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Integrating Nature into High-Rise Buildings: Innovative Design Approaches

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Abstract

High greenery-covered buildings are a new type of architecture that incorporates plants and trees into the design, aiming to create more sustainable and livable urban spaces. This paper introduces this building typology, presents examples of innovative projects and design strategies, and evaluates the social, environmental, and economic benefits of adding greenery to tall buildings. By analyzing successful cases, the paper distinguishes intentional greenery integration from superficial additions, providing insights for architects, developers, scholars, and the public. The article also addresses the drawbacks and challenges of planting trees and plants on tall buildings, such as construction costs, maintenance issues, and compliance with building and fire codes, and suggests solutions. This research enhances the understanding of the potential of greenery-covered tall buildings to transform urban landscapes into greener, more resilient, and socially beneficial environments by contributing to the architectural discourse on this emerging building typology.

Keywords: *High-rise buildings, Vegetation, Advantages, Disadvantages, Biophilic design, Sustainability, Greenwashing*

1. Introduction

1.1. The Increasing Demand for Nature

People demand reconnecting with Nature for multiple reasons, including massive urbanization, health problems, energy crises, artificial digital proliferation and increase in screen time, climate change and resilience, environmental and air quality degradation, the spread of the pandemic and Covid-19, and poor aesthetics and urban design. Densely populated cities are often characterized by high-stress levels and noise pollution from traffic, construction, and other urban activities. Prolonged exposure to constant noise can lead to irritability and difficulty in relaxation and concentration. The constant presence of large crowds and congestion in urban areas can create a sense of claustrophobia and anxiety. Busy streets, crowded public transportation, and packed public places can contribute to feeling overwhelmed (Heidt and Neef, 2008; Hesslerová *et al.,* 2022; Mathey *et al.,* 2011; Pretty, 2012; Wolf *et al.,* 2015; Nash, 2005).

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Long periods of electronic device use have further increased the demand for reconnecting with Nature. As modern life progressively revolves around electronic devices, such as smartphones, computers, and tablets, finding ways to disconnect from the digital world and reconnect with the natural world has become essential. Nature provides a respite from the constant stimuli of electronic devices and offers an opportunity to relax, unwind, and refresh mentally and physically. Outdoor activities like strolling through a park or relaxing in a green area can aid lower stress levels, elevate mood, and advance general well-being. Nature's calming effects can counteract the potential negative impacts of prolonged screen time and electronic device use (Berkhout and Hertin, 2004; Roco and Bainbridge, 2002).

Urban areas are often plagued by poor air quality, increasing the demand to integrate Nature into urban living. The concentration of human activities, industries, transportation, and construction in urban settings leads to the emission of pollutants that can negatively impact air quality. Manufacturing plants and industrial facilities in urban areas release various pollutants into the atmosphere, including sulfur dioxide (SO_2), carbon dioxide (CO_2), and other hazardous substances. Poor air quality can harm public health, leading to respiratory, cardiovascular, and other health complications. Buildings are significant sources of CO_2 emissions in urban environments (Figure 1). The energy used for lighting, cooling, heating, and operating appliances in residential, commercial, and institutional buildings often relies heavily on fossil fuels. The combustion of these fossil fuels, such as coal, natural gas, and oil, contributes to the greenhouse effect and climate change by releasing CO_2 into the atmosphere (Bellucci *et al.,* 2012).

Recently, Covid-19 further emphasized the importance of cleaner air for public health and the need to reintegrate Nature into cities. As a respiratory disease, Covid-19 has underscored the critical role of clean air in maintaining public health and well-being. Poor air quality, often prevalent in urban areas due to pollution, can exacerbate respiratory issues and weaken the immune system, making individuals more vulnerable to respiratory infections. This realization has prompted cities to reevaluate their urban planning and environmental policies, focusing on creating greener and more sustainable living spaces. The importance of reintegrating nature into cities has become evident during the pandemic (Slater *et al.,* 2020; Jevtic *et al.,* 2022).

Overall, the growing demand for reconnecting with nature stems from a recognition of the many benefits that nature offers in improving physical and mental health, promoting sustainability, and creating more pleasant and resilient urban environments. As cities face numerous challenges in the 21st century, integrating nature into the urban landscape has become a key priority for creating healthier, happier, and more sustainable places to live.

1.2. Biophilic Design

Biophilic design is a concept that recognizes the inherent human need to connect with nature and seeks to bridge the gap between the built environment and the natural world. By incorporating elements of nature into architectural and

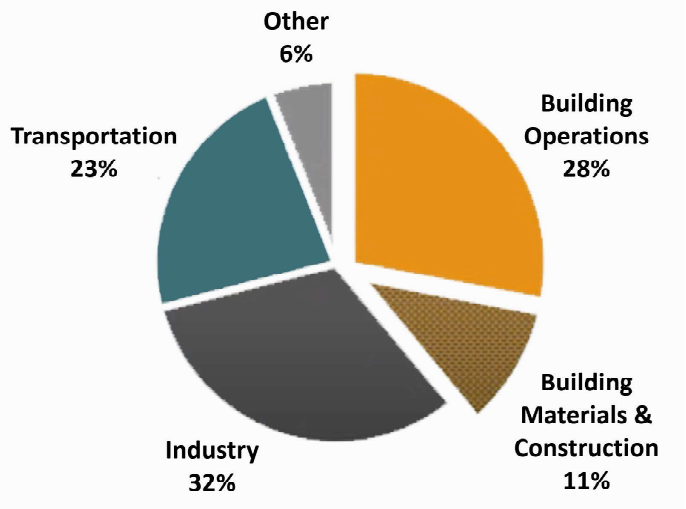


Figure 1: Global CO_2 Emissions by Sector

Source: Graph by Author, Adapted from (Bellucci *et al.*, 2012)

interior design, biophilic design aims to create spaces that evoke positive emotional responses and enhance the well-being of occupants. Integrating vegetation, plants, and greenery into buildings can profoundly impact the occupants' mental and physical health. Exposure to natural elements such as plants and natural light has been shown to reduce stress levels, improve mood, and increase productivity. Greenery and living plants in indoor spaces can also improve indoor air quality, as they absorb pollutants and release oxygen, creating a healthier and more pleasant indoor environment. Using natural sounds, such as running water or birdsong, and scents, such as the aroma of fresh flowers or wood, can also contribute to a more immersive and sensory experience, further strengthening the connection to nature.

Incorporating natural materials, such as wood and stone, can evoke a sense of grounding and connection to the natural world, promoting feelings of warmth and comfort. Additionally, incorporating natural patterns and textures into the design can create a sense of harmony and balance, further enhancing the overall experience of the space. Using natural sounds, such as running water or birdsong, and scents, such as the aroma of fresh flowers or wood, can also contribute to a more immersive and sensory experience, further strengthening the connection to nature. Biophilic design seeks to create spaces that provide functional utility and evoke a sense of well-being, tranquility, and connection to the natural world. By integrating natural elements and processes into the built environment, biophilic design offers an innovative and holistic approach to designing spaces that promote human health and resilience in the face of modern urban challenges (Downton *et al.,* 2017; Dalay and Aytaç, 2022; Kellert, 2008; Guan *et al.,* 2018).

1.3. Vertical Landscaping and Planting

Cities are getting denser, leaving little space for "horizontal" landscaping and planting. Consequently, architects have had to get creative in using the vertical plane for planting. They believe vertical green spaces can act as natural air purifiers, absorbing pollutants and improving air quality, making cities more resilient to public health crises. As such, they diligently explore vertical gardening, making lush vegetation and trees grow on the upper floors, terraces, balconies, walls, and roofs. They have been designing new projects that bring Nature and gardens, usually found on ground level, onto the high-rise building, allowing users to reconnect with Nature and create natural environments in the sky (Golasz-Szolomicka and Szolomicki, 2019; Abel, 2010).

Politicians may back up these projects for their merits. Increasingly, cities oppose all-glass skyscrapers because of their environmental harm. For example, Bill de Blasio, former New York City Mayor (from 2014 to 2021), has proposed a bill to ban all-glass skyscrapers to decrease NYC's greenhouse emissions by 30% (Mays, 2019). According to de Blasio, all-glass towers are "incredibly inefficient" since so much energy escapes through the glass—they are the city's primary source of greenhouse gas emissions. Toronto, Canada, has been encouraging using timber framing—highly compressed wood, called cross-laminated timber wood, which is extremely strong—in constructing high-rise buildings (Azarbayjani and Thaddeus, 2022; Poirier, *et al.,* 2016). Utrecht, Netherlands, has required all buildings to have green or solar roofs (Osseweijer *et al.,* 2017). In Singapore, the government supports structures that integrate greenery by covering up to half the cost. As a result, nearly all new buildings in Singapore are rich in vegetation. Many European cities are witnessing the proliferation of vertical greenery features such as living walls, vegetated terraces, and green roofs (Wang, 2017).

Italian architect Stefano Boeri invented the "vertical forest" concept, which involves constructing high-rise buildings extensively covered with trees and plants on various floors, creating a vertical ecosystem within urban environments. The core idea of the vertical forest is to bring nature back into urban centers by integrating lush greenery into tall buildings. Boeri demonstrated his concept in Milan, Italy, and "replicated" the model in different projects, including Trudo Vertical Forest in Eindhoven, Netherlands; Easyhome Huanggang Vertical Forest City Complex in Huanggang, Hubei province, China; and Nanjing Vertical Forest in Nanjing, Jiangsu Province, China. He has also proposed the same model for cities like Dubai (Boeri, 2023).

Further, Boeri has proposed giant visions based on his original "vertical forest" model in Milan. He has suggested Liuzhou Forest metropolis as a model for a Chinese metropolis of around 1.5 million inhabitants in the hilly Southern region of Guangxi, one of the most smog-affected urban areas in the world due to excessive industrialization and overpopulation. The concept depicts an urban composition along the Liujiang River that spans an area of 175 hectares and includes buildings such as offices, houses, hotels, hospitals, and schools that are almost totally contained by plants and trees of varying species and sizes. About 40,000 trees and one million plants representing over one hundred

species will call the Liuzhou Forest City home. According to Boeri's website, the project claims to absorb almost 10,000 tons of CO_2 and 57 tons of microparticles annually while concurrently creating approximately 900 tons of oxygen, assisting in the fight against severe problems associated with air pollution. It promises to absorb nearly 10,000 tons of CO_2 and 57 tons of microparticles yearly, simultaneously producing about 900 tons of oxygen, thereby combating severe air pollution problems (Boeri, 2022).

STH BNK by Beulah is a groundbreaking architectural project in Melbourne, Australia that aims to become the world's first-ever supertall vertical garden. The development comprises two twisting towers, one rising to 366 m and the other to 288 m, connected by a sky bridge. These towers will be situated above the Yarra River and will house a mix of residential, commercial, and retail spaces, a wellness hub, and a vertical school. With over five and a half kilometers of vertical gardens and sky parks extending as high as 365 m above street level, the project aspires to set a new standard for sustainable and green urban development. The towers' various levels will feature dramatic planting, with greenery adorning the building's facades, terraces, and sky parks. This extensive use of vegetation enhances the aesthetic appeal and contributes to environmental benefits like air purification and temperature regulation. The STH BNK project is designed by UN Studio and Cox Architecture, renowned architectural firms known for their innovative and sustainable design solutions. Construction has already commenced, and the project is expected to be completed by 2028 (Beulah, 2023).

1.4. Controversy

As integrating greenery into tall buildings becomes a growing trend, growing controversy arises concerning this new building typology. The proponent of this architectural design approach claims the greenery-covered tower model offers multiple benefits, including improving the health of people and the environment and mitigating climate change challenges. Greenery-covered tall buildings have many benefits, such as purifying the air, reducing ambient temperature and noise, reducing stress, boosting productivity, and showing a longer residence time. Green coverings can significantly reduce other air pollutants, including soot and dust (Yeang and Powell, 2007; Yeang, 2008;Yeang and Richards, 2007).

A growing concern is that this could be a new "greenwashing" propaganda. Architects are taking advantage of the positive public perception of plants and trees and their many health and environmental benefits by integrating trees and plants into a proposed building to "sell" their designs. However, adding plants and trees to tall buildings poses several challenges that the public (even some professionals and scholars) may not be aware of Beldon (2023). Due to the additional structural requirements, irrigation systems, and specialized planting techniques required to support the weight of the vegetation, creating green spaces in tall buildings can be costly. Green areas in tall buildings require routine and specialized maintenance to ensure the health and vitality of the plants. This consists of pruning, watering, pest control, and monitoring for prospective problems. Incorporating vegetation into structures necessitates compliance with fire and building codes, which may have specific requirements for fire resistance, egress routes, and safety measures. Green spaces within towering buildings may affect the space's functionality. For instance, windows and views may be obstructed, and interior floor plans may need to be modified to accommodate the natural elements. Maintaining green spaces in lofty buildings frequently necessitates centralized management and control to ensure uniform care and a consistent appearance. This can inhibit the organic and spontaneous growth typically observed in natural environments (Miller, 2017).

2. Objectives

This paper aims to explore and delve into the unique building typology of greenery-covered tall buildings, which involves integrating vegetation into the design of tall structures. At its core, the paper stimulates a qualitative architectural discourse, encouraging readers to engage in thoughtful discussions and reflections on this innovative concept. By highlighting critical issues surrounding greenery-covered tall buildings, the paper fosters a deeper understanding and appreciation of the potential and challenges associated with this emerging architectural model. Exploring greenery-covered tall buildings opens up a world of possibilities for architects, developers, scholars, and urban planners. By investigating the integration of vegetation into vertical structures, the paper inspires creative thinking and sparks curiosity about the sustainable, aesthetic, and societal implications of such projects.

At the idea level, the paper invites readers to contemplate the harmony between nature and urban environments. It prompts discussions on the positive impact of greenery on the well-being of inhabitants, the potential contributions to

ecological sustainability, and the enhancement of urban aesthetics. It also encourages critical examination of the challenges that must be addressed, such as water management, maintenance, and compatibility with existing urban infrastructure. Through this qualitative architectural discourse, the paper encourages stakeholders to envision the future of urban landscapes, where greenery-covered tall buildings play a pivotal role in shaping environmentally responsible and socially conscious cities. By fostering meaningful conversations around this novel typology, the paper serves as a catalyst for further research, exploration, and development in sustainable architecture and urban planning.

The key objectives are as follows:

1. Raise Awareness and Introduction: By offering an overall introduction to greenery-covered tall buildings, the paper aims to raise awareness among architects, developers, scholars, and the general public about this novel building typology. This introduction is a starting point for understanding the principles, benefits, and potential of integrating greenery into tall buildings.
2. Mapping Innovative Projects: The paper explores and highlights innovative ideas and design concepts by mapping novel projects that integrate greenery. The paper showcases successful implementations that can serve as transformative architectural solutions. By reviewing these projects, the readers can differentiate them from "afterthought" greenery additions.
3. Review Social, Environmental, and Economic Benefits: The paper aims to comprehensively review the many benefits of integrating greenery into tall buildings. This examination delves into how such projects positively impact the well-being of urban residents, contribute to sustainability, and enhance the urban environment.
4. Addressing Challenges: The paper intends to discuss the challenges of integrating trees and plants into tall buildings. These challenges include construction costs, maintenance considerations, and compliance with building and fire codes. Understanding these obstacles is essential for developing successful and sustainable greenery-covered tall buildings.

The paper seeks to contribute valuable knowledge to the architectural discourse by accomplishing these objectives, inspiring further research, innovation, and responsible urban development. It encourages stakeholders to consider the potential of greenery-covered tall buildings in shaping more sustainable, vibrant, and nature-oriented urban environments. Moreover, the paper offers practical insights into overcoming challenges, promoting well-informed decision-making, and fostering a deeper understanding of this emerging architectural model.

3. Methods

A quantitative analysis of the construction and performance of greenery-covered tall buildings would be essential. However, quantitative assessments of these buildings are complex and unattainable since data about their construction and actual performance are unavailable. Building owners hesitate to share construction and utility bills for privacy issues or to protect themselves from exposure if the building does not stand up to claims, honors, and certifications it received for its design, e.g., LEED certification. Also, many utility bills show the summation of usage; for example, energy consumption does not show the breakdown of use among elevators, HVAC, lights, appliances, etc.

A common problem with the claims of "sustainable" design is that they are often based on computer-based projection models, which are not transparent or reliable. These models use variables determined by formulas hidden in a "black box," which may introduce errors, biases, or uncertainties. Additionally, these models only show what the building design predicted concerning energy consumption, carbon emissions, and other environmental implications; they do not reflect the actual performance of the building (Xikai *et al.,* 2019).

Therefore, this study retreats to a qualitative discussion at the idea level by conducting a literature review to examine the innovative concepts applied in greenery-covered tall buildings. Literature sources are increasingly abundant as the online environment is flourishing. To meet the study's goals, this paper reviews vast sources of information about the topic, including academic literature, architectural magazines, websites, blogs, documentaries, and videos. It also uses the Council on Tall Buildings and Urban Habitat (CTBUH) Skyscraper Center's database, one of the most comprehensive tall buildings databases.

In conducting the review, there must be a process and criteria for selecting projects for examination. Here are the primary criteria:

- Extensive Greenery Coverage: The building should showcase a significant amount of greenery covering a substantial portion of its envelope, such as vegetated balconies, terraces, or vertical gardens. In the case of tall buildings, the roof area is proportionately much smaller than the entire building's envelope. As such, if a tall building has implemented only a green roof, it does not fit the "greenery-covered tall building" typology and is not selected for examination.
- Integration of Greenery in Design Scheme: The greenery should be an integral part of the building's design scheme, reflecting a deliberate effort towards sustainability rather than a superficial addition after the building's design was finalized. The greeneries should not just sprinkle a few trees and shrubs on the building or an afterthought scheme. It is essential to go beyond superficial additions and ensure that greenery is thoughtfully incorporated from the early stages of the design process. This deliberate effort towards sustainability ensures that the green elements are aesthetically pleasing but also functional and beneficial.
- Completed Construction and Inhabitation: The project must be completed, construction finished, and the building should be inhabited. Numerous proposed and visionary projects show massive integration of greeneries into buildings. However, these projects stay on the drawing board. Completed projects offer more practical insight than visionary ones.
- Minimum Height Requirement: The building should be 10+ stories tall, ensuring that the study focuses on tall buildings embodying the challenges and benefits of greenery in high-rise structures. Please see Appendix A to discern the rationale.

After examining the architecture literature while applying the above criteria, the study identified thirty-one projects. Table 1 lists these projects chronologically to trace the development and evolution of this building typology across the globe. It summarizes each project concisely, indicating the name, location, architect, number of floors, function, year of completion, distinctive vegetating features, and thumbnail image.

Table 1: Major Greenery-Covered Tall Buildings

#	Building Name	Location	Architect	Num. of floors	Function	Year of Compl.	Distinctive vegetative features	Thumbnail Image
1	Consorcio Building	Santiago, Chile	Enrique Browne and Borja Huidobro	17	Office	1993	Vegetative skin at the outer side of the western façade, articulated in three recessed vegetative bands of 4 floor-height for each. (Browne, 2007)	
2	ACROS Fukuoka Prefectural International Hall	Fukuoka, Japan	Emilio Ambasz	17	Civic Center	1995	Fifteen-stepped, vegetated terraces with mature trees connected via stairs and spraying jets of water-Green roof (Belogolovsky, 2020)	
3	The Met	Bangkok, Thailand	WOHA	36	Residential and Hotel	2005	Vegetated balconies -Sky gardens-Sky terraces. (Ünaldi, 2013)	

Table 1 (Cont.)

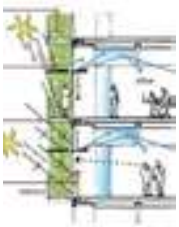
4	Council House 2 (CH2)	Melbourne, Australia	City of Melbourne	10	Office	2006	Vegetated façades articulated via metal meshes that hold plants and connect balconies vertically. (Hoogland and Bannister, 2013)	
5	Newton Suites	Singapore	WOHA	36	Residential	2007	Rooftop planting-Vegetated balconies-Green walls (Sumn *et al.* , 2012)	
6	School of the Arts Singapore (SOTA)	Singapore	WOHA	10	Educational	2009	Green walls-Vertical strips of plants along the building's facades-Green roofs (Wong *et al.* , 2014).	
7	Khoo Teck Puat Hospital	Singapore	CPG Consultants in collaboration with RMJM	10	Hospital	2010	Green terraces-Green roofs (Yen, 2012).	
8	One Central Park	Sydney, Australia	Jean Nouvel	34, 14	Residential	2013	Façade-supported green walls (Nouvel, and Beissel, 2014)	
9	CDL's Tree House	Singapore	CDL	24	Residential	2013	Green walls cover more than 2,300 square meters of the building's facades. (*Singapore's "Tree House"* 2014)	
10	Bosco Verticale, "Vertical Forest"	Milan, Italy	Stefano Boeri Architetti	27, 19	Residential	2014	Balconies are placed in a staggered pattern, allowing trees to grow up multiple floors. (Flannery, 2015)	

Table 1 (Cont.)

11	CapitaGreen	Singapore	WOHA	16	Office	2014	Vegetation wraps around the building's perimeter-Considerable indoor plants (Al-Kodmany, 2018)	
12	Santalaia	Bogotá, Columbia	Exacta Proyecto Total	11	Residential	2015	Vertical garden of more than 115,000 plants of 10 different species, covering an area of 3,117 square meters (Naqvi, 2023)	
13	East Village	Beirut, Lebanon	Jean Marc Bonfils and Associates	12	Residential	2015	Vertical garden that covers the facade of one of the blocks (Maamari, 2020)	
14	M6B2 Tower of Biodiversity	Paris, France	Maison Edouard François	18	Residential	2016	The tower's titanium cladding creates moiré patterns that give it a subtle and fluctuating appearance. (Comino *et al.,* 2021)	
15	Oasia Downtown	Singapore	WOHA	27	Office	2016	Steel exoskeleton that holds plants along the entire height of the building-Vegetated sky-courts (Wong *et al.* , 2018)	
16	ParkRoyal on Pickering	Singapore	WOHA	16	Hotel and Office	2016	Large terraces that contain excessive plants, tall trees, and water features-Green walls-Plants along the building's parameter (Schröpfer *et al.,* 2019)	
17	Le Nouvel KLCC	Kuala Lumpur, Malaysia	Ateliers Jean Nouvel	49 43	Residential	2016	Vegetated façade-Living walls-Green roof (Botti, 2023)	

Table 1 (Cont.)

18	Clearpoint Residencies	Colombo, Sri Lanka	Arosha Perera	47	Residential	2017	Garden terraces for each apartment along the entire height of the tower. (Gamage, 2014)	
19	Huaku Sky Garden	Taipei, Taiwan	WOHA	38	Residential	2017	Vegetative balconies-Plants that grow along vertical concrete screens (*Huaku Sky Garden/WOHA,* 2018)	
20	Kampung Admiralty	Singapore	WOHA	11	Residential/ Mixed-use	2017	Sky parks-Community plazas (Azzali *et al.*, 2022)	
21	The Tao Zhu Yin Yuan	Taipei, Taiwan	Vincent Callebaut	21	Residential	2017	Vegetated balconies and terraces (trees, shrubs, and plants) are incorporated at each floor, wrapping the entire tower. (*Rendering to Reality,* 2016)	
22	Torre Rosewood	São Paulo, Brazil	Jean Nouvel	22	Hotel	2018	Vertical garden-Terraces and rooftops-Flowers, plants, and trees (Botti, 2023)	
23	Check Point	Tel Aviv, Israel	Itamar Lensky and Noa Zuckerman	12	Office	2019	Living wall that covers more than 80% of its exterior surface-Green roof that collects rainwater (*Plant-covered buildings can tame summer heat, Israeli study finds,* 2021)	
24	Qiyi City Forest Garden Tower 4	Chengdu, China	Chengdu Qiyi Real Estate Co., Ltd	30	Residential	2019	Balcony in every unit containing lush plants-The vegetation scheme consists of 20 types of plants that create a vertical forest effect (*Skyscrapers Dripping in Gardens Look Great — Until the Mosquitoes Swarm,* 2020)	

Table 1 (Cont.)

25	'1000 trees'	Shanghai, China	Heatherwick Studio	10	Mixed-use	2019	Vertical planters that contain trees and a mixture of plants also have the structural function of holding the building together. (Carlson, 2021)	
26	Sky Green Residential & Retail Tower	Taichung City, Taiwan	WOHA	26	Mixed-use	2019	Protruding balconies with plants and trees.-Sky gardens-Trellises for green creeper plants (*Sky Green Residential & Retail Tower/WOHA,* 2019)	
27	Eden	Singapore	Heatherwick Studio	26	Residential	2020	Curved balconies overflow with trees, shrubs, and plants along the entire height of the tower. (Ravenscroft, 2020)	
28	Trudo Vertical Forest	Eindhoven, Netherlands	Stefano Boeri Architetti	19	Residential	2021	Protruding balconies that incorporate excessive plants, trees, and shrubs. They are placed in a staggered pattern, allowing tall trees to grow up multiple floors. (Boeri *et al.* , 2021)	
29	Easyhome Huanggang Vertical Forest City Complex	Huanggang, Hubei province, China	Stefano Boeri Architetti	28	Mixed-use	2022	Protruding balconies that incorporate excessive plants, trees, and shrubs. They are placed in a staggered pattern, allowing tall trees to grow up multiple floors. (*Easyhome Huanggang Vertical Forest City Complex/Stefano Boeri Architetti,* 2022)	
30	Ravel Plaza	Amsterdam, Netherlands	MVRDV	29, 23, 19,	Residential	2020	Vegetation covers the residential units' balconies, terraces, roofs, and facades. (Nevescanin, 2017)	
31	Nanjing Vertical Forest	Nanjing, Jiangsu Province, China	Stefano Boeri Architetti	35, 18	Residential	2023	Two towers that host a variety of plants on their balconies, creating a vertical forest that covers an area of 4,500 square meters (Saravanan *et al.* , 2017)	

Source: by Author

Ideally, it would be valuable to examine all the listed buildings. However, due to the space limit in a single article, the author had to select a few projects for examination. The study aims to investigate tall buildings that incorporate distinctive or "innovative" vegetative concepts. It looks at various elements related to greenery integration in these buildings, listed in Table 1. These elements include:

- Vegetated balconies: Tall buildings with vegetative balconies feature greenery or plantings on their outdoor balconies, providing residents with a connection to nature and enhancing the building's aesthetics.
- Terraces and rooftop gardens: Buildings with vegetated terraces incorporate green spaces or gardens on elevated platforms, creating outdoor spaces for relaxation and recreation while promoting biodiversity.
- Façade-supported green walls: They use elements (e.g., wires, cables, netting, lat-tice, or mesh) to support climbing plants, allowing them to spread and grow along the building's façade.
- Vegetated exoskeleton: The exoskeleton is an external support structure that may also be designed to accommodate greenery and vegetation, contributing to the building's sustainability and aesthetics.
- Façade-integrated green walls: Façade-integrated green walls are a type of living wall system where the plants, substrate, and structural support are directly attached to the building wall. They may involve modular panels or containers pre-planted with various plant species and mounted on the wall.
- Vertical Planters: Buildings with vertical planters incorporate specially designed containers or structures to house plants and vegetation, often installed on the building's exterior.

By examining these elements in tall buildings, the study seeks to understand how innovative vegetative concepts are integrated into urban architecture and how they contribute to sustainability, aesthetics, and the overall urban environment. The research may shed light on best practices and inspire future architectural designs that embrace greenery and enhance the quality of life in urban settings. Table 2 reorganizes the listed buildings in Table 1 based on their prime vegetative elements.

The next step involved focusing on one representative building from each of the six categories, which is a pragmatic approach that responds to the limit of what a single article can cover while still providing valuable insights into the subject matter. By selecting one representative building from each category, the research can showcase a diverse range of greenery-covered tall buildings and explore their unique characteristics, design concepts, challenges, and benefits. Each selected case study can act as an exemplar, representing its respective typology and providing valuable information for the overall research.

To help in choosing just one representative for each category, an additional criterion concerning receiving awards and recognitions was applied. Accolades indicate that the projects have been acknowledged and appreciated by experts and professionals in the field, further validating their innovative design and sustainable features. By focusing on projects with accolades and certifications, the research can highlight exemplars of greenery-covered tall buildings that have excelled in sustainability and have been celebrated for their positive contributions to the urban landscape. These projects can serve as role models and inspire other architects and developers to incorporate greenery into their designs thoughtfully and effectively.

The following explains the selection process for buildings representing each category.

1. Vegetated Balconies: Vegetated balconies represent one of the most popular concepts in greenery-covered tall buildings. They offer a practical and accessible way to integrate greenery into the building's design while providing numerous benefits for occupants and the environment. Vegetated balconies offer a direct connection to nature for building occupants. Residents can have their private green spaces, allowing them to enjoy the benefits of nature, such as improved well-being and stress reduction, without having to leave their homes. Table 2 illustrates that almost half of the 31 listed projects use vegetative balconies. Among these projects, Bosco Verticale in Milan, designed by Stefano Boeri, stands out as a pioneering example that has garnered worldwide interest and acclaim. The innovative use of vegetative balconies in Bosco Verticale has sparked a new wave of interest in integrating greenery into building typologies, making it a crucial case study for this research. The project has received worldwide recognition and is considered an exemplary green-covered tall building. It is a must-case study.

2. Terraces and Rooftop Gardens: Spacious vegetative terraces and rooftop gardens are distinctive features of greenery-covered tall buildings. The ACROS Fukuoka Prefectural International Hall, completed in 1995 in Fukuoka, Japan, stands as one of the earliest and most remarkable examples of greenery-covered tall buildings. The building's

Table 2: It Lists Greenery-Covered High-Rises Based on the Dominant Vegetative Feature

	Dominant Distinctive, Innovative Vegetative Features	**Buildings**
1	*Vegetated balconies*	Bosco Verticale
		The Met
		Newton Suites
		CapitaGreen
		Clearpoint Residencies
		Qiyi City Forest Garden Tower 4
		Huaku Sky Garden
		Torre Rosewood
		The Tao Zhu Yin Yuan
		Eden
		Trudo Vertical Forest
		Sky Green Residential & Retail Tower
		Easyhome Huanggang Vertical Forest City Complex
		Ravel Plaza
		Nanjing Vertical Forest
2	*Terraces and rooftop gardens*	ACROS Fukuoka Prefectural International Hall
		Khoo Teck Puat Hospital
		ParkRoyal on Pickering
		Kampung Admiralty
3	*Façade-supported green walls (wires, cables, netting, or lattice/mesh)*	One Central Park
		Consorcio Building
		Council House 2 (CH2)
		M6B2 Tower of Biodiversity
		Le Nouvel KLCC
4	*Exoskeleton*	Oasia Downtown
5	*Façade-integrated green walls*	CDL's Tree House
		Santalaia
		East Village
		Check Point
		School of the Arts Singapore (SOTA)
6	*Vertical planters*	'1000 trees'

unique design incorporates a stepped garden facade, creating a series of terraces that rise from ground level to the rooftop. These terraces are filled with lush vegetation, creating a visually stunning and environmentally friendly addition to the urban landscape. This building's innovative design has garnered appreciation and admiration over the years, proving its longevity and relevance in sustainable architecture. The building's design is a testament to the seamless integration of architecture and nature, dedicating significant areas to accommodate substantial greenery. Therefore, it is selected as a representative case study.

3. Façade-supported Green Walls: One Central Park is a remarkable example of a greenery-covered tall building, exemplifying the successful integration of vegetation and innovative design. The project has received considerable praise for its innovative approach to urban greenery and sustainability, mainly due to the design team of famous architect Jean Nouvel and landscape architect Patrick Blanc. The green walls of One Central Park feature a diverse selection of plant species that add color and texture to the urban landscape. These vertical gardens enhance the building's aesthetic appeal and contribute to several sustainable features.

   Jean Nouvel and Patrick Blanc have extended their innovative vegetative facade system to a larger scale with the Le Nouvel KLCC project in Kuala Lumpur, Malaysia. Le Nouvel KLCC comprises twin towers, with one tower containing 49 floors and the other 43 floors. The project represents another impressive example of greenery-covered tall buildings, showcasing how the integration of vegetation can be successfully applied to urban architecture on a grand scale. Like One Central Park, the vegetative facade system in Le Nouvel KLCC involves lush vertical gardens that adorn the building's exterior. These green walls add a distinctive and aesthetically pleasing element to the towers and contribute to various sustainable features. The above two buildings could be ranked as "tied," and both will be examined.

4. Vegetated Exoskeleton: The concept of a "vegetative exoskeleton" is indeed an innovative and original design approach, expanding on the idea of lattice structures by enveloping the entire building with greenery, as in the case of Oasia Downtown. The building's distinctive design and sustainable and biophilic features have earned it architectural recognition and acclaim. Oasia Downtown, designed by WOHA Architects, exemplifies sustainable architecture that seamlessly integrates nature into its urban setting. The vegetative exoskeleton enhances the building's visual appeal and is an effective environmental solution. The green facade acts as a natural sunshade, providing passive cooling for the building's interior and reducing energy consumption. The building's numerous accolades reflect its success as a model for sustainable and biophilic architecture.

5. Façade-integrated Green Walls: The concept of façade-integrated green walls is another innovative and distinctive feature of greenery-covered high-rises, showcasing the seamless integration of vegetation into the building's walls. Several notable buildings, such as the School of the Arts Singapore (SOTA) in Singapore, Santalaia in Bogotá, Colombia, and Check Point in Tel Aviv, Israel, have embraced this design approach, creating visually striking and environmentally friendly structures.

Table 3: The Seven Examined Case Studies, their Geographic Locations, Years of Completion, and Distinctive Vegetative Features

	Buildings	Location	Year of Completion	Dominant Distinctive/Innovative Vegetative Features
1	Bosco Verticale	Milan, Italy	2014	Vegetated balconies
2	ACROS Fukuoka Prefectural International Hall	Fukuoka, Japan	1995	Terraces and rooftop gardens
3	One Central Park	Sydney, Australia	2013	Façade-supported green walls (wires, cables, netting, or lattice/mesh)
4	Le Nouvel KLCC	Kuala Lumpur, Malaysia	2016	
5	Oasia Downtown	Singapore	2016	Exoskeleton
6	CDL's Tree House	Singapore	2013	Façade-integrated green walls
7	'1000 trees'	Shanghai, China	2019	Vertical planters

CDL's Tree House in Singapore is a remarkable example of applying the concept of façade-integrated green walls with greater height, showcasing how greenery can wrap around the entire building surface. This design enhances the building's aesthetic appeal and contributes to its environmental sustainability and biophilic qualities. CDL's Tree House's recognition through various awards, including the BCA Green Mark Platinum Award, FIABCI Singapore Property Awards, Skyrise Greenery Award, and Southeast Asia Property Awards, underscores its success as a sustainable and nature-oriented architecture model.

6. Vertical Planters: Vertical planters are an innovative concept in greenery-covered tall buildings, and '1000 trees' in Shanghai, China, stands as a unique example of their application. The building's design revolves around the idea of incorporating vertical planters, showcasing how vegetation can be creatively integrated into the building's facade. The vertical planters act as a prominent visual element, giving the building its distinctive and environmentally friendly appearance. Overall, '1000 trees' in Shanghai is a compelling example of vertical planters in greenery-covered tall buildings, and exploring its design can provide valuable knowledge for furthering the understanding of this innovative building typology.

Table 3 lists the seven selected case studies with their associated distinctive, innovative vegetative features.

4. Case Studies

4.1. Bosco Verticale, Milan, Italy

Bosco Verticale (Vertical Forest) is the pioneering and most representative of the greenery-covered high-rise building model. Its boldness, significant height, and extensive greeneries have promoted this project among the most remarkable. Bosco Verticale was Stefano Boeri's invention. It is considered a revolutionary project—a model for a sustainable residential building—that sparked and inspired other projects worldwide. Located in Milan, Italy, Bosco Verticale comprises two residential towers (27 and 19 stories, respectively 112 and 80 m high).

Completed in 2014, the main feature of the towers is their vast, staggered, overhanging balconies, each around three meters long. These spacious balconies fit massive outdoor tubs for vegetation and permit the growth of larger trees—giving the towers a forest-like appearance (Figure 2). As such, the buildings integrate 800 trees, each standing 3, 6, or 9 meters (10, 20, or 30 feet) tall, and a diverse assortment of shrubs and flowers. Plants total about 15,000 perennials and ground-covering plants and 5,000 bushes. The project offers 30,000 m^2 of woodland on a 3,000 m^2 footprint (Boeri, 2014; Flannery*et al.,* 2015; Flannery, 2015; Varrato, 2017; Ishween, 2021; Belcher *et al.,* 2018).

Years after its completion, Bosco Verticale established a habitat inhabited by various animal species, including more than 1,600 bird and butterfly specimens. This established an outpost for the metropolitan area's natural recolonization of flora and fauna. The plant-based facades filter the Sun's rays, creating a comfortable indoor microclimate. Greeneries generate oxygen, absorb CO_2 and microparticles, and "regulate" humidity. In addition, the project uses an energy system that produces electricity by employing photovoltaic panels. The demand for irrigation is also centralized; a "smart" system tracks the needs of the plants (Tokuç and Inan, 2017).

The plants' colors and shapes create an iridescent landmark visible from afar in every season. This trait has made Milan's Vertical Forest a new symbol in just a few years. The choice of plants and trees on the towers' sides and floors reflect aesthetic and practical requirements to adapt to the facades' orientation and heights. The botanical part resulted from three years of research with botanists and ethnologists. It started in the summer of 2010 when the plants that would go on the towers were grown in a special botanical "nursery" near Peverelli Nursery and garden center to get them used to living in conditions like those in their natural habitat (Pribad *et al.,* 2021).

Since its completion, Bosco Verticale has received several recognition, certification, and awards for its innovative and sustainable design. Some of the most notable ones are:

- The 2014 International Highrise Award
- The 2015 Best Tall Building Worldwide by the Council on Tall Buildings and Urban Habitat (CTBUH)
- The 2015 CTBUH Urban Habitat Award (In addition to winning the Best Tall Building Worldwide award, Bosco Verticale also received the CTBUH Urban Habitat Award in 2015)
- The 2018 Emporis Skyscraper Award

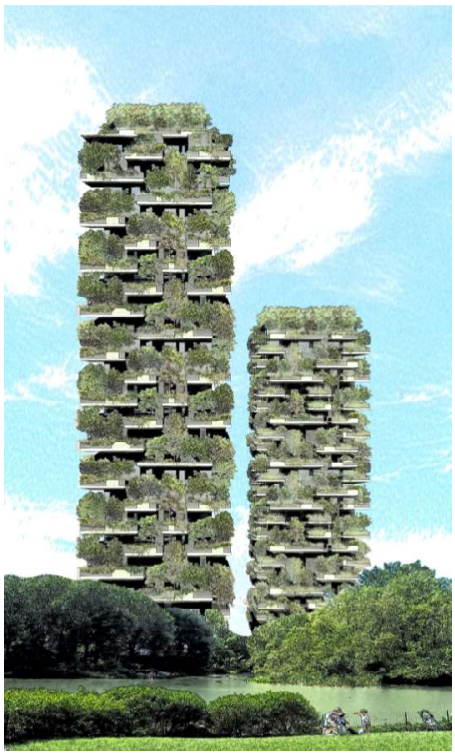


Figure 2: Bosco Verticale (Vertical Forest) in Milan, Italy. The Towers' Facades Feature Extensive Vegetation

Source: Sketch by Author

4.2. ACROS Fukuoka Prefectural International Hall, Fukuoka, Japan

Located in the heart of Fukuoka City, Japan, the ACROS Fukuoka Prefectural International Hall is a hub for international, cultural, and informational interaction. It aimed to provide an innovative solution to a prevalent urban issue: combining a developer's desire for lucrative site use with the public's need for open green space. By developing an innovative agro-urban model, Fukuoka's strategy satisfies both objectives.

Designed by a pioneering green architect Emilio Ambasz, the Asian Cross Roads Over the Sea (ACROS) is a 17-story civic center building that was completed in 1995. The building integrates nearly 100,000 sq. m of park space onto fifteen stepped, vegetated terraces with staircase-shaped rooftops that ascend the entire structure's height (Belogolovsky, 2020; Majerska-Palubicka and Latusek, 2021). Each terrace floor features a variety of gardens for contemplation, relaxation, and retreat from the city's congestion (Figure 3).

The terraces are connected by upward-spraying water jets to create a climbing waterfall resembling a ladder to conceal the ambient city noise. Open to the public, the building culminates with a magnificent rooftop observation deck, providing a breathtaking view of the bay of Fukuoka, the mountains, and the surrounding natural landscape. With spacious green roof terraces, the building provokes the image of a lush green mountain that extends into the adjacent park—making the park and the building inseparable. Since the project's construction, it has become a new landmark for the city (Mabon *et al.,* 2019).

Growing media depth ranges from 12 to 24 inches. Initially, there were 76 plant varieties comprising 37,000 plants. After 25 years, birds carried in seeds and increased the step garden's plant life to 120 species and 50,000 plants (Prefectural, 2022). On the garden's top, tenth, sixth, and fifth levels, longwave and shortwave radiation meters, ultrasonic three-dimensional wind speed and temperature meters, and scintillometers were installed to capture data on the thermal environment. The study found a 15°C difference between the surface temperatures of exposed surfaces and plant-covered areas, concluding that vegetation inhibits an increase in ambient air temperature (Velazquez, 2016).

ACROS Fukuoka Prefectural International Hall has received several recognitions and awards for its innovative and sustainable architecture. Some of them are:

Figure 3: ACROS Fukuoka Prefectural International Hall in Fukuoka, Japan

Source: Sketch by Author

- The 1995 Nikkei New Office Building Award
- The 1996 Architectural Institute of Japan (AIJ) Annual Architectural Design Commendation
- The 1997 Fukuoka City Architecture Award
- The 2012 Asian Townscape Award

4.3. One Central Park, Sydney, Australia

Located in Sydney, Australia, and designed by Jean Nouvel, One Central Park (OCP) [or Block 2] comprises two residential towers (34 and 14 stories) that were completed in 2013. A network of cascading planted terraces connects the tower to the nearby park. The building's landscape vertically extends the planted area of the nearby urban park, providing occupants with extraordinary living space and a potent green symbol on Sydney's skyline. About 50% of the building's façade is covered with a vertical landscape created in partnership with French botanist and artist Patrick Blanc (Nouvel and Beissel, 2014).

OCP's facades are vertical gardens with over 200 native Australian plant species that grow from planters on every floor (Figure 4). Thirty-eight thousand exotic and native plants are packed within hydroponically nourished felt-faced panels. These plants were chosen for their climatic tolerance, durability, and beauty. Plants create a "musical composition" consisting of buds, vegetation and vines blooms, and leafy foliage that climbs on walls and metal strings. In addition to outstanding aesthetics, the "green veil" offers essential functions, including shade and purifying the air—plants sequester carbon dioxide, emit oxygen, and absorb heat. The plants serve as a natural solar control system that adapts to the seasons, protecting the apartments from direct sunlight in the summer and letting in the most sunshine possible in the winter (Narwal, 2022; McLean and Roggema, 2019).

Noticeably, plants are irrigated via recycled water supplied by the on-site stormwater collection tanks and the central blackwater treatment plant. A computerized irrigation system adds minerals and fertilizers to water based on data from sensors and weather stations—informing about plants' needs and microclimatic conditions (humidity, wind, temperature, and Sun).

OCP's summit is crowned with a hovering cantilever full of mirrors. In conjunction with heliostat motorized mirrors (which track the Sun's movement) placed on the roof of the shorter building, the system captures sunlight and directs rays downward to dark spaces between the two towers. Due to a combination of sustainable design features, Block 2 is the first residential tower in Sydney to earn a 6 Green Star rating (Narwal, 2022). Other recognitions the building received include:

Figure 4: One Central Park, Sydney, Australia (Credit: By Sardaka (Talk) 08:28, 8 July 2014 (UTC) - Own Work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=33832728)

- 2014 Council on Tall Buildings and Urban Habitat (CTBUH) Best Tall Building Award -Asia & Australasia
- 2014 International Highrise Award
- 2014 Australian Institute of Architects (AIA) National Architecture Awards - Jørn Utzon Award for International Architecture
- 2014 Asia Pacific Property Awards - Best Residential High-Rise Development
- 2014 World Architecture Festival (WAF) - World Building of the Year

4.4. Le Nouvel KLCC, Kuala Lumpur, Malaysia

Le Nouvel KLCC is a luxury residential development located in the heart of Kuala Lumpur, Malaysia. The project comprises two towers of 49 and 43 stories, totaling 195 units. Jean Nouvel, a renowned French architect known for his innovative and distinctive style, designed it. The towers offer a range of amenities and facilities for its residents, such as a sky lounge, a fitness center, a swimming pool, a jacuzzi, a sauna, a steam room, and a landscaped garden. The development is situated in the heart of Kuala Lumpur's city center, near the iconic Petronas Twin Towers and KLCC Park (Botti, 2023; McLean and Roggema, 2019).

The architectural design of the towers is distinguished by its unique and innovative green facades, featuring climbing plants, intricate geometric patterns, and dynamic lines (Figure 5). The facades add aesthetic appeal and serve practical functions such as sun shading and optimizing natural light. Incorporating greenery contributes to the well-being of the occupants, fostering a connection with nature while enjoying the convenience of urban living. The towers boast lush vertical gardens and a few terraces, creating a refreshing and serene environment within the bustling urban setting. The use of eco-friendly materials, energy-efficient technologies, and green building practices align with contemporary standards for sustainability and contribute to reducing the project's ecological footprint (Halawa *et al.*, 2018).

Le Nouvel KLCC stands as a symbol of architectural excellence and a testament to the harmonious integration of modernity and nature. With its innovative design, extensive greenery, and strategic location, the development exemplifies

Figure 5: Le Nouvel KLCC, Kuala Lumpur, Malaysia

Source: Photo by Author

a new paradigm of urban living, offering a balance of luxury, sustainability, and convenience. The project has received significant awards, including:

- The 2018 International Highrise Award
- The 2018 FIABCI Malaysia Property Award

4.5. Oasia Downtown, Singapore

The Oasia Hotel Downtown is a lush tower of green in the middle of Singapore's congested Central Business District (CBD). It serves as a model for land use intensification in tropical cities. This "living tower" presents an alternative representation to the sleek and sealed skyscrapers that sprang out of the West. Oasia Downtown is a 27-story (190 meters) office building that was completed in 2016.

As an integral aspect of the development's internal and external material palette, landscaping is used extensively, creating a haven for avian and mammalian wildlife and supporting biodiversity in the urban environment with a Green Plot Ratio of 1,100% (Wong *et al.,* 2018). The tower's red aluminum mesh covering is meant to serve as a backdrop, emerging from behind the 21 different species of creepers that cover it. These creepers provide nectar and pollen for the birds and insects that live in the area (Generalova *et al.,* 2017; Boby *et al.,* 2019). The building's peak is not a flat surface but a tropical bower full of flowers and other soft and vibrant plants. Vegetation provides shade, which helps absorb heat, maintain a comfortable temperature, and clean the air (Figure 6).

Each sky garden is designed as a verandah on an urban scale, shielded at a high level by the sky garden that precedes it and with open sides for visual transparency. To keep the tower cool, the architects interspersed open-air sky gardens with the vegetal façade at 30 m (98 ft) intervals and incorporated several energy-efficient fans. As a result, instead of being contained in internalized air-conditioned spaces, the public areas become practical, comfortable, tropical environments with plants, natural light, and fresh air (Boby *et al.,* 2019).

The Oasia Downtown building has received outstanding awards for its innovative and green design. Some of them are (*Architizer Journal,* 2016):

Figure 6: Oasia Downtown in Singapore

Source: Photo by Author

- The 2016 Skyrise Greenery Awards
- The 2016 CTBUH Urban Habitat Award
- The 2018 FIABCI Singapore Property Award

4.6. CDL's Tree House, Singapore

The Tree House, designed by CDL, is a residential development in Singapore that showcases a variety of innovative green features and technologies. One of the most striking aspects of the project is the plants and vegetation scheme, which covers more than 2,300 sq. m of the building's facade. The plants and vegetation scheme consists of several layers and types of plants, carefully selected and arranged to create a harmonious and sustainable living environment. The main components of the scheme are:

- The green wall is the scheme's most significant and visible part, covering the four sides of the 24-story tower (Figure 7). The green wall comprises modular panels containing various plants, such as ferns, orchids, bromeliads, and vines. The panels are irrigated by a rainwater harvesting system and monitored by sensors to ensure optimal growth conditions. The green wall reduces the surface temperature of the building by up to 3°C and lowers the energy consumption for cooling by up to 15% (Guinness World Record, 2014).
- The sky gardens are landscaped terraces on every four tower floors, providing residents access to green spaces and views. The sky gardens feature different themes and plant species, such as tropical, edible, medicinal, and aromatic gardens. The sky gardens also serve as communal areas for social interaction and recreation.
- The roof garden: This is the highest level of the scheme, covering the entire roof area of the tower. The roof garden consists of a lawn, a pavilion, a playground, and a jogging track. The roof garden offers panoramic views of the surrounding landscape, cityscape, outdoor activities, and relaxation opportunities. The roof garden also reduces the heat island effect and stormwater runoff (Guinness World Record, 2014).

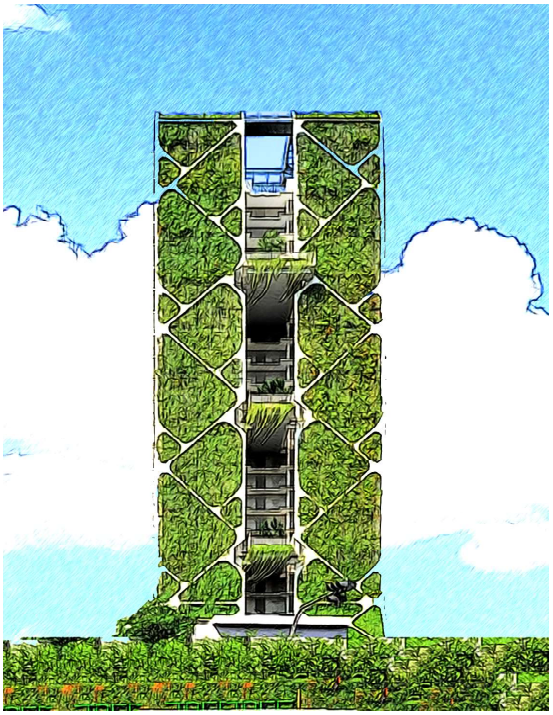


Figure 7: CDL's Tree House, Singapore

Source: Sketch by Author

Overall, the vertical greenery enhances the structure's aesthetic appeal and provides multiple environmental benefits, such as reducing heat gain, improving air quality, and promoting biodiversity. The project has received several awards, including:

- The 2014 Building and Construction Authority (BCA) Green Mark Platinum Award
- The 2014 Singapore Institute of Architects (SIA) Architectural Design Awards – Hon orable Mention
- The 2015 BCA Green Mark Platinum Award
- The 2015 FIABCI Prix d'Excellence Awards - Silver Winner

4.7. '1000 Trees', Shanghai, China

"1000 Trees," also known as "1000 Trees Plaza," is a mixed-use development in Pudong district, Shanghai, China. The complex integrates retail spaces, office areas, cultural venues, and public areas to create a vibrant, dynamic environment that encourages interaction and engagement. Designed by Heatherwick Studio, the project was completed in 2019.

The building represents a unique and innovative "green" architectural concept. The most distinctive feature of "1000 Trees" is its undulating exterior facade, which appears like a mountain range covered in vegetation (Figure 8). The facade is adorned with over 1,000 large planters, each accommodating a tree or various types of plants. In addition to the tree-filled planters, the building incorporates extensive vertical gardens that cascade down the facades, further enhancing the greenery and contributing to the project's sustainability (Carlson, 2021).

The abundant greenery provides a visually striking appearance and helps improve air quality, regulate indoor temperatures, and mitigate the urban heat island effect. The landscape design of the complex is carefully curated to complement the architecture and provide an oasis-like environment amidst the bustling urban setting of Shanghai.

Overall, the "1000 Trees" development has become an iconic landmark in Shanghai, representing the city's commitment to sustainable urban development and innovative architectural design. It showcases how green spaces can be creatively integrated into high-density urban environments to create a harmonious and inspiring living and working experience (Carlson, 2021). The project has received several awards, including:

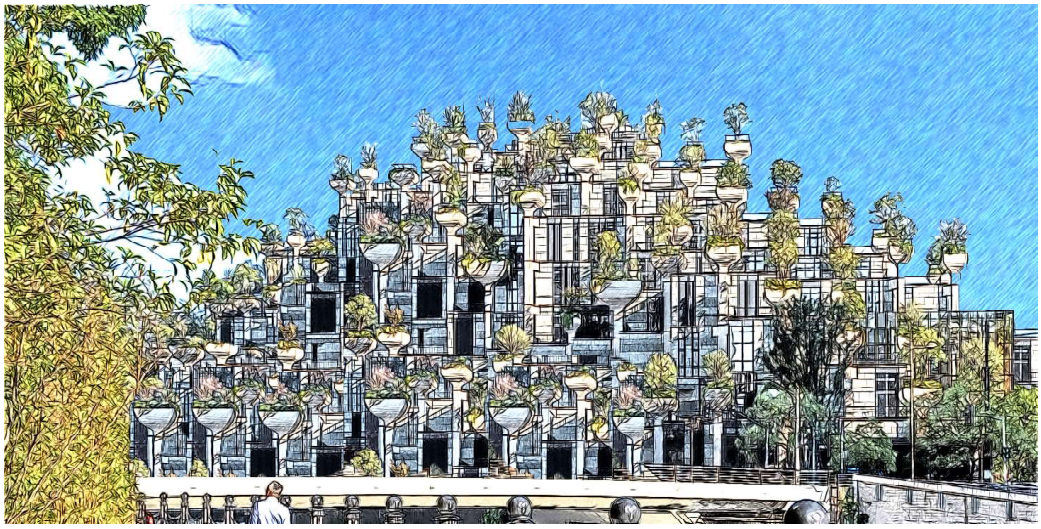


Figure 8: '1000 Trees', Shanghai, China

Source: Sketch by Author

- The 2021 CTBUH Award of Excellence for Best Tall Building 100-199 m
- The 2020 Blueprint Award for Best Non-Public Project: Commercial
- The 2019 MIPIM Asia Award for Best Futura Mega Project
- The 2018 LEAF Award for Best Future Building Under Construction

5. Discussion

The greenery-covered tall buildings offer benefits and face challenges. The following discussion dwells on ten benefits and ten challenges.

5.1. Benefits

The positive image painted by the discourses of the reviewed projects, building designers, and developers highlight the numerous advantages of integrating greenery into tall buildings. These benefits encompass environmental, social, and economic aspects, making greenery-covered tall buildings an attractive and sustainable architectural model for urban development (Schröpfer *et al.,* 2019; Sanjaya *et al.,* 2020; Tan *et al.,* 2017). The following attempts to summarize all the claimed benefits in 10 points.

5.1.1. Improved Air Quality

Improved air quality is a crucial benefit of greenery-covered tall buildings. The vegetation on building facades acts as a natural filter, capturing and sequestering harmful pollutants like carbon dioxide (CO2) and fine particulate matter (PM2.5). CO_2 is a significant greenhouse gas contributing to global warming and climate change, while PM2.5 can cause respiratory and other health problems when inhaled. By absorbing these pollutants, green facades help reduce their concentration in the surrounding urban environment, leading to cleaner and healthier air for both building occupants and the public. This is especially important in densely populated cities where air pollution can reach hazardous levels and adversely affect public health and well-being (Tan and Sia, 2005; Irvine and Warber, 2002).

5.1.2. Urban Heat Island Mitigation

Urban heat island mitigation is another significant advantage of tall vegetation-covered structures. The urban heat island effect occurs when cities experience higher temperatures than the rural areas surrounding them, predominantly due to human activities, dense infrastructure, and heat-absorbing materials such as concrete and asphalt. Greenery-covered tall buildings are crucial in mitigating this effect by providing natural shade and cooling. The vegetation on

building facades, terraces, and rooftops acts as a protective layer, blocking the direct sunlight that would otherwise heat up the building's surfaces. This natural shading helps reduce the amount of solar radiation absorbed by the building, lowering its temperature (Hopkins and Goodwin, 2011).

The process of transpiration, where plants release water vapor into the air, helps to cool the surroundings. As the plants transpire, the evaporation of water absorbs heat from the environment, effectively reducing ambient temperatures. This cooling effect, known as evaporative cooling, contributes to mitigating the urban heat island effect. By incorporating greenery into tall buildings, architects and urban planners can create more comfortable microclimates for occupants and the surrounding urban environment. Cooler temperatures reduce the demand for energy-intensive air conditioning, resulting in lower energy consumption and greenhouse gas emissions and a more sustainable and eco-friendlier urban environment (Hopkins and Goodwin, 2011).

5.1.3. Biodiversity Support

Biodiversity support is another significant advantage of greenery-covered tall buildings. By integrating vegetation on building facades, rooftops, and terraces, these structures create new habitats for various wildlife, including birds, insects, butterflies, and other pollinators. This increase in urban green spaces helps promote ecological balance and enhances biodiversity within densely populated cities. Urban areas often lack natural green spaces and suffer from habitat fragmentation due to extensive development. Greenery-covered tall buildings provide valuable refuges for wildlife, allowing them to find food, shelter, and nesting sites amidst the concrete jungle. This support for urban biodiversity is crucial, as it helps maintain ecosystem services and fosters a healthier urban environment (Downton *et al.,* 2017; Dalay and Aytaç, 2022; Aruga, (2023).

5.1.4. Enhanced Well-Being

Enhanced well-being is a significant advantage of greenery-covered tall buildings. Access to green spaces and nature profoundly impacts mental health and overall well-being, and these buildings offer a unique opportunity for occupants to connect with nature in the heart of dense urban environments. Numerous studies have shown that spending time in green spaces and surrounded by nature can positively affect mental health. Exposure to vegetation is associated with improved mood, decreased stress levels, and enhanced feelings of relaxation and contentment. It is a natural stress reliever, providing a respite from the fast-paced and often hectic urban lifestyle (Slater *et al.,* 2020; Jevtic *et al.,* 2022; Sandifer *et al.,* 2015).

Access to green spaces in urban areas is especially important because many city dwellers may have limited opportunities to routinely interact with nature. Greenery-covered tall buildings bring nature closer to people's daily lives, providing a sanctuary amidst the concrete jungle (Sandifer *et al.,* 2015). Occupants of these buildings can enjoy the benefits of greenery in various ways, such as relaxing on vegetative terraces, rooftop gardens, or balconies or simply admiring the lush vegetation from indoor spaces. These experiences create a sense of connection with nature and contribute to an enhanced quality of life. Moreover, improved mental well-being can increase productivity and creativity among building occupants. Studies have shown that exposure to nature can boost cognitive function and foster a positive and productive work environment.

5.1.5. Energy Efficiency

Energy efficiency is a significant advantage of greenery-covered tall buildings. Vegetated facades contribute to enhanced insulation. The layer of vegetation creates an additional barrier that helps to regulate indoor temperatures, keeping the building warmer during colder months and cooler during warmer months. This insulation effect can result in a decreased reliance on heating systems during winter and reduced energy consumption for cooling during summer (Sheweka and Mohamed, 2012).

The reduced energy demand for heating and cooling systems translates into lower energy consumption and carbon emissions, contributing to the building's overall sustainability and environmental impact. It aligns with the broader goals of mitigating climate change and promoting energy-efficient practices in urban development. Moreover, greenery-covered tall buildings' natural cooling and shading effects can lead to cost savings for building owners and occupants. The decreased use of air conditioning and heating systems can result in lower energy bills, making greenery-covered buildings economically attractive in the long run. The energy efficiency of tall buildings clad in vegetation reduces their

environmental impact. It makes them more sustainable, cost-effective, and conducive to a healthier and more comfortable living and working environment for occupants (Sheweka and Mohamed, 2012).

5.1.6. Protection of Building Structure

The presence of greeneries can protect the building envelope, including the outer surfaces of the structure, such as walls and roofs. Greenery can be a natural shield against the sun's ultraviolet (UV) rays. UV rays can damage building materials, causing deterioration, fading, and degradation over time. Covering the building's exterior with vegetation reduces the direct impact of UV rays on the building envelope, helping preserve the materials and prolonging their lifespan. In other words, greenery-covered facades and roofs can help regulate temperature fluctuations on the exterior surfaces of a building. Plants and vegetation provide insulation that can mitigate the effects of external temperature fluctuations. This can reduce tension and strain on the building envelope, thereby preventing potential problems caused by thermal expansion and contraction.

The presence of greenery can shield the building envelope from harsh weather conditions, such as heavy rain, strong winds, and hail. The vegetation acts as a protective layer, absorbing and dispersing the impact of raindrops and reducing the force of strong winds, which can help prevent damage to the building's exterior surfaces. Facades clad in vegetation can also aid in controlling moisture levels on the building envelope. Vegetation can absorb and retain rainfall, preventing excessive moisture from penetrating the walls of a structure. This can reduce the likelihood of water-related problems, such as mildew growth and water damage.

5.1.7. Noise Reduction

In addition to protecting the building envelope from physical elements, greenery can also reduce noise. Greenery, such as plants and foliage, has acoustic properties that enable it to absorb sound waves. When sound waves encounter the leaves and other plant materials, they are partially absorbed, reducing the overall sound energy in the surrounding environment. This absorption helps to dampen noise and creates a quieter indoor space.

The presence of vegetation can also aid in diffusing sound waves. When sound encounters the irregular surfaces of leaves and branches, it scatters in various directions, preventing the buildup of sound in specific areas. As a result, the noise is spread out, making it less noticeable and more pleasant to the human ear. Vegetation, especially dense and thick greenery, can act as a barrier that physically obstructs sound transmission (Chang and Chang, 2022).

5.1.8. Rainwater Management

Rainwater management is another critical benefit of greenery-covered tall buildings. In urban areas, extensive impervious surfaces like concrete and asphalt prevent rainwater from being absorbed into the ground, leading to increased stormwater runoff. This excess runoff can overwhelm stormwater systems, leading to flooding and other water-related issues during heavy rainfall events. Greenery-covered facades and roofs act as natural sponges, absorbing and storing rainwater through the process of transpiration and evaporation. When it rains, the vegetation on the building's facade captures the rainwater, which evaporates into the atmosphere or is released slowly into the surrounding environment. This natural water retention helps to reduce the burden on stormwater systems, minimizing the risk of flooding and alleviating pressure on urban drainage infrastructure.

By managing rainwater runoff, greenery-covered facades and roofs improve urban water management and reduce the strain on municipal water treatment facilities. This, in turn, enhances the resilience of cities to extreme weather events and climate change. Moreover, rainwater management through greenery-covered facades has environmental benefits. The plants and vegetation act as natural filters, removing pollutants and contaminants from rainwater as it is absorbed into the vegetation. This filtration process helps to improve water quality and protect local water bodies from pollution (Li *et al.,* 2019).

5.1.9. Enhancing Aesthetics

Enhancing aesthetics is a notable advantage of greenery-covered tall buildings. These buildings stand out from conventional structures due to their visually striking and unique facades, which are adorned with lush vegetation and greenery. Incorporating greenery on tall buildings transforms the urban landscape, creating a harmonious blend of nature and architecture. The living, breathing facades add a touch of natural beauty to the otherwise concrete-dominated cityscape, fostering a more visually appealing and inviting environment (Grinde and Patil, 2009).

5.1.10. Branding and Marketing

Branding and marketing are significant benefits of greenery-covered tall buildings, as they have the potential to become iconic landmarks that elevate the reputation and identity of a city or a development project. They showcase the city's commitment to sustainable and eco-friendly practices, positioning it as a progressive and environmentally conscious urban destination. The iconic nature of these buildings attracts media attention and generates buzz, leading to increased publicity for the city or the project. Tourists and visitors often visit greenery-covered tall buildings to experience their unique architectural features and lush green spaces. The buildings become attractions in themselves, contributing to increased tourism and foot traffic in the surrounding area. They contribute to the city's brand as an innovative and eco-friendly destination, attracting talent, businesses, and investments. As such, incorporating greenery into tall buildings can be a valuable marketing strategy for developers and real estate companies.

5.2. Challenges

However, the less explored aspects concern the disadvantages and challenges of integrating greenery in tall buildings, a typology that this paper focuses on. The below section evokes a greenwashing conversation by raising concerns about important issues such as the construction costs, maintenance, and viability of the greenery-cover tall buildings. It also proposes some remedies and solutions. This conversation could form a foundation for future empirical research as data becomes available.

5.2.1. Construction Costs

First, the added construction costs for accommodating plants and trees, irrigation systems, and maintenance should be examined. The building design should account for and adjust for its tree's increase in weight and size. "In absolute terms, trees 100 cm in trunk diameter typically add 10 kg to 200 kg of aboveground dry mass each year (depending on species), averaging 103 kg annually. This is nearly three times the rate for trees of the same species at 50 cm in diameter and is the mass equivalent to adding an entirely new tree of 10-20 cm in diameter to the forest each year" (Grinde and Patil, 2009). Therefore, structurally, buildings incorporating trees require special consideration and additional strengthening and reinforcement.

In the case of Bosco Verticale in Milan, to ensure trees' stability in the wind, they are tethered to the building using steel wires. The largest and most delicate trees were re-restrained into steel safety cages and secured in place once the superstructure was finished (Figure 9). According to the ARUP's structural engineers, "While all the medium and large trees have a safety cable to prevent the tree from falling in case the trunk breaks, the largest trees in those locations most exposed to wind have safety steel cages that restraint the root-bulbs and prevent them from overturning under major windstorms" (Ge, 2022). Overall, the plant- and tree-covered buildings should be built more potent than ordinary structures, adding construction costs.

In the case of '1000 trees' project in Shanghai, some researchers have questioned the cost-effectiveness of the employed vertical planters. The design and installation of one thousand vertical planters require careful planning and engineering expertise. Ensuring proper irrigation, drainage, and structural stability can pose technical challenges that may drive up costs.

Time is money, and "innovative" buildings require additional construction time. Because of adding complexity to the design, the construction time often increases. For example, the Bosco Verticale project in Milan took five years to complete, whereas a project of the same size not integrating greenery takes about three years in the same city (Nevescanin, 2017). As such, prolonging the period of construction incurs additional costs. Innovation models, expertise, and techniques are needed to reduce costs and improve the efficiency of constructing this model. Overall, "horizontal" landscaping costs are often lower than vertical landscaping.

5.2.2. Utility

One of the challenges of incorporating green elements into the building's facade is the trade-off between outdoor and indoor space. For example, the stepped garden design of ACROS Fukuoka creates terraces on the building's exterior, providing green spaces and promoting a biophilic environment. While this design has been celebrated for its innovation and architectural ingenuity, it also reduces the usable floor space for interior functions. Some critics have questioned whether this space could have been more efficiently utilized for additional offices, meeting rooms, or other functional

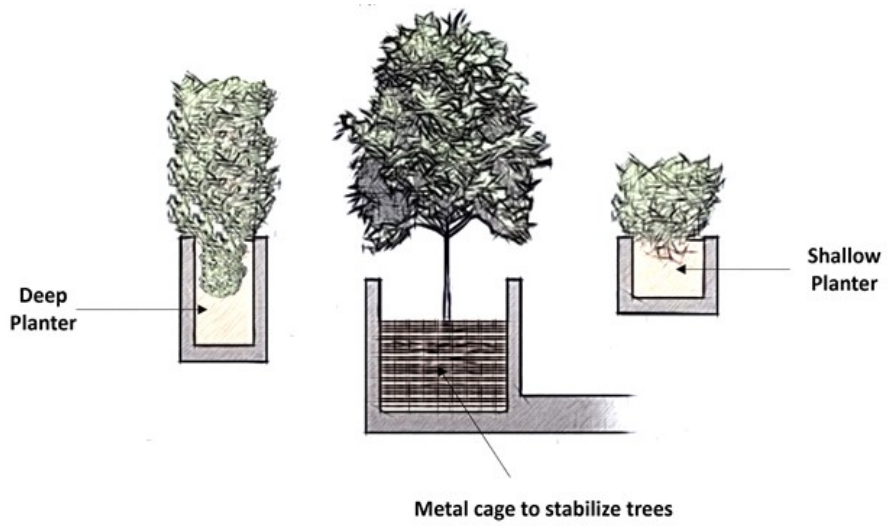


Figure 9: Planters in Bosco Verticale

Source: Sketch by Author

areas, potentially maximizing the building's indoor space and functionality. Buildings in dense urban environments often face limitations on available land, making efficient use of space essential. Balancing the desire for greenery and outdoor spaces with the need for functional indoor areas can be complex for architects and developers.

Similarly, some researchers have questioned the effectiveness of large balconies, particularly in unfriendly weather locations. In places that experience overly cold or hot weather, tenants will likely not use these balconies and will be rendered a waste of space. Even on a single day, the temperature may vary substantially, limiting their use time. Also, the wind is usually more robust at higher altitudes, so balconies on higher floors could be less useable. Unlike the project renderings showing tenants using balconies, a review of photographs of many tall buildings with balconies shows little use. A simple Internet image-based search exposes this issue—it is a no-brainer.

When the interior space is small, tenants may convert balconies into enclosed spaces, hurting the original design of the building—a phenomenon documented worldwide (Smektala and Baborska-Narozny, 2022; Aronis, 2009; Irwin *et*

Figure 10: Integrating Vegetation May Occupy Valuable and Limited Space on Balconies

Spurce: Sketch by Author

al., 2008). Still, at the idea level, vegetation may occupy a sizable portion of balconies, raising questions about their cost-benefit effectiveness (Figure 10). In Bosco Verticale, researchers (Visser, 2019) have critiqued balconies for occupying a sizable portion of each floor plan (Figure 11).

Similarly, studies (Haykal and Lissimia, 2021) have critiqued Singapore's Oasia Hotel for dedicating 40% of its volume to green, open-air terraces, significantly reducing the number of hotel rooms that can fit in the building and reducing the Return on Investment (ROI). While these green spaces contribute to the building's biophilic design and provide various environmental and social benefits, there is a trade-off between the amount of greenery and the revenue-generating capacity of the hotel. Reducing the total number of rooms might impact the hotel's occupancy rates, as fewer rooms are available to accommodate guests. With fewer rooms, the hotel's revenue potential could be affected, as it may not be able to accommodate as many guests at any given time.

Large vegetated balconies and terraces with lush plants and sizable trees could substantially block sunrays and natural daylight from entering indoor spaces, demanding artificial light and increasing electricity bills. The combination

Figure 11: Balconies Occupy a Sizable Portion of Every Floor Plan in Bosco Verticale

Source: Sketch by Author

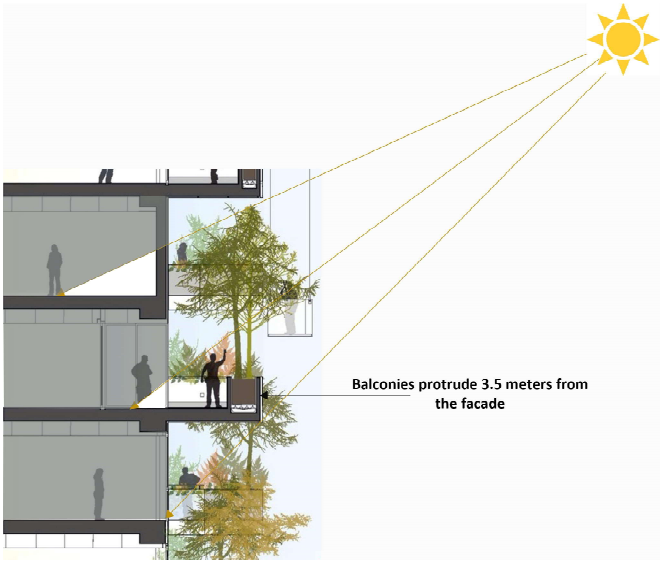


Figure 12: Large, Cantilevered Balconies, Lush Greenery, and Tall Trees Block Sunrays and Natural Daylight from Bosco Verticale's Indoor Spaces

Source: Sketch by Author, Adapted from Boeri (2014)

of shadows from vegetation and cantilevered elements (balconies and terraces) worsens the problem. These together cast substantial shadows exacerbating sunray blocking and making indoor spaces feel gloomy. As such, a large, cantilevered balcony or terrace with heavy vegetation could be a deadly combination, reducing natural light and sunrays that enter indoor spaces. In the case of Bosco Verticale, balconies cantilever 3.5 m with a thickness of 28 cm, making this issue severe (Figure 12).

Likewise, in the case of the ACROS Building, plants, and trees veil blocks the whole southern façade from sunlight, leaving indoor spaces gloomy. It also prevents natural ventilation rendering indoor space unhealthy (Figure 13). In response to UVB rays, sun exposure produces vitamin D in the epidermis, lowers blood pressure, suppresses appetite, and reduces the risk of obesity, type 2 diabetes, and certain autoimmune disorders (Velazquez, 2016).

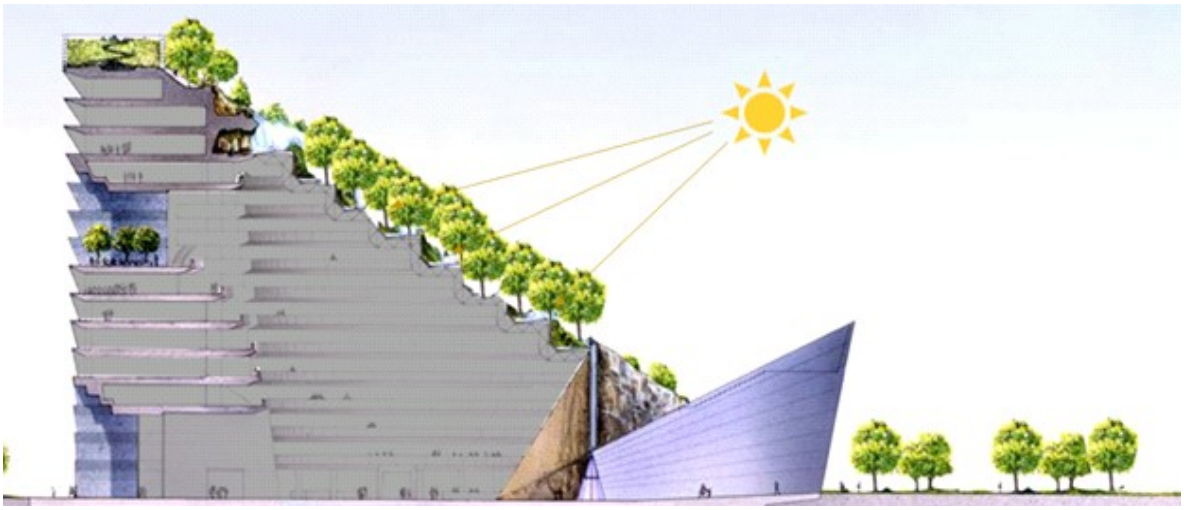


Figure 13: The Vegetated Terraces Block Sunrays and Natural Daylight from Entering ACROS's Indoor Spaces

Source: Sketch by Author Adapted from Belogolovsky (2020)

Overall, the vegetated balcony concern is essential because many greenery-covered tall buildings have embraced this architectural element in their design (see Table 2) (Miller, 2017). Notably, the vegetated balcony concept is copied in tall buildings regardless of climatic conditions. For example, plants may require extra care in a hot climate, such as in Dubai, or a cold climate, like the Netherlands. The balcony and terrace utilities in extreme climates is questionable.

Further, the amount of greenery in these buildings' four facades seems equal regardless of their solar orientation. The southern, northern, western, and eastern facades have similar amounts of vegetation, where light and solar conditions differ. Green design teaches that each façade should receive different treatment to adequately address wind direction and solar orientation. Eastern and western facades may need vertical fins to protect from sun rays, southern facades may need light shelves, while northern facades (which do not receive sunrays) need none.

A similar problem prevails in Oasia Downtown in Singapore. The building's four facades receive the same architectural and planting treatment, violating sustainable design principles. By providing the same treatment on all four facades, Oasia Downtown may miss out on opportunities to maximize the benefits of greenery integration. Different orientations and environmental conditions on each side of the building could be better addressed through tailored planting schemes and design strategies. For example, particular facades may require more shade-providing vegetation to reduce heat gain, while others could benefit from plant species that enhance wind protection and ventilation.

There are other issues to consider when building high-rises to accommodate trees (e.g., environmental costs), including carbon emissions in producing steel and concrete used in construction. In the case of the Bosco Verticale, one study [67] estimated that the concrete production used to build the towers' balconies emitted 990 tons of CO_2. Meanwhile, the integrated trees and plants sequester 18 tons of CO_2 annually. Therefore, the tower would need approximately 55 years to offset the carbon footprint of its balconies alone (Pribadi *et al.,* 2021).

5.2.3. Fire

Indeed, fire is another difficulty this novel building design creates due to the abundance of organic materials bonded to the facades. Several national building codes require designers and engineers to create solutions that safeguard occupants and the building itself from spreading fire through the exterior cladding or facade. New vegetation must be cared for in a way that complies with all applicable regulations. Typically, that translates to keeping them to a particular size, preventing them from becoming too dry, and incorporating the correct fire suppression and evacuation systems. Maintaining a low percentage of organic matter in the soil and performing routine pruning and irrigation can reduce the likelihood of a fire breaking out.

5.2.4. Building Codes

Innovative projects face passing building code requirements. Design justification is needed since they were not built before, and developers and architects need the authorities' backing. For example, some claim Bosco Verticale received the government's support because it was built before the Millan Expo (Pribadi *et al.,* 2021). Therefore, the local authorities supported the project as a showcase project for the city, which doesn't always happen. It is another game for cities with strict building codes, such as New York City or a historic district that advocates preserving the historic fabric and prohibits "outlier" buildings, such as buildings with very different perceptual characteristics (NYC Codes).

Singapore is an excellent case illustrating the government's support for integrating greenery in buildings, including tall ones. The Skyrise Greenery Incentive Scheme (SGIS) provides funding of up to 50% of installation costs for rooftop and vertical greenery initiatives on existing buildings, with a cap of $200 per sq. m for rooftop greenery and $500 per sq.m for vertical greenery. NParks instituted SGIS in 2009 to increase Singapore's greenery provision (Zingoni de Baro, 2022). Projects supported by SGIS include edible community rooftop gardens, recreational and therapeutic rooftop gardens, extensive green roofs, and luxuriant verdant green walls on more than 200 buildings. Some project examples include Oasia Hotel Downtown, Khoo Teck Puat Hospital, the National Parks Board (NParks) headquarters, and the School of the Arts. With these various initiatives and support from developers, building professionals, and owners, Singapore is well into achieving a target of 200 hectares of sky greenery by 2030 and towards a greener biophilic Singapore (Zingoni de Baro, 2022; Yi, C. (2020).

5.2.5. Maintenance

One of the critical issues for the success of this building prototype is the continuous maintenance demanded by plants and trees. Living and perpetually growing vegetation may threaten the façade's integrity and cover windows, preventing natural light from entering indoor spaces. Bosco Verticale boasts of creating a forest in the sky. However, as mentioned earlier, the dilemma is that having the forest too close to indoor spaces blocks sunlight, an essential element for healthy living. At any rate, plants need to be pruned over time—trees must be trimmed to avoid façades. Otherwise, plants may hurt wall surfaces and turn them into habitats for potentially invasive species and insects.

Simply put, gardens need gardeners. The rooftop garden of the ACROS building was critiqued for requiring constant watering, pruning, and pest control (Prefectural, 2022). Some examples of this building typology have received no maintenance, leading to unfortunate results. For instance, some plant- and tree-covered high-rises in Chengdu, China, experienced a lack of maintenance and care for their plantings. Consequently, these buildings suffered from securing adequate clientele. Many people abandoned or refused to live in them. In the case of Oasia Downtown Singapore, the green façade that covers the building is a massive vertical garden that requires maintenance. This creates some noise and disturbance for the hotel guests.

Vertical gardening requires specialized gardeners. Richard Hassell explained that this building typology involves a team of flying gardeners who are both "Spidermen" and experts with local vegetation. He referred to the Vertical Forest example, where they fly around the building every four months. They hang by rope from the roof's edge, descend, and jump between balconies. As mentioned earlier, the Vertical Forest has exploded with wildlife since its construction, providing a habitat for over 1600 birds and butterfly species. However, that in itself does create a maintenance issue.

Notably, most of the completed towers of the plant- and tree-covered prototype are young and have not passed the test of time. The wear and tear effect may create problems in the irrigation system, such as water leak, which could be a serious problem in high-rise buildings since water leak affects multiple floors below. Water can seep into walls,

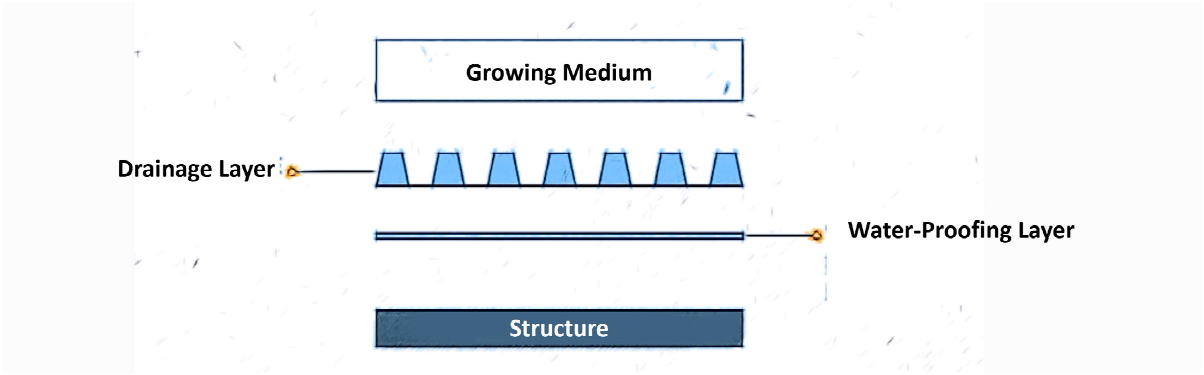


Figure 14: Integrating Trees and Plants in Structures Requires Special Treatment to Avoid Water Leakage

Source: Sketch by Author

ceilings, and floors, causing damage to the building's structure and interior finishes. It can also lead to the growth of mold and mildew, posing health risks to occupants and further compromising the building's integrity (Yussof and Ho, 2022) (Figure 14). Several measures can be taken to mitigate the risk of water leaks in greenery-covered tall buildings. Regular inspections of the irrigation system and building envelope are crucial to detect any signs of leaks or potential issues. Early detection allows for timely repairs and prevents further damage. High-quality irrigation and waterproofing materials are essential to ensure durability and longevity. Investing in robust, reliable components can help prevent water leaks and reduce maintenance needs.

Similarly, the roots of trees and plants may go out of control over time and cause cracks in the building's structure and facades. Tree roots have the potential to exert considerable force as they grow, seeking out moisture and nutrients from the soil. If tree roots encounter weaknesses in a building's foundation or cracks in the walls or facades, they can exploit these vulnerabilities and exacerbate the damage. As the roots grow and expand, they can push against the building's structure, leading to cracks and potential instability. To address this challenge, architects, engineers, and landscape designers need to carefully plan and implement greenery-covered building projects. Proper selection of tree and plant species with non-invasive root systems can help mitigate the risk of damage. Additionally, using specially designed root barriers and structural systems can help guide root growth away from critical areas of the building.

Further, the building should prevent harmful mold. Under some circumstances, certain types of molds, such as Stachybotrys and Aspergillus, can produce poisons known as mycotoxins (Jarvis and Miller, 2005). Severe sickness could occur because of mycotoxin exposure. Therefore, the building's façade should be permanently sealed to prevent undesirable molds and insects from crawling into interior spaces. Any maintenance done at higher elevations will be more expensive and complicated. Adequate ventilation is crucial to control indoor humidity levels. High humidity can create a conducive environment for mold growth. Proper ventilation helps to expel excess moisture and maintain a dry indoor environment.

5.2.6. Watering

Sustaining a vertical forest in an urban environment demands significant water resources for irrigation. Critics have raised concerns about the amount of water required to keep the vegetation healthy and whether this level of water consumption is sustainable in water-stressed cities such as Milan. Water scarcity is a critical issue in many urban areas around the world where the availability of freshwater resources may be limited, especially during periods of drought. The large-scale irrigation required to maintain a vertical forest can strain the city's water supply and exacerbate existing water challenges.

Therefore, depending on the water requirement for different plants, availability of rainwater, and local fees, water costs could be high, making this prototype unaffordable to some segments of society. For example, in tropical regions (as with Singapore), growing trees and plants are relatively more effortless due to supportive climatic conditions that feature an abundance of rainwater and humidity. With a naturally high level of rainfall, the need for additional water

resources for irrigation is minimized, resulting in lower water consumption and reduced strain on local water supplies. The self-sustaining nature of the tropical climate in providing water and humidity can lead to lower watering costs for greenery-covered buildings than locations with drier climates.

To reduce water consumption, architects should choose indigenous plants that require minimal watering. Opting for drought-resistant plant species requiring less water can reduce irrigation needs while maintaining a lush green appearance. Shading could be crucial to cut watering costs. Employing shading devices and elementscould help reduce watering costs and improve the health of plants. Implementing advanced irrigation technologies, such as drip irrigation or intelligent irrigation systems, can minimize water wastage by delivering water directly to the plant roots where it is most needed. Similarly, capturing and storing rainwater for irrigation purposes can offset the demand for potable water and reduce the strain on the city's water supply. Utilizing treated greywater from showers, sinks, and other non-potable sources can be an environmentally friendly way to water the vertical forest. Also, solar-powered irrigation systems should be examined since they may offer a Nature-Based Solution (NBS) for sustainable water management.

5.2.7. Plants' Health

Disease can affect any plant, whether wild or cultivated. When infected by a disease, plants can become ill, just like humans. Plant disease is described as the state of improper local or systemic physiological functioning of a plant resulting from the continuous, sustained 'irritation' generated by phytopathogenic organisms. There is a wide range of plant-infecting bacteria, fungi, viruses, and nematodes. Some infections infest the roots from below ground, while others thrive in the air and attack the plant's leaves (Raskin *et al.,* 2002). Pathogens affecting plants, and the variants of those pathogens that have arisen over time, are a constant source of discoveries for plant pathologists. Plant healthcare gives plants the essential nutrients to flourish while safeguarding them from insects and illness (Manso *et al.,* 2015). The treatments incorporate fertilization, insect control, and disease prevention. It is necessary to treat destructive plant pests when they are active each year to contribute to population reduction and maintain the health of plants. If we don't take this precaution, there's a good chance that the plant's existence will be cut short by illnesses or pests that are harmful to it. As such, sustaining the health of plants entails added burden and cost (Parker and Wood, 2013).

As weather conditions alter at higher altitudes, the health conditions of trees and plants are in question. The lack of space for root growth could impact the health of large trees. Similarly, establishing light/shade balance becomes an issue of concern. Overall, selecting the right plants for each façade and elevation is important. The French botanist Patrick Blanc took a great effort in choosing the plants for Sydney's One Central Park tower so that they would thrive in the city's unique environment and seasonal changes. Vegetation is successfully adapted to its location and growth conditions by employing acacias (wattles) and poa (grasses) on higher levels and Goodenia (hop bush) and viola (native violet) on lower levels. Over 1,100 sq. m of wall space are home to a wide variety of plants, most of which are local to Sydney (Nouvel and Beissel, 2014; Wood *et al.,* 2014). So far, these plants have shown resilience in withstanding hot, dry, and windy Australian summers.

5.2.8. Experiencing Nature

Innovative methods to bring Nature into sky living are appreciated. However, they may not offer tenants the whole experience of interacting with Nature. For example, planting in greenery-covered high-rises rely on artificial watering systems, depriving residents of the natural experience of watering plants, checking on their needs for water, and observing the effects of watering them on their growth and well-being. Watering plants activates interest in weather conditions (sunny, cloudy, rainy, etc.) and awareness of solar orientation and sun path (Khazraie, 2017). Similarly, professional gardeners carry out pruning, obviating residents' interactive experience with plants and trees. Checking on plants' health is a caring human experience. Residents may want to check plants' growth, needs, and soil conditions. Similarly, they may enjoy "digging" and planting their own vegetation. Tenants may want to perform seeding, transplanting, pruning, and harvesting. These tasks and aspects of interacting with vegetation can positively affect human well-being, cognition, and psychology (Kahn and Weld, 1996). Further, plants seem to be given in these buildings, and tenants have no say in choosing the ones they love and desire.

Some people have acrophobia, the fear of heights that can cause significant distress and impairment. People with acrophobia may experience panic attacks, nausea, dizziness, sweating, trembling, and difficulty breathing when exposed to high places or situations involving height. Consequently, they may not feel comfortable interacting with Nature in

vegetated balconies and terraces on the upper floors. Interacting with Nature involves engaging all our senses, being present in the moment, and feeling awe and gratitude for the natural world (Kupfer, 2003). As such, this solution has some limitations and challenges to achieving biophilic design by not offering a fully immersive experience with Nature (Al-Kodmany, 2018).

5.2.9. Exclusivity and Gentrification

The higher construction and maintenance costs associated with greenery-covered tall buildings are usually passed on to the owners or renters, potentially making these developments less accessible to a sizable portion of society. As mentioned, incorporating extensive greenery, vertical gardens, and sustainable features can increase upfront costs during construction and ongoing maintenance expenses. As a result, the price of residential units or rental rates in such buildings may be higher, limiting affordability for lower-income individuals and families.

Furthermore, the "luxury" nature of some of these developments, which often emphasize unique design features and premium amenities, can contribute to gentrification in the surrounding area. As these greenery-covered tall buildings become sought-after symbols of high-end living, they may attract wealthier residents and investors. The influx of affluent individuals can increase demand for nearby properties, potentially driving up property prices and rents in the neighborhood. Some critics have pointed out that the luxury nature of Once Central Park in Sydney and Le Nouvel KLCC in Kuala Lumpur could contribute to gentrification in the surrounding area, potentially leading to increased property prices and displacement of lower-income residents (Narwal, 2022; Halawa *et al.,* 2018). Likewise, others have argued that Bosco Verticale's iconic design might have influenced nearby property values, potentially leading to gentrification and displacement of lower-income residents.

Gentrification can have both positive and negative impacts on a community. On the one hand, it may lead to improved infrastructure, amenities, and investment in the area. However, on the other hand, it can also result in the displacement of lower-income residents who may be unable to afford the rising living costs. This can lead to issues of social inequality and loss of community cohesion.

To address these concerns, urban planners and developers must carefully consider the social impact of greenery-covered tall buildings. Implementing policies that promote affordable housing and mixed-income developments can help maintain diversity and inclusivity in urban areas. Additionally, encouraging developers to incorporate affordable housing components within luxury developments or allocating space for public amenities can contribute to a more balanced and sustainable urban environment.

By striking a balance between promoting innovative and sustainable architecture while ensuring affordability and inclusivity, cities can harness the benefits of greenery-covered tall buildings without exacerbating issues of gentrification and social inequality. Collaborative efforts between developers, local governments, and community stakeholders are crucial in creating vibrant and accessible urban spaces for everyone.

5.2.10. Urban Wildlife and Pest Control

The presence of greenery in urban environments can attract various forms of urban wildlife and pests. While greenery-covered buildings contribute positively to biodiversity and provide a habitat for beneficial species like birds and insects, they can also lead to challenges in managing wildlife and pests. Insects, rodents, and snakes are just some of the critters that vegetation could attract, making these structures unfit for human habitation. Even what seems to be a small problem, such as the spread of mosquitoes, could disinvite people from living in these high-rise buildings. Maintenance measures must be taken against these issues (Prefectural, 2022).

In response, developers may choose landscaping and greenery less susceptible to pest infestations, reducing the likelihood of attracting unwanted pests. They may need to implement an Integrated Pest Management (IPM) approach that combines various pest control techniques, such as biological controls, physical barriers, and targeted use of pesticides, only as a last resort. Building owners should regularly inspect and maintain the greenery to promptly identify and address pest issues. Early intervention can prevent infestations from spreading. They may employ non-harmful deterrents like reflective surfaces, noise-emitting devices, or netting to deter birds and other wildlife from nesting in undesirable areas. They should also ensure proper waste disposal and minimize food sources that can attract pests, such as rodents and insects.

6. Conclusion

Integrating vegetation into tall buildings is an emerging architectural model that aims to enhance environmental and social performance. This paper reviews several examples of greenery-covered tall buildings and analyzes their design concepts, objectives, and outcomes. It also discusses the opportunities and challenges of this building. Overall, the paper meets its stated four objectives as follows:

1. Introduction and Awareness: The paper raises awareness about this innovative approach to urban development by offering an overall introduction to greenery-covered tall buildings. Integrating greenery into tall buildings presents a promising solution to enhance the urban environment while addressing pressing environmental concerns. This design direction could be the future of dense areas with limited "horizontal" land.

2. Innovative Design Concepts: Mapping novel projects has provided valuable insights into innovative ideas and design concepts. Distinguishing the novel projects from "afterthought" greenery additions would allow identifying successful implementations and showcasing their potential as sustainable and transformative architectural solutions. In these projects, integrating greeneries into structures is not a cosmetic treatment to enhance the appearance of the building. It is integral to the design process. The visual expression in this model stems from genuine "green" design objectives to improve environmental and human health. These projects differ from those that sprinkle plants and trees on buildings to make them look cool!

   By examining and classifying projects based on their design approaches toward incorporating greenery, the paper showcased the potential of greenery-covered tall buildings as transformative architectural solutions. The novel projects, which purposefully integrated greenery from the outset of their design, demonstrated a commitment to sustainability and a genuine vision for creating green urban spaces.

3. Social, Environmental, and Economic Benefits: The paper highlighted the multiple advantages of this architectural typology. The examined projects have been shown to positively impact well-being by providing urban residents access to green spaces promoting physical and mental health. Additionally, greenery-covered tall buildings contribute to urban sustainability by improving air quality, reducing the urban heat island effect, and supporting biodiversity. Access to green spaces within tall buildings allows city dwellers to reconnect with nature, relieving the stresses of urban life. Studies have shown that exposure to green environments can enhance mental health, reduce stress levels, and promote relaxation and cognitive restoration. The presence of greenery within tall buildings creates unique urban sanctuaries, fostering a sense of serenity and tranquility amid the bustling cityscape.

4. Challenges and Solutions: Lastly, exploring the challenges of integrating trees and plants into tall buildings has underscored the importance of careful planning and design, and collaboration among architects, engineers, and developers. Construction costs, maintenance considerations, and adherence to building and fire codes are crucial factors that require thorough evaluation to ensure greenery-covered tall buildings' long-term success and sustainability. "Vertical planting" is far more expensive than "horizontal planting." Integrating plants in towers requires complex engineering solutions to support the plants' weight and movement and incorporate irrigation systems. Plant maintenance involves regular pruning, fertilizing, pest control, and replacement. Integrating greeneries and associated irrigation systems in tall buildings requires unique expertise and technical knowledge. Repairing and upgrading these systems and maintaining plants demand operational and maintenance costs. Water costs could also be considerable. We also need to reduce the carbon footprint in constructing these buildings.

Overall, the paper contributed valuable knowledge to the architectural discourse on greenery-covered tall buildings. The research gives architects, developers, scholars, and the public a deeper understanding of this emerging building typology and its potential to transform urban landscapes into more sustainable, green, and livable spaces. Through discussions of opportunities, challenges, and potential greenwashing, the study encourages stakeholders to approach the implementation of greenery-covered tall buildings with informed decision-making and a commitment to genuine sustainability. Integrating nature into urban architecture offers a promising path toward more resilient, vibrant, and environmentally conscious future cities.

7. Future Research

High-rise landscaping is still a relatively new concept in the design and development industries. While this paper has provided valuable insights into greenery-covered tall buildings and their potential as an innovative architectural

typology, several avenues for future research could further enrich the understanding and development of this concept. The following areas are suggested for exploration:

1. Economic Analysis: A limited amount of financial research and analysis is available on this topic. The Return on Investment (ROI) for greenery-covered tall buildings is an important aspect that requires more in-depth analysis. Conducting longitudinal studies on existing greenery-covered tall buildings can provide valuable data on these projects' long-term performance and sustainability. Assessing the ecological impact, energy efficiency, and occupant satisfaction over extended periods will help validate the benefits of this building typology.
2. Biophilic Design and Human-Environment Interaction: Investigating the psychological and physiological effects of greenery-covered towers on occupants will contribute to our understanding of biophilic design principles and the impact of nature on human well-being. Future research could delve into the cognitive benefits, stress reduction, and productivity improvements associated with proximity to green spaces within tall buildings.
3. Design Optimization and Adaptation: Exploring design strategies that optimize the integration of greenery into tall buildings can enhance the effectiveness and practicality of such projects. Research into innovative materials, irrigation systems, and plant selection may lead to more sustainable and resilient greenery-covered towers.
4. Comparative Studies: Comparative analyses between greenery-covered towers and conventional tall buildings can better understand this architectural typology's relative advantages and challenges. Evaluating performance metrics, construction costs, and maintenance requirements will help stakeholders make informed decisions regarding greenery integration in future urban projects.

By delving deeper into the abovementioned areas, researchers can further advance our understanding of this innovative building typology and its potential to create greener, more resilient, and socially inclusive urban environments. Continued research and collaboration among architects, developers, and scholars will drive the evolution of greenery-covered towers as a transformative approach to sustainable urban development.

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Appendix A

Tall Buildings

There is no commonly acknowledged definition of the term "tall building." Governments throughout the world define "tall buildings" differently. For instance, German regulations define a "tall building" as a structure higher than 22 m (72 feet) with space for permanent human habitation. City officials derived this restriction from the length of ladders used by firefighters. The Leicester City Council in the United Kingdom defines a tall building as any structure over 20 m/66 ft in height. Cork City defines towering buildings in Ireland as ten stories or more structures (Al-Kodmany, 2018). Other cities define it as a building of any height significantly taller than most of the surrounding area or a building that would significantly alter the city's skyline.

The perception of what constitutes a tall building can vary based on local building regulations, architectural norms, and the urban context of a specific city or region. In some cities or regions, a 10-story building might indeed be considered tall, especially if it significantly rises above the surrounding structures and is distinct in height and appearance. On the other hand, in urban areas with numerous high-rise buildings and skyscrapers, a 10-story building might be considered more of a mid-rise structure.

Integrating greenery vertically in buildings can be more challenging than doing so horizontally, as vertical greenery requires careful consideration of structural and engineering aspects and irrigation and maintenance requirements. Given the challenges of integrated greeneries in higher altitudes, a threshold of 10 stories could be reasonable. Yet, this is a subjective viewpoint, and the classification of a building as "tall" can vary based on different criteria and contexts.

While the number 10 may be considered arbitrary in classifying buildings as tall or high-rise, it serves a valuable purpose in research as it provides a baseline to map buildings of a unique typology, like greenery-covered or vegetated buildings. In research, establishing a baseline is crucial for creating a common framework and reference point for comparison. By using a specific number, such as 10 stories, as the threshold for tall buildings, researchers can differentiate and categorize buildings based on their height relative to this baseline. This helps organize and analyze data, identify trends, and understand the characteristics of buildings within a specific typology.

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