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A New Urban Forest Rises in Milan

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Elena Giacomello, architect, graduated cum laude in architectural design from the Università Iuav di Venezia.

In 2011 she obtained her PhD in building technology at the Università degli Studi di Ferrara, with an experimental thesis entitled *An Artificial Soil: the Role of Water in Green Roof Design,* which was named as the "best PhD thesis in building technology" of that year. The research analyzes the runoff regulation of green roofs through rain chamber tests and evaluates the benefits derived by application of vegetated and draining built surfaces in the urban environment.

From 2011, Giacomello has been a professor of building technology and a temporary research fellow at Iuav.

Recently, she completed a year-long monitoring research project on Bosco Verticale, funded by the 2013 CTBUH International Research Seed Funding program sponsored by Arup.

Her main research interest concerns technologies that combine plants and construction.

The Bosco Verticale "vertical forest" in Milan, Italy, takes the definition of "green skyscraper" to a new level, deploying more than 13,000 plants across 90+ species, including full-sized trees, on all façades of both its towers. The project was cited as a case study in the CTBUH 2014 Technical Guide ***Green Walls in High-Rise Buildings.*** In 2013, the CTBUH International Research Seed Funding Program, sponsored by Arup, awarded a grant of US$20,000 to a team led by the author of this paper, Dr. Elena Giacomello, which spent a year studying the Bosco Verticale, examining all aspects of its design and construction, especially the extensive plantings that give it its name. The full report will be published in the forthcoming CTBUH research report: ***Bosco Verticale: Evaluating the Promise of Vertical Greenery.*** This case study introduces the project and its many innovations.

Introduction

The Bosco Verticale in Milan supports one of the most intensive living green façades ever realized. 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 Bosco Verticale consists of two residential towers, 26 and 18 floors high respectively, characterized by the presence of dense vegetation along their outer envelopes (see Figure 2). There are about 13,000 plant specimens, including about 700 trees up to six meters high, on both towers.

All the plants take root in containers located on the external side of deep cantilevered terraces, which are accessible from each 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 (see Figure 1).

From outside, the plants realize an urban vertical reforestation, providing several environmental and microclimate benefits particular to trees' physiology: dust

Figure 1. Planters are located on each balcony.

absorption, pollution reduction, BVOC (Biogenic Volatile Organic Compounds) production, carbon sequestering, air temperature mitigation, and air humidity all increase or improve as an effect of evapotranspiration.

As result, the envelope of Bosco Verticale is an active interface to the environment, with a special architectural quality. The dynamism of plant life, in fact, is also expressed in the combination of forms and colors that derives from the carefully selected distribution of different species and specimens, which change over the seasons and the years. The greenery of the plantings is underscored by the grey color of the exterior walls, making the plants the protagonists of an architectural story of great visual, environmental, and ultimately, societal impact.

Site Conditions

The Bosco Verticale is part of the new Porta Nuova area, an extended urban transformation of a neglected area of Milan. This 34-hectare area is completely new; before the construction of 20 towers in the last decade, it was one of the last unbuilt sites in the city. Before the Porta Nuova project began, the area was partially occupied by an amusement park; much of the remainder was abandoned, vestigial land.

In 2004, the urbanization project was approved and the available surface was arranged for a radical urban transformation, comprising an investment of more than €2 billion (US$2.51 billion) to create a mixed-business and residential district.

The new Porta Nuova project is divided into three neighborhoods: Isola, where the Bosco Verticale is located, Porta Garibaldi, and Varesine, taking advantage of its proximity to the city center.

In addition to lying about 2,200 meters from the main cathedral, excellent accessibility is provided by two nearby railway stations, two

Figure 2. Bosco Verticale, Milan. © Kristen Bucher

> "The greenery of the plantings is emphasized and underscored by the grey color of the exterior walls, making the plants the protagonists of an architectural story of great visual, environmental, and ultimately, societal impact."

Figure 3. Porta Nuova development, Milan. © Residenze Porta Nuova S.r.l.

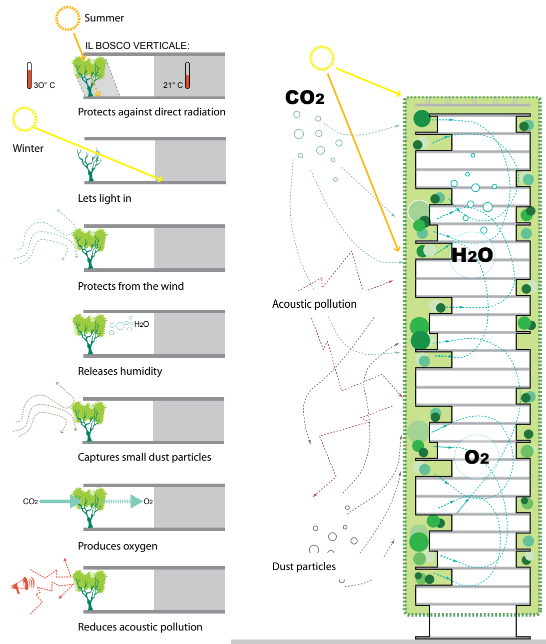

Figure 4. Bosco Verticale life cycle concept. © Stefano Boeri Architetti

underground metro lines and a third under construction, a new auto tunnel under the platform of the Unicredit Tower, and several tram and bus lines.

The entire transformation project introduces a functional mix that includes offices, retail spaces, and residential buildings interconnected by green areas with pedestrian paths.

The site of the Bosco Verticale is located to the north of the Unicredit Tower, and borders a nine-hectare park called the "Library of Trees", now under construction (see Figure 3). Both towers are oriented exactly along the cardinal directions.

Design Concept

In recent years, significant improvements have been made to building envelopes generally. They have become more sustainable from an energy point of view, in that they are increasingly better insulated and shaded and, sometimes, integrated with systems for energy generation. Still, tall buildings are normally clad in hard-surfaced materials that "mineralize" the urban environment (by using ceramics, glass, metal, bricks, etc.).

According to the architect of Bosco Verticale, Stefano Boeri, the project "represents a different idea of sustainability" (Giacomello 2014). The Bosco Verticale faces the challenge of sustainability by introducing a new level of biodiversity into the city.

Following this concept, the two towers of the Bosco Verticale represent "a medium" for a new ecosystem (see Figure 4), realized through an exceptional variety of more than 90 plant species.

The greenery of the Bosco Verticale is not simply decorative; rather, it is a composition of plants that, in addition to being able to live in the artificial condition of a tall building, recreate a very rich biodiversity. Trees, shrubs, and herbs, with their flowers, berries, and seeds – present in large quantities – produce a natural support to the plants themselves, and to small animals, introducing into the city center of Milan a high concentration of natural life.

In this way, the two towers become a "station" along a green corridor that connects the large green suburban areas with urban gardens and the very few uncultivated small plots of land in the city center, which have been colonized by important "vagabond plants." At Bosco Verticale, the implementation of biodiversity through the use of plants installed on a tower envelope is an innovative operation of a technical complexity that has never been attempted so far at such a scale.

The design of the primary systems has been conducted through collaboration between the architect and the landscape designer with an interdisciplinary team that has worked at the highest level of professionalism.

Structural Performance Tests

The resolution of the structural design of the Bosco Verticale was essential to proving that the "vertical forest" concept was feasible. The structure is fashioned entirely in concrete: the columns are made of reinforced concrete, while the floors are post-tensioned reinforced concrete.

The characteristics of the project required a precise calibration of the following factors: the gravity loads of trees and the soil, the

3.3-meter-deep cantilevered terraces (see Figures 5 and 6), the unsupported corners, with a maximum span of seven meters, and the dynamic loads of the wind and its effect on the trees' stability and security.

To meet these criteria, defining the dynamic loads became a major part of the design process, including scale-model tests and full-scale tests on real trees in the field.

Beyond the standard structure, the geometrical and dimensional characteristics of the plants at their likely fullest extent needed to be taken into consideration. A botanic analysis obtained the height of the trunk, the surface area and center of gravity of the canopy, and the air permeability of each of the selected species. Experimental tests were performed in a wind tunnel at the Politecnico di Milano, with the objective of defining local wind phenomena around the Bosco Verticale façades.

For this purpose, the tower was modeled at 1:100 scale, with pressure sensors. A dynamometer was installed on the base of some trees in order to balance and evaluate forces, moments, and aerodynamic coefficients.

Additional full-scale tests were performed in the "Wall of Wind" wind tunnel at Florida International University. These tests determined the aerodynamic coefficient of the trees' real dimensions to confirm the design values applied to the project and the stresses that would be placed on the tree-restraining devices. The wind speed of the tests was 67 m/s, which is considered an extreme speed for Milan. The average wind speed at ground level is 25 m/s, but short-duration bursts can be 1.5 to 2 times higher.

All of the performed tests were essential to deepen knowledge of the specific issues of design, and thus facilitated the design of safe and efficient solutions that were also respectful of the botanical and architectural requirements.

Figure 5. Typical plan showing the terraces cantilevered from the main tower plans. © Stefano Boeri Architetti

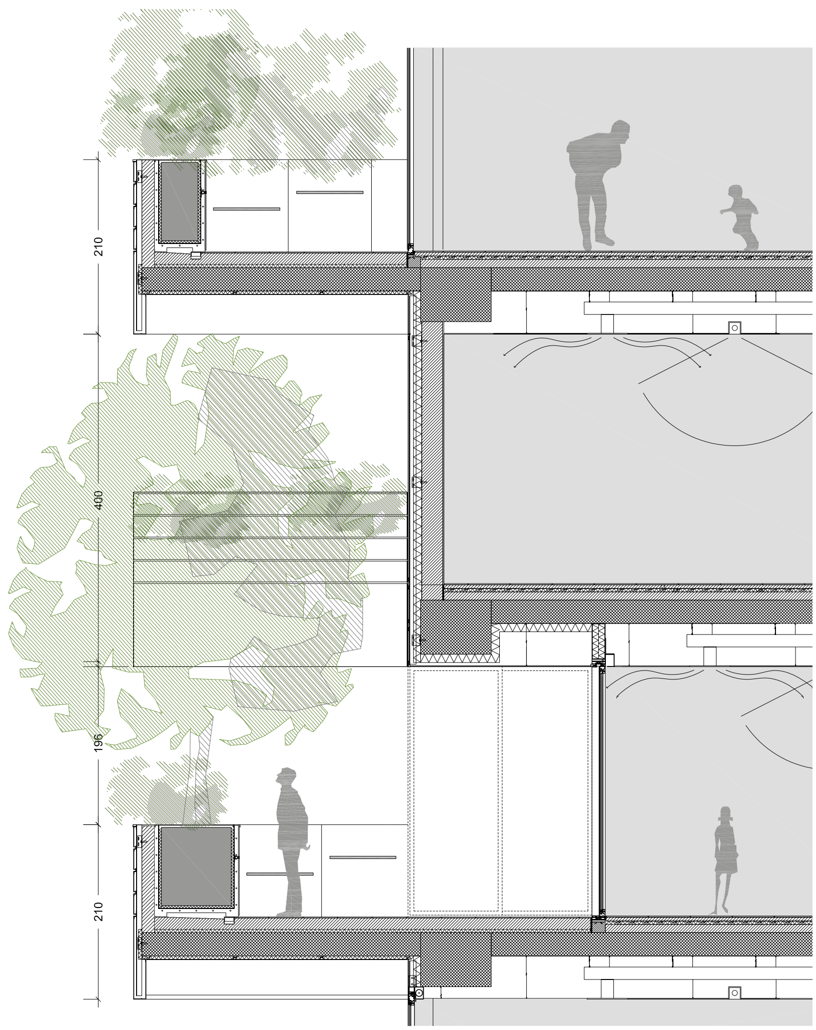

Figure 6. Detail section showing cantilevered terraces. © Stefano Boeri Architetti

Figure 7. Temporary bind. © Hines Italia

Figure 8. Basic bind. © Hines Italia

Figure 9. Redundant bind. Source: Arup Italia

Restraint System

Linked to the structural design is the restraint system, which provides three protections against falling trees:

1. **Temporary bind:** The root ball of each tree is anchored to the plant container through textile belts (see Figure 7). This system is required in the early life of the trees, until the roots have grown to take hold.

2. **Basic bind:** Each tree is fixed, with three elastic belts, to a retaining steel cable, anchored to the terrace above (see Figure 8). This is the main fall-arrest device for grown trees.

3. **Redundant bind:** A #1 steel cage fixes the root ball to the plant containers (see Figure 9). This bind is used for the trees located in the windiest positions and on the top floors of the towers.

Plant Containers

The plant containers of the Bosco Verticale are located on the side of the terraces furthest from the exterior wall. The volume of the containers varies to provide the best adaptation of a given plant's roots to the artificial context of the façade. Depending on the plant, the dimensions of the containers are: in the case of a tree, 1.10 meters deep and 1.10 meters wide; in the case of shrubs and bushes, a minimum 0.5 meters' depth and 0.5 meters' width was specified.

The structure of the container is entirely protected with a bituminous waterproofing membrane, preserved by protective sheeting against root penetration (see Figure 10).

Along the interior surfaces of the plant container is a layer of separation and drainage, made of two synthetic nonwoven filters with a three-dimensional filament core. This layer has a drain structure with high suction capability to ensure optimal drainage of any possible out-flowing water (see Figure 11). The layer of separation and drainage is very important, as it protects the permeability of the filters and the drainage pipe over time. It also serves as an additional mechanical protection of the waterproofing membrane and of the sheeting against root penetration and air circulation along the container sides.

Next in the sequence is the welded-steel net that anchors the root ball of the trees. Above the layer of separation and the welded-steel net lies the vegetation support course.

The internal stratigraphy (soil layering) is uniform for all plants, and was composed according to the standard for green roofs. The stratigraphy is carefully designed to accommodate the roots of the plants as they grow over time, and to protect the constructed elements of the container.

The substrate is a key element of every green living technology: it respects many parameters and requirements identified in the Italian standards for green roofs (Giacomello 2014). The substrate is composed of a mixture of inorganic and organic loose earthy materials, which have to ensure optimal functions of water retention, permeability, structural stability, and density. The main material that composes the substrate is volcanic *lapilli*, an inorganic material characterized by excellent properties for living green technologies, such as an optimal water retention curve, dimensional stability, and high ionic

Figure 10. View into a plant container with membrane and protective sheeting.

Figure 11. Plant containers' drainage system.

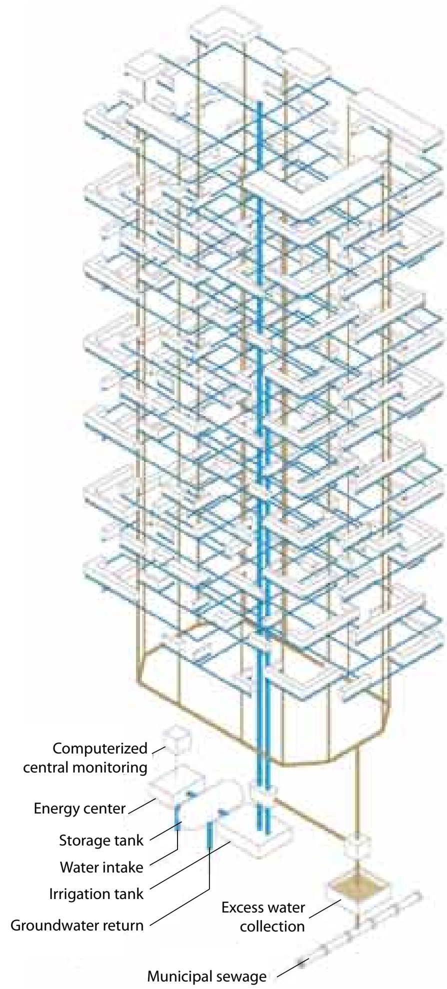

Figure 12. Water supply system. © Stefano Boeri Architetti

exchange capacity. The *lapilli* has been selected with different grain sizes and mixed with green compost and topsoil.

Irrigation

The water distribution network for irrigation is composed of four main elements: the principal network, which brings underground water to the terraces; the control group in each plant container, which regulates the water supply; the widespread distribution in the plant containers (the drip line), and the humidity control system (the humidity sensors).

1. **The principal tower network**
   The project uses groundwater for irrigation. In the basement of each tower there is a water storage tank, which is continuously fed with groundwater (see Figure 12). From the water storage tank to all floors of each tower, the water is distributed through different groups of pumps. Every group of pumps supplies one sector of the towers. In Tower E there are three sectors (one of low, one of medium, and one of high hydraulic head); in Tower D there are two sectors (one of low and one of high hydraulic head).

   The combined fertilization and irrigation ("fertigation") occurs between the water storage tank and the groups of water lifting pumps. The main irrigation tubes are located on the façades. Since they are not insulated against low temperatures, for safeguarding against frost, the system automatically empties when the temperature reaches 0°C, and recharges when the temperature returns to 5–6°C.

2. **The control group in the plant containers**
   Each plant container has one "control group" of irrigation. The control group receives water from the main distribution network and regulates the water flow inside the container. The control group is composed of three elements, partially buried in the substrate of the plant container: a solenoid valve, a filtration unit, and a pressure regulator. The plant container, therefore, has one solenoid valve that is independent from all the others. The irrigation is electrically operated, and every solenoid valve works independently. This feature allows different irrigation flows to be programmed for each container, according to the variability of the plants' water demand. All the valves in the Bosco Verticale irrigation system operate by independent open/close commands.

3. **The widespread distribution element in the plant container**
   Downstream from the control group, in each plant container is the drip line, hardened against root penetrations and siphoning by a chemical/mechanical barrier in the emitter and air-vent valves in the tubing, which distributes the water on the surface of the substrate.

4. **The humidity control system**
   Although irrigation is programmed valve by valve, a humidity control system is installed to monitor its progress. Inside each plant container, there are two humidity sensors that register the humidity level of the substrate, one near the water distribution point, the other on the far side of the distribution point.

   The recorded data are used for controlling the efficiency of the irrigation schedules and for verifying any failure of water supply in the plant containers (such as obstructions or water loss).

Figure 13. Bosco Verticale's living façade. © Eleonora Lucchese

Challenges and Resolution

The innovations incorporated into the Bosco Verticale are numerous, starting from the plants' precultivation methods, to their continuing maintenance program.

In addition to the specific design solutions, which are in some cases traditional and in other cases revolutionary, the most significant challenge seems to have been the capacity to integrate all the different disciplinary approaches and needs, which, in the case of Bosco Verticale, are widely disparate.

The plant selection and the structural and system design, unified by a strong architectural definition, were carried out successfully thanks to a determined interdisciplinary team.

However, the challenges for the Bosco Verticale remain. Maintenance activities will play a fundamental role in the health, beauty, and lifespan of its plants. Furthermore, another unknown factor emerges: How will the Bosco Verticale be occupied and interpreted by its human inhabitants? What do the users expect from such an unusual building?

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Conclusion

With 18,000 square meters of living green façade, the Bosco Verticale is the most extensive integration of plants ever applied to a tall building (see Figure 13). This huge experiment symbolizes a new idea of sustainability that includes biodiversity as an element of environmental enhancement. The full understanding of the impact of these design choices will occur in the future, interpreted through the transformations of its mini-ecosystem. Though repeated measurement and verification will be necessary, the Bosco Verticale today stands as a reference model for the next generation of living façades on tall buildings. In the field of agro-technologies applied to buildings, the Bosco Verticale is already an exemplar of innovation.■

Unless otherwise noted, all photography credits in this paper are to the author.

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Project Data

Completion Date: October 2014
Height: 85 meters (Tower D), 117 meters (Tower E)
Stories: 18 (Tower D), 27 (Tower E)
Total Area: 30,501 square meters
Use: Residential
Owner/Developer: Fondo Porta Nuova Isola/ Hines Italia
Architect: Stefano Boeri Architetti
Structural Engineer: Arup
MEP Engineer: Deerns
Main Contractor: ZH Construction Company S.p.A.
Other Consultants: Deerns (LEED consultant & vertical transportation), Stefano Boeri Architetti (landscape designer), Studio Emanuela Borio (landscape designer), Studio Laura Gatti (landscape designer)