THE ULTIMATE FOR SKYRISE GREENING

BUILDINGS LIKE TREES, CITIES LIKE GARDENS

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Images courtesy of Tee Swee Ping and Chan Chung Leong
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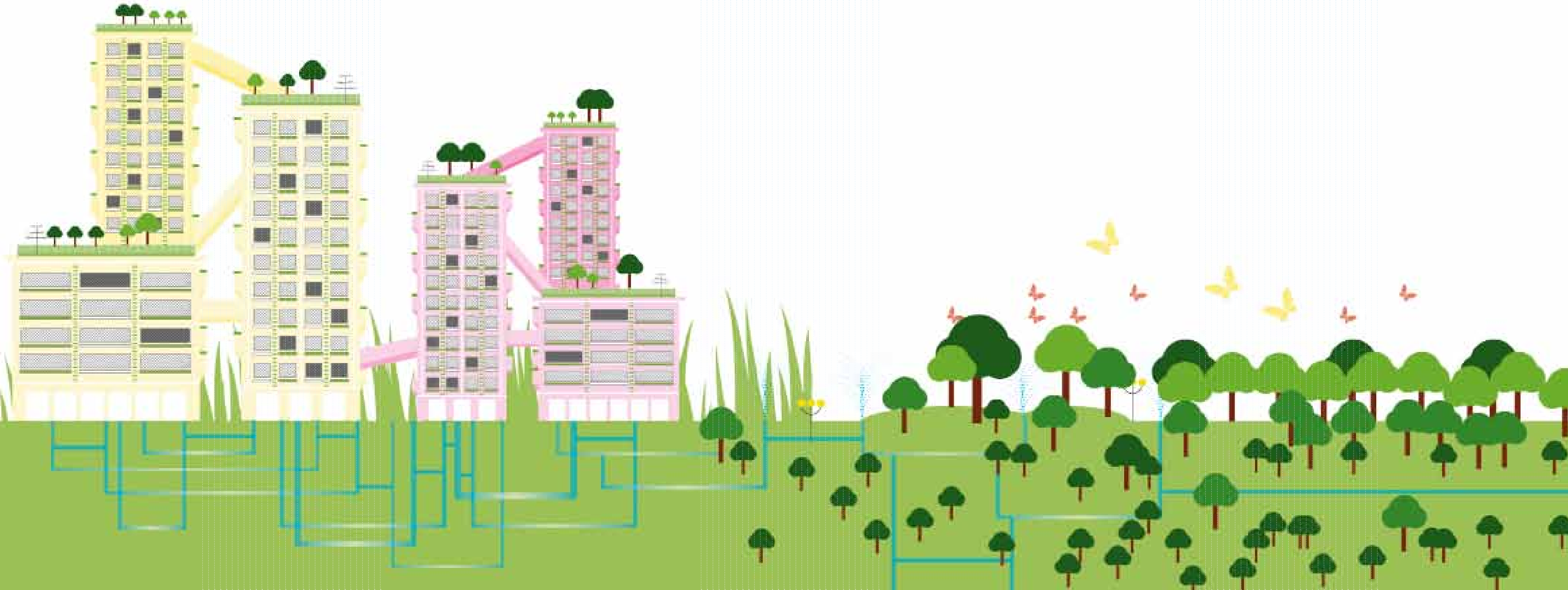
Planning for urban greenery in a city is usually an exercise in making trade-offs between (1) green and grey, (2) land for greenery and other infrastructural needs and (3) nature conservation and development. On the one hand, the benefits of urban greenery[1] have been adequately researched, justified and accepted to be an important green infrastructure of the city. On the other hand, a city also needs to set aside sufficient land to sustain economic growth, be a magnet for talent and investment, be culturally vibrant, and bring in tourism dollars.

So, what can urban planners do? Zoning or parcelling land to safeguard green spaces is a solution that has been tried and tested, and is still used in many cities. This inherently competitive process of deciding land use involves a loss versus gain of one or more of the land uses. Instead of taking a zero-sum mindset, one alternate strategy that could be pursued more vigorously is the integration of land, space and function, so that the whole is more than the sum of its parts. Skyrise Greening, the integration of greenery into the superstructure of buildings, is a good illustration of this strategy. Through its various forms, namely rooftop gardens, green roofs, vertical green walls and landscaped sky terraces, podiums, and balconies, skyrise greenery brings building occupants into direct and close contact with plants, using spaces such as roofs and building walls that are typically underutilised. Rather than lamenting that green spaces have been lost as a result of buildings, when appropriately designed, skyrise greenery can help to restore most, if not all, of the functions of original greenery at grade level. Specifically, it helps to improve the performance of the buildings, enhance its character, and act as a "carrier" of biodiversity, injecting flora and fauna into the built environment.

While attractive and functional in many ways, the current forms of skyrise greenery are best described as a layer of green clad onto the superstructure of buildings, be it at the horizontal or vertical plane. Such forms of skyrise greenery reflect the level of technology that is currently available. Unfortunately, this has probably not changed much from the days of the Hanging Gardens of Babylon and the early sod roofs of the Scandinavian countries. What if, sometime in the future, we progress from cladding a building with greenery, to designing a building that functions and behaves like a tree? An ideal endpoint will mean that a building is totally driven by solar energy as a tree is, regulates its internal temperature as a tree would through its leaves, drives its internal transport network using processes that drive the movement of solutes and water within a tree, and structurally supports itself using elements that keep even the tallest tree upright.

In the words of William McDonough, "What if buildings were alive? What if our homes and workplaces were like trees, living organisms participating



productively in their surroundings?" Achieving this will make buildings truly environmentally responsive, be in equilibrium with the environment, and not mere structures that consume energy and contribute to our high carbon and ecological footprint. Buildings can be an important component that blurs the boundaries and contrast between the built and the living world. Achieving this requires a transition from merely limiting buildings' impact on the surroundings to forging an affinity and interactive relationship with the living environment. This needs to be supported by new design concepts, innovations and technologies.

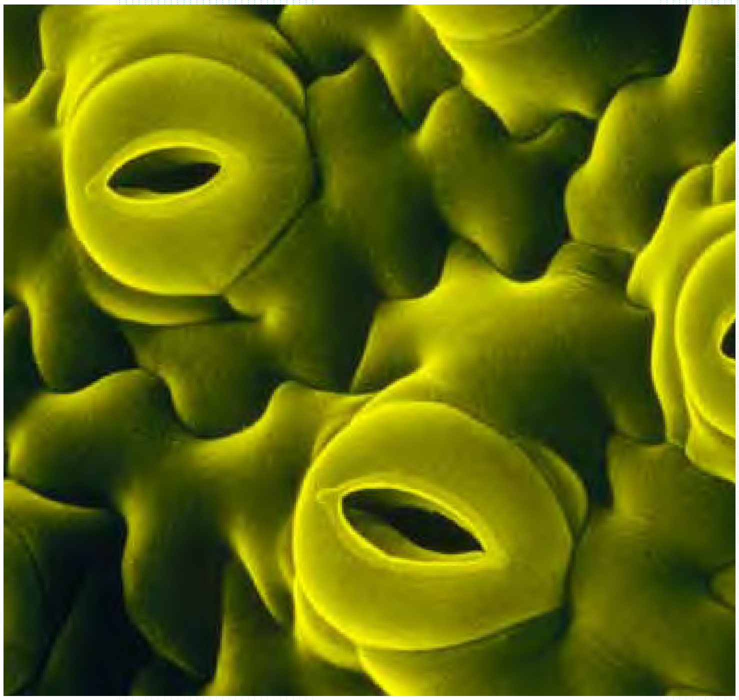
Much can be learnt from nature, where biological systems and processes have been optimised over millions of years of evolution. Learning from the laws of nature can spur innovations within the architectural and building professions. And the application of such innovation in turn makes a building interact more productively with its environment. A developing field in this area is biomimicry (also known as bionics, biomimetics, or biologically inspired design), the science of innovation inspired by nature, originally proposed by Janine Benyus.

Some ideas of how we can learn from nature in the design and construction of buildings, which are perhaps overly optimistic suggestions from someone who primarily deals with plants, are highlighted below.

THE BUILDING ENVELOPE

The building envelope separates the indoors from the outdoors, and exists primarily to protect the enclosed space from external climatic conditions, by moderating solar radiation, temperature extremes, rainfall and humidity, dust and wind. Current building envelope materials, such as glass, brick, concrete, stone, and wood, perform this function primarily through exclusion or separation. If one compares a building surface to a leaf, with the leaf lamina (or commonly known as leaf blade) equivalent to the envelope, and veins of the leaves equivalent to the supporting trusses, there are similarities, as well as unique features from the more natural system, that may be drawn out.

The external "walls" of the leaf lamina, called the epidermal layer, consisting of the cuticle layer, cell wall and plasma membrane, perform a similar set of functions to the building envelope. The epidermal layer protects the delicate photosynthetic and conducting cells, prevents ingress of pathogens, excessive loss of water and harmful radiation, and offers resistance against mechanical damage. Three other distinct functions of the epidermal layer can be models for future building envelope design and functions, as outlined below.



ABOVE Stomata. (Image copyright © Dr.Jeremy Bugess/ Science Photo Library)

The first is that the leaf's epidermal layer breathes. Leaves breathe predominantly through specialised "guard cells", which control thousands of apertures on the epidermal layer. These apertures are called stomata. It is through the stomata that gas and water exchanges take place between the leaf's interior surfaces and the external atmosphere. The gas exchange is, of course, critical for the process of photosynthesis, allowing carbon dioxide to be taken in by the leaf, and oxygen, as a by-product of photosynthesis, to be released into the surroundings. This tightly regulated process is indeed a fundamental defining feature of plants. Its importance is such that it has been estimated that twice the water content of the atmosphere and 40% of the atmospheric carbon dioxide in the tropics are cycled through the stomata of plants. The process of water exchange also cools the leaf's interior spaces and prevents overheating, which would otherwise occur under a constant radiation load from the sun.

What if the building envelope breathes like a living skin, allowing accumulated carbon dioxide, or other gaseous pollutants, to diffuse from the building's interior to its exterior, or allowing water vapour to diffuse from the exterior, where relative humidity is typically higher, into the building interior, where relative humidity is usually below human comfort level because of the air-conditioned environment? This would probably not replace a building's heating, ventilating, and air-conditioning system, but supplement it and reduce the energy load required.

The second unique feature is that the leaf senses the environment through the guard cells, in response to factors in the environment, ranging from the relative humidity of the atmosphere, and dryness of the soil, to the ambient light conditions. It is through such sensing that a plant is able to optimise its photosynthetic rate or trigger mechanisms for survival under unfavourable conditions. Imagine an intelligent building that regulates its internal conditions (for human comfort) according to surrounding environmental conditions!

The third unique feature of the leaf cells are morphological adaptations that reduce the heat load on the leaves. In wet and hot climates, evaporative cooling in plants, through the loss of water vapour from the leaves, helps to cool the leaves. In dry and hot climates, with limited water resources, many plants rely on adaptations like leaf hairs and depositing waxy materials to reflect radiation and reduce the heat load on the leaves. Such adaptations are also known to increase turbulent airflow over the leaf surfaces, which in turn help to cool down surface temperatures. These are learning points for innovation that may one day become alternatives to high albedo materials or heat-reducing paints, both currently advocated for use to reduce heat influx into buildings.

Beyond using plant-inspired mechanisms for designing building envelope materials, another area of research and development using biological or biomimetic methods of harvesting solar energy has been in progress for many years. The photosynthetic machinery of green plants can be simplistically broken down into two parts: a light harvesting component that captures solar energy and stores it in electrochemical forms, and a second component that uses the stored energy to run a sugar factory. Biological or biomimetic solar energy conversion methods, which attempt to use or mimic the light harvesting component of plants, could overcome disadvantages and limitations of current silicon-based photovoltaic systems. In fact, one such form of artificial photosynthesis, using specialised dyes in dye-sensitised solar cells, is now being commercialised as personalised solar power for consumers. When applied as another generation of building-integrated photovoltaics, this will help to move buildings closer to the ideal of trees, which harvest all of their energy needs from the sun.

THE BUILDING STRUCTURE

Trees are the tallest self-supporting and self-replicating living organisms built on a superb engineering material, wood, which has both strength and flexibility. Some, like the giant redwoods of California, can reach a height close to 100 metres. At such heights, a tree will have to resist high bending, twisting and possibly shearing and compressive forces imposed by wind loads to maintain its structural integrity. We are still unable to exactly describe how this is achieved mechanistically, but knowledge on this is slowly being advanced in the field of tree biomechanics. Fundamentally, advances will need to rely on understanding the structural composition of cells and tissues, as well as their spatial arrangement, to provide the necessary strength.

What is amazing too, is the adaptive capability of trees to react to localised mechanical stresses. For instance, when the trunk is deflected from the vertical, a specialised cell type that forms tissue called reaction wood is put up on the windward or leeward side of the trunk to straighten it vertically towards light. Reaction wood is further classified as tension or compression wood, depending on the speed and direction of the wind. While it is probably far-fetched to expect a building to respond in a similar fashion, learning the mechanisms and functions of reaction wood may lead to better optimi-

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sation in the structural design of buildings, hence avoiding over-engineering of building structures.

It has also been observed that trees growing in high wind conditions develop spirally-oriented wood fibre that tends to wind around the tree trunk, rather than grow parallel to the trunk. Such a "spiral grain" arrangement is thought to provide more flexibility to reduce wind drag and allow the tree to reconfigure more efficiently away from the wind. Understanding the mechanics of this may allow similar designs to be applied to structural columns or skyscrapers of the future.

It is important to note that imperfect knowledge does not stop innovations inspired by trees to be applied to architecture. One good example is the "tap-root" structural system of a building originally conceived by Frank Lloyd Wright in as early as the 1920s. Much has been written about how he thought about designing buildings with a central core, like the trunk of a tree, held in the ground by a deep central foundation, like a tap-root of a tree. From the central core runs cantilevered floors, like the branches of a tree, and building envelope walls hang from the floors, like the leaves off the branches. Such a design cleverly reduces the need for load-bearing interior elements. His first building, the Price Tower in Oklahoma, was described as "the tree that escaped the crowded forest". The Fusionopolis, part of the one-north business park in Singapore, is fundamentally also based on the concept of a single super-core and central column.

ABOVE Trees that grow in high wind conditions may develop spirally-oriented wood fibre that tends to wind around the tree trunk. (Images courtesy of Tee Swee Ping)

Similar to the tenets of biomimicry, the cradle-to-cradle concept of William McDonough and his colleagues promotes a holistic approach towards design and construction that is efficient and reduces waste. It is founded on three key principles: nature is driven by sunlight, nature recycles everything, where waste equals food, and diversity is key in nature. The concept of greening the highrise environment is a positive step towards biomimicry and cradle-to-cradle designs. It pushes developments to be more in equilibrium and in-tune with their immediate environment. Yet more can be achieved if innovations learnt from nature can be applied to the design and construction of buildings.

We can also make tremendous progress if we recognise that it is fundamental that the built environment we construct be allowed the maximum connection to the living environment and imposes the lowest possible disturbance to its surroundings. If one subscribes to these principles, it would not be far-fetched to expect that in the future, as we expect a myriad of flora and fauna growing on and around a tree in the forest, we should expect a building to be similarly designed to support flora and fauna, and be a biodiversity hotspot within the built environment, just as in nature. This will be the ideal and ultimate state of skyrise greening, whereby a building functions like a tree. A city with these tree-like buildings will truly become a garden for both humans and other biodiversity.

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[1] Some of such benefits include ameliorating the negative environmental impacts of excessive urbanisation, improving the comfort and quality of life of urban dwellers, increasing the resilience of cities to climate changes, and allowing biodiversity to establish in the built environment.

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