Design for longevity – the maximum age of trees and palms

The oldest living organisms are trees, some as old as 5,000 years. What design principles promote longevity?

By F.S.P. Ng

A tree is a big plant with a single woody trunk. Trees massively increase the amount of living space for the diverse and numerous life forms that populate a forest. It takes a lot of effort to build a tree and the death of a tree, often by sudden collapse of the tree trunk, is a major catastrophe for those that depend on it.

The oldest living trees have been found to be bristlecone pines (*Pinus longaeva*) in the White Mountains of California, 4000 – 5000 years old. We know the age of these trees because wood is formed in concentric rings, and these rings are countable.

The tree trunk in cross section reveals a circle of bark around a core of wood. Between the bark and wood is a dividing line known as the cambium, which consists of tiny actively dividing cells. Actively dividing cells are said to be 'meristematic'. Cells in the middle of the cambium remain meristematic but the new cells adjacent to the bark change into bark cells and those adjacent to the wood change into wood cells. In a seasonal climate, the cambium rests in the cold or dry season and activates in th warm wet season, hence the production of new wood and bark is cyclical and the cycles are registered as annual growth rings.

Annual growth rings as seen in a block of wood from temperate China, used in a carving

In the bark, the growth rings are not obvious because the bark gets stretched and disrupted as the tree trunk expands and the outer layers of the bark are shed. The wood, on the inside of the cambium, does not get stretched and broken up. Instead, each new layer is preserved in the order in which it produced and each layer marks one year of life. The diameter of the tree increases with its age.

Water moves up the tree through the wood and nutrient-rich sap moves down through the bark. The strength of the tree trunk is provided by tough elongated fibre cells that are distributed evenly throughout the wood. Radial transport of sap in the trunk is made possible by radial bands of soft cells known as parenchyma cells that run from the bark to the centre of the trunk.

In most trees, the wood cells live for several years and as they reach the end of their lives they darken due to chemicals deposited in them. Hence the woody core of a tree consists of an outer zone of light-coloured living wood known as sapwood, and an inner core of darker-coloured dead wood known as heartwood. This 'classic' model is found in conifers and dicots.

In the classic model, the heartwood provides physical support, and the living tissues and organs such as sapwood, leaves, flowers and fruits, occupy the periphery of the tree. In cool and dry climates as in the mountains of California, the giant redwoods grow into huge old trees 250 ft tall because their heartwood layers accummulate and are almost immune to decay under local environmental conditions.

Trees in the humid tropics

Trees in humid tropics tend to grow uniformly in response to consistently warm and humid conditions, so rings are absent or weak and non-annual. Until recently, all tropical conifer and dicot trees were thought to conform to the classic model, with the wood differentiated into sapwood and heartwood. Then in 1986, it was proven that some trees in the humid tropics do not form heartwood; their trunks consist entirely of sapwood. The two kinds of trees achieve old age by radically different means.

Tropical trees that develop heartwood. In the continuously warm and moist environment of the humid tropics, decay organisms such as fungi, bacteria and insects can enter tree trunks through dead branches and cause decay in the heartwood. Heartwood is protected by the chemicals deposited in it but the degree of chemical protection has been found to vary greatly between species. The most durable species include *chengal* (*Neobalanocarpus heimii*) and *belian* (*Eusideroxylon zwageri*). *Chengal* grows to a maximum diameter of about 367 cm (12.7 ft) (Symington, 1943). Buildings made of *chengal* have lasted for about 100 years, hence it can be concluded that the chemical protection in the heartwood of the best-protected trees in the humid tropics is about 100 years. Wood older than that would begin to decay if decay organisms enter the tree trunk. The decay would result in a hollow trunk. The hole would eventually get too big and the whole structure would collapse in a storm (Ng, 2014). From observations on collapsed hollow trees it would appear that the limit of stability is when the hole in the centre is three or four times the thickness of the wall around it. A *chengal* tree could develop a solid trunk for about 100 years, after which it could develop a hole for another 200 years before it becomes unstable, making a total life-span of 300 years.

Even if we allow a wide margin for variation, it is unlikely that a chengal tree can be older than 600 years. Species with heartwood of lower

Logs in a logyard in Perak, many with decaying cores

durability would become unstable at a much younger age. Hence heartwood that enables a tree to live for several thousand years in a cold dry climate, limits the life of a tree in the humid tropics to several hundred years.

In a tropical rain forest community, the rate of mortality of trees has been found to be about 1 – 2% per annum and the cause is usually attributed to storm damage. It is very rare for fallen trees to be inspected immediately before the evidence is lost, so we do not know what proportion of fallen trees are actually primed for collapse by internal decay.

Tropical sapwood trees. There are trees in the humid tropics that never develop hollow cores. The best-known of these is the *jelutong* (*Dyera costulata*), which has a maximum diameter of 250 cm (about 8.3 ft) (Setten, 1963). In cross section, the wood is seen to be uniformly light-coloured, with no distinction between sapwood and heartwood (Desch,1941). *Jelutong* is never recommended for outdoor construction, only for light articles used indoors, like pencils, toys and picture frames. It has no durability when exposed outdoors.

We now know that the massive trunk of the *jelutong* tree consists entirely of living sapwood. The evidence for this was brought together and announced to an astonished audience at a conference in Montpellier in 1986 (Ng, 1987). The wood of *jelutong* has a high content of starch grains in all parts of the trunk (Desch, *l.c.*), which, together with lack of chemical protection, explains why its wood is highly susceptible to decay when a tree is cut down and its life-support system terminated. The most striking evidence that the standing tree

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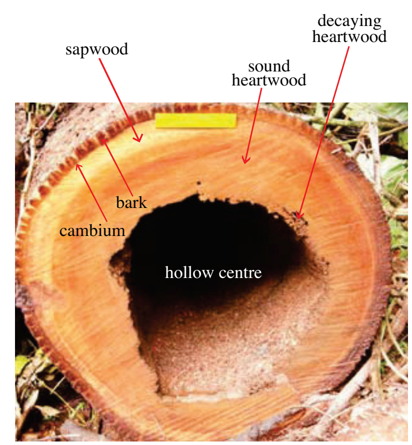
A hollow *chengal* tree in primary forest, Negeri Sembilan.

trunk is completely alive was obtained when I was closely examining a jelutong tree that had been newly felled. I noticed white latex oozing out not only from the cut bark as expected, but amazingly, also from the pith in the centre of the tree trunk and from the bands of parenchyma tissue that run radially across the trunk from the pith to the bark. Hence all of the wood was permeated with latex-containing tissues. After exposure, the latex hardened and became discoloured. Desch and other wood anatomists had known about the presence of latex-bearing tissues in jelutong wood but had dismissed them as minor defects of wood.

At the time when I made my observations, work by Gomez and Muir (1979) at the Rubber Research Institute Malaysia had already

Post-mortem of a broken hollow tree

Broken tree trunk



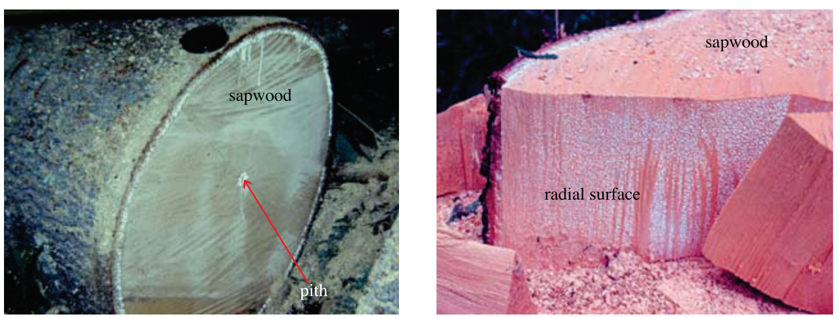
This large *bayur* (*Pterospermum javanicum*) collapsed in a storm because it had become unstable because of its hollow centre. The yellow scale measures 15 cm (6 inches).

A *jelutong* tree in a primary forest in Selangor, with Prof Laurence Roche. Photo 1985

established that latex is a form of protoplasm, with nuclei, mitochondria other subcellular organelles dispersed in the liquid. The latex of *jelutong* is closely related to the latex of rubber and, indeed, 20% of the dry weight of *jelutong* latex is rubber (Burkill, 1935). The presence of latex throughout the wood tissues in *jelutong* was the undeniable proof of concept that there are sapwood trees in which the whole of the tree trunk consists of living wood.

There are many other species with uniformly white wood that begins to decay only when the tree is cut, yet is immune to decay when the tree is alive. Such trees must be sapwood trees even where the sap is transparent instead of white. Among them are many fast-growing light-coloured timbers like *Albizia, Anisoptera, Endospermum* and *Macaranga*. Logs of *Anisoptera* are highly favoured for plywood production because the centre is sound enough to hold a clamp for rotation against a peeling knife.

Post-mortem of a felled sapwood tree, *jelutong* (*Dyera costulata*)



The white latex exuding from the cut bark, pith and exposed radial surface is a living sustance

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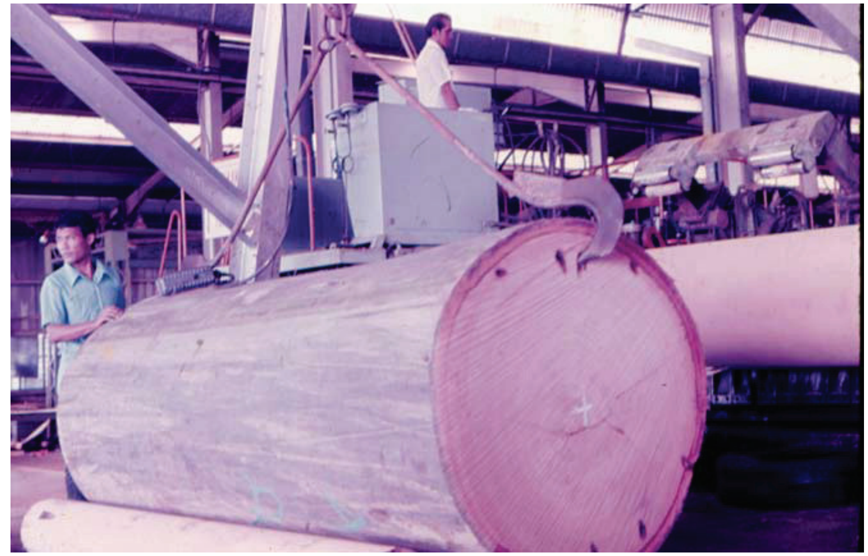


A log of *mersawa* (*Anisoptera* sp.) being prepared for veneer peeling in Sabah. Note absence of sapwood-heartwood differentiation and sound condition of the wood throughout the trunk, indicating that it is a sapwood tree

The maximum recorded diameter growth rate of *jelutong* is 3.4 cm per annum (Edwards, 1930) hence a tree of 250 cm diameter could be achieved in about 74 years but most trees would be slower growing. At a growth rate of 1 cm diameter per annum a 250 cm diameter tree would be 250 old. Since all the cells are alive, those in the centre would be as old as the tree itself. This would be truly amazing for individual cell longevity. Nothing is known about how a standing sapwood tree dies. In the Forest Research Institute, some *jelutong* trees get sick and drop twigs and branches but do not die. One tree had a broken crown which it could not repair. After many years it was felled and the trunk was found to be completely free of decay but after felling, the stump began to decay immediately and was totally disintegrated in less than two years. It so happened that an old stump of a felled *tembusu* (*Fagraea fragrans*) tree was located nearby. *Tembusu* is famous for its durable heartwood which is almost of the same classs as *chengal*. When I began to monitor it, the sapwood and parenchyma tissues that run radially had already disappeared but there was almost no further change after that.

Implications for forestry and the timber industry

Heart rot reduces the volume of timber that can be recovered from a log, hence a smaller diameter log without a hole is better than a big log with a big hole. In plantations of trees that develop heartwood, the best time to harvest

Decay in heartwood versus sapwood

Tembusu (*Fagraea fragrans*) felled at some unknown date was represented by heartwood only; its sapwood and radial parenchyma bands (indicated by radial slits in the stump) had already been decayed when photographed in September 2013. Two years later its condition was almost unchanged.

This *jelutong* tree, was felled in 2013 at about 83 years old. The wood was sound but began to decay soon after felling. In less than two years between September 2013 and August 2015 it was completely disintegrated. This comparison shows that heartwood can take a long time to disintegrate, up to 100 years for the most durable species, due to chemical protection. In contrast, sapwood is highly resistant to disease and insects while the tree is alive and disintegrates rapidly when the tree is felled.

would be before the heartwood begins to rot. For chengal 100 years would be good time to harvest. For species with moderately durable heartwood, 50 years or less would be more appropriate. In contrast, plantations of sapwood trees could be grown to produce logs of big size without danger of rot developing in the centre.

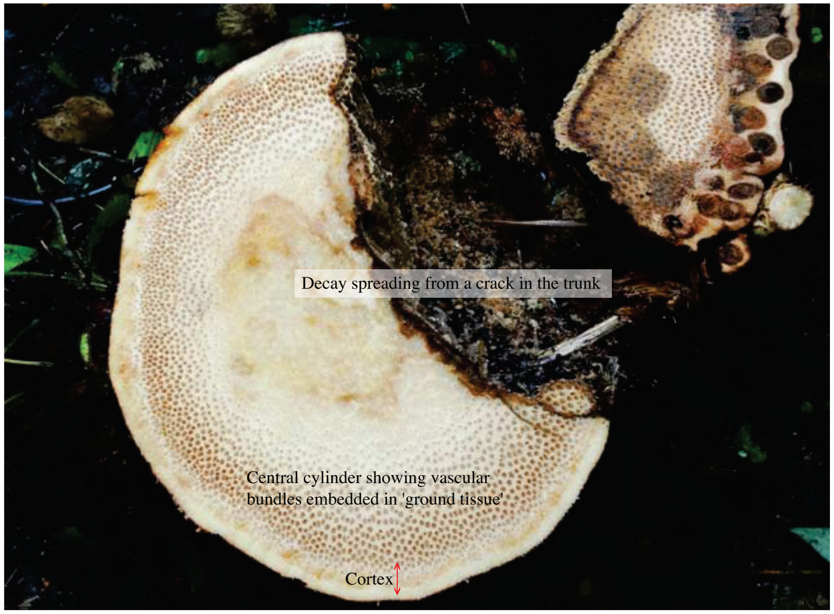
Palms. Palms are monocots. The palm trunk is organized on a different plan from conifers and dicots. Instead of water-conducting and sap-conducting functions being performed separately by wood and bark these two functions are combined in 'vascular bundles' that run vertically through the stem and each bundle is reinforced by tough fibre cells. In transverse section, the trunk is seen to consist of many vascular bundles embedded in a bed or 'ground tissue' of soft spongy parenchyma cells. The vascular bundles are usually denser towards the periphery of the trunk. Often a tough outer layer of densely-packed cells, called the 'cortex', can be distinguished from the rest of the trunk which is called the 'central cylinder', but there is no structural demarcation between the two zones (Tomlinson, 1990). The cortex of a palm can be removed without killing the palm, as we have shown with the Canary Island palm *Phoenix canariensis* (see box), the cortex is also naturally eliminated in *Sabal palmetto* (Tomlinson *l.c.*). Most palm trunks have a constant diameter after its juvenile phase and new trunk growth is restricted to its apex. Palms keep increasing in height without increasing in girth. To transport water and sap between its crown and root system, the entire trunk must stay alive, which means that the cells at the base of the trunk must be as old as the palm itself.

The last of the original oil palms in Bogor, in October 1982. It collapsed in 1993 at the age of 145 years

A small minority of palms have a fixed life cycle, growing to full height, then flowering and fruiting at the apex and dying after reproduction. In the vast majority, including the coconut and oil palm, the flower and fruit bunches are produced in the leaf axils where the leaves are attached to the trunk. Such palms could grow indefinitely.

The first oil palms to be planted in Asia were planted in the Botanic Gardens in Bogor, Indonesia in 1848. Four plants were grown and they collapsed one by one when they were over 100 years old. The last one collapsed in 1993 at the age of 145 years.

Post-mortem of a broken palm tree, *Areca catechu*



There are two ways in which a palm could overcome instability due to height. One way is for its trunk to rest horizontally on the ground so that it is well supported and stable. This design solution is adopted in the *nipah* (*Nypa fruticans*) palm that grows along the banks of tidal rivers. Pure nipah forests are also found on coastal mudflats in some places. Because the crown can keep growing indefinitely. a *nipah* tree could be as old as the *nipah* forest itself.

Another way is to avoid building a trunk. A trunk is made up of nodes and internodes. A node is the part of the stem that bears a leaf and its associated inflorescence, and it is indicated by a scar when the leaf is shed or dead. The part of the stem between two nodes is called an internode. In the Canary Island palm (*Phoenix canariensis*) the internodes are eliminated and the nodes are stacked on top of each other like pancakes but there is a bulge in each node marking the position where the thick leaf stalk arises. The trunk is built up by the accumulation of nodes. If the node could be eliminated the palm would have no trunk. Trunkless or acaulescent palms already exist and provide ready models for study.

Nipah (Nypa fruticans) in Malacca

The most striking of the trunkless palms are various species of *Johannesteijmannia* such as *J. altifrons* and *J. magnifica*.

The seedling stem of *J. altifrons* is shaped like two short cones fitted one above the other. The upper cone (shoot cone) bears the leaves and the lower cone (root cone) bears the roots. The shoot cone is slightly wider than the root cone where the two cones meet, so there is a slight overhang. New leaves are produced by a small meristem at the apex of shoot cone. The leaf bases form concentric rings around the meristem with the youngest in the centre. As new leaves arise in the centre the older leaf-rings are pushed progressively outwards until the outermost leaf-ring reaches the periphery of the shoot cone, where it overhangs the root cone. At this point the leaf decays together with the ring of nodal tissue bearing it. The node is thereby eliminated. Sometimes in *J. altifrons* there is a short trunk-like structure below the crown, which is covered with leaf litter and soil brought by ants nesting in the litter. The origin of this 'underground stem' needs to be examined further. Possibly this is the accumulated shrivelled core of the shoot cone after the cortex (node-bearing) region has been elimated.

In the oil palm (*Elaeis guineensis*) the internodes have been eliminated by selection. The modern oil palms have also been selected to start bearing fruits at their juvenile stage before building up the trunk. If the oil palm could be redesigned to automatically eliminate the nodes together with the spent leaves and fruit bunches, as in

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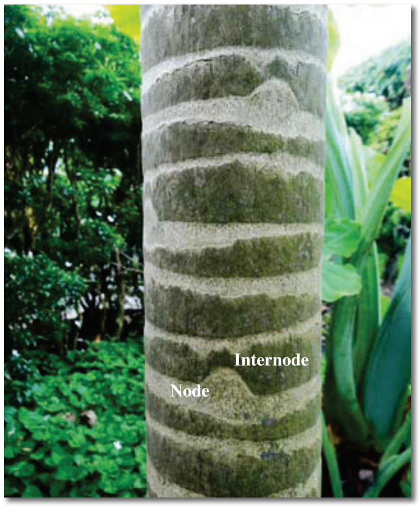
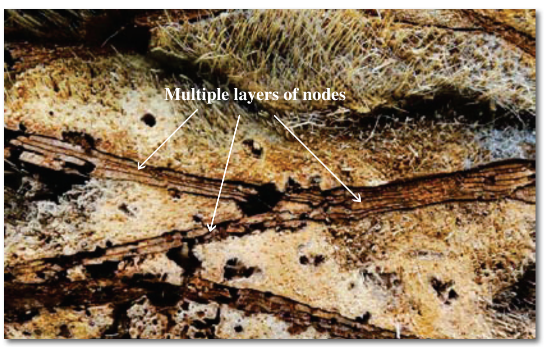
Examples of the elimination of internodes, cortex, nodes and trunk



Trunk of *Cocothrinax* sp. showing clear demarcation of nodes and internodes.

Trunk of *Phoenix canariensis* with cortex being cut off using a chain saw in August 2013. The palm survived without cartex and had grown another metre by August 2015.



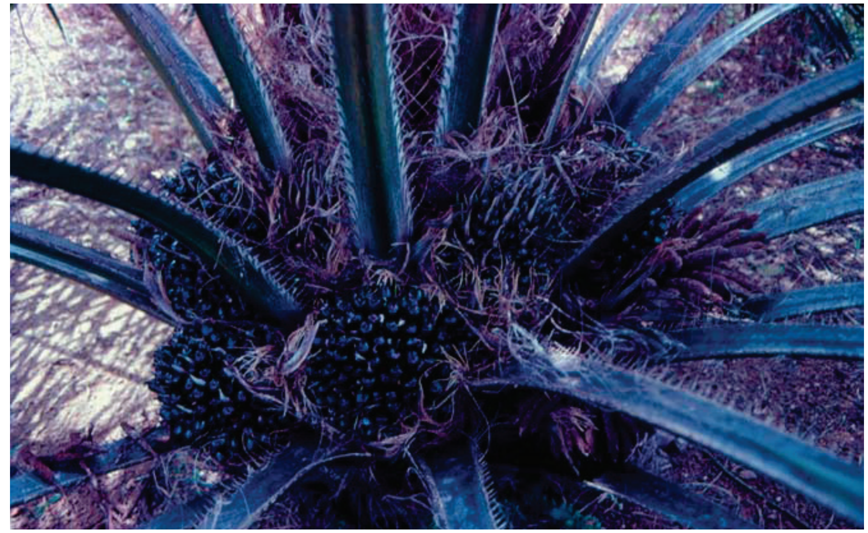
Close up of *Phoenix canariensis* exposed cortex, to show how the nodes (indicated by leaf bases) are stacked like pancakes on top of each other but bulging where the massive leaf stalks arise.

Johannesteijsmannia altifrons seedling

Johannesteijsmannia altifrons seedling in longitudinal section showing elimination of old leaves and their nodes as they are pushed out to the periphery of the leaf cone.

Mature *Johannesteijsmannia altifrons* with short "underground stem". The knife blade inserted into the soil indicates absence of structure below this level.

Johannesteijsmannia magnifica



Oil palm *Elaeis guineensis* before trunk elongation.

Johannesteijmannia, it would be trunkless. *J. altifrons* and *J. magnifica* have no trunks but *J. perakensis* in the same genus has a prominent trunk, hence the genetic distance between the trunked and trunkless condition may be relatively small. A trunkless long-lived oil palm might be quite achievable.

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