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CTBUH Research Seed Funding Project 2013 – Green Living Façade for Tall Buildings: The Bosco Verticale

CTBUH研究种子基金项目2013——高层建筑的绿色种植立面: 空中森林

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埃琳娜•乔科莫罗是威尼斯建筑大学建筑技术方向的兼职教授和临时研究员。在费拉拉大学建筑系获得建筑技术博士学位。其研究集中在这两个领域: 植被与建筑物的结合、建筑修缮和翻新。她出版了许多出著作，并与意大利和国外研究机构合作。她是意大利卷材屋面标准工作组的成员，并参与组织有关建筑技术课题的会议和研讨会。

Abstract

The possibility of creating green surfaces over the structures is an opportunity which is seen with increasing interest by planners and investors, due to the appreciation expressed by users.

Nowadays, however, the knowledge of green living technologies is not yet fully established. This issue applies in particular to tall buildings, where the conditions of plants are more severe than in any other building type and the maintenance is more difficult.

Since the Bosco Verticale, consisting of two residential towers, achieves a full integration between vegetation and all the façades, it has been possible to perform –for various project components– specific monitoring activities, including several physiological tests on the plants and thermal reliefs of the envelope.

Keywords: Bosco Verticale, Living Green Systems/Technologies/Envelope, Vegetated Façade/Roof

摘要

由于建筑使用者表现出对绿色建筑的欣赏和认同，规划者和投资商越来越关注在上创建绿色生态的结构可能性。

然而，当今绿色生态技术并未完全建立完善，在高层建筑领域尤其如此。相比其他建筑类型，高层建筑上植物生存的条件更为严峻，维修保养也更加困难。

空中森林项目包括两座住宅大楼，实现了植被和全外墙之间的充分融合，并且项目的各部分和具体的监测活动都具有高度的可行性，其中包括植物的生理试验和建筑表面的散热效应测试。

关键词: 空中森林，绿色生态系统/技术/立面，植被外墙/植被屋顶

ARUP

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The Research Program

James et al. (2009) –identifying the emergent research questions regarding the green spaces in European cities– states that "increasingly, urban green space is seen as an integral part of the cities providing a range of services to both the people and the wildlife living in urban areas." Green spaces are widely recognized as key elements for the planning of more sustainable cities (Hoyano, 1988; Lay Ong, 2003). Plants and trees in particular help to mitigate the urban heat island through direct and indirect contributions (Wilmers, 1988; Akbari et al., 2001; Yu, Nyuk Hien, 2006; Rizwan et al., 2008) and improve the air quality absorbing dust, particulates and pollutants (Nowak et al, 2006). Green areas contribute to maintain the urban biodiversity (Alvey, 2006; Kong et al. 2009) and

研究计划

James等人 (2009) 的研究确定了当今在欧洲城市绿色空间面临的严峻的问题，指出，"城市绿地越来越被视为城市的重要部分，能给城市中的人和野生动物提供一系列的服务"。绿地被广泛认可为可持续的城市规划的关键要素 (Hoyano，1988年; Lay Ong，2003年)。植物，特别是树木，能通过直接和间接的方式缓解城市热岛效应 ((Wilmers，1988年; Akbari 等人，2001年; Yu，Nyuk Hien，2006年; Rizwan 等人，2008年)，并且能通过吸收灰尘，微粒和污染物改善空气质量 (Nowak 等人，2006)。绿色空间也有益于维持城市生物的多样性 (Alvey，2006年; Kong 等人，2009年)，并且能通过简单的视觉作用对人类心理的健康产生积极影响 (Ulrich，1991年; Maas，2006年)。

have positive effects on human psychophysical health and well-being, even through simple visual fruition (Ulrich, 1991; Maas, 2006).

As the urban areas are densely built and "the soil sealing is essentially an irreversible process" (Prokop et al., 2011), the green can be restored in the built environment through the integration of plants also on buildings' envelopes. For several years the living green roofs have been extensively used because the reproduction of a vegetated soil –in a reduced thickness– guarantees good thermal performances for interiors and useful benefits for external environment (Palomo Del Barrio, 1998; Theodosiou, 2003; Liu, 2007), particularly in terms of storm water management (Mentes, 2006; Palla, 2010, Giacomello, Zannoni, 2012). In contrast, living green façades –indeed an advanced technological system– are newer applications and, compared to green roofs, are characterized by a higher level of maintenance requirements and a more extensive presence of systems.

Nowadays, green living technologies applied to the envelope of tall buildings can be defined as "borderline:" in fact the conditions for the plants are more extreme than in any other building type, due to the distance from ground level in conjunction with the intensity of atmospheric agents (wind in particular).

This research consists in a monitoring program of the Bosco Verticale during the early stages of its life cycle. The Bosco Verticale is characterized by the presence of vegetation uniformly distributed over deep cantilevered terraces along the façades of both towers (see Figure 1). Since such an extensive implementation of trees and plants on a tall building façade is unprecedented, the monitoring program can help to define a new subject area concerning the use of trees and plants as environmental and construction components of a skyscraper.

The monitoring is achieved through the collection of suitable data from experimental tests in twelve different exposure areas: low, mid and high areas of each façade of the taller tower (Tower E). The façades are orientated exactly towards the four cardinal points.

For each of the twelve areas the arranged tests measure:

1. Physiological functions of taller tree species (chlorophyll content, percentage of engraftment and trend of growth, fluorescence and nutrition);
2. Effect of the urban pollution on the vegetation (content of pollutants and heavy metals on foliage);
3. Chemical-physical properties of the substrate (since it is characterized by the loss of initial stability).

Moreover, the analysis of thermal effects to the near external environment of the terraces is conducted with a microclimatic station, in order to assess how the contribution of vegetation to the well-being feeling experienced by users is.

The objectives of the research are primarily to provide scientific data, descriptive of the Bosco Verticale. Furthermore the data, analyzed in relation to the living green technologies applied and the design choices adopted, provide useful information for:

- What types of vegetation are better suited to different areas of a tall buildings and why;
- Identifying key parameters and values for the design of living green technologies applied to tall buildings;
- Evaluating how to contain the maintenance activities.

The monitoring research of the Bosco Verticale – funded by the CTBUH Seed Funding Research 2013 – is still in progress.

城市建设的密度越来越高，并且"土壤硬化过程基本上是不可逆的" (Prokop等人，2011年)，因此绿色可通过植物与建筑立面的结合在建筑环境中得以恢复。近几年来，绿色生态屋顶被广泛使用，因为植被土壤厚度减小能保证内饰良好的热性能，对外部环境有益 (Palomo Del Barrio，1998年; Theodosiou，2003; Liu，2007年)，特别是在暴雨的条件下这种益处更为显著 (Mentes，2006年; Palla，2010年; Giacomello，Zannoni，2012年)。相比于绿色屋顶，绿色生态立面是一个先进技术系统，应用更为先进，维护要求更高并且系统的集成性更高。

如今，适用于高层建筑立面的绿色生态技术可以被定义为"边缘性技术": 对比其他建筑类型，在高层建筑上植物的生存条件更加恶劣，原因是位于离地面更高的位置，并且要承受更高的大气强度 (特别是在有风的条件下)。

在项目早期的阶段，这项研究就已经包含对空中森林的监控程序。空中森林的特点是，两座大楼的所有立面的深悬臂式露台都均匀地分布植被 (见图1)。由于这种高楼外墙上密集种植方式是前所未有的，监控程序可以帮助开拓一个全新的学科领域，对树木的使用和植物作为摩天大楼环境和建筑构件的作用进行研究。

监控则是通过实验测试中十二个开敞区域的数据收集而实现，这些区域包括: E号塔楼每个立面的低、中、高区域。这些外墙正好朝向东南西北。

对12个区域的测试及测量内容包括:

1. 较高大树种的生理功能 (叶绿素含量，移植成活率和生长状况，荧光和营养信息);
2. 城市污染对植物的影响 (污染物和叶子上的重金属含量);
3. 种植基质的化学物理特性 (初始稳定性损失的情况常常发生)。

另外，小气候站对露台外部环境附近热效应进行分析，以评估植物对用户幸福感体验的作用。

本研究的目的主要是为空中森林项目提供科学数据和描述性统计。此外，由绿色技术应用和设计选择的分析得到下列有用的信息:

- 适合高层建筑不同位置的植物类型，以及差异的原因;
- 确定适用于高层建筑的绿色技术的设计关键参数和价值判断标准;
- 评估维护工作

空中森林项目由CTBUH种子研究基金2013年资助，并仍在进行中。

Figure 1. The Bosco Verticale Towers
The Bosco Verticale consists of two residential towers. The Tower E (on the right) is 112 meters high by 26 floors, the Tower D (on the left) is 87 meters high by 18 floors.
图1. 空中森林双塔
空中森林包括两幢住宅大厦。E座 (右) 高112米，26层; D座 (左) 高87米，18层。

The Urban Context of the Bosco Verticale

The Bosco Verticale consists of two residential towers located in the Porta Nuova area in Milan, North-East of the historic center of the city; the Tower E is 112 meters high, while the Tower D is 87 meters high.

The two towers (currently in the final stage of construction) are part of a wide urban transformation project, one of the largest currently under construction in Europe. The lot of the Bosco Verticale is located in front of the Unicredit Tower and will border the urban park called "Library of Trees" which will have an extension of 9 hectares.

The large urban project, divided into the three areas Garibaldi, Isola and Varesine, benefits from the proximity to the city center and the excellent accessibility (two nearby railway stations, two underground metro lines, a new tunnel passing under the plate of the Unicredit Tower, several tram and bus lines), and introduces a functional mixité which includes offices, retail spaces and residential buildings interconnected by large green areas and pedestrian paths.

Description of the Living Green Envelope

The study of the green living envelope of the Bosco Verticale is the core of the monitoring program. The envelope is a tridimensional combination of constructed and natural elements: structures and floors, walls, windows, systems on one side; plants, substrate and water on the other. Referring to the different behavior of the building technologies and agro-technologies, the constructed elements can be defined as "inert" while the natural elements can be defined as "dynamic" (Weiler, 2009).

There are essentially three elements that compose the envelope (see Figure 2): the outward walls (which separate the internal spaces from the external environment), the cantilevered terraces and the vegetation. All the terraces of the Bosco Verticale are characterized by a remarkable depth (about 3,30 meters), a distribution along more of 50% of each floor perimeter and the presence of dense vegetation (including trees up to 9-10 meters high (see Figure 3). A large part of the outward walls are shielded by the cantilevered terraces and the foliage of plants.

The terraces represent at the same time an extension of the flats to the outside, an element of architectural characterization and qualification, a shield for the backward space and shading elements for the outward walls and floors.

The Outwards Walls

The layering of the outward walls of the Bosco Verticale is quite simple. The infill wall is made of honeycomb bricks, coated on the outside with mineral fiber panels for thermo-acoustic insulation.

The exterior finishing consists of slabs in stoneware, charcoal gray colored, aerated, supported by a metal frame.

The doors to the terraces and all the windows are floor-to-ceiling in height. These characteristics significantly expand the illuminating surfaces of each flat, emphasizing the protagonist role of the trees in the perception of the external environment from the inside. The external environment and the city can in fact be seen through the foliage of plants located on the own terrace, or on other terraces one or two floors lower.

空中森林项目的城市文脉

空中森林包括两幢住宅大厦，位于城市历史中心东北米兰波特•诺瓦区域 (见图2) : E塔高112米，而D座高87米。

双塔项目 (目前在进行最后阶段的施工) 是欧洲目前规模最大并正在建设的大型城市改造工程的一部分。空中森林项目紧靠意大利联合信贷银行大厦，并将成为"树图书馆"城市公园的边界，未来公园的范围将扩展9公顷。

更大尺度的城市项目分为三个区域: 加里波第，伊索拉和瓦来希娜地区，项目地理位置优越，靠近市中心且交通便捷 (邻近两个火车站、两条地铁线，多个条电车和公交线路穿越，而且一条新隧道正好在联合信贷银行大厦下方穿过)，并引入了功能混合使用方式，包括办公室、零售空间、通过大型绿地和人行道相连的住宅楼等多种类型建筑。

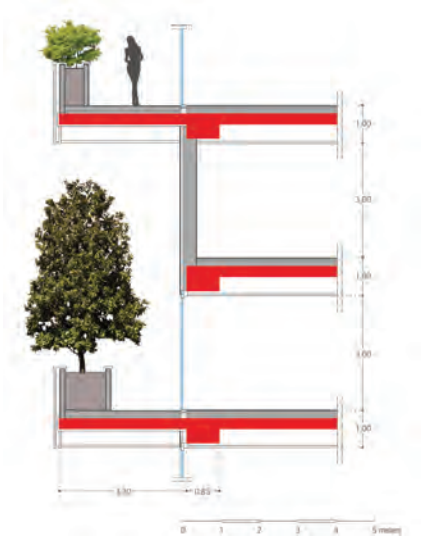

Figure 2. Vertical Section Of The Living Green Envelope
The load-bearing structure of the floors and of the cantilevered terraces is made in post-tensioned reinforced concrete. The depth of the cantilevered terraces is about 3,30 meters and, in some cases, the width is up to 14 meters. The plant containers of the terraces are placed towards the outside.
图2. 绿色生态立面的纵向剖面
楼板和悬臂式露台的承重结构由后张预应力钢筋混凝土制成。悬臂式露台深度大约是3.30米，宽度不等，最宽处达14米。露台的植物种植器朝向外部。

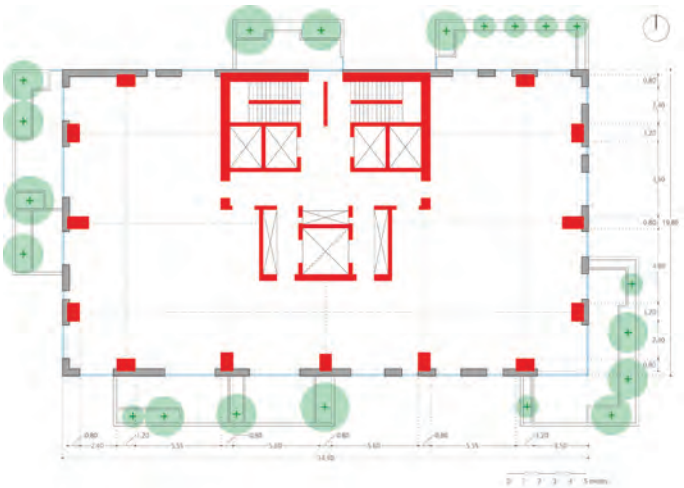

Figure 3. Horizontal section of the typical floor plan of the Tower E
The structure of the Bosco Verticale is made entirely of reinforced concrete. The vertical load-bearing structures are formed by 13 pillars, placed on the perimeter of the floor plan, and by the service core, containing two staircases, three lifts and five ducts for the systems.
图3. 塔E标准层平面图
空中森林的结构完全是由钢筋混凝土组成。垂直承重结构包括放置在建筑平面边界上的13个柱子，核心筒包含两个楼梯、三部电梯、和五管道系统。

The Cantilevered Terraces and the Plant Containers

The cantilevered terraces of the Bosco Verticale are 3.30 meters deep, with different widths up to 14 meters. All the plant containers are aligned to the outer edge.

The volume of the containers depend on the dimensions of the plants installed: in case of a tree the internal volume is 1.10 meter high and 1.10 meter deep, while in case of shrubs and herbs the volume is around 50 centimeters high and 50 centimeters deep.

The containers are filled with a substrate made of a mixture of volcanic lapillus, soil and a low rate of organic substance (according to the Italian Standard for Green Roofs, Uni 11235, 2007). Being a key element of the living green technologies for buildings, the substrate ensures optimal functions of water retention, permeability, structural stability and density.

The substrate is separated from the waterproofing membrane of the container by a protection layer against root penetration and by a drainage layer made of two synthetic non-woven filters with a tri-dimensional filament core in polyamide. This layer has a drain structure with a high level of vacuum to ensure an optimal drainage of excess water, the permeability of the drainage pipes over time, the air circulation along the sides of the containers.

The Trees and the Vegetation

The vegetation, the real revolutionary element of the Bosco Verticale, has influenced every aspect of the design: structures, façade design, organization of the flats, systems, etc.

The vegetation allows a special use of the terraces. The terraces are protected and shaded by the trees which create unexpected and comfortable locations: the terraces are outdoor, private, and at high altitude with a long view on the city of Milan. Moreover the vegetation, being an outer and dense layer, is the main element of the façade definition. The strong effect on the perception of the façades is given by many factors, including an excellent chromatic combination between the charcoal gray of the outward walls, the white of the cladding panels of the terraces and the many hues of green, and a very well balanced sequence of terraces and transparent and opaque surfaces. Furthermore the vegetation itself is a valuable element value for the architecture: the plants have a variable geometry, they move with the breeze, they reflect the light and produce irregular shadows, they gradually change colors, shape and appearance during the months and the seasons.

The vegetation of the Bosco Verticale is made by an exceptional variety of selected species.

The plants belong to three different categories: trees and large shrubs; shrubs and bushes; ground cover plants and herbaceous perennials, with more than 90 different species and around 13,000 plants. Approximately 700 trees, which belong to 23 different plant species, are living on the two towers (see Figure 4).

绿色生态立面说明

空中森林绿色生态立面研究的核心是监控程序。立面是构造和自然元素的立体组合，一方面包括结构、楼板、墙壁、窗户、运行系统; 另一方便包括植物、种植基质和水。根据建筑技术和农业技术，静态构造元素无生命，而自然元素具有"动态性"和生命活力 (Weiler，2009年) 。

建筑立面的三个必备元素是 (参见图2) : 建筑外墙 (分割了建筑外环境和内部空间) ，悬臂式露台和植被。空中森林大楼每一层都有较大的深度 (约3.30米) ，每层大于周长50%的边界上都分布着茂密的植被 (树木高达9-10米) (参见图3) 。建筑外墙很大一部分被悬臂式露台和植物的叶子遮蔽。

每层公寓的悬挑露台都同时向外部延伸，这是建筑特征和质量的体现，同时也能遮蔽后部空间，并为建筑外墙和楼层提供阴影。

延伸的外墙

空中森林延伸的外墙分层方式十分简单。该填充墙由蜂窝砖砌成，表面涂抹矿物纤维面以达到隔热效果。

外部装修包括地面瓷砖，由金属框架支撑的灰色加气木炭。

露台的门和窗户都从地板到天花板通高，这能扩大每个居住单元的采光面，并强调了室内视角向外观看环境时树木的主角地位。实际上，户主可以透过自己露台上植物叶子或者在楼下一两层露台上看到城市外部环境。

悬挑露台和植物容器

空中森林的悬臂式露台深3.30米，宽度不等，最大宽度达14米。所有植物容器外边缘对齐。

容器的大小取决于所其中种植植物的尺寸: 植树容器高1.10米，深1.10米; 灌木和草本植物容器高50厘米，深50厘米。

Figure 4. The Tower D Seen from the Tower E
The trees species planted on the Bosco Verticale are 23. It is possible to notice that some trees are expected to grow up to three floors which mean 10 meters.
图4. 从E座塔楼视角看D座塔楼
空中森林的树种有23个。一些树木可生长达10米，约等于三层楼的高度。

The plant species were selected in order to meet most of the characteristics listed below:

1. tolerant of unfavorable urban conditions, such as the high rates of pollution;
2. withstand high winds (i.e wood flex);
3. tolerant of pruning;
4. not stimulants allergies;
5. resistance to pests, diseases, and fungus;
6. do not produce big fruits (to avoid the risk of injury in case of fall from high);
7. need reduced and easy maintenance.

The placing of the trees in different orientations follows the ability of the species to adapt to sunlight rather than shade. In the south and west façades are located ever-green species, widespread mainly in Mediterranean climates (or similar), tolerant to heat, as Olive trees or Holly oaks. Differently, to the east and the north are placed species able to adapt to shade and cooler temperatures, chosen between those living in hilly-mountainous areas of Italy, but also Southern and Central Europe, such as, field maple or spring cherry.

Other criteria were considered for the placing of the trees in height. On the upper floors smaller, slower growth or shrub-shaped species were installed in order to control two important problems. Firstly, to limit maintenance activities such as pruning consequently minimizing the volume of organic waste removed from the site. Secondly, slower growth creates stronger wood avoiding breakage of tree-branches due to the wind. For example, on Tower E, the European beech has been planted up to the 8th floor and the Persian ironwood has been planted from the 13th to the 26th floor. The two species are very decorative having similar leaves. They are both hardwood species, but the first is a large tree and does not well tolerate pruning, while the second, Persian ironwood is a shrubby tree characterized by a very slow growth (see Figure 5).

It is also very important to emphasize that on the two towers are coexisting trees and plant species that in nature would not have developed close to one another. Despite the name, the Bosco Verticale does not imitate a natural forest. It is a designed combination of plants placed in highly artificial conditions, selected to resist to the unfavorable microclimatic conditions of the two towers, assisted by frequent professional maintenance. Nevertheless, the biodiversity of the Bosco Verticale is high and will likely affect the animal biodiversity of the district (also considering that the front of the two towers will be composed of an urban park of 9 hectares). Many plants, in fact, produce fruits, berries, and flowers. The vegetated wall system provides shelter and water: for these reasons the colonization of small animals, such as birds and insects, is already underway.

The Anti-Fall Safety System

The anti-fall safety system represents a fundamental device of the façades. The trees are secured to the structure of the terraces, through two systems:

1) the anchoring of the root ball: on the bottom of the plant container is positioned a steel-welded-net through which three textile belts are passed in order to fix the roots ball (see Figure 6);

2) the fall arrest system of the trunk and broken branches is a steel cable anchored to the plant container (where the tree is installed) and to the structure of the upper terrace. Three elastic belts, that wrap the

容器中填充火山峨螺土壤和有机物质 (根据意大利屋顶绿化标准，Uni 11235，2007)，以及小部分的有机质。绿色生态建筑技术的一个关键因素是基板的保水性，透气性，结构稳定性和合理密度，具有优良的特性才能发挥最佳功效。

具有对根渗透作用的保护层、排水层将基底与容器的防水膜隔开，排水层由两层聚酰胺无纺布合成。这样的构造具有排水性结构并且高度真空，以确保排出多余的水分; 排水管具有透气性，空气能沿着容器的侧面流通。

树木和植被

植被作为空中森林的真正革命性元素影响了设计的各个方面，包括结构，外观设计，居住单位组织和整个系统。

植被对露台有特殊的功能。树木给露台提供了保护和遮蔽，并创造了意想不到的舒适环境: 露台为使用者提供了户外私人空间，使用者能够在高空远眺城市。此外，位于外部茂盛植被是建筑立面的主要元素。强烈的视觉效果有很多原因: 延伸的外墙、白色露台覆面板、满眼深深浅浅的绿色、露台的和谐排列、透明和不透明的立面的组合。此外，植被本身也是一个有价值的元素: 植物具有

Figure 5. Trees Species Choices: European Beech (Fagus sylvatica) and Persian Ironwood (Parrotia persica)
The European beech (first from the left) has been planted until the 8th floor of the Tower E; the Persian ironwood (second and third from the left) has been planted from the 13th floor to the 26th floor. Both species are characterized by a hard wood, but the first is a large tree with a main trunk, while the second is a shrubby tree that grows very slowly. The Persian ironwood, compared to the European beech, should produce less waste from pruning and should better tolerate the wind effect.
图5. 树种选择: 欧洲榉木 (欧洲山毛榉) 和波斯铁力木 (伊朗银缕梅)
E座1层至8层种植欧洲榉木 (左一)；13层到26层种植波斯铁木 (左二和左三)。这两个品种非常具有装饰性和外观相似，因为它们具有相似的叶子。木质坚硬，但是前者的体量较大，且修剪不易; 而第二个是灌木品种，生长缓慢。

Figure 6. Anchoring System Of The Root Ball
The textile belts fix the roots ball of the trees passing through a steel-welded-net positioned on the bottom of the plant container.
图6. 锚定根球系统
植物容器的底部放置三条皮布捆绑的钢网以固定植物的根球。

Figure 7. Telescopic arm on the roof of Tower D
The arm should drop the maintainers from the outside of each tower.
图7. D座屋顶伸缩臂
维护电梯由伸缩臂从每个塔外部降下。

Figure 8. Maintainers In Rope
Currently the maintenance activities take place from inside the terraces or from men in rope.
图8. 用绳索悬吊在外部的维护人员
目前的维修工作从露台内部展开，或者人系上绳子从外部进行维护。

main trunk together with the cable, allow the oscillation of the tree and, at the same time, retain the damaged parts of the tree in case of a breakage and allow the recovery of the wooden broken parts.

The Maintenace Activities

Maintenance is a key aspect for living green technologies. The green should be designed according to the expected maintenance. The quality and the success or failure of a green living system is closely related to the estimation of the maintenance. This is particularly true for tall buildings. In the case of the Bosco Verticale, all the vegetation is "property of the condominium" and the residents cannot operate independently on the plants. The ownership of the flat, indeed, does not include the vegetation and the plant containers.

There are two principals to the maintenance of Bosco Vertical:

1. Access to the plant containers through the apartments, 4 times per year;
2. Access to the plant containers from the outside with a basket lift (moved by a telescopic arm placed on the roof of each tower) that drops the personnel from the top to carry out the pruning and the activities that cannot be done from the inside, with a frequency of 2 times per year (see Figures 7 and 8).

可变几何形状，随着微风摇摆，对光进行反射，并产生不规则阴影，在不同的季节或月份呈现出不同的颜色，形状和外观。

空中森林的植被品种丰富，并经过严格筛选。

这些植物属于三个不同的类别: 树木和大型灌木; 灌木; 地被植物和多年生草本植物，总计超过90种品种，数量大约为13000株。两幢塔楼共包含树木700棵，属于23种不同品种 (见图4) 。

植物的品种以满足下列要求为条件来选择:

1. 具有较高耐受性，能抵御不良城市环境，如高污染;
2. 能抵御风，这得益于木材的韧性;
3. 能承受修剪;
4. 不具过敏性;
5. 能抵御虫害;
6. 果实小 (以避免高坠物的风险) ;
7. 维护方便。

根据植物适应阳光能力而非适应阴影的能力的不同将其摆放在不同方位。南面和西面的外墙布置常绿品种，这些植物能在地中海气候 (或类似) 条件下广泛生长，并具有良好的耐热性，比如橄榄树或冬青橡树。相比之下，东面和北面的品种能更适应荫蔽的环境和更低的温度，如意大利的丘陵山区、南欧和中欧的植物: 枫树或樱桃木。

考虑树木的放置高度的标准: 在上部楼层种植增长较慢的或灌木状的植物，以便解决下面两个重要问题: 一方面尽可能减少围护工作和有机废物的体积; 另一方面，避免由于风造成的破坏。例如: 在E座，欧洲榉木种到8楼，波斯铁力木种植从13到26层。这两个品种非常具有装饰性且外观相似，因为它们具有相似的叶子。两个品种都具有木质坚硬的特点，但是前者的体量较大，且修剪不易; 而后者是灌木品种，生长缓慢 (参见图5) 。

另外还有非常重要的一点需要强调，在双塔上的植物属于共存关系，它们在自然界中不会相互接近。尽管空中森林的名称如此，但是项目并不模仿自然森林。它是高度人工化条件下的植物组合设计，选择能抵抗两塔的不利气候条件的品种，并需要频繁的维护。但是空中森林项目中的植物群具有高度的生物多样性，并可能影响到城市此区的生物多样性 (考虑两塔前即将完成的9公顷城市公园) 。许多植物能够生产水果，浆果，花卉，而绿色植被系统提供了庇护所和水。由于这些原因许多小动物，比如鸟类和昆虫的栖息行为已经展开。

The costs of the ordinary maintenance are the sum of several items (including man-hours, transport and disposal of the plant scrap from pruning, water irrigation and fertilization) and are still unknown, since the ordinary services are not fully operational.

However, with the available information it is possible to assume that the time taken for the maintenance of each tree of the Bosco Verticale is 5 times higher than that of a tree of the same species placed on the ground.

Conclusion

The research activities carried out so far and the planned ones will help to answer the main question: how does a vertical forest work?

The scheduled tests and the data collection, the observations of the living green, the study of the façade technologies and the interviews with the protagonists of the project are addressed to:

1. Evaluate the applied technologies and agro-technologies, and the maintenance required;
2. Assess the thermal behavior of the living green envelope, in terms of benefits for the internal environment and the near external one;
3. Identify useful tools for the design choices in the field of living green technologies.

The future goal of this research is to set a protocol for designing the integration of plants to tall buildings and the Bosco Verticale monitoring may provide a fundamental contribution for this purpose.

防坠落安全系统

防坠落安全系统是外墙的基本设备。树木通过两个系统固定在露台的结构上:

1. 根球的锚固: 植物容器的底部放置三条皮布捆绑的钢网以固定植物的根球 (见图6) ;
2. 树干和碎枝的防坠系统，包括: 固定在植物的容器上和上部平台的结构上的钢线 (位于树种植的位置) 。三条将电缆与树干缠绕松紧带能够允许树的摆动，同时，支撑树的受损部位以防断裂，并允许受伤部位的康复。

维护工作

围护是对绿色生态技术的一个重要方面。绿色应该根据预期维修而设计: 绿色生态策略应用的成败与预估的维护密切相关，特别是高层建筑中。在空中森林项目的情况下，所有的草木都是"公共物业"，居民不能私自处理。该公寓的所有权不包括植被和种植容器。

维护活动包含以下两个方面:

1. 每年4次检修种植容器;
2. 用升降机到达种植容器 (由放置在每个塔的屋顶伸缩臂驱动) ，人员从顶部下降到一定的高度进行修剪和围护活动，不能从内部进行修剪，保持每年2次的频率 (见图7和8) 。

普通保养的费用包括人工费，运输和处置树枝，灌溉和植物的施肥，这些费用都是不确定的，因为这不包含在普通服务内。

然而根据可用的信息能够推断，空中森林中每棵树的维护成本和维护时间比地面上树木高5倍。

结论

到目前为止的研究能够帮助规划者回答一个主要问题: 垂直森林如何运转?

制定测试和数据收集，绿色生态观察，立面技术研究，与项目负责人访谈针对下列几个方面:

1. 应用技术和农业技术的评估和所需的维护工作;
2. 在内部和外部环境效益方面评估绿色生态立面的热效应;
3. 确定在绿色生态领域选择设计的有用工具。

研究的未来目标是建立一个用于高层建筑植物一体化设计框架。对此，空中森林项目的监测经验能够做出基础贡献。

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