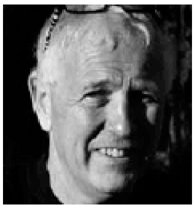
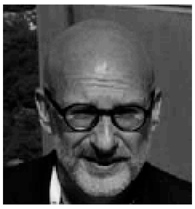
A "Flight Manual" for Air Plants


Lloyd Godman


Stuart Jones


Grant Harris

Authors

Lloyd Godman, Ecological Artist
90 Shaftesbury Ave., St. Andrews
VIC 3761, Australia
t: +61 44818 8899
e: Lloydgodman@gmail.com
www.lloydgodman.net

Stuart Jones, Technical Director
Hyder Consulting
Level 16, 31 Queen St., Melbourne
VIC 3000, Australia
t: +61 3 8623 4000
e: Stuart.Jones@hyderconsulting.com
www.hyderconsulting.com

Grant Harris, Principal
Ironbark Environmental Arboriculture
3/11 Coate Avenue, Alphington
VIC 3078, Australia
t: + 61 41560 7375
e: contactgrantjharris@gmail.com

Lloyd Godman is an ecological artist and has an MFA from RMIT University, Melbourne. He has had more than 45 solo exhibitions and been included in more than 250 group exhibitions. His current work explores living plant works and "super-sustainable" art. In 2011, he began creating suspended rotating plant sculptures and since then has worked with plants on tall buildings, including Eureka Tower, Melbourne.

Stuart Jones has recently been appointed Technical Director for Hyder Consulting in Melbourne. Previous to this he was the Owner/Director of Point 5 Consulting in Melbourne for 14 years. Stuart has over 25 years' professional experience in all phases of project delivery and specializes in creative structural design, with extensive experience in Australia and throughout Asia.

Grant Harris is the principal of Ironbark Environmental Arboriculture, with more than 12 years' experience in the arboricultural sector. He also holds a degree in Environmental Science (Wildlife and Conservation Biology). His particular areas of interest are the use of green infrastructure to mitigate urban heat island effects and urban ecology.

The green fabric that clothes the earth is fraying. Sadly, through overuse, the garment we depend upon is wearing out. The construction of buildings and urban infrastructure like roads and car parks become "dead pixels" in the living image of the planet. Repairing the old garment by stitching plants into the structures of our cities is a vital option. Incorporating plants into tall building design is an important aspect of this restoration project. This paper describes the successful installation of plants on the exterior of Melbourne's iconic Eureka Tower (see Figure 1) and provides an example of a selective vertical gardening system with a high Environmentally Sustainable Development (ESD) factor, which eliminates the requirement for plant growth substrate.

The Importance of Vertical Gardens

From simple organisms, evolving through millions of years to complex biological systems, vegetation has obeyed its innate compulsion to cover the planet with a living green membrane that supports all other life. Plants have waxed and waned in their fight to cover geological surface since the Ordovician period (495 million years ago), and as we progress through our current era, the Anthropocene, it is evident that human actions are the primary determinant for the survival or extinction of species. The exponential rate at which our cities have expanded demands that we now plan and act to integrate our urban centers into the biosphere of the planet. The combined surface of high-rise buildings and other urban infrastructure can provide significant areas to support plants, and weave back the threads of green fabric.

Integrating plants into the built environment improves air quality, moderates temperatures (Saadatian et al. 2013), improves human well-being, lifts the spirit (Townsend & Weerasuriya 2010), and can provide habitat for other species (Oberndorfer et al. 2007). In March 2015, it was promising to see a law passed in France, which mandates that rooftops on new buildings built in commercial zones must either be partially covered in plants or solar panels. This mandate draws a line, whereby inspiring contemporary architecture will be measured by the successful integration of living green texture into the fabric and form of the structure. Imagination and experimentation have driven a welcome expansion of roof and vertical gardens in recent years. The urbane tall buildings we now see may quickly become historic symbols of a past age, when architecture was less connected to nature.

Vertical Garden Systems

Utilizing living plants as an effective façade poses many problems. Unlike metals, glass and concrete, which are inert, plants require nurturing. Concerns over increased maintenance costs (Zhang et al. 2012), damage to façades, and increased loading on structural systems (Wood et al. 2014) are barriers to the implementation of green roofs and walls. Zhang et al. provide a succinct definition of "intensive" and "extensive" green roof systems.

Intensive green roof systems are characterized by deep (greater than 15 centimeters) growing media, opportunities for a diverse plant palate on the rooftop, and high maintenance requirements. In many cases, intensive green roofs are being replaced by *extensive* green roofs, which have a much thinner, lighter media (thus fewer structural requirements), and offer fewer, but potentially more practical plant choices.

Building on Zhang's categorization of green roofs, the authors propose that incorporating vertical gardens into a building's design can employ two systems, which are adaptive or selective.

Adaptive systems

Analogous to intensive green roofs, adaptive vertical gardens require the environment to be adapted to support the plants' biological demands, which will vary depending on the ecophysiological characteristics of the selected species. This condition is met by mesh-mounted plant growth substrate, irrigation and fertilization. The benefit of adaptive systems is that they allow a greater selection of species; however, they have limitations, including the cost of installing and maintaining structures to support plant growth substrates (Pérez et al. 2011).

Selective systems

Akin to extensive green roofs, selective systems use critical species selection to identify plants that naturally grow in environments similar to those encompassing an existing building's façade. They have the advantage of reducing or eliminating the requirement for plant growth substrate and associated installation and maintenance costs. The limitation of selective systems is a reduced plant palette.

Plant Selection

Epiphytic plants are those that use other plants for mechanical support; a diversity of plant groups has evolved to fill this environmental niche. Life as an epiphyte, high in the forest canopy, exposes the plant to greater fluctuations in moisture availability in comparison to their terrestrial cousins, nestled comfortably in the soil below. Tillandsia (see Figure 2), which is a genus of the Bromeliad family, includes more than 1,000 epiphytic species (Benzing 1990) that have evolved to have no requirement for soil and tolerance of extremes in moisture availability. Both of these are attractive characteristics when choosing plants for utilization in a selective vertical garden system.

Tall buildings present an extremely challenging environment for plant growth, where consistently high wind speeds increase transpirational losses and thereby increase water stress on plants growing in these environments. *Tillandsia bereri* and a hybrid, Houston, were selected to test the concept of a selective vertical garden system because they have the following characteristics:

Drought tolerance

Bromeliads minimize transpirational water losses by utilizing the crassulucean acid metabolism (CAM) cycle, in which the stomata are closed in the heat of the day and open to uptake CO_2 at night, releasing oxygen during darkness (Benzing 1990). Moisture and nutrient uptake occur through specialized trichome cells, further reducing transpirational water losses; these adaptations make Tillandsia very drought-tolerant.

No requirement for soil

One adaptation of Tillandsias to the epiphytic life-mode is the modification of the role of the roots from that of moisture and nutrient absorption to that of "hold-fasts" that function only to attach the plant to the substrate (Benzing 1990). The leaves of the plant replace the role of the roots and sequester moisture and nutrients directly from the atmosphere,

Figure 1. Eureka Tower, Melbourne. © John Gollings

leading to the colloquial name of "air plant." This adaptation removes the requirement for a plant growth substrate to be installed on the building façade. The lack of water-seeking roots also negates building managers' concerns about potential damage and maintenance costs.

Absorption of airborne pollutants

The trichomes of Tillandsia have a high absorptive capacity, which allows them to absorb air pollutants rapidly (Li et al. 2015). The installation of large Tillandsia screens on tall buildings has the potential to act as an air filter for the building and surroundings.

Minimal weight

Based on previous installations, the weight of a Tillandsia screen is estimated to be 3 kg/m^2, which is minimal in comparison to adaptive systems that require plant growth substrates and supporting structures. The light weight of Tillandsia means they are perfectly suited for use on screens (Pérez 2011) and can be placed in arbitrary shapes on the building

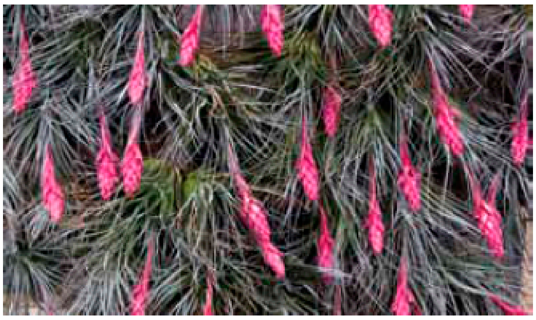


Figure 2. Tillandsias, the "air plants" chosen for the experiment.

> "The leaves of the Tillandsia sequester moisture and nutrients directly from the atmosphere, removing the requirement for a plant growth substrate to be installed on the building façade."

Figure 3. Tillandsia plant cages installed at Eureka Tower.

exterior (Wang et al. 2011). Plant screens have demonstrated effectiveness as passive energy-saving systems (Pérez 2011).

Methods

The project team installed eight Tillandsia plants in wire cages in groups of two, affixed to secure points at four locations on the Eureka Tower. Plant cages were installed at Levels 56, 65, 91, and 92 (see Figure 3). The aspect of the building at which the plants were placed was determined by the location of available balconies and cage attachment points. Plants were photographed and labeled prior to placement in the cages.

Plants were inspected four times in the period between June 17, 2014 and May 20, 2015, and health categories were recorded for each specimen (see Table 1 and Figure 4). The proportion of living foliage was used to evaluate plant health (Costello 2003) and observations were assigned to one of six ordinal health categories. These were *dead* (<10% live growth), *very poor* (<25% live growth), *poor* (<50% live growth), *fair* (>50% live growth), *good* (>75% live growth), and *excellent* (>90% live growth). Plant health was assessed by visual observation of each leaf of the subject plant. When an individual leaf was in a state of decline (>35% dead tissue) this was categorized as *dead*. The relative proportion of live and dead leaves was used to assign a health category to each plant. No supplementary irrigation or fertilization was provided to the plants during the installation period.

Weather records were obtained from the Eureka Tower meteorological station, and periods of low rainfall and high temperatures were identified during the survey period.

Results

During the October 16, 2014 inspection session, some leaf die-back at locations farthest from the growing tip was observed. This is attributed to the acclimatization of the plants to the new environment. All of the plants maintained high levels of health, with the exception of one on Level 91. This plant was located in the most sheltered position, an external stairway niche receiving the least rain and sunlight.

During the February 25, 2015 inspection, this plant was observed to be the only plant to have flowered during the experiment period and to have formed new "pups" (vegetatively produced new plantlets). During the May 20, 2015 inspection, plants on Levels 56 and 65 were also observed to be forming pups.

Discussion

The trial results indicate that Tillandsias are able to survive on the exteriors of tall buildings without supplementary irrigation. At approximately 300 meters above grade, the Level 92 installation is the world's highest

> "The trial results indicate that Tillandsias are able to survive on the exteriors of tall buildings without supplementary irrigation. At approximately 300 meters above grade, the Level 92 installation is the world's highest plant installation on a building and a proof of concept for selective vertical garden systems."

Level	Height (m)	Plant	Date of visit			
			winter	summer		winter
			Jun 17, 2014	Oct 16, 2014	Feb 25, 2015	May 20, 2015
56	179.5	B1	●	●	●M	●M
56	179.5	H2	●	●	●M	●M
65	208.5	B3	●	●	●M	●M
65	208.5	H4	●	●	●M	●M
91	292.3	B5	●	●✿	●M	●M
91	292.3	H6	●	●	●M	●M
92	298.3	B7	●	●	●M	●M
92	298.3	H8	●	●	●M	●M

B *Tillandsia bergeri* H Tillandsia 'Houston' ✿ Flower M Pups

Plant state: ● Excellent ● Good ● Fair ● Poor ● Dead

Table 1. Tillandsias installation results over time.

plant installation on a building and a proof of concept for selective vertical garden systems.

Buildings within the urban environment are essentially pieces of refined geology, so when endeavouring to integrate plants into high-rise buildings, one must first observe plants that inhabit similar hostile environments in nature. Basically, buildings are high vertical cliffs of rock with no humus, often no water retention, and extreme temperature changes, which is the type of environment to which some species of Tillandsia have adapted and thrive in. Plants on tall buildings are subjected to high wind speeds and limited soil volumes, which places great pressure on irrigation systems to provide water to counteract transpirational losses. Such demanding ecophysiological environments mean that, for some plant species, no matter how much water is provided to the root system, they are simply not able to uptake water at the rate of transpiration. For adaptive systems the functioning of the irrigation is critical, and there have been high-profile cases of green walls dramatically failing (Klettner 2009). The advantage of selective systems is that they are insulated from this threat.

Figure 4. The Tillandsias at Level 92 of Eureka Tower on May 20, 2015. Pups can be seen on the rightmost plant. © Toby Reed

Tillandsia in Other Urban Greening Projects

The CH2 building experiment

In 2011, the opportunity arose to stage a demonstration of the Tillandsia in a vertical urban condition. Collaborating with Ralph Webster, senior architect of the Melbourne City Council, the opportunity came to experiment with a few air plants in a demanding location on the new CH2 building located at 240 Little Collins Street (see Figures 5, 6, and 7). Existing climbing plants had struggled to thrive along the north wall, which is subject to very hot, dry winds, with the wind tunnel effect of a narrow alley exacerbating the dehydration. After 18 months, the Tillandsias proved that, while they grew slowly, they could thrive solely on their adaptive biological systems, requiring no soil or reticulated (pressurized) watering system, whereas the climbing plants originally installed continued to struggle. By February 2015, the climbing plants were still in place, but covered much less of the netting than in 2011, suggesting the effort to replant and maintain them had exceeded the environmental reward. The simple experiment offered a model for a larger project with City of Melbourne – *Airborne*.

The Airborne project

Supported through a City of Melbourne Arts Grant in 2013, the Airborne project presented eight air plant sculptures, which were installed for 13 months in central Melbourne with no soil or auxiliary watering system in a demanding location: Les Erdi Plaza, Northbank, Melbourne, adjacent to a busy rail corridor at Flinders Street Station. Despite prolonged periods of dryness, including record heat (with five consecutive days over 41°C), the plants grew and even flowered.

After 13 months, the growth habit of the plants had changed. They were more compact in structure, with shorter, harder leaves, and more silver in color due to increased levels of trichomes. However, pup production was more prolific, with seven or eight per plant, many more than in a less stressful location, where pup production

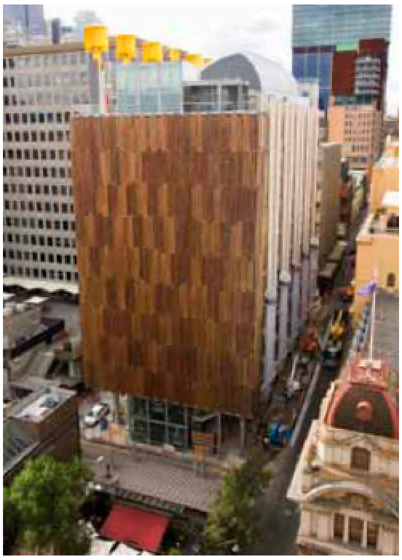


Figure 5. CH2, Melbourne. © David Hannah

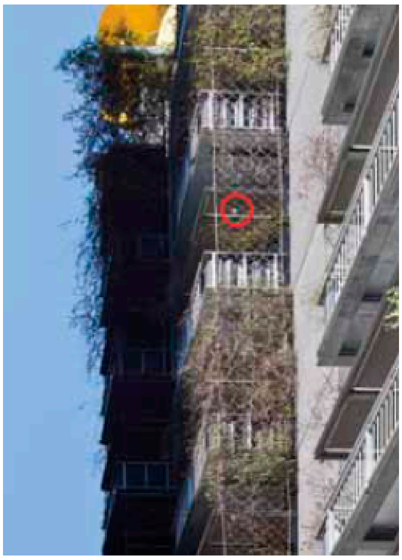


Figure 6. CH2 north façade in 2011. The location of the Tillandsia is marked with the red circle. Note the inconsistent growth of the climbing pants.

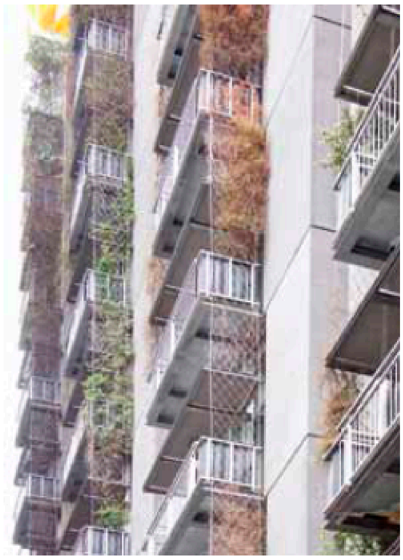


Figure 7. CH2 north façade in February 2015 shows the climbers with less growth than in 2011.

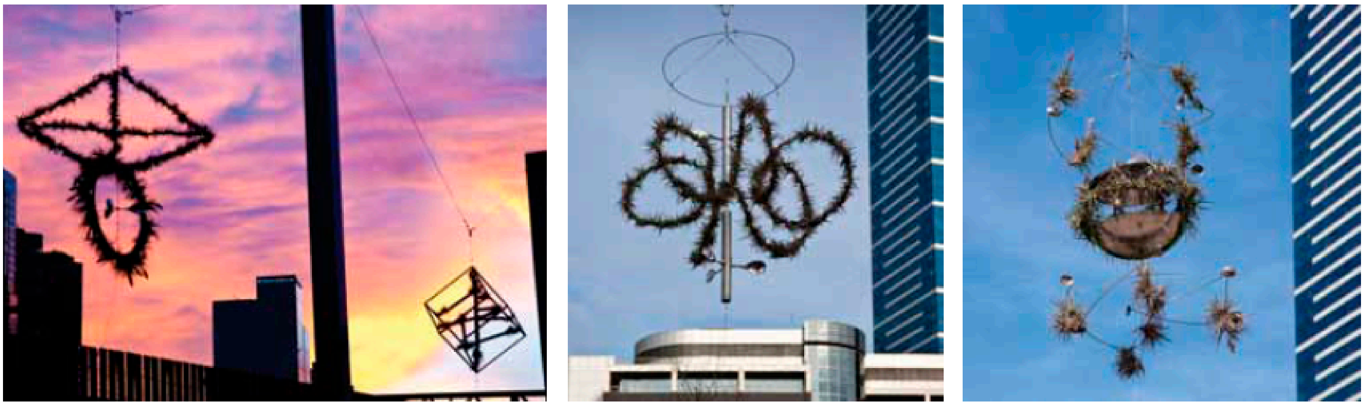


Figure 8. The *Airborne* project, Melbourne.

might normally be two or three. The authors attribute the increased production to the plants' biological "insurance" – if one or more pups die, then the plant has more reserve shoots from which to prosper. Also, a clump of plants creates greater shade, protecting other plants in the colony. Of several thousand individual Tillandsia used on the eight sculptures, only two plants died during the 13-month installation.

Rotating on swivels, the air plant sculptures dissipated energy instead of becoming excited, as a fixed sail might. During this period, a storm with winds of up to 115 kph ripped a large sculpture from its mounts only a few hundred meters away, and tragically brought down a brick wall that killed three people – but it had little effect on the living sculptures. While vertical and rooftop gardens occupy surfaces, the Airborne project proved that air gardens can successfully step beyond earthly confines to suspend between structures in open space, providing living, overhead screenings (see Figure 8).

Biological Insurance

The Eureka air plant experiment strongly suggests that Tillandsia plants can be grown with no soil or auxiliary watering system on the tallest of buildings in a city like Melbourne, and opens a portal for installing plants in a creative but effective and environmentally beneficial manner on high-rise buildings. The management of the Eureka Tower was very supportive of the experiment, and there is potential for a larger project in the future.

The authors continue to believe that "air plants" provide a significant advantage over plants that need to be supported by active watering and fertilization systems, not least because of the probability of "extreme events" that could rob the plant of its water and/or nutrients.

With a reticulated watering system, an extreme event might be:

- a pump failure, blocked pipe or drain
- a weather event like wind, cold, heat, or drought
- tracking, a condition where the liquid drips from the wall, down a leaf surface, and falls onto the ground below, which denies water to the plants below this point

Vertical and roof gardens most often fail because these factors are not considered or maintained. Because Tillandsias have no need of soil medium or a reticulated watering system, the risk factors are reduced. Importantly, there is also no risk of water ingress to an undesired aspect of a building, nor is there risk of roots penetrating and damaging the façade or structure.

Therefore, even if such an experiment should prove a "failure" with widespread plant deaths, the lightweight characteristics of the Tillandsia would not pose the same kinds of issues as hard-tissue plants like vines, such as scarring on and penetrations in the façade, if at any time they were detached from the building.

The Future: A "Flight Manual" for Air Plants

Buildings are statements; architects define surfaces and geometries within the overall structure through the use of metals, glass, concrete, and synthetics. However, responsible architecture in the 21st century not only considers the advantages of plants within the urban environment and simply "tacks" a vertical garden onto a wall, but draws from the diverse array of possible living textures of green, juxtaposing them against existing materials and textures, into the overall visual design of the structure at the concept stage. The addition of this new living material offers an exciting potential for the future, where imagination can soar to greater heights.

Imagine tidal gardens with multiple screens that move independently at various rates up and down a building's façade. Imagine whole façades of plants that shimmer on the wind and move from aspect to aspect on a building. Imagine a modular system, where Tillandsia are suspended across an open public space like a plaza during summer, creating dappled shade, and then simply moved onto a building's façade for the cooler winter months when the sun is welcome. Imagine roof gardens with suspended Tillandsia screens designed to create modulated shade patterns to complement other, less stress-tolerant plants that might grow on the roof surface below.

Figure 9. Example of Tillandsia screen.

Figure 10. View from inside of experimental movable living Tillandsia plant screens.

Tillandsia screens (see Figures 9 and 10) could be:

- moved horizontally or vertically in parallel from the building's façade across a window
- rotated on a curved axis, so while they can be set to block direct sunlight, they can also allow a clear view out the window
- set on a swivel off the building and rotated
- positioned horizontally out from the building for shading, or hinged upward.

Because there is no need for reticulated liquid, screens of Tillandsia can defy gravity in ways that are restrictive for other vertical garden systems. They can be mounted on façades that overhang or have complex, intricate geometric or organically curved surfaces. For future green architecture, they offer a flexible living texture which, with little maintenance, can be juxtaposed against glass, steel, or concrete. In fact it is possible to create living façades that alter their shape and form during the day.

As bromeliads grow asexually, over time they can be harvested to provide a bioresource to create new material. A significant advantage of integrating Tillandsias into a green building design is that a "living wall" can be completed in sections, along which, over time, the plants are harvested and assigned to the next section of a wall. A high-rise façade might be completed several levels at a time. Unlike current vertical gardens, there is no operating cost of water, pumps, and no need for replacement plants.

The results of these experiments with Tillandsia over the past few years have shown that designers can act with the knowledge and confidence that these systems work. Air gardens break new ground, offering fresh dimensions by incorporating plants in our cities for high environmental benefit. They write a "flight manual" for plants to escape their earthly confines in the urban habitat and occupy new and existing space within our cities. ■

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

References

BENZING, D. H. 1990. ***Vascular Epiphytes.*** Cambridge: Cambridge University Press.

COSTELLO, L. R.; PERRY, E. J.; MATHENY, N. P.; HENRY, M. J. & GEISEL, P. M. 2003. ***Abiotic Disorders of Landscape Plants: A Diagnostic Guide.*** Richmond: University of California Agriculture & Natural Resources Publications.

WANG, F.; ZHANG, X.; TAN, J. & LI, X. 2011. "The Thermal Performance of Double Skin Façade with Tillandsia Usneoides Plant Curtain." ***Energy and Buildings.*** Vol. 43: 2127–33.

KLETTNER, A. 2009. "Amazing Pictures: London's First Living Wall Dies." ***Architect Journal.*** http://www.architectsjournal.co.uk/news/daily-news/amazing-pictures-londons-first-living-wall-dies/5207086.article.

LI, P.; PEMBERTON, R. & ZHENG, G. 2015. "Foliar Trichome-aided Formaldehyde Uptake in the Epiphytic Tillandsia Velutina and Its Response to Formaldehyde Pollution." ***Chemosphere.*** Vol. 119: 662–67.

OBERNDORFER, E.; LUNDHOLM, J.; BASS, B.; COFFMAN, R. R.; DOSHI, H.; DUNNETT, N.; GAFFIN, S.; KÖHLER, M.; LIU, K. K. Y. & ROWE, B. 2007. "Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services." ***BioScience.*** Vol. 57: 823–33.

PÉREZ, G.; RINCÓN, L.; VILA, A.; GONZÁLE, J. M. & CABEZA, L. F. 2011. "Green Vertical Systems for Buildings as Passive Systems for Energy Savings." ***Applied Energy.*** Vol. 88: 4854–59.

SAADATIAN, O.; SOPIAN, K.; SALLEH, E.; LIM, C. H.; RIFFAT, S.; SAADATIAN, E.; TOUDESHKI, A. & SULAIMAN, M. Y. 2013. "A Review of Energy Aspects of Green Roofs." ***Renewable and Sustainable Energy Reviews.*** Vol. 23: 155–168.

TOWNSEND, M. & WEERASURIYA, R. 2010. ***Beyond Blue to Green.*** Melbourne: Beyond Blue Limited.

WOOD, A.; BAHRAMI, P. & SAFARIK, D. 2014. ***Green Walls in High-Rise Buildings.*** Chicago: Council on Tall Buildings and Urban Habitat.

ZHANG, X.; SHEN, L.; TAM, V. W. Y. & LEE, W. W. Y. 2012. "Barriers to Implement Extensive Green Roof Systems: A Hong Kong Study." ***Renewable and Sustainable Energy Reviews.*** Vol. 16: 314–19.