and Green Wall	Ratih Widiastuti*, Chely N. Bramiana, Bangun I.R.H, Bintang N. Prabowo, Mirza Ramandhika	2018	Indonesia	Experimental test
20	EN, E	Thermal evaluation of vertical greenery systems for building walls	Nyuk Hien Wong, Alex Yong Kwang Tan*, Yu Chen, Kannagi Sekar, Puay Yok Tan, Derek Chan, Kelly Chiang, Ngian Chung Wong	2010	Singapore	Experimental test
21	EN, E	The use of green walls in sustainable urban context: with reference to Dubai, UAE	M. A. Haggag	2010	Dubai	Perception study
22	EN, E	Living walls and their contribution to improved thermal comfort and carbon emission reduction: A review	Sasima Charoenkit*, Suthat Yiemwattana	2016	-	Perception study
23	EN, E	Orientation effect on thermal and energy performance of vertical greenery systems	Lan Pan, Shen Wei, L.M. Chu	2018	China	Experimental test
24	EN, E	Assessment of the effect of living wall systems on the improvement of the urban heat island phenomenon	Elham Shafiee*, Mohsen Faizi, Seyed-Abbas Yazdanfar, Mohammad-Ali Khanmohammadi	2020	Iran	Experimental test and Simulation
25	EN, E	Role of specific plant characteristics on thermal and carbon sequestration properties of living walls in tropical climate	Sasima Charoenkit*, Suthat Yiemwattana	2017	Thailand	Experimental test
26	EN, E	The impact of vertical greenery system on building thermal performance in tropical climates	Nur Dinie Afiqah Mohammad Shuhaimi, Suzaini Mohamed Zaid*, Masoud Esfandiari, Eric Lou, Norhayati Mahyuddin	2021	Malaysia	Experimental test
27	EN, E	An environmental Life Cycle Assessment of Living Wall Systems	V. Oquendo-Di Cosola*, F. Olivieri, L. Ruiz-García, J. Bacenetti	2020	Spain	Experimental test
28	EN, E	Thermal regulation impact of green walls: An experimental and numerical investigation	Erdem Cuce	2017	Nottingham, England	Experimental test

Table 1 (continued)

S.No	Theme	Title	Author	Year	Location	Methods
29	EN, E	Environmental performance of a cork-based modular living wall from a life-cycle perspective	Andreia Cortes, Joao Almeida*, Maria Ines Santos, Antonio Tadeu, Jorge de Brito, Carlos Manuel Silva	2021	Coimbra, Portugal	Experimental test
30	EN, E	Experimental investigation on the energy performance of Living Walls in a temperate climate	Ugo Mazzali*, Fabio Peron, Piercarlo Romagnoni, Riccardo M. Pulselli, Simone Bastianoni	2013	Italy	Experimental test
31	EN, E	ARE GREEN WALLS AS "GREEN" AS THEY LOOK? An Introduction to the Various Technologies and Ecological Benefi ts of Green Walls Mike	Mike Weinmaster	2009	-	Perception study
32	EN, E	Life cycle assessment of felt system living green wall: Cradle to grave case study	Ghofran M.J.A. Salah*, Anna Romanova	2021	United Kingdom	Experimental test
33	EN, E, H, S, U	The Living walls as an Approach for a Healthy Urban Environment	Dr. Samar Sheweka,Arch. Nourhan Magdy	2011	-	Perception study
34	EN, E, W	Green Facades as a New Sustainable Approach Towards Climate Change	Dr. Samar Mohamed Sheweka, Arch. Nourhan Magdy Mohamed	2012	-	Perception study
35	EN, E, W	Vertical Greenery System in urban tropical climate and its carbon sequestration potential: A review	Suzaini Mohamed Zaid*, Eeswari Perisamy, Hazreena Hussein, Nik Elyna Myeda, Nurshuhada Zainon	2018	-	Perception study
36	EN, E, W	Behaviour of green facades in Mediterranean Continental climate	G. Perez, L.Rincon, A.Vila, J.M. Gonzaalez, L.F.Cabeza	2011	Spain	Experimental test
37	EN, E, W	Effect of plant traits and substrate moisture on the thermal performance of different plant species in vertical greenery systems	Lan Pan, Shen Wei, Po Ying Lai, L.M. Chu	2020	Hong Kong	Experimental test
38	EN, E, W	Vertical Greenery Systems (VGS) for energy saving in buildings: A review	Gabriel Perez*, Julia Coma, Ingrid Martorell, Luisa F. Cabeza	2014	-	Perception study
39	EN, H	Vertical greenery systems: from plants to trees with self-growing interconnections	Xiuli Wang*, Wolfgang Gard, Helena Borska, Bob Ursem, J. W. G. van de Kuilen	2020	-	Perception study
40	EC, EN, E	Living Wall Systems: a technical standard proposal	Roberto Giordanoa*, Elena Montacchini, Silvia Tedesco, Alessandra Perone	2017	-	Perception study
41	EC, EN, E	Quantifying the thermal performance of green facades: A critical review	Annie M. Hunter, Nicholas S.G. Williamsa*, John P. Rayner, Lu Aye, Dominique Hes, Stephen J. Livesley	2014	-	Perception study
42	EC, EN, E, W	Vertical greenery systems: A systematic review of research trends	Rosmina A. Bustamia*, Martin Belusko, James Ward, Simon Beecham	2018	-	Perception study
43	EC, EN, E, H, W, U	Creating urban health through the promotion of green walls	Ashraf Muahram, Joseph Kennedy, Mitra Kanaani, Vuslat Demircay	2019	-	Perception study
44	EC, EN, E, H, W	The impact of living walls in the reduction of atmospheric particulate matter pollution	Udeshika Indumali Weerakkody Appuhamillage	2018	United Kingdom	Test on real case
45	EC, EN, H, W, U	Living Walls and Their Potential Contribution to Sustainable Urbanism in Brisbane	Yael Stav	2008	Brisbane	Simulation

Table 1 (continued)

S.No	Theme	Title	Author	Year	Location	Methods
46	EC, EN, W, U	Urban reconciliation ecology: The potential of living roofs and walls	Robert A. Francis*, Jamie Lorimer	2011	London	Perception study
47	EC, EN, W	The state of the art of living walls: Lessons learned	Benjamin Riley	2017	England, France, Japan	Perception study
48	EC, EN, E	Green wall systems: A review of their characteristics	Maria Manso*, Joao Castro-Gomes	2015		Perception study
49	EC, EN, E, U	Living skins: environmental benefits of green envelopes in the city context	D. Roehr; J. Laurenz	2008	Vancouver	Simulation
50	EN, E, S	Living wall (vertical greening): Benefits and Threats	Mehdi Rakhshandehroo*, Mohd Johari Mohd Yusof, Roozbeh Arabi	2015	-	Perception study
51	EN, E, H, S, W	Comparative life cycle analysis for green facades and living wall systems	Marc Ottelé*, Katia Perini*, A.L.A. Fraaij, E.M. Haas, R. Raiteri	2011	Delft, The Netherlands	Experimental test
52	EN, E, H, S, W	Transfunctional Living Walls—Designing Living Walls for Environmental and Social Benefits	Yael Stav	2016	Tel-Aviv,Israel	Experimental test and simulation
53	U	Applications of Green Walls in Urban Design	Ana Virtudes, Maria Manso	2016	-	Perception study
54	EC	Valuation of Green Walls and Green Roofs as Soundscape Measures: Including Monetised Amenity Values Together with Noise-attenuation Values in a Cost–benefit Analysis of a Green Wall Affecting Courtyards	Knut Veisten*, Yuliya Smyrnova, Ronny Klaeboe, Maarten Hornikx, Marjan Mosslemi, Jian Kang	2012	European cities	Experimental test
55	EC	Holistic analysis and prediction of life cycle cost for vertical greenery systems in Singapore	Ziyou Huang, Chun Liang Tan, Yujie Lu*, Nyuk Hien Wong	2021	Singapore	Test on real case
56	EC	The value of green walls to urban biodiversity	Rebecca Collinsa, Marije Schaafsma, Malcolm D. Hudson	2017	England	Experimental test
57	EN, S	Vertical Greening Façade as Passive Approach in Sustainable Design	Ahmad Ridzwan Othman*, Norshamira Sahidin	2016	Indonesia	Experimental test
58	EC, EN, E, S, W	Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefit	Mina Radic*, Marta Brkovi Dodig, Thomas Auer*	2019	-	Perception study
59	EN, E, S	Green Wall Design Approach Towards Energy Performance and Indoor Comfort Improvement: A Case Study in Athens	Margarita-Niki Assimakopoulos, Rosa Francesca De Masi, Filippo de Rossi,Dimitra Papadaki, Silvia Ruggiero*	2020	Athens, Greece	Simulation
60	EC, EN, E, S	A review of energy characteristic of vertical greenery systems	Tabassom Safikhani*, Aminatuzuhariah Megat Abdullah, Dilshan Remaz Ossen, Mohammad Baharvand	2014	-	Perception study

EN energy consumption pattern, *E* environmental benefit; *W* water consumption pattern; *EC* economic benefit; *H* health benefit, *S* social benefit, *U* urban context

provide them. Literature with empirical results has been reviewed and elaborated in the "Environmental benefits," "Health benefits," "Water consumption pattern," "Energy consumption pattern," and "Economic benefits" sections. The "Social benefit" section has been analyzed with the help of fourteen case studies like Quai Branly Museum-Paris, Semiahmoo Public Library-Canada, Caxia Forum-Madrid and installations on Indian and Mexican flyovers.

The second part elaborated in the "Discussion" section analyzes the results gathered in earlier sections and leads to the conclusion for the paper.

Results

A systematic analysis of the existing literature was done. The following section elaborates the existing literature on environmental benefits, health benefits, social benefits, water consumption pattern, energy consumption pattern, and economic benefits.

Environmental benefits

All industries add to pollution levels directly or indirectly in the form of greenhouse gases, pollutants and noise, which affect the wellbeing and quality of life of residents. As per the World Health Organization in 2014, 92% of people worldwide were living in regions with poor air quality (Weerakkody 2018). It is a known fact that plants absorb carbon dioxide and improve air quality (Li et al. 2015). The more trees there are, the less the impact of pollution will

be. A tree possesses the capacity to filter an average car's exhaust of approximately 4,000 km (2500 miles) per year (Muahram et al. 2019). One square kilometer area of trees can produce one to three tones of oxygen per day (Muahram et al. 2019). Greenery also extracts carbon dioxide from the atmosphere. Taking Living walls as an example, the substrate of Living walls can capture carbon in the range of 3—4 kg/cm2 which is 50–70% of the total carbon trapped in Living wall systems (Charoenkit and Yiemwattana 2016). The negative impact of industry can be observed by considering the example of the COVID-19 pandemic. During the initial COVID-19 outbreak, industries were shut down and urban air quality significantly improved in cities like Beijing, Bengaluru, Delhi, Lima, Mumbai, Rome and Wuhan (Kumari and Toshniwal 2020). They witnessed a decline in PM2.5 by 20.2 to 34.2%, PM10 by 23.7 to 47.3% and Nitrogen dioxide (NO2) by 31.6 to 64.5% (Kumari and Toshniwal 2020).

Living walls also act as a sound barrier and can dampen noise pollution (Azkorra et al. 2015; Romanova et al. 2019; Veisten et al. 2012). A Living wall of just 10 square meters can reduce noise pollution (with a frequency between 100 and 5000 Hz) by 40% (Davis et al. 2017; Muahram et al. 2019). Sound absorption property for a Living wall (2.5 m wide and 1.8 m tall) comprising of plants with high leaf area is enhanced by 1000 Hz (Romanova et al. 2019). An experiment in Spain compared different materials used in building facades as shown in Fig. 1, it is observed that green walls are more efficient in sound absorption and reducing reverberation time than most other building materials except a 25-mm-thick fiberglass board (Azkorra et al. 2015).

Fig. 1 Comparison of Sound absorption coefficient values for different facade materials (Azkorra et al. 2015)
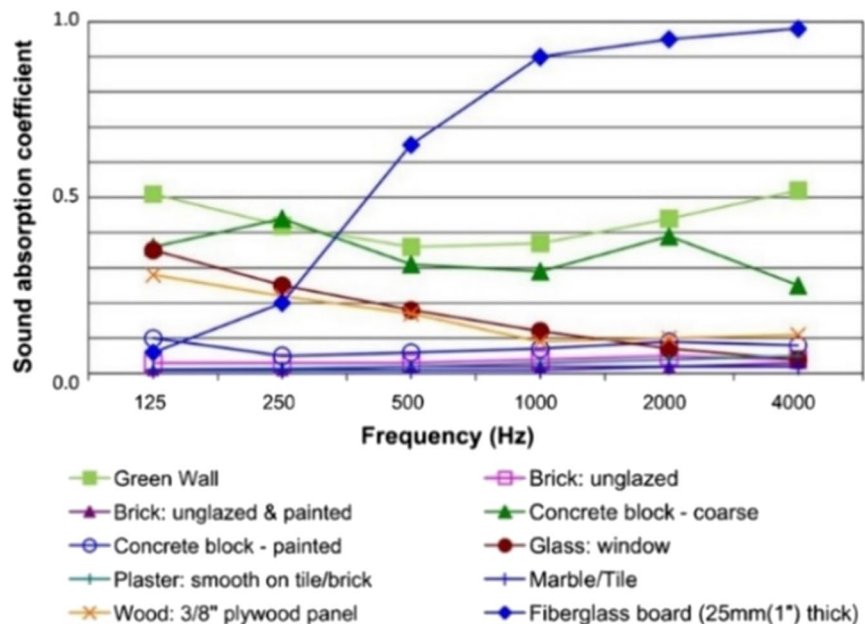
Sound absorption coefficient value comparison between the green wall and common building materials.

According to United Nations, the urban population of India will grow from 483 million in 2020 to 876 million by 2050; an increase of 81% (United Nations n.d.). Due to mass migration to urban areas, pollution levels have increased tremendously and will continue to do so (Verma and Raghubanshi 2018; Wang et al. 2021). To accommodate the human demand for shelter and wellbeing, the amount of area under hardscape is increasing while that under softscape is decreasing (Sheweka and Magdy 2011). This increase in hardscape area has not only impacted climate at the local level but also the global level. More area under accommodation implies more area under hardscape, which increases the usage of material and heat-absorbing surfaces (Sheweka and Magdy 2011).

The percentage under hardscape can be reduced by maintaining green spaces in the surrounding areas. It is observed that there is a temperature difference of 10ºC between an area surrounded by hardscape, i.e., urban area and that surrounded by softscape, i.e., rural area (Muahram et al. 2019). For example, during summers in Oregon, USA, areas without greenery experience a temperature up to 50ºC, whereas those surrounded by greenery experience temperatures only up to 25ºC (Muahram et al. 2019). The areas under hardscape are prone to the urban heat island effect due to the densely built environment, land profile change and anthropogenic heat generation (Sheweka and Magdy 2011). The temperature difference is dependent on the climatic zones.

Living walls have different substrates in which plants are installed on vertical surfaces and grown. These typologies of Living walls are explained by Alex Yong Kwang Tan in a study conducted at Hort Park, Singapore, on the thermal impact of Living walls in 2010. A vertical surface was divided up into nine sections, eight vertical green systems and a control wall (a bare wall), as shown in Fig. 2. These typologies are based on different systems like modular, felt, moss tile and framed planters' type which are combined with mixed, inorganic and soil type substrate. These eight types of vertical greenery systems are defined in Table 2 (Pérez et al. 2014; Wong et al. 2010).

The experiment concluded that these systems reduced the underlying surface's temperature by up to 11.58ºC. The Living wall system 3 (grid and modular, vertical interface and mixed substrate) performed the best (illustrated in Table 2) (Pérez et al. 2014; Wong et al. 2010). This reduction is possible due to the evapotranspiration phenomenon which has the capacity to consume 680 kWh of heat by a cubic meter of water (Pérez et al. 2014). The Hort Park experiment proves that different types of Living walls help in reducing the temperature of the underlying surface and that system typology affects the amount of temperature reduction.

Living walls reduce the heat flux, i.e., the amount of heat that is transferred indoors through hard surfaces, reducing the inner temperature of a building by up to 10ºC (Radić et al. 2019). A lush green wall is proven to absorb or reflect sun radiation ranging from 40 to 80% during summers (Muahram et al. 2019). With such benefits, Living walls can help with issues like global warming and climate change while improving human wellbeing. To tackle climate change worldwide, the Paris Agreement has been signed by 189 countries as of 2020. The principal aim of the agreement is to reduce the global greenhouse gas emissions, global temperature and shift to a low-carbon world (Agreement n.d.).

Health benefits

For holidays, one travels into the lap of nature, usually to a remote hilly or forested area to roam around, explore new places and most importantly, relax (Packer 2021). Away

Fig. 2 Experiment at Hort Park, Singapore (Pérez et al. 2014; Wong et al. 2010)
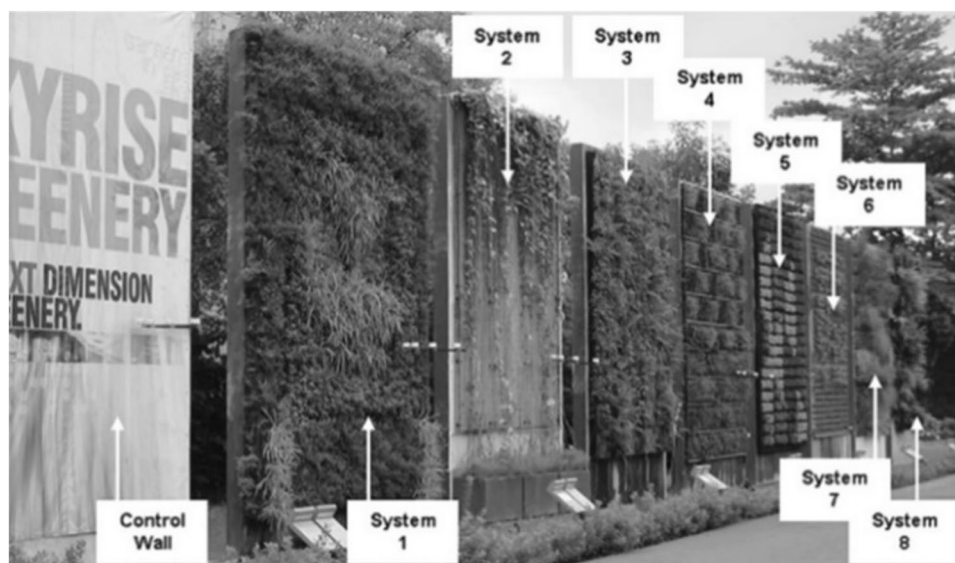
Table 2 Description of vertical greenery systems in HortPark with Summary of average wall surface temperatures on 28 Apr 08 (Pérez et al. 2014; Wong et al. 2010)

S.No	System typology	Description	Maximum reduction of average wall surface temperature (ºC)
1	Living wall – Modular panel, vertical interface, mixed substrate	Combination of 2 systems: the versicell-based and 'plug-in' slot planter system. Versicell planters have drainage cells with selected mixture of green roof and soil planting media wrapped in geo-textile membrane while the slotted planters are mainly planter cages system	10.03
2	Green façade – Modular trellis	Climber plants in planters forming green screens across mesh panels on the wall	3.33
3	Living wall – Grid and modular, vertical interface, mixed substrate	Plant panels embedded within stainless steel mesh panels inserted into fitting frames	11.58
4	Living wall – Modular panel, vertical interface, inorganic substrate	Employed the Parabienta system with a patented growing medium (composite peat moss) as a planting media inlay. The peat moss panel encased in a stainless-steel cage is hung onto supports lined with integrated irrigation	10.94
5	Living wall – Planter panel, angled interface, green roof substrate	This system uses a UV-treated plastic as a molded base panel with integrated horizontal planting bays	10.03
6	Living wall – Framed mini planters, horizontal interface, soil substrate	Individual mini planters placed and secured onto stainless steel frame	6.85
7	Living wall – Vertical moss-tile, vertical interface, inorganic substrate	Patented ceramic tiles shipped with pre-grown moss species. Suitable for creating tiling designs	-
7a	Living wall – Flexible mat tapestry, horizontal interface, soil substrate	Lightweight panel comprising 2 layers of moisture retention mats secured onto a supporting grating or mesh. Plants slotted and pre-grown in between mats. Suitable for flat and curved surfaces. Allows ease of change	6.58
8	Living wall – Plant cassette, horizontal interface, soil substrate	Use of planters to hold wider variety of plant types and of larger sizes. Planters are secured onto the wall through hinges. Lightweight growing medium is used	9.27

from the daily hassle of life, a person usually finds such places peaceful and calming. In contrast, prevailing urban lifestyle trends have been causing serious economic, social, environmental and health issues (Ghazalli et al. 2018; Grimm and Schindler 2018; Wang et al. 2020). Growing migration to cities has rapidly increased the urban population density which in turn has led to a shortage of adequate infrastructure and affordable housing for residents (Kabisch and Haase 2014). It is estimated that 70% of the world's population will live in cities by 2050 (Lu et al. 2018). This shortage has led to the creation of threatening and unhealthy urban environments (Grimm and Schindler 2018; Verma and Raghubanshi 2018).

Cities are crowded and land is expensive (Collins et al. 2017). Mumbai is a prime example (Boulton et al. 2018), with a population density of 32,400 persons/km^2 (Jim and Chan 2016), the second highest in the world. People, especially the youth, are increasingly suffering from stress, blood pressure and depression (Chan et al. 2021; Elsadek et al. 2019). The urban population is also exposed to a higher risk of diseases, both communicable and non-communicable like coronary heart disease, hypertension, obesity, diabetes, malaria, diarrhea, etc. (Eckert and Kohler 2014). Another issue in cities is noise pollution. Noise pollution has increased with the increase in traffic and industry (Veisten et al. 2012). It has been proven that noise makes people uncomfortable as well as causes heart diseases, blood pressure, stress and sleep disorders (Muahram et al. 2019; Sheweka and Magdy 2011). Integrating green zones in urban areas reduces these issues significantly (Li et al. 2015; Wu et al. 2020; Xia et al. 2021). Symptoms like cough, fatigue, and dry or itchy skin are reduced by 37, 30, and 23% respectively in the vicinity of greenery (M 2009). Cities will benefit from maintaining green spaces in their midst as it improves mental health, wellbeing and quality of life. The urban environment plays a vital role in affecting the mental health of an individual (Xia et al. 2021).

Living walls are a solution that offer the possibility of being surrounded by nature and benefit people of all classes and improves wellbeing (M 2009; Muahram et al. 2019).

Greenery promotes the development of better concentration, memory, productivity, creativity and facilitates healing (M 2009; Wang et al. 2020). Plants additionally provide

Fig. 3 A Buildings covered with vertical greenery); B buildings covered with green paint instead of greenery (Chan et al. 2021)

Fig. 4 Visual stimulations. A—green facade. B—control wall (Elsadek et al. 2019)

health benefits by reducing blood pressure, tension, fear, stress, anger and sadness (Boulton et al. 2018; Muahram et al. 2019; Xia et al. 2021). They help in improving people's mood, reducing the usage of medication and length of stay in the hospitals (Boulton et al. 2018; M 2009; Wang et al. 2020).

An experiment was conducted by Sarah Hian May Chan, Lin Qiu, Gianluca Esposito and Ky Phong Mai in 2021 in Singapore to examine the buffering effect of vertical greenery on stress levels with the help of virtual reality. In this experiment, participants were asked to walk through two scenarios, first a noisy street with buildings covered with vertical greenery as shown in Fig. 3A and second, a similar noisy street where vertical greenery was replaced by green paint as shown in Fig. 3B. It was observed that participants' stress levels did not increase when they walked through the street with vertical greenery, whereas when walking through the same area without vertical greenery, their stress levels increased (Chan et al. 2021).

A 6-day long experiment was conducted in 2018 by Mohamed Elsadeka, Binyi Liua, and Zefeng Lian at a university in Shanghai, China. In this experiment, two building scenarios were created to provide visual stimulation to participants. A climbing plant formed the facade on one side of the building whereas, on the other hand, a blank wall constituted the control as shown in Fig. 4A and B respectively. The participants were fitted with the electrodes and sensors for the physiological measurements and asked to concentrate on the visual stimuli of the green facade and the blank wall separately. After the testing session, they were requested

to fill a questionnaire containing subjective psychological questions (Elsadek et al. 2019).

This experiment concluded that after visual stimulation of the control wall, the participants' mood profiles were observed to be negative, and their total mood disturbance (TMD) increased. Conversely, after the visual stimulation of the green façade, the participants exhibited a positive mood and TMD decreased. Results are elaborated in Fig. 5A and B (Elsadek et al. 2019).

The Centre for Urban Design and Mental Health was founded in 2015 to identify ways to integrate mental health into our cities. It aims to publish an approach note for architects, designers and planners to promote mental health by designing better cities. They mention approaches like the "Mind the GAPS (Green Places, Active Places, Prosocial Places, Safe Places)" framework which can be applied to any plan or built form. "Green Places" should be accessible to all in daily life and over time, they improve and maintain the health and wellbeing of residents. "Active Places" are used for rhythmic activities and provide opportunities for social interaction. Such places bring positivity to people, improve mood and wellbeing. "Prosocial Places" provide an opportunity for interaction as well as a sense of community and belonging. They provide opportunities to observe as well as participate in activities. The "Safe Places" approach is about having a sense of safety and security which is an integral part of a person's wellbeing and mental health. A person can feel unsafe due to traffic, loss of bearings, pollution or due to other people (Health n.d.). Living walls provide benefits under all these four headers of the GAPS framework by providing a green place that improves health and wellbeing (discussed in the "Environmental benefits" section). Active place, Prosocial Place and Safe place will be further discussed in the "Social benefit" section.

Social benefit

Urban green space as part of the urban built environment provides benefits such as shade, landscape, fragrant atmosphere and absorption of pollutants (Wu et al. 2020). As per Alexander (1977), it is also a factor for an active street that offers walkability. These green spaces form an urban realm, affecting human activity and behavior in terms of usage of space through their intensity, direction of movement and point of concentration, while creating image and identity for the space (Teixeira 2021). Exposure to green spaces also increases social interaction among children and adolescents (Putra et al. 2021).

Activity pattern

Caixa Forum Museum, Madrid, is a great example that highlights how greenery transforms a space and makes it active while forming a relationship with visitors. Earlier, the museum was an old power station that was repurposed in 1899. Beside the museum, a plaza was developed by demolishing an old gas station. In Fig. 6, the brown-colored building represents the old power station, which is presently the museum, whereas the pink-colored building represents the old gas station. It was demolished as shown in Fig. 7 and converted into a plaza (blue color). In Fig. 8, after the introduction of the Living wall (on the green color wall as shown in Figs. 6 and 7) by Herzog & de Meuron and Patrick Blanc, the footfall at the plaza increased. It became a recreation and tourist spot (Herzog and de Meuron 2008; Magazine n.d.).

The Living wall is a four storeys high hydroponic system and has approximately 15,000 plants from 250 species. Madrid is one of the hottest cities in Europe, but people experience lower temperatures in the museum's vicinity
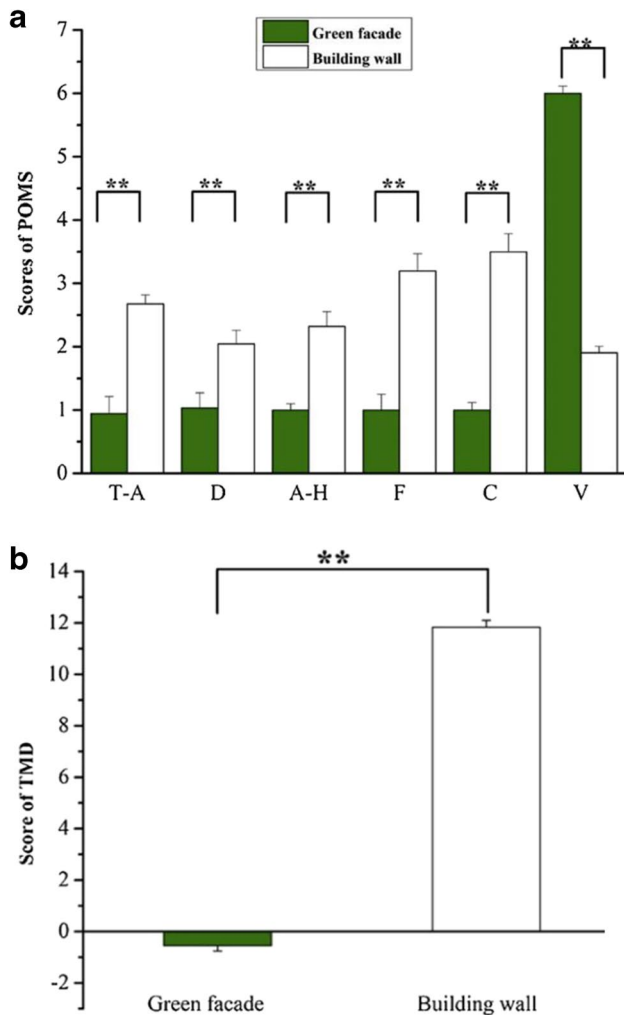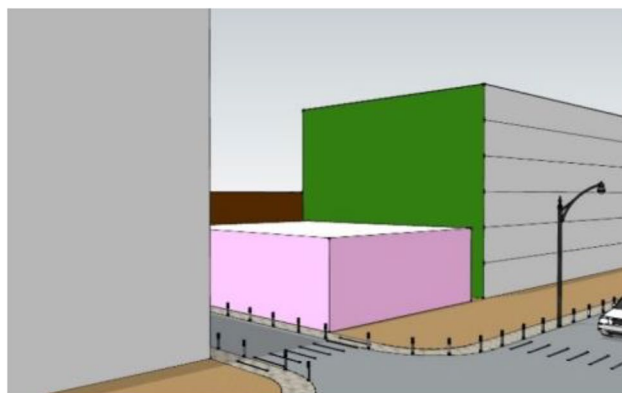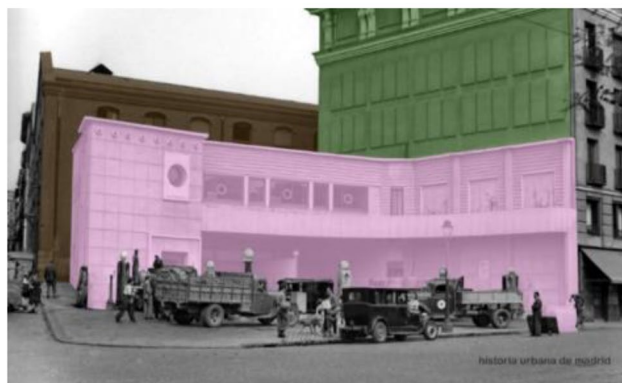

Fig. 5 A Responses in the profile of mood state (POMS) questionnaire between viewing a wall and a green façade compared for tension-anxiety (T-A), depression-dejection (D), anger-hostility (A–H), fatigue (F), confusion (C), and vigor (V). B Total mood disturbance (TMD) score for green façade vs building wall (Elsadek et al. 2019)

Fig. 6 A Conceptual diagram showing the scenario of the museum prior 1899 which had an old power station (brown) with an old gas station (pink) [Sketchup Drawing Author 1]. B Original image of the old power station (now Caixa Forum Museum, Madrid (Herzog and de Meuron 2008)
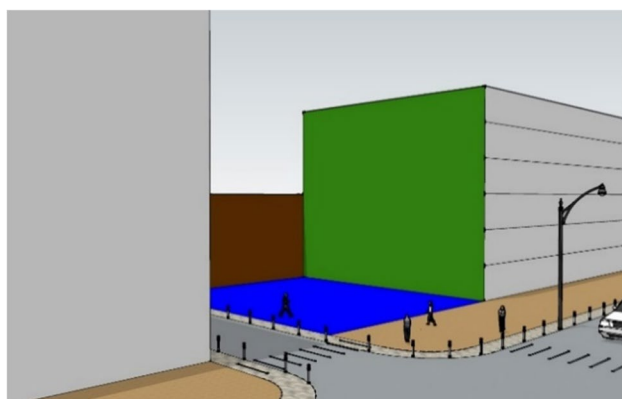

Fig. 7 Conceptual diagram showing museum and art gallery (brown) with the plaza (blue) [Sketchup Drawing Author 1]

than in any other neighborhood of the city. The Living wall also establishes a visual connection to the gardens across the street. To accommodate pedestrian traffic, authorities have had to divert traffic flow around the area. That has made it

Fig. 8 Conceptual diagram of Living wall added to the plaza enhancing the activity pattern [Sketchup Drawing Author 1]

Fig. 9 The plaza beside Caixa Forum Museum, Madrid (Blanc n.d.)

easier for pedestrians to cross the street and enter the plaza. In the mornings, this space is used by nearby residents for jogging. By afternoon, it transforms into a place for admirers, tourists and children. As the day moves on, the space transforms into an open square corner for gathering (Fig. 9). Ergo, the plaza and the Living wall offer a place for social and cultural gatherings forming an urban realm as well as act as a local way-finder or meeting point while forging image and identity (Magazine n.d.).

Considering another example of an experiment at Australian National University (ANU), Canberra, two narrow parallel corridors 1.8 m wide and 37 m long were selected. The aim was to investigate the impact of vertical greenery in altering the use of space. A vertical garden system (VGS) was installed in the south corridor while the north corridor was left unaltered as mentioned in Fig. 10. Before the experiment, the North corridor had 201 more users than the south corridor. After the experiment, it was observed that

Fig. 10 Floor plan of the building used for experiment (Ghazalli et al. 2018)
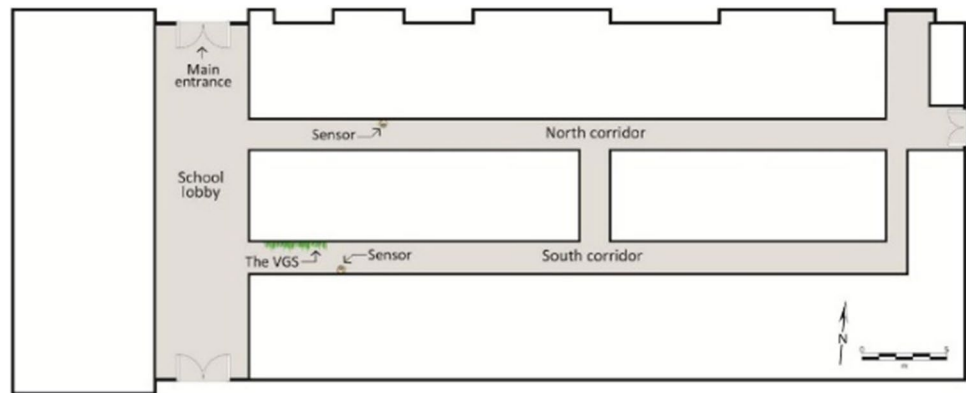
the number of users for the south corridor increased by 58%. The addition of a Living wall to the south corridor impacted human behavior by being an attractive element (Ghazalli et al. 2018).

Behavioral pattern

Human behavior is influenced by their physical and social environment. The design of spaces affects how people respond to and utilize them. The spaces should be designed to be comfortable, usable in all seasons, welcoming, accessible to all, adaptable, legible and memorable enough to allow people to establish an association with space (Alexander et al. 1977; Gehl 1989; Jacobs 1982). As per Montgomery (1998), any space which incorporates the above-mentioned factors can be transformed into a place.

The case study of the Mevlana Museum, Turkey showcases how people's behavior patterns change in response to the design of a space. The museum used to have a park in its foreground which was used by residents as a place to relax and spend their time (Fig. 11). The museum underwent renovation from 2008 to 2014, during which the park was converted into a hardscape area (Fig. 12). Post that, people stopped utilizing the space to spend their leisure time. The hardscape increased the surrounding temperature and changed the association and symbolism of the place. People found it difficult to connect back to the space (Zeybek 2020). Therefore, it is a must to understand human needs and behavior before providing any architectural and urban solution in order to form an urban realm while creating image and identity for the stakeholders (Sussman and Hollander 2015).

Streetscape

According to A Pattern Language (1977) and Life Between Buildings (1989) book, people tend to walk along the edges as it gives them a sense of safety and privacy. People do not walk in the middle of the street even if it is empty, they walk

Fig. 11 Mevlana Museum, Turkey before renovation conceptual diagram [Sketchup Drawing Author 1]. B Original image of the Mevlana Museum, Turkey before renovation (Zeybek 2020)

along the street edge mostly. This tendency or concept of walking along the edges is known as "Thigmotaxis" which represents an aspect of cognitive architecture (Sussman and Hollander 2015). This concept helps in the wayfinding process and creates landmarks for people (Sussman and Hollander 2015). As per Alexander (1977), people do not use space and streets without character. Currently, most building designs do not promote the usage of the building edges
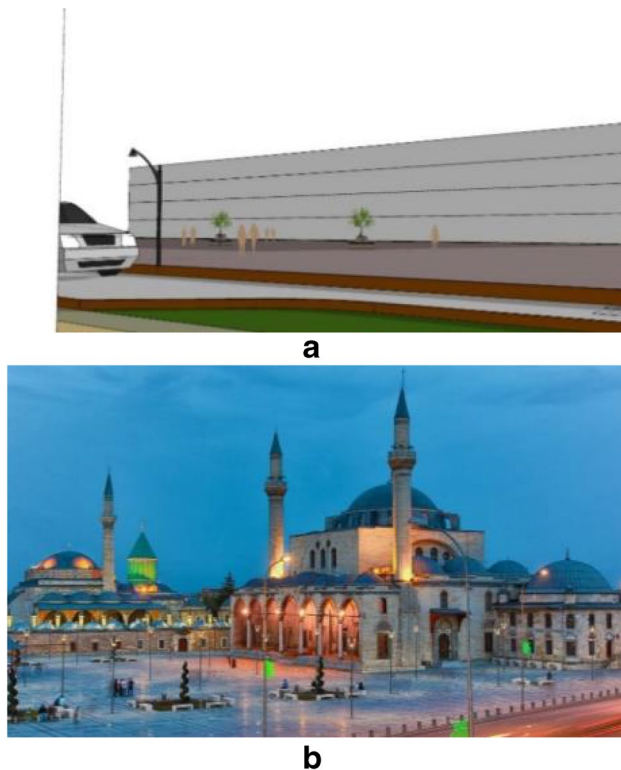
Fig. 12 Mevlana Museum, Turkey after renovation conceptual diagram [Sketchup Drawing Author 1]. B Original image of the Mevlana Museum, Turkey after renovation (Zeybek 2020)

around them. Street edges play a vital role in developing the streetscape with the built fabric to develop an enclosure. Greenery along the street defines the edges and helps in orienting people (Sussman and Hollander 2015). Therefore, by installing a Living wall on building facades, we create an active edge along the urban streetscape.

Having a Living wall on a facade with design and proportions based on the building layout will add to the building's image and identity. With the help of these identifiable buildings, people can easily orient themselves (Sussman and Hollander 2015). Adding Living walls to narrow and deep streets can transform them into active streets. Living walls increase footfall which in turn makes streets safer and thus enforces a sense of security to pedestrians crossing the street (Virtudes and Manso 2016). Living walls can become memorable landmarks that help orient people in the right direction and create a streetscape that is lively and provides a sense of security (Riley 2017).

The Indian state governments of Delhi, Karnataka, Telangana, Tamil Nadu. Kolkata, Maharashtra, and Haryana are putting up green walls on flyover pillars. At some places, they have installed green walls on stretches of pedestrian walkways or roads. For example, pedestrian walkways like the Nizamuddin Bridge in Delhi (Fig. 13A and B) and

Khairatabad junction in Hyderabad; flyovers like Electronic city flyover in Bangalore, Begumpet Flyover in Hyderabad (Fig. 13C), MAA flyover in Kolkata and Mahatma flyover in Pune. These installations combat air pollution, offer wellbeing, a space for gathering, increase the aesthetic value and forms urban realm with an image and identity of an active edge with the street.

Building frontage

Walls are considered as the medium of communication between the inside and outside (Virtudes and Manso 2016). They play a meaningful role in promoting or preventing visual and auditory contact. Their orientation and punctures alter the social interaction (Gehl 1989). On the other hand, blank walls give an impression of unplanned urban development (Virtudes and Manso 2016). It is unpleasant to move around a space that has blank walls, causing a person to lose a sense of place and belonging or make him/her feel that life is on the other side of the wall and cut off from the building (Alexander et al. 1977). Living walls alter the user's experience of the space (Ghazalli et al. 2018). Installing them on facades, parking structures, park walls, campuses, retail shops and transit shelters presents an opportunity to create an envelope that improves visuals and thus, contributes to aesthetic enhancement (Ghazalli et al. 2018; Rakhshandehroo et al. 2015).

A survey was performed by Yael Stav in 2016 on "Transfunctional Living Walls — Designing Living Walls for Environmental and Social Benefits" to analyze the reactions of residents to the installation of Living walls. The option which got the most responses was "It looks nice" as shown in Fig. 14 (Stav 2016). By incorporating them in the built environment, they will offer the opportunity to fulfill the concept of "Life between buildings" and "Eyes on the street", and act as a point of attraction, enhancing the aesthetic of the surroundings while forming image and identity of a space (Gehl 1989; Ghazalli et al. 2018; Jacobs 1982; Rakhshandehroo et al. 2015; Riley 2017).

Water consumption pattern

Researchers have predicted a water scarcity affecting more than 60% of the global population by 2025–2030 (Hagare et al. 2016). The usage of recycled water will play a vital role in resolving the water shortage in urban areas. Recycled water is produced by removing solids and impurities in wastewater from kitchens and washrooms (Hagare et al. 2016). Recycled water from these sources can be used for irrigating Living walls (Hagare et al. 2016; Riley 2017). To promote the use of recycled water, the World Health Organization (WHO) and the US Environmental Protection Agency (USEPA) have issued guidelines that are followed

Fig. 13 A and B Nizamuddin Bridge, Delhi (DNA n.d.); C Begumpet Flyover, Hyderabad (Express n.d.)

Fig. 14 Reasons for using Living walls according to survey results (Stav 2016)
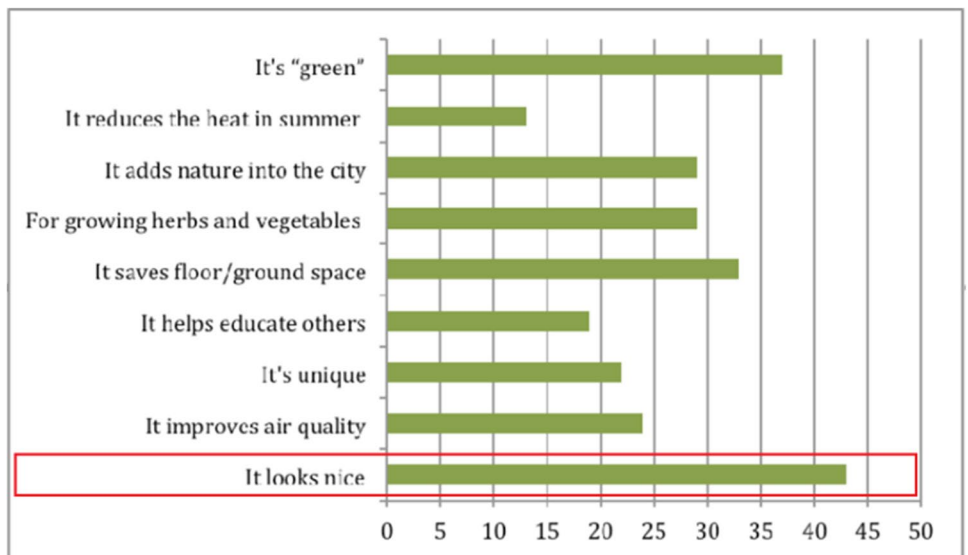
by Australia, some countries of Europe, and some states of the USA. Recycled water when used as fertilizer can increase the average yield of garlic by 10% and maize by 33% (Hagare et al. 2016). The reason for promoting the use of recycled water is to reduce freshwater consumption. A Living wall is a vertical surface that loses much less water to evaporation as compared to horizontal surfaces (Verma and Raghubanshi 2018). The hydroponic systems implemented in Living walls recycle water continuously, preventing any nutrient loss to drainage (Riley 2017).

Energy consumption pattern

Indian cities are concrete jungles, and with the increase in concrete volume, there has been an increase in the urban heat island effect (Anguluri and Narayanan 2017; Verma and Raghubanshi 2018; Widiastuti et al. 2018). Unplanned urban development has increased the surface area which absorbs and retains heat from sunlight. This causes an increase in temperature, which in turn increases the energy cost to cool the interiors (Anguluri and Narayanan 2017; Verma and Raghubanshi 2018; Widiastuti et al. 2018). Cooling the interiors increases the climatic temperature in the long term, thus causing a vicious cycle. Living walls break this vicious cycle. They reduce the interior temperature and create a micro-climate for the building and surroundings as well (Hunter et al. 2014; Teixeira 2021). They reduce the need for air-conditioning (Davis et al. 2016; Pérez-Urrestarazu et al. 2016). Research shows that with the installation of shading, insulation and green elements, heat is blocked and a temperature difference of up to 10ºC is experienced. Living

walls act as a heat buffer and help in reducing energy consumption by up to 20% (Radić et al. 2019).

In Vancouver, Canada, a study compared the energy consumption of a building with living skins (green cover) to a typical building as shown in Table 3 and 4 respectively. The energy performances of both buildings were simulated using the Energy-10 software. The simulation shows that a typical building consumes about 100 MWh of energy for cooling whereas a living skin building consumes no energy for the same. Comparing the overall energy consumption of the typical building to the living skin one, the typical building consumes 747.46 MWh annually whereas the living skin one consumes 677.24 MWh. Annually the living skin building consumes 70.22 MWh or 9.3% less energy (Roehr and Laurenz 2008). To further save energy, researchers suggest use of solar panels to power the hydroponic systems. making Living walls a carbon sink.

Economic benefits

Living walls not only benefit the surroundings, environmentally and aesthetically but economically as well (Riley 2017). Living walls add to the visual, aesthetic and social aspects of an urban area that engage people (Stav 2016). An increase in green space brings in visitors and tourists, which will improve the economy of the neighborhood. Property values will increase if Living walls are included in the urban area (Muahram et al. 2019). Therefore, installing a Living wall is an investment, rather than an expense. The global market for Living walls is expected to grow at a CAGR of 9.6% from 2020 to 2027 (Salah and Romanova 2021). Buildings

Table 3 Energy consumption of Living skins building (Roehr and Laurenz 2008)

Living Skins Building				
Peak Load	Month/ Hour		Energy 10	
			Cooling	Heating
			2 Aug-15 pm	28 Jan -9am
	Total Load	kW	**70,92**	**-202,79**
Loads/ Demands Monthly	January	MWh		**-137,731**
	February			**-95,65**
	March			**-76,59**
	April			**-39,50**
	May			**-4,64**
	June			**-12,51**
	July			**-0,05**
	August			**-1,76**
	September			**-24,66**
	October			**-47,25**
	November			**-101,78**
	December			**-135,13**
	Annual		**0,00**	**-677,24**

Table 4 Energy consumption of a typical building (Roehr and Laurenz 2008)

Typical Building				
Peak Load	Month/ Hour		Energy 10	
			Cooling	Heating
			2 Aug-17 pm	28 Jan -9am
	Total Load	kW	150,04	-204,55
Loads/ demands monthly	January	MWh		-139,134
	February			-96,85
	March			-77,81
	April			-40,45
	May			-5,34
	June		20,2	
	July		40,02	
	August		39,33	
	September		0,71	
	October			-48,16
	November			-102,96
	December			-136,50
	Annual		**100,26**	**-647,20**

with Living walls are priced 15% higher than similar buildings without them (Muahram et al. 2019). In Toronto, Canada, vegetation increases property values by 6 to 15% (Radić et al. 2019). Living walls possess a useful life of 25–50 years, based on the system used. The annual maintenance cost is around 8.5% of the installation cost (Riley 2017). However, the payback period in terms of environmental benefits is 4.6 years, post which the benefits accrue (Salah and Romanova 2021). Government provided incentives like tax rebates or subsidies can help curb the initial construction and subsequent maintenance cost (Riley 2017).

Singapore launched a scheme "Skyrise Greenery Incentive Scheme" (SGIS) in 2009, which had the target of covering 50% of its buildings (existing or new upcoming projects) with a green roof and vertical greenery system (Giordano et al. 2017; Scheme n.d.). Till 2017, more than 110 buildings have been covered by greenery under this scheme (Giordano et al. 2017; Scheme n.d.). They also enacted legislation called LUSH (Landscaping for Urban Spaces and Highrises) in 2009, in which the government would pay half of the cost of the green roof and the vertical greenery system (Muahram et al. 2019). Similarly, Toronto, Canada, offers 50–70% subsidy, the USA offers 70%, and Basel, Switzerland offers 20% of the cost (Muahram et al. 2019).

Discussion

With increasing population, pollution, housing needs and temperature, the need for Living walls is increasing day by day (Salah and Romanova 2021; Wong et al. 2010).

With limited space and rapid urbanization, we need to install many more green areas than the horizontal space we have. Vertical greenery can cover more exposed hard surfaces than horizontal greenery (Pérez et al. 2014; Radić et al. 2019). Living walls provide twice the green coverage while giving an opportunity for cultural gathering, play, enjoyment, health benefits and a place to admire for viewers (Sheweka and Magdy 2011; Stav 2016). They transform grey surfaces to green volumes reducing energy consumption and thus, consumption of natural resources (Grey n.d.). They benefit the environment by improving air quality through absorption of around 2500 miles of car exhaust per year per plant (Muahram et al. 2019) and reducing noise pollution by up to 40% (Muahram et al. 2019). They also reduce the urban heat island effect by up to 10ºC (Radić et al. 2019); reduce symptoms like cough, fatigue, and dry/itchy skin (M 2009); even the recovery rate for patients with various physical and mental ailments is faster.

Living walls should be installed taking climate into consideration as it affects the energy consumption of a building (Roehr and Laurenz 2008). Hence, Living walls should be installed taking the same into account. As per the climatic conditions, plant foliage density and vertical green system used, the effects will vary. In the Indian context, the heat flux will vary as per the orientation, so a wall on the south facade will produce a different effect from one on the north side (Stav 2016). For Living walls to perform at their best, we need to understand the type of system, underlying structure's orientation, plant foliage density, plant carbon content and climatic zones (Charoenkit and Yiemwattana 2017; Cuce

2017; Hunter et al. 2014; Muharam 2019; Pérez et al. 2014; Wong et al. 2010).

Living wall provide an opportunity for social interaction without barriers. It gives an equal opportunity for all to come and enjoy. It also adds to the aesthetics of the surroundings while offering a view to people and an opportunity to escape the mundaneness of daily life (Rakhshandehroo et al. 2015). Greenery, if removed, converts an active space into an inactive space, i.e., converts a place into a space. The cases of Mevlana Museum, Turkey and Caixa Forum Museum, Madrid, proves that people have an association with greenery and their response and behavior change as per the surrounding conditions. Adding them to building frontage will create an interactive edge with the street, giving opportunity for social gatherings.

Despite the benefits demonstrated above, Living walls as an element in urban areas are rare (Virtudes and Manso 2016). People are not aware of the physiological, psychological and environmental benefits that Living walls provide. They just "look nice" (elaborated in Fig. 14) (Stav 2016). Therefore, efforts should be invested to make people aware of their benefits. Installing them on the building facades will attract people's attention. They tend to make spaces active and welcoming; contribute to walkability, increase the aesthetic rating, encourage outdoor activities, provide an opportunity for social interaction, and improve the microclimate (Ghazalli et al. 2018; Rakhshandehroo et al. 2015).

Henceforth, Living walls enhance the image and identity of urban streetscape which increases their value while providing environmental, health, economic, and social benefits. The chasm between our natural environment and existing urban spaces can be bridged using Living walls.

Conclusion

Looking at the ongoing climate crisis, due to increasing population density and concrete cities, we need Living walls to secure our future. An urbanized strategic framework integrating them into the streetscape mandatorily while subsidizing costs can encourage their adoption by citizens while helping governments achieve the Paris agreement targets. We should implement them not just at the building level, but at the neighborhood and eventually at the city level. The benefits provided by Living walls will rise exponentially as more and more surface area is covered. If this integration happens and is followed by each neighborhood, the number of Living walls will increase exponentially, which will lead to the formation of a sense of place and provide a new identity to the place.

As part of their future research, the authors will create a strategic framework to implement Living walls at streetscape level. It will focus on the installation of Living walls at different locations in the urban streetscape and analyzing their impact on various variables which enhance the urban realm. It is essential to emphasize the categories of plants and technology to be used in facades as per the climatic zones. This framework will act as a guide for architects, urban designers, and urban planners to design and implement them to bring their advantages to city dwellers. Living walls offer scope for multidisciplinary research due to the myriad benefits they provide. However, it is noticed in Table 1, that there are few empirical studies which focus on social and health benefits in the urban context as compared to other benefits. The authors recommend that the social impact of Living walls at urban level be researched upon, and strategic frameworks formulated as per climatic zones.

Declarations

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