Bosco Verticale
Engineering a forest in the sky
ARUP
Arup Offices

Project office: Milan, Italy
Other offices involved: London, UK
Midlands Campus, UK
San Francisco, USA
Madrid, Spain
The Project
Structure
Geotechnics
Advanced Technology
Engineering the Trees
The Team
Arup
International Highrise Award 2014 for the world’s most innovative highrise goes to Bosco Verticale.

On November 19th 2014, the International Highrise Award (IHP) 2014 jury unanimously resolved that Bosco Verticale, was to win the prize for the world’s most innovative highrise building.

Bosco Verticale are two residential towers built in Milan, Italy within the Porta Nuova area, one of the biggest urban redevelopment project in Europe. Bosco Verticale building is placed in Porta Nuova Isola area which was historically dedicated to light industrial and craft activities.

The motivation behind the award was that the project “blazes the trail for greened highrises and can be considered a prototype for the cities of tomorrow”.

The award was presented by the City of Frankfurt am Main together with Deutsches Architekturmuseum and DekaBank.

Boeri Studio (Stefano Boeri, Gianandrea Barreca, Giovanni La Varra), now Stefano Boeri Architetti and Barreca & La Varra, and the developer Manfredi Catella (CEO, Hines Italia SGR S.p.A.) received the prize at the awards ceremony in Frankfurt’s Paulskirche.
Designed by Boeri Studio (Stefano Boeri, Gianandrea Barreca, Giovanni La Varra) and developed by Hines, Bosco Verticale, in the heart of Milan, includes two residential towers which are respectively 110m and 78m high. A total of 900 trees between 3m and 6m in height have been planted on the terraces up to the 27th floor, along with 5,000 shrubs and 11,000 floral plants.

The project was set to create a new standard for sustainable housing and was developed with the support of Arup’s engineers who delivered the structural and geotechnical design and provided consultancy services on acoustics, vibrations, ground-borne noise and tunneling. Arup also provided advanced design solutions to counteract the effects of the two existing railway tunnels by means of a vibration base-isolation system for the main buildings.

As a new model for urban regeneration, the design creates a biological habitat within a total area of 40,000m². The designers’ aim was to inspire greater urban biodiversity to contrast Milan’s increasing pollution threat. The vast amount of greenery on the building encourages the production of energy. The plants produce oxygen and humidity and absorb CO₂ and dust particles thus improving the surrounding environment.
Structures
Arup designed Bosco Verticale structures from Concept to Construction incorporating advanced solutions

Arup adopted high-strength concrete and unbonded post-tension for the slabs. This solution allowed limited dimensions for the structural elements with significant loads and cantilevers (up to 3.5m for the terraces and a maximum span of the cantilever in the corners of approx. 7.5m).

Several advanced contributions were made to the structural design and have been coordinated to address specific project needs (e.g. interaction with the existing underground tunnels, coordination with the existing ventilation shaft, interaction with the adjacent existing buildings, wind loading and wind climate analysis, vibrations and structure-borne noise, stability of trees and definition of design loads related to the trees).

Three of the buildings have been designed with a base-isolation system to mitigate ground-borne vibration from the metro trains. The system has also been designed to provide additional seismic protection to the buildings.

Due to the peculiar layout of the terraces, cantilevering slabs have been poured on a self-supported cantilevering scaffolding.
A detailed interaction analysis with the existing metro tunnels and the adjacent buildings was carried out
Despite the good soil characteristics and limited influence of the water-table, several site constraints required a thorough geotechnical design of the project.

The presence of existing buildings adjacent to the site, the existing M2 metro tunnels underneath the North portion of the site and the new Metro5 tunnel under construction on the East side, required specific design of several diaphragm walls' typologies with many different temporary restraint solutions (e.g. soil nailing with different number and length of ground anchors, temporary propping from within the site and cantilever solutions with no temporary restraints).

The existing tunnels have been assessed with desk-studies, surveys and in-situ tests to allow detailed analyses of the structure during the planned construction of the new buildings typically only 3.5m above the tunnel crowns.

The behaviour of tunnels has been analysed for the direct effect of the new buildings, for the construction of the diaphragm walls and excavation and for the indirect loading effect of the towers. The analyses predicted the evolution of settlements and stresses in the tunnels with an incremental finite element load-analysis.

During the construction of the buildings, the tunnels have been monitored to control any possible unexpected effects and to verify that the real behaviour matched the numerical predictions.
Advanced Technology
This risk of ground-borne vibration from the metro was mitigated by designing a base isolation system

Bosco Verticale site lies above the M2 line of the Milan Metro system between the Garibaldi and Gioia stations. The line comprises two tunnels with the tunnel crown less than 4m under the buildings’ foundations. Rail systems generate ground-borne vibration (GBV) partly due to irregularity in the wheel tread and rail head surfaces and partly due to the dynamics of the track structure and vehicles. The transmission of rail GBV to the building structures is a particular risk as it may impact comfort in relation to vibrations perceived by the occupants and structure-borne noise if not properly addressed.

Vibration surveys were carried out on site before construction started in order to quantify site vibration performance and confirm the need for isolation.

Base isolation systems involve floating the building structure on an array of resilient elements. Isolation frequencies of 3.5Hz or lower were projected and achieved with helical steel springs.

A finite element model of the building structure was developed and a dynamic analysis carried out so that the performance of the isolation system could be evaluated at the design stage and compared with the performance criteria. The analysis also enabled the required isolation frequency to be confirmed and the design of the spring array to be developed.
Engineering the Trees
Three levels of stability devices have been designed and verified in wind tunnel facilities to provide the highest safety.

The structural stability of the trees has been designed through the botanical analysis of the species and their geometry, a detailed wind climate assessment and two different wind tunnel test campaigns.

The first set of tests in the wind tunnel facility of the Politecnico di Milano assessed the forces on the trees in a 1:100 scale model. The second set of tests, carried out in the open-flow facility of the Florida International University, was designed to verify the forces on real trees.

Following the results of the analyses and tests, three restraining devices have been designed: all the trees have elastic temporary bands that connect the root bulb to a steel mesh embedded in the soil; 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 a safety steel cage that restraints the root-bulb and prevents it from overturning under major windstorms.
Porta Nuova Isola | The Team

Client and Developer: Hines Italia SGR SpA per conto del Fondo Porta Nuova Isola

Architects:
• Masterplan and Bosco Verticale: Boeri Studio (Stefano Boeri, Gianandrea Barreca, Giovanni La Varra) now Stefano Boeri Architetti and Barreca & La Varra
• Office building: William McDonough + Partners
• Low-rise residential building: Lucien Lagrange Architects

Bosco Verticale’s Landscape and Botanical Consultants: Laura Gatti and Emanuela Borio

Landscape Architect of Public Spaces: Land

Coordination and Executive Architecture: Tekne

Structures, Geotechnics, Tunnelling, Wind, Acoustics related to vibrations and structure-borne noise, Advanced Technology: Arup: Luca Buzzoni (Lead Engineer), Lorenzo Allievi, Andrew Allsop, Enrica Barzaghi, Luca Dellatorre, Xiaonian Duan, Silvia Ferrero, Patricio Garcia, James Hargreaves, Simon Hart, Oronzo Lacirignola, Yi-Jin Lee, Ziggy Lubkowski, Enrico Manganelli, Lorenzo Marengo, Alvaro Martinez, Riccardo Merello, Paolo Micucci, Valeria Migliori, Angelo Mussi, Nick O’Riordan, Adrian Passmore, Vincenzo Patruno, Roberto Persio, Francesco Petrella, Luca Rossi, Maurizio Teora, Roland Trim, Francesco Uggetti, Michael Willford, Peter Young

Mechanical, Electrical, Plumbing, Acoustics: Deerns Italia

Civil Works of Public Spaces: Alpina

Project Management and Cost Control: J&A Consultants

General Contractors:
• Phase 1: ZH General Construction Company
• Phase 2: Colombo Costruzioni

Wind Tunnel Facilities:
• Politecnico di Milano
• Florida International University

Base-Isolation System Supplier: Gerb

Site Supervision Teams:
• Phase 1: MiPrAv
• Phase 2: Studio Ceruti

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We exert a significant influence on the built environment and are the creative force behind many of the world’s most innovative and sustainable designs.

The firm has 91 offices in 39 countries, with 11,000 planners, designers, engineers and consultants.

Arup has three main global business areas – buildings, infrastructure and consulting – although our multi-disciplinary approach means that any given project may involve people from any or all of the regions in which we operate.

Arup established an office in Milan, Italy in 2000 and with a headcount of around 80 people today, it can offer the following disciplines locally:

- Structures
- Geotechnics
- Mechanical, Electrical, Public Health and Sustainable Strategies
- Façade Engineering
- Urban Planning
- Architecture
- Sports Design
- Programme and Project Management
- Transaction Advice
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