ISTRUCTE STRUCTRAL AWARDS 2013 – SUBMISSION BY ATELIER ONE

GARDENS BY THE BAY, SINGAPORE

COOLED CONSERVATORIES, SUPERTREES & AERIAL WALKWAYS

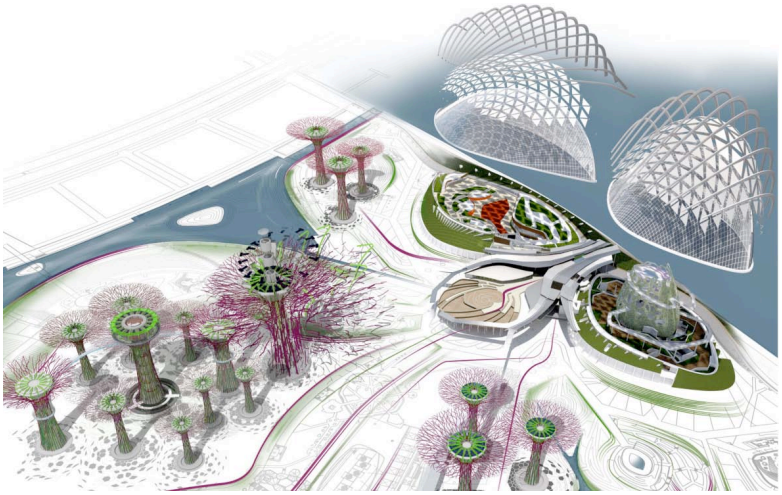
© Craig Sheppard, courtesy of Wilkinson Eyre

OVERALL PROJECT INTRODUCTION & OVERVIEW

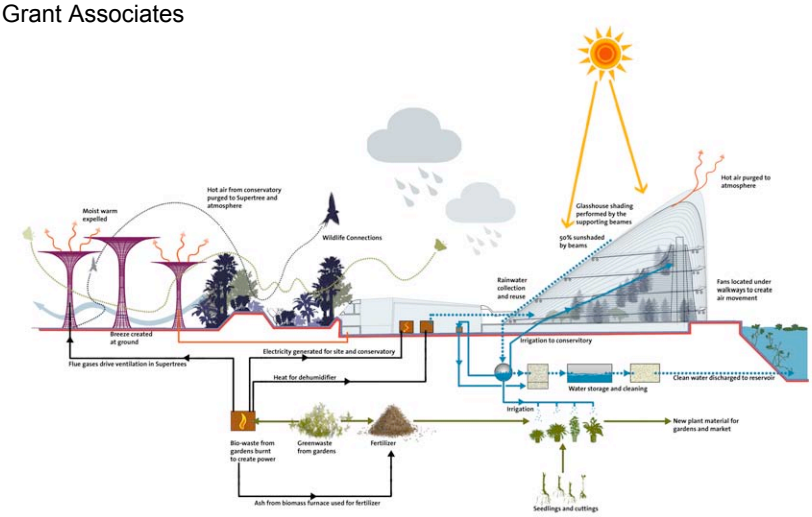
Gardens by the Bay is an integral part of Singapore's 'City in a Garden' vision, designed to raise the profile of the city globally (in 2012 it was voted the 4th most visited attraction on the planet) whilst showcasing the best of horticulture and garden artistry.

Following an International design competition, a team led by landscape architects Grant Associates was appointed in 2006. The team included Wilkinson Eyre (Architects), Atelier Ten (Environmental Engineers), Atelier One (Structural Engineers), Land Design Studios (Museum and Visitor centre designers) and Thomas Matthews (Communication designers). The basic proposal was to build two cooled conservatories within 90 hectares of a new tropical garden.

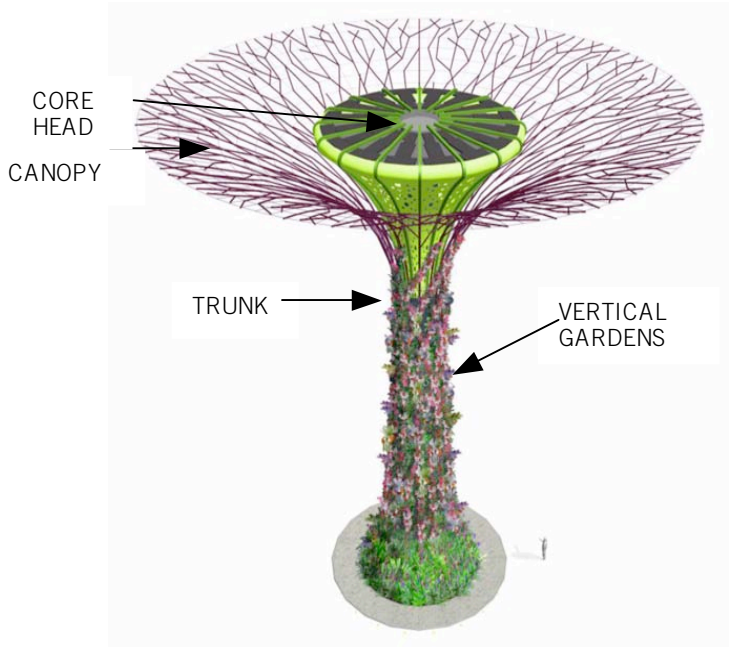
It could be argued that building two cooled conservatories so close to the equator, in a world where fuel resources are fast disappearing, was bordering on madness. However, a chance remark at a cocktail party provided a solution as a way around potentially vast energy use. Talking to Mr Ng (then CEO of National Parks), Patrick Bellew, discovered more about the greening of Singapore and Mr Ng's role in the care of some 4 million trees in the metropolitan area of Singapore. This care included the maintenance of each tree every two years, which then raised the question as to what N.Parks did with 4 tonnes of tree cuttings per week. The solution to the potential enormous energy use had been found! Biomass furnaces would burn horticultural waste and the furnaces would produce heat which enables dehumidification and cooling of the conservatories.



Courtesy of Grant Associates



The environmental loop shown here is the foundation for the architecture at Gardens by The Bay.



Courtesy of Grant Associates

The exhaust gases from the biomass furnaces were required to be released at high level necessitating the use of chimneys. Instead of bemoaning the chimneys, Grants Associates put them to positive use. Thus was the birth of the Supertrees.

They combine a whole host of roles within the site. They act as exhaust chimneys for the biomass furnaces, and they provide an outlet for steam from dehumidification. They provide the location for solar energy collection, solar heat collection, water collection, whilst at the same time giving shading to the site. These practical applications were further interwoven with Grant Associates' desire to grow vertical gardens. The core of the Supertrees handle all the practical requirements whilst the outer skins and canopy form the infrastructure onto which the planting is applied. They are also the key visual symbol for the Gardens.

COOLED CONSERVATORIES

© Craig Sheppard, courtesy of Grant Associates

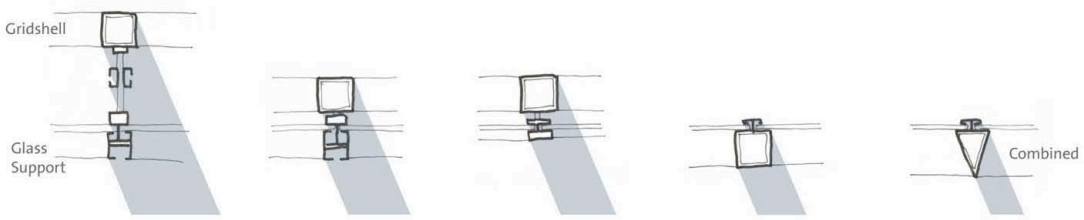
Driven by the statement “the plants are your client” our brief for the cooled conservatories was to allow for as much light as possible into the conservatories to promote maximum plant growth. The final form combined two different structural systems i.e. a gridshell and radiating arches.

With Wilkinson Eyre Architects two different conservatories were developed. The first, cool moist, would be tall to contain an artificial mountain. The second, the cool dry, would be low producing a large plan surface area for planting. Both biomes were placed on the Marina waterfront to avoid any obstruction (now or with future development around the bay) to ensure maximum sunlight is maintained as required.

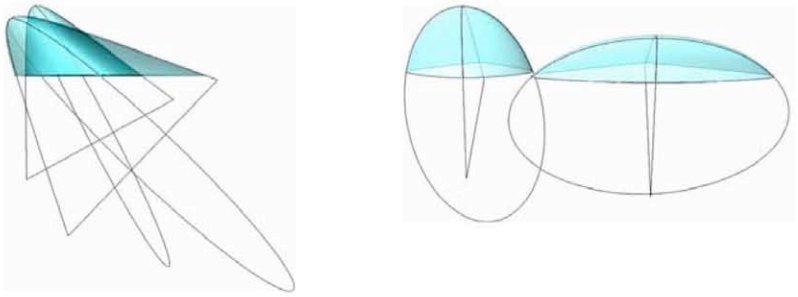
Gridshells were chosen; however due to the size of both biomes gridshells alone would have led to large section sizes thus obscuring the much needed sunlight.

The delicacy of pure compression gridshells has often been lost due to out of balance loads due to wind or concentrated loads. This generates local bending in the surface, resulting in substantially larger member sizes and a very inefficient structure. We wanted to optimise the benefit of the form and refine the member sizes in the shell to their absolute minimum, thereby increasing daylight. We therefore chose to introduce an additional structure to address these asymmetric loads and enhance the shell where necessary. The arches have far greater ability to accommodate these variable loads allowing the shells to do what they do best, work efficiently in compression, and achieve lightness. Atelier One consulted with Dr Chris Williams and his colleague Roy Hudson at the University of Bath to develop parametric equations and a family of curves to define and refine the geometry of the gridshells and arches.

The arches are separated from the envelope surface and attached by slender hangars. This separation was introduced to improve light transmission through the surface of the envelope. The arches permitted the gridshell sections to be refined to produce the profile with the least sunlight silhouette.



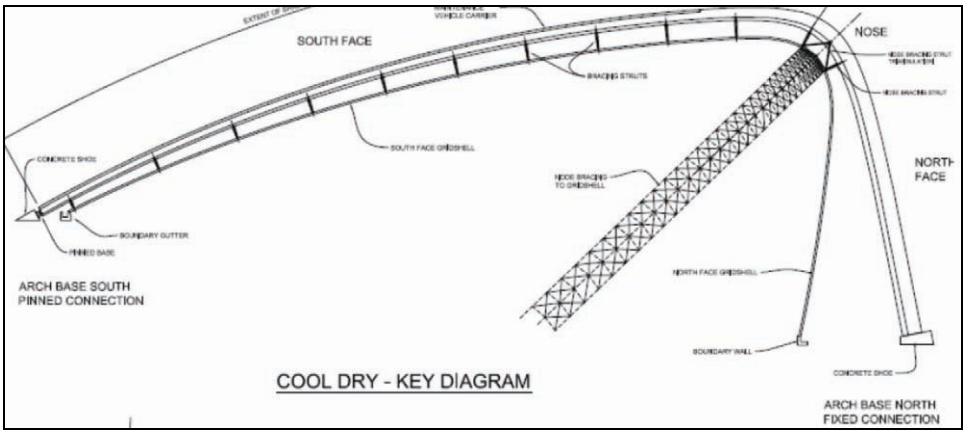
Each biome form was generated to suit the internal environment. However both surfaces formed from the same rotated hyperbolic curve.



In order to achieve the effect of highland experience an artificial mountain was envisaged, constructed in reinforced concrete with precariously cantilevering walkways into space. The envelope was then formed tall and vertical meaning the gridshell arch combination worked particularly well.

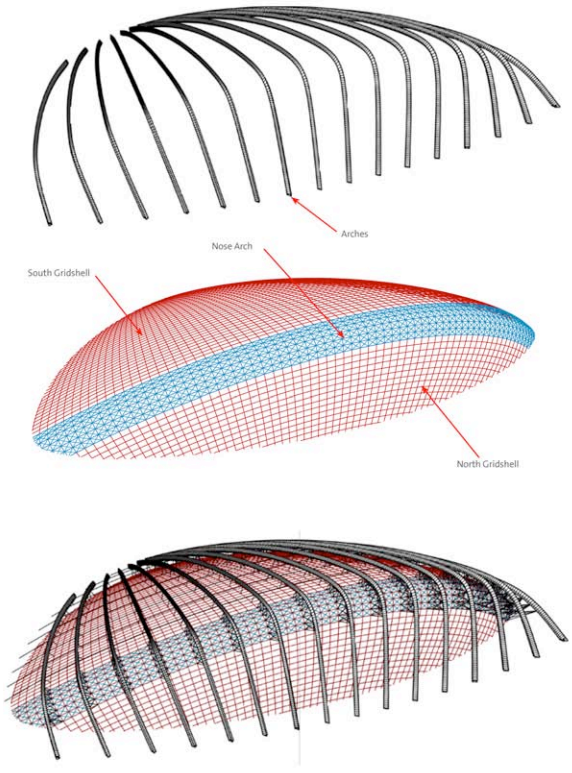
© Jordan Tan

The cool dry conservatory was more challenging due to its asymmetry.



Therefore an even more elaborate combination of structures was employed. The nose or apex of the hyperbolic surface was attached to the arches and tensioned, effectively prestressing the arches to form a rigid boundary. Between this boundary and the ground spanned the large south gridshell.

The north surface, since it is exposed to low wind loads, did not required the support/enhancement from the arches, allowing the arches to lean forward (away from the glass façade) from the hyperbolic apex down to the ground forming a cathedral like route/promenade down the marina front. Being on the north side and seeing no direct sunlight the surface is clear.



© Luis Fernandez, Atelier One

Other elements incorporated into the biome include retractable shading devices. With the sun directly over head the heat produced is sufficient to burn the plants and overload the air conditioning system. Because maximum sunlight penetration is required, the fabric shading panels retract into the body of the arch offering no additional silhouette.

To maintain the blinds drive systems and all parts of the conservatory envelope itself it is necessary to access the whole surface. The novel solution is a building maintenance unit which is capable of travelling all the way over the surface between pairs of arches. A lattice frame beam, spanning between adjacent arches, supports two independent cradles and a crane hook for replacement of glass panels. The design incorporates a complex configuration of contraction/expansion between the variation in the arches and rotation in two axis adjustment details, enabling access to most of the glass roof area and keeping the cradles vertical at all times.

SUPERTREES & AERIAL WALKWAY

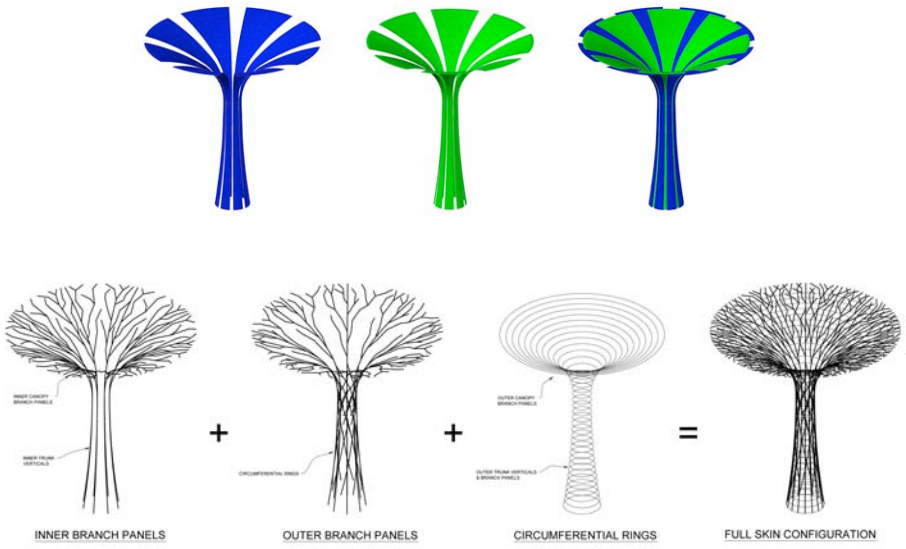
Courtesy of Grant Associates

Between 25 and 50 metres in height, the 18 Supertrees are the iconic vertical gardens in two clusters of three trees and one cluster of twelve trees.

The Supertree cluster closest to the main entrance contains the chimneys for the biomass furnaces, which even though extensively scrubbed to ensure emissions are non-toxic are required to be at high level. The lake edge cluster contains the discharge chimneys for the liquid desiccant system. Apart from these providing exhausts there is a third larger cluster at the centre of the gardens; this cluster contains the smallest tree at 25m high and the largest containing a restaurant at 50m high.

Each individual tree is supported by a concrete core, cantilevering from the ground. Each then has a core 'head' which supports all the environmental devices. This core head also helps to support the supertree canopy.

The skin is separated into two zones; the canopy skin and the trunk skin; each is defined by a series of radial and diagonal members (CHS). These give the appearance of branches growing from the ground, increasing in number from the trunk skin towards the outer edge of the canopy skin. The strength is in the shape of the surface. The light upper canopy employs a conic form, very common in membrane structures. However, the surface is reversed to act in compression, not tension. The structural frame consists of a double layer lattice that uses the offset between the inner and outer layer to enhance stiffness out of plane. The inner and outer layers are divided into 8 panels of identical branch patters that are rotated half a bay, overlapping creating an apparent randomness across the skin. Stability is then provided by connecting the radials to a series of equally spaced circumferential cables, which complete the anticlastic surface that works together as a whole structure (mutually supportive) with a high level of structural redundancy.



Courtesy of Grant Associates

A central attraction of the Supertrees is an Aerial Walkway which is proposed to mimic the tree top walkways so synonymous with Australia. Obviously, it differs in that it is suspended from the Supertrees via extremely light and sensitive skins. The walkway is designed with very specific criteria in mind - due to the sensitivity it is designed only for a limited capacity and use.

The aerial walkway is elevated 22 m above ground and measures 123 m long as it curves out from one 42 m tall Supertree to the other, wrapping around one side of the 50 m tree. The structure is suspended from wire rope cables that are spaced generally at 1 m intervals and connect to the 42 m trees as well as to three of the smaller surrounding trees, one 37 m tall and two 30 m tall structures. The walkway is formed from 140 mm diameter steel tube stringers that are supporting rectangular hollow section cross beams of varying depths, spaced at 1 m intervals which in turn provide support to the steel galvanized decking.

IMAGE & DRAWING CREDITS in order of appearance

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