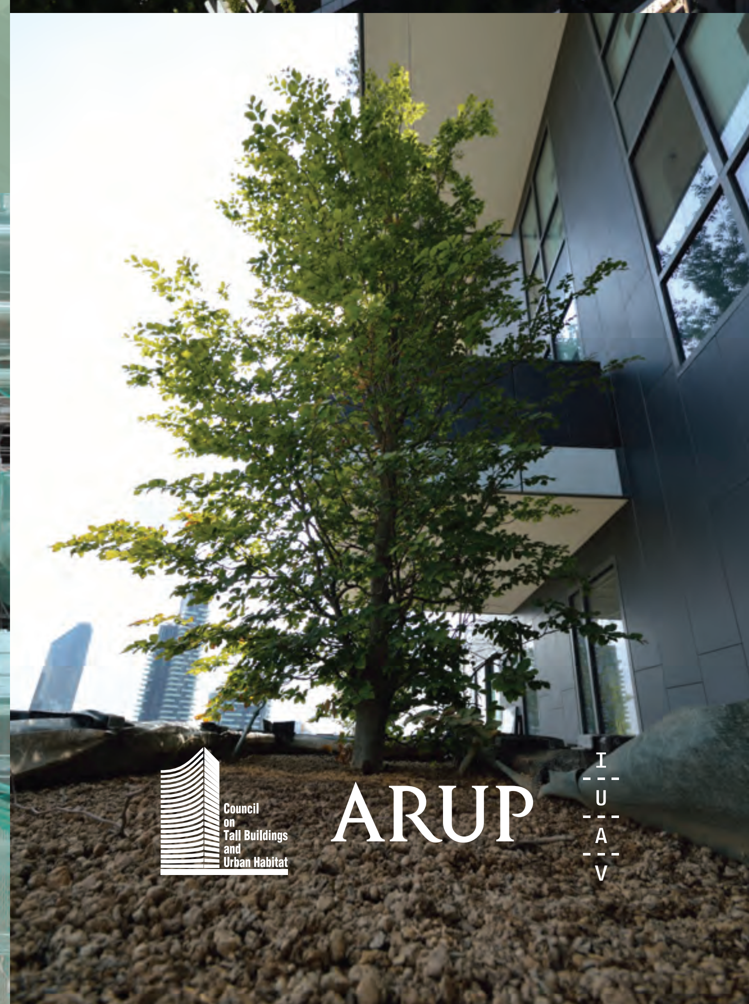
CTBUH Research Report

Vertical Greenery

Evaluating the High-Rise Vegetation of the Bosco Verticale, Milan

Elena Giacomello & Massimo Valagussa



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Front Cover: Multiple vantage points of the Bosco Verticale, Milan, Italy

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Preface

"The tree, standing, makes a trunk: a deposit of lignin, which is considered a plant's inert waste, once organized in a column, then in a work of architecture. The living part, essential to its survival, is a thin layer protected by its bark," (Clément, 2012).

When I saw the lifting of a single big tree onto the Bosco Verticale building in Milan, the words of Gilles Clément, which I'd read numerous times before, came into my mind. I thought: "How do they lift up a tree, one hundred meters from the ground, without affecting that "living part", the cambium, under the bark…?"

I was very much impressed by that "transport operation": the tree was ascending upright, somewhat rapidly, and was then brought close to the tower with a rope, to be gently set down inside the container on the terrace. It was emotionally stirring to see a tree, a vulnerable creature, out of the ground, out of context, flying to a new "home"… and what a home: a skyscraper! I was incredulous to imagine that many trees, hundreds of trees, would be placed on the two towers, and I realized that the Bosco Verticale was not only an outstanding feat, and important project for Milan and for Italy, but for the world. An extremely important experiment in the history of tall building design was actually being realized.

Many questions came to my mind. How could trees adapt there; how much would they grow? What is the supporting layer inside the container? How is wind resisted? How will they be cared for? What are the selection criteria of the species and specimens, and the exclusion criteria? What impact would they have on the energy performance of the envelope and the internal spaces?

From that moment, the desire to study Bosco Verticale became an idea, and later a possibility, thanks to the 2013 CTBUH International Research Seed Funding program, sponsored by Arup, which awarded my proposal with Massimo Valagussa to monitor the visionary project.

The research, presented in this report, does not answer all those initial questions, but several important aspects of the Bosco Verticale's living green technologies have been observed and analyzed during the earliest stage of the towers' life, i.e. in the intervals of June-October 2013 and April-June 2014, when the Bosco Verticale was completing construction. In this given time window, we did our best to understand this extraordinary project.

The main question, posed in our research proposal, was: "How does a vertical forest work?" To answer it, we first planned a monitoring program of the taller trees installed on Tower E (the higher of the two) up to the 18th floor. The monitoring was intended to check, through instrumental tests and laboratory analyses (commonly applied in agronomics) the overall health conditions of the selected trees. We wanted to verify if the position in height or the orientation to the sun somehow affected the growth and health of the 27 chosen specimens (Chapter 3 and Appendix).

Next we explored the maintenance issues more deeply, since the maintenance regime is crucial for living green technologies in general, and in particular for the Bosco Verticale. With the acquired information regarding the project, the climatic data of the site and the evapotranspiration data from scientific literature, we applied two different methods for calculating the irrigation needs of the trees. Since the trees were in their earliest stage of implementation, the effects of pruning activities and fertilization were hypothesized (Chapter 5).

In addition, we addressed the expected energy needs of the living green envelope by modeling the sixth floor of the building with energy simulation software. Different façade configurations were modeled, each highlighting the specific contribution to shading supplied by the vegetation. Moreover, a calculation method for assessing the shadows cast by vegetation was applied, with the Leaf Area Indexes of standard trees and plants introduced into the assessment (Chapter 4).

Lastly, we provided a description of the technologies in use at Bosco Verticale, according to our direct observations, supplemented with information supplied by the architect Stefano Boeri and other professionals involved in the project (Chapter 2).

This book collects all the results achieved from working on the Bosco Verticale site, in the laboratory and at the desktop during the 12-month project. The results reflect a wide range of methods, but, as much as possible, are consistent with scientific methods. We believe that the limitations of our research project (namely, the assessment occurring before the building's occupation) were much less significant than the value of the opportunities. It is hoped that, as a result of this initial study, we can continue to conduct a more significant post-occupancy study of the Bosco Verticale, and other relevant projects, in the near future.

It is important to underline that the results of the research provide data and information regarding not only Bosco Verticale, but also methods and approaches for evaluating other types of living green façade technologies, whether applied to tall or smaller buildings. As a final note, the chapters of this book do not need to be read in sequence; each introduces and concludes one specific topic.

Elena Giacomello
Venice, Italy, December 2014

1.0 An Overview of the Bosco Verticale

Introduction & Overview

The Bosco Verticale in Milan, Italy, supports one of the most intensive living green façades ever realized (Figure 1.1). The combination of its sophisticated plant selection, the deployment of greenery in all orientations, the structural design to accommodate the plants, and the maintenance, safety, and irrigation systems, represents one of the most innovative tall building projects in recent memory.

The project consists of two residential towers, 27 and 18 floors high respectively, characterized by the presence of dense vegetation along their outer envelopes. There are about 20,000 specimens, including about 700 trees up to six meters high, installed on both towers. All the plants take root in containers located on the external side of deep cantilevered terraces, which are directly accessible from

Figure 1.1
View of the Bosco Verticale Towers (Source: Eleonora Lucchese)

Project Team

Owner: Fondo Porta Nuova Isola
Developer: Hines Italia
Architect: Boeri Studio
Structural Engineer: Arup Italia
MEP Engineer: Deerns
Main Contractor: ZH Construction Company S.p.A.
Other Consultants: Emanuela Borio and Laura Gatti (landscape design)

Building Data

Year of Completion: 2014
Height: Tower D: 85 meters; Tower E: 117 meters
Stories: Tower D: 18; Tower E: 27
Building Gross Floor Area: 18,717 square meters
Building Function: Residential
Structural Material: Concrete
Green Wall Type: Tree planters on cantilevering balconies
Location on Building: All orientations of façade, at all levels
Surface Area of Green Coverage: 10,142 square meters (approx.)

Design Strategies

- A project for metropolitan reforestation and a model of the vertical densification of nature. The objective was to reproduce the equivalent of 1 hectare of forest vertically, with the attendant benefits of noise and pollution reduction, shading for cooling, and aesthetic enhancement
- Projecting balconies on each floor and on each face are enhanced by trees and bushes placed in concrete planters, which act as parapets

each residential apartment. Acting as an extension of the exterior envelope of the towers, the plants represent a filter between the interiors of the towers and the urban environment. From inside, the plantings offer inhabitants a special experience of their terraces, which are pleasantly shaded by luxuriant tree crowns, and a "green-filtered view" to the city, in addition to an enhanced feeling of privacy. The envelope of the project is an active interface to the environment, with a special architectural quality. The dynamism of plant life is also expressed in the combination of forms and colors that derives from the carefully selected distribution of different species and specimens, which changes over the seasons and the years. The greenery of the plantings is emphasized and underscored by the gray color of the exterior walls, making the plants the protagonists of an architectural story of great visual, environmental, and ultimately societal, impact.

Local Climate

Milan has a humid, subtropical climate that is characterized by hot and humid summers with cold and damp winters. It experiences four seasons and a wide range of temperatures, typically varying from -1 °C to 31 °C. There is often measurable snowfall from December through February (an average 300 to 400 millimeters). The remainder of the year consists of rain in springtime and temperatures ranging from 20 °C to 30 °C during the summer and -1 °C to 10 °C during the winter. The most common forms of precipitation are light and moderate rain, occasionally augmented by thunderstorms. In recent years, Milan has seen a reduction in the industrial sector within the city, which has reduced the heat island effect as well as the haze that had become synonymous with Milan's skyline.

Climatic Data[1]

Location: Milan, Italy
Geographic Position: Latitude 45° 37' N; Longitude 8° 143' E
Elevation: 211 meters above sea level
Climate Classification: Warm Temperate with fully humid, hot summer
Mean Annual Temperature: 11.8 °C
Average Daytime Temperature during the Hottest Months (June, July, August): 21.7 °C
Average Daytime Temperature during the Coldest Months (December, January, February): 1.6 °C
Annual Average Relative Humidity: 71% (hottest months); 76% (coldest months)
Average Monthly Precipitation: 85 millimeters
Prevailing Wind Direction: North
Average Wind Speed: 0.9 meters per second
Solar Radiation: Maximum: 784 Wh/m^2 (July 21); Minimum: 660 Wh/m^2 (October 21)
Annual Average Daily Sunshine: 5.1 hours

[1] The climatic data listed was derived from the World Meteorological Organization (WMO), British Broadcasting Corporation (BBC) and the National Oceanic and Atmospheric Administration (NOAA).

Benefits of Green Walls

Designing with green walls, or façade-integrated vegetation, offers multiple benefits. The benefits of green walls vary depending on many factors, such as geographic location and climate, building geometry, orientation, plant species, and green wall components and systems. According to the 2014 CTBUH Technical Guide, *Green Walls in High-Rise Buildings* (Wood, Bahrami, Safarik, 2014), these benefits can be categorized as being on the "urban scale" (benefits for the urban community beyond the building itself) and "building scale" (addressing green wall benefits for a building's users and owners).

Benefits: Urban Scale

- Reduction of the Urban Heat Island Effect / Air Temperature Mitigation
- Improvement of Air Quality / Dust
- Absorption
- Sequestering of Carbon
- Aesthetic Appeal
- Providing Biodiversity and Creating
- Natural Animal Habitats

Benefits: Building Scale

- Health Benefits
- Improvement of Building Energy
- Efficiency
- Internal Air Quality, Air Filtration and Oxygenation
- Envelope Protection
- Noise Reduction
- Agricultural Benefits

2.0 Technology Overview

In this chapter, some of the elements and technologies of the Bosco Verticale that are directly influenced by the presence of trees are summarized. The sections, as well as the descriptions, are not meant to be comprehensive; rather, they provide technical information regarding several topical aspects of the design and intend to display the unity of the architectural project with the vegetation and structural schemes.

Building Structural Systems

The structure of the project's towers consists entirely of reinforced concrete. The vertical load-bearing structure of tower E is formed by 13 pillars, placed on the perimeter of the floor plan – with unsupported corners – and by the service core, which contains two staircases, three elevators and five ducts for mechanical, electrical and plumbing systems (Figure 2.1). The pillars are rectangular and measure approximately 80 x 120 centimeters.

The service core is centered on the north façade of Tower E and has a floor area of about 160 square meters, comprising about 24% of each floor plate, excluding the terraces. The load-bearing structure of the floors and the cantilevered terraces is made of 28-centimeter-thick post-tensioned reinforced concrete.

The depth of the cantilevered terraces is about 3.3 meters in plan, and in some cases, the width is up to 14 meters. The terraces are accessed directly from the apartments. The plant containers on the terraces are placed on the outside edge of the balconies opposite the exterior wall (Figure 2.2).

The profiles of the terraces repeat every six floors, while the containers have variable layouts.

The required load support calculated for the terraces was determined by the weight of the deepest container, with large trees installed every 3 meters, and medium trees installed in the remaining space between the large trees.

The trees generate the significant portion of the loads, not so much in terms of weight, but in terms of wind force that they transfer to the structure. Defining the dynamic loads was a fundamental part of the structural design process. It was assessed through scale-model tests and full-scale tests on real trees in the field.

After the botanical classification of the selected trees, aimed at defining the maximum area of the canopy, the next task was to identify the center of gravity and the air permeability. An experiment at 1:100 scale was performed in the wind tunnel of the Politecnico di Milano, with the objective of defining local wind phenomena around the façades. Additional full-scale tests were performed in the "Wall of Wind" tunnel at Florida International University. These tests determined the aerodynamic coefficient of the trees' real dimensions, confirming the design values applied to the project and the stresses that would be placed on the tree-restraining devices. The test wind speed was 67 m/s, which is considered extreme for Milan.[1]

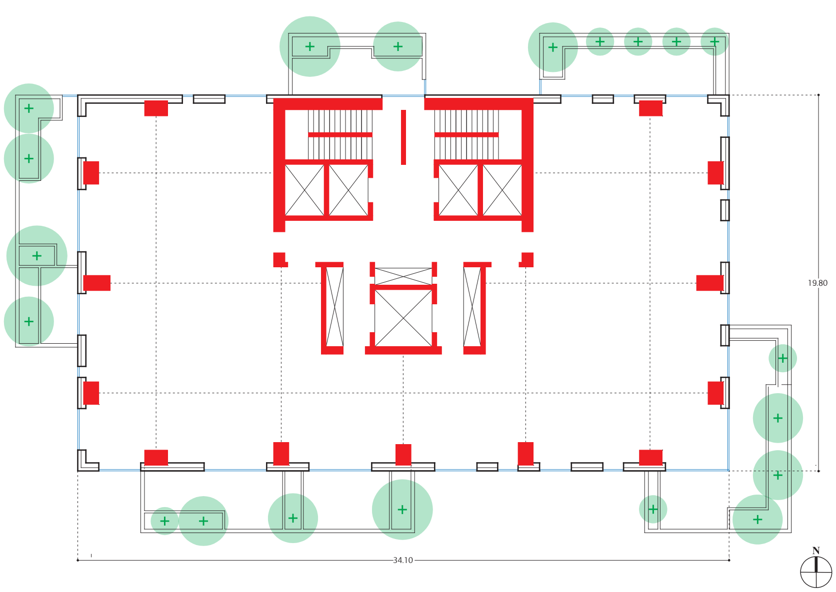

Figure 2.1
Tower E: Vertical structure, in plan, 6th floor (Source: Elaboration from document provided by Stefano Boeri)

[1]The information regarding the structure and the binds has been provided by Luca Buzzoni in 2014.

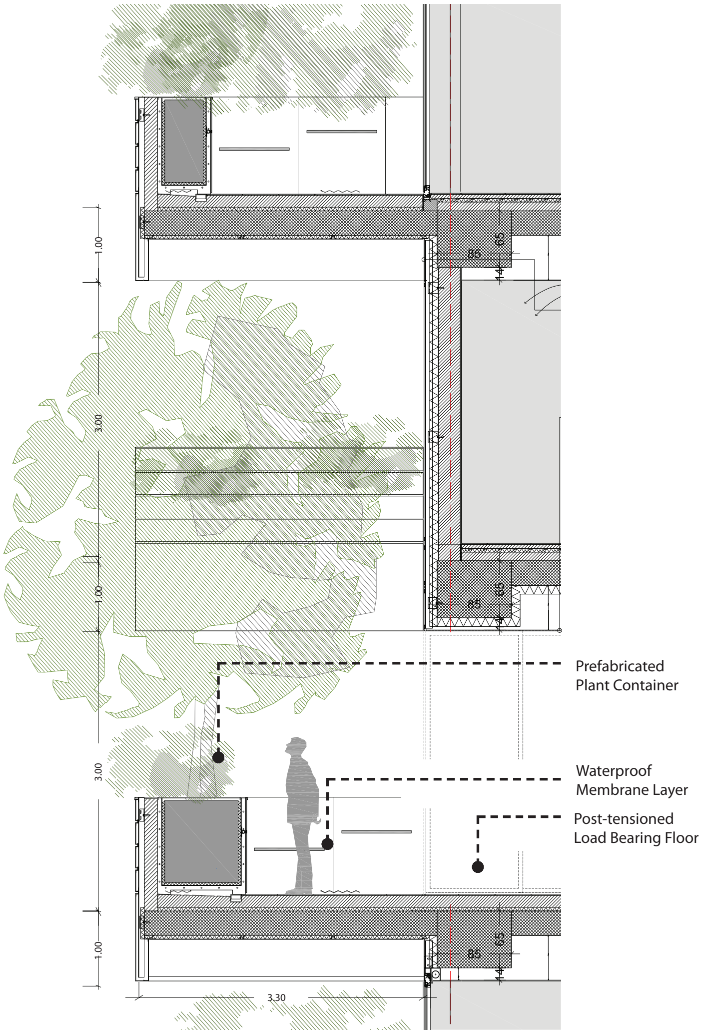

Figure 2.2
Tower E: Horizontal structure, typical vertical section showing location of plant containers (Source: Stefano Boeri)

Planting Restraint Safety System

The trees classified as "large" and "medium" are secured to the structure of the terraces, by way of three different devices:

Temporary Bind

This system consists of textile belts that anchor the root ball of the tree. In the bottom of the plant container, a steel welded net is positioned, through which three textile belts pass to fix the root ball (Figure 2.3).

This system is considered "temporary," since the belts (which are made of textile material) lose their tension over time. The textile belts are primarily important in the early life of the

Figure 2.3
Temporary bind: closure of the belts

3.0 Monitoring Bosco Verticale's Trees: Methodology and Results

Monitoring Objectives

The aim of the tree-monitoring program is "describing by measuring" the state of health of the trees installed on Bosco Verticale.

The monitoring data provides useful information to determine if plants are in good health, or if they suffer from some deficit that can negatively affect their physiology. Such a deficit could have dramatic consequences in this particular building, because intervening with corrective maintenance can be difficult and expensive. Replacing diseased trees by lifting new trees of similar dimensions into position is not practical, with the exception of the lower floors.

Therefore, through this data, it is possible to assess the effectiveness of the adopted agro-technical solutions and their respective requirements for ordinary or focused maintenance.

Lastly, the collected data represents a "historic archive" that can potentially be useful for future checks of Bosco Verticale's trees. The assumption of the monitoring is that the more intense climatic and environmental conditions on the terraces of the tower at height could be "aggressive stressors" for plants that take root inside the containers.

In order to assess the health of the trees, the monitoring program is based on the following activities:

- Selecting testing areas and trees
- Checking the success rate of planting and measuring growth activity
- Assessing nutrition
- Determining the effects of possible environmental stressors
- Data collection and results discussion

All tests described here were conducted on the plants of Tower E.

Selection of Testing Areas and Trees

Considering the state of the planting site at the beginning of monitoring, Tower E has been divided into three different classes of height:

- Class 1: the "low" class, up to the 7th floor
- Class 2: the "middle" class, from the 8th to the 12th floor
- Class 3: the "high" class, from the 13th to the 18th floor

At the beginning of the first monitoring period in July 2013, the trees of the last eight floors of Tower E had not yet been installed. The trees and the shrubs of these highest floors were planted on site after the beginning of the monitoring, so the research team decided to repeat in 2014 testing on the same trees tested in 2013, in order to obtain comparative data.

For each class, the tested trees are oriented to the four cardinal points, except for class 2, in which no trees were tested on the north façade. Twenty-seven trees were selected in all: 10 trees in class 1; seven trees in class 2; and 10 trees in class 3 (Figure 3.1).

The chosen trees were classified according to the maximum height that the species can reach in nature. "First magnitude" species of trees naturally grow higher than 25 meters; "second magnitude" species range in height from 15 to 25 meters). The decision to analyze the taller species is based on the reasoning that the taller species may be assumed to require higher levels of maintenance. They may have more difficulties, when compared to smaller trees, growing in such artificial conditions. Further, they are not commonly applied in general living green technologies, so the opportunity to test their application here was seen as fortuitous.

In Figure 3.1 and Table 3.1, the trees selected for the monitoring are listed and schematically represented.

The tree numbering system works as follows:

QI.02.V01
The first two characters represent the scientific name of the tree species, e.g., *Quercus ilex* = QI.

The second two characters indicate the floor number where the tree is located.

The third set of characters indicates the number assigned to the terrace during research.

All the specimens of the species listed below (installed on Tower E) were analyzed:

- *Fagus sylvatica*, European beech = FG
- *Parrotia persica*, Persian ironwood = PP
- *Quercus ilex*, Holly oak = QI

Figure 3.1
The four façades of the Tower E with the trees selected for the first monitoring program, June - October 2013

Only some of the specimens of the species listed below (installed on Tower E) were analyzed:

- *Corylus columa*, Turkish hazel = CC
- *Prunus subhirtella*, Higan cherry = PR
- *Prunus subhirtella autumnalis*, Higan cherry = PR

The only species of first-magnitude trees not analyzed, although it was present on both towers, was the *Gleditsia triacanthos* "Sunburst" (Thorny locust), because the crown of this tree is high on the trunk and thus difficult (and forbidden) to reach without a fall-arresting safety system. Only some

"The assumption of the monitoring is that the more intense climatic and environmental conditions on the terraces of the tower at height could be 'aggressive stressors' for plants that take root inside the containers."

4.0 Shading Capacity of Vegetation: Evaluation of the Envelope's Energy Performance

Greenery in the Context of Tall Buildings

Façades covered with plants are generally considered positive for sustainability because of the benefits that vegetation brings to the external environment, such as air temperature mitigation, air humidity increase as an effect of evapotranspiration, dust absorption, pollution reduction, BVOC (Biogenic Volatile Organic Compounds) production, carbon sequestration, and so on (for more on this, see Chapter 1.0).

Those benefits are variable, depending on the positioning of the vegetation. Their magnitude is influenced by the size and thickness of the crop, and by the leaf characteristics specific to each species.

As to the benefits to the internal environment of a building, the vegetation on the façade reduces the cooling load during the warm season, due to reducing solar gain through the envelope. This advantage is one of the most significant and depends essentially on three main factors and their interaction:

1. Plants acting as a sunscreen: The shielding capacity of the leaves (which is particularly efficient due to phototropism) reduces the absorption of solar radiation of the shaded layers, and therefore the heat transfer to the indoors
2. Plants acting as a windscreen: Although leaves are characterized by certain levels of wind permeability, they help to reduce convective heat transfer
3. Plants using solar energy for their transpiration and photosynthesis: These two processes are responsible for air temperature reduction, since the sensible heat is converted into latent heat, and lower external air temperatures imply less consumption of cooling energy in interiors.

In recent years, numerous vertical greenery systems have been implemented, with increasing success.

Green Wall Definition and Typologies

As per CTBUH Technical Guide, Green Walls in High-Rise Buildings (Wood, Bahrami, Safarik, 2014)

The "green wall" or "vegetated façade" is defined as a system in which plants grow on a vertical surface, such as a building façade, in a controlled fashion and with regular maintenance. Climbing plants grow naturally on building façades by attaching themselves directly to vertical surfaces by means of various mechanisms. Self-clinging climbers and self-supporting woody plants can attach themselves directly to the façade surface or grow along the façade without any added support. Other plant species, including climbers with aerial roots, suckers or tendrils, twining climbers, and lax shrubs (ramblers), require additional support, such as trellises, netting, or wires attached to the façade surface, to promote or sustain vertical growth.

The main elements of green walls are thus:

- plants
- planting media
- structures that support and attach plants to the façade
- the irrigation system

Depending on the plant species, planting media, and support structures used, one can distinguish multiple types of green walls, which are broadly grouped into two categories: "Façade-Supported Green Walls" and "Façade-Integrated Living Walls" (Figure 4.1). Further categories include "Stepped Terraces" and "Cantilevering Tree Balconies," the latter of which is the type of system used at Project.

Façade-Supported Green Walls

A façade-supported green wall is a green wall system supported off a façade, in which the planting medium is not integral to the façade. Usually it is carried in horizontal planters, which may be supported directly from the façade.

A façade-supported green wall structural system is usually comprised of steel, wood, or plastic trellises externally attached to a building façade, where plants are supported by horizontal, vertical, or diagonal trellis members. Climbing plants and vines used in green façades grow from planters located on the ground or at multiple intervals along the height of the façade. Green façades can be two-dimensional, formed by cables, ropes, and meshes, or three-dimensional, formed by rigid frames and cages.

Sub-categories of façade-supported green walls are recognized according to their structural support system, as outlined below.

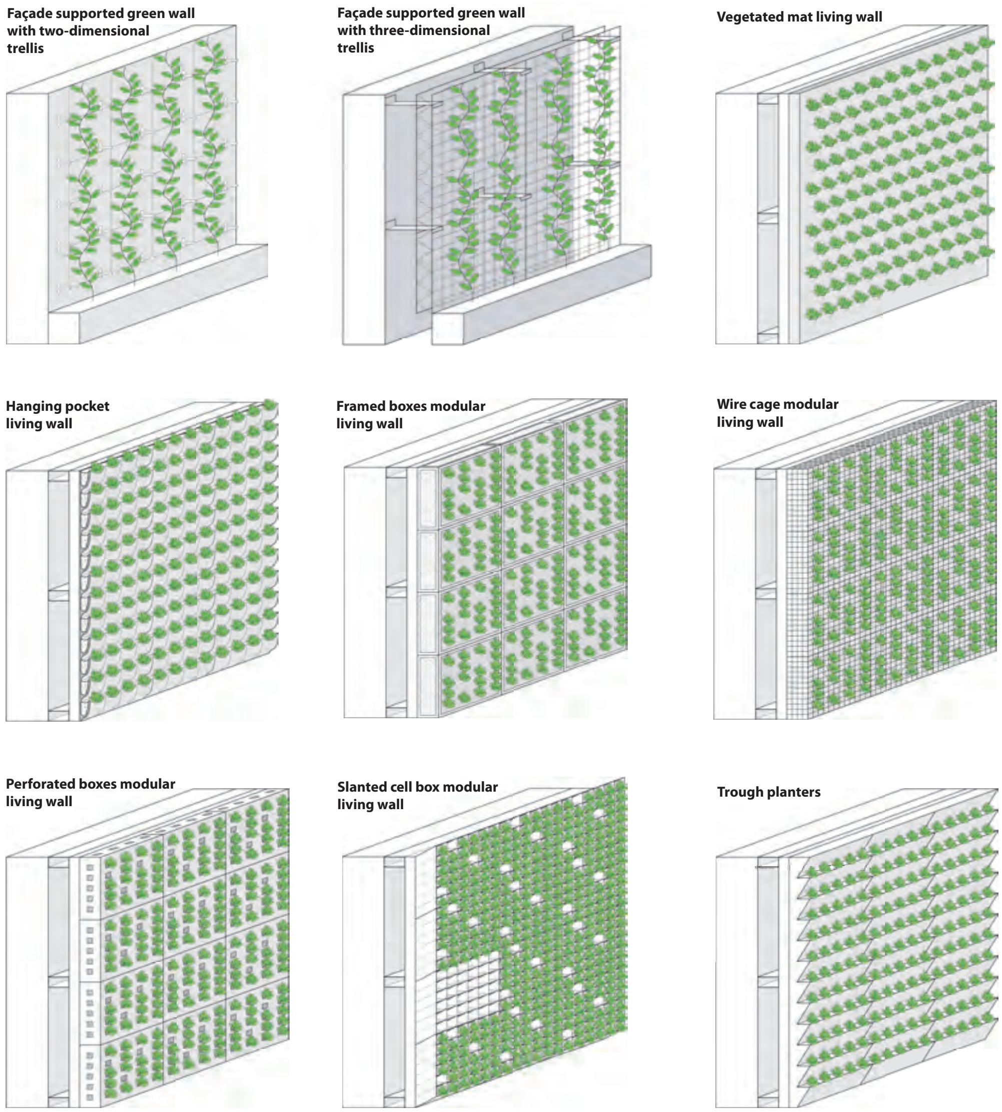

Figure 4.1
Diagrammatic representation of varying types of green walls (Souce: Irina Susorova, CTBUH Technical Guide *Green Walls in High-Rise Buildings (Wood, Bahrami, Safarik, 2014) page 16*)

Metal Mesh Green Wall
A metal mesh green wall uses a tightly intertwined grid of aluminum or lightweight steel attached to the façade via brackets. Plants typically grow from planters or troughs at the base of the wall.

Cable-Supported Green Wall
This type of green façade uses flexible cables that are used to support plants in irregularly-shaped and wide-span installations.

Rigid Green Wall
This system can utilize two and three-dimensional trellises that can be attached to a wall substrate, built around columns, or can be free-standing.

Living Walls
A living wall is a system in which vegetation is not only attached to a building façade, but is fully integrated into the façade construction, in which plants and planting media are both placed on the vertical surface of the exterior wall. Typically, living walls are separated from the façade surface by a waterproof membrane layer intended to protect the rest of the façade construction from unwanted moisture. Irrigation systems can be accompanied with rain sensors to make the living wall's needed irrigation more efficient and sustainable. There are multiple variations of living walls, as highlighted below:

Vegetated Mat Living Wall
This type of living wall consists of a fabric layer attached to a rigid substrate. Pre-grown plants are inserted into

5.0 Assessment of Tree Maintenance at Bosco Verticale

Maintenance of Tall Buildings at Height

The plants of the Bosco Verticale are part of a condominium property. All of the vegetation is owned and maintained by the building management, and not by the individual owners of the apartments. The ownership of the apartment thus does not include the vegetation. So, the residents are not permitted to independently maintain or interfere with the plants without prior authorization.

According to the information acquired during the research time –when the maintenance was not ordinary- the maintenance would take place in two ways:

1. Terraces are accessed via apartments, possibly 3-6 times per year;
2. Terraces are accessed from the outside by a basket lift (moved by a telescopic arm placed on the roof of each tower) (Figure 5.1) that will drop personnel from the top to carry out the pruning and other maintenance that cannot be done from the inside, possibly 1-2 times per year.

Figure 5.1
The telescopic arm on top of the tower that controls the basket lift for maintenance of the vegetation

Since the trees of Bosco Verticale have been installed, maintenance and observation of the health conditions of vegetation have been carried out. It is important to note a few existing conditions at the time of the monitoring:

The maintenance performed until the conclusion of the observation period cannot be considered as "ordinary" or routine maintenance, but rather as "initial maintenance". Since their installation between autumn 2012 and spring 2014, the trees were not pruned, because they had already been treated in the nursery and because, immediately after planting, the trees needed to grow their roots without suffering trauma of any kind (such as pruning).

As of this writing, the control room that governs the automated irrigation system had not yet begun working.

For the reasons listed above, there are no available data concerning the maintenance of non-woody vegetation (i.e. bushes and ground level plants).

This chapter, then, addresses only the maintenance of the Bosco Verticale trees.

The main concerns around the routine management of the trees are threefold: pruning, watering and fertilization.

Pruning is very important, since the installed trees need to be dimensionally constrained, and there are restrictions on maintenance personnel gaining access to the terraces of private apartments.

Fertilization has to be carried out simultaneously with watering, because the main chemical nutrients for plants are distributed with the water. Irrigation management has a great impact, not only on the trees' growth, but also on the energy consumption of the whole building. Such an artificial vertical landscape will need a large amount of water. It is reasonable to assume at least as much water is necessary to maintain vertical greenery as would be needed for the same number of plants placed on the ground.

Nowadays, water use needs to be reduced, monitored, and properly divided for the various needs of society, agriculture, industry, and the natural environment. At Bosco Verticale, careful management of water resources is needed to limit waste, and to supply the right amount of nourishment for trees and smaller plants.

Thus, the following chapter provides some consideration and methods for the global management of the Bosco Verticale vegetation, based on calculation procedures for traditional crops and observations in the field.

In the near future, it would be desirable to conduct this study again, so as to compare the methods applied in this chapter with ongoing data about pruning and automated irrigation activity at the building, in order to verify the accuracy of the applied formulas and, possibly, develop correction factors for the baseline formulas for trees and vegetation living on a tower.

Estimating Pruning Costs

The building's trees are classified according to their height in three different size classes: first, second, and third magnitude. It is expected that the maintenance activities, in particular the pruning, will be higher for trees of first and second magnitude, since these tree species tend to grow more vigorously.

For estimating the duration and costs of pruning, it is important to remember that access to the plant containers is not conventional, nor simple.

The pruning operations at height obviously take more time than at ground level. The removal of branches and pruned material is more difficult and slower on the towers. It is important to identify what type of pruning will be undertaken on the trees, since the type and period of pruning can significantly affect the growth of trees and, in general, the frequency of the maintenance.

In order to cause the minimum damage to the trees, the research team believes that pruning could be annual and "green." "Green pruning" is performed during the summertime, i.e. during the vegetative cycle, with the purpose of removing the vegetative vigor of some parts of the plant, so that the plant material to be removed is not bulky and may be disposed of outside the building. In this way, the containment of trees is easier and faster. Furthermore, green pruning is not so traumatic for the trees themselves, in particular for those plants with low tolerance for cuts.

Following observations during the building monitoring, together with information obtained by green operators, it may be assumed that the median time for pruning one tree at

"Terraces are accessed from the outside by a basket lift (moved by a telescopic arm placed on the roof of each tower) that will drop personnel from the top to carry out the pruning and other maintenance that cannot be done from the inside, 1-2 times per year."

Cities are facing unprecedented expansion through population growth and urbanization in the coming decades, and the horizontal-suburban model of urban development is increasingly being discredited on sustainability grounds. With less available land to build on, the logical solution is to build upwards. However, a major human need – access to greenery – must be addressed by any viable plan for increased height and density.

The Bosco Verticale in Milan, Italy – whose name literally means "Vertical Forest" – is a stunning example of the potential of deploying substantial greenery at height. The building was chosen as the subject of a one-year research study, funded via the CTBUH International Seed Funding Program, because of the extensiveness of its implementation. Some 13,000 individual plants from 90 species cover its many balconies, forming a "second skin" that provides valuable shade and privacy, and makes a statement about the viability of "green" architecture in tall buildings in an unprecedented fashion.

This Research Report chronicles the project in five main chapters and includes dozens of detailed photos, drawings, and diagrams explaining the general urban plan, design concept, and specifics of the implementation of several different kinds of restraining and securing systems for the trees, as well as the process for evaluating the health and effectiveness of the plants as part of the building envelope. An appendix contains an inventory of the study results for each tree included in the survey.

This CTBUH Research Report is intended to further the body of research on the design and operation of tall buildings, with a specific interest in greening the environment, both at the building and the urban scale. The CTBUH Research Report series chronicles the research projects undertaken directly by CTBUH or funded through its initiatives. Each examines strategies for improving the performance of tall buildings, including reducing their environmental impact, while taking the industry closer to an appreciation of the myriad factors that constitute sustainability in the context of tall.

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