Potential of Thai Coconut Wood as an Alternative Structural Material

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Abstract

Seeking alternative materials to reduce energy consumption and CO_2 production has become common during this global warming conscious era. In the construction industry, the most energy efficient way is to acquire construction materials as near as possible to the origin of source. Thailand's GDP mostly comes from agricultural trade. There are many forms of agricultural waste and by-products that can be investigated for their potential use. This research investigates one of the primary agricultural products of Thailand, the coconut. Thais utilize many different parts of the coconut and turn it into many forms, mostly from seeds or actual coconuts. Coconut trees stop producing seeds at 15-20 years of age. At this point, the trees are cut down to accommodate more new-growns. This results in large numbers of coconut trunks with no further use. The research found that the outside cross section is a harder wood than the inside. To ensure the highest structural properties, therefore, the outside portion was chosen to be tested. The research uses coconut beams to test for properties, so it is easy to see the applicability of use. Four specimens were selected at 2x5" section and 3 meters in length because it is a commonly cut size. The beam test format is a four-pointed configuration, so beams will break from bending. The test results found that coconut wood's structural properties are still somewhat inferior to Thai soft wood, but this does not mean it does not have bearing capacity. Coconut wood can still be used in small load structures like residential buildings. Given its abundance, low energy production, and renewability, the sustainability of coconut can add high value to this structural material. There is potential to further develop this material by applying technology, such as composite or laminated materials.

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Introduction

Searching for alternative materials for construction has become a common trend in this era of global warming. Structural materials that can do less damage to the environment will be targeted, using natural materials that require low energy consumption such as wood. Wood has been used as a structural material for thousands of years. However, the typical process of harvesting wood does not offer the most environmentally friendly solution. It will take 20 years or more to take each log down. The search will focus on plants that can be harvested in short cycles and can grow abundantly. In the tropical belt, the area between the tropics of Cancer and the tropics of Capricorn, many tropical crops are grown abundantly, like bamboo and coconut. Bamboo can reach maturity within 5 years, and be harvested at 3-4 years. We can consider bamboo as a renewable source. However, while much research on bamboo and its great potential has been conducted, there has been relatively little investigation into coconut, though it can grow fast as well. Therefore, this research examines the potential of coconut as an alternative structural material.

Importance of this study

Construction choices for smaller structures in Thailand are mostly dominated by concrete, while steel is an alternative for owners with a higher budget. Wood has become either a special or an inexpensive option. In special cases, it may be used in construction that is focused on the craftsmanship of the wood and the owner is willing to deal with high maintenance, especially against the threat of termites in Thailand. In urban areas, development is now widespread and termites, while living underground, really have nowhere to go and will therefore invade wherever they can, especially where buildings are not fully protected. As for its use as an inexpensive option, wood may be used in construction to avoid the higher cost of concrete or steel. However, now that the issues of global warming, low energy consumption and carbon production have become very important, the materials that use less production energy are now highly valued: natural materials have become a material of choice. Wood grown as a structural material will take 20 years or more to harvest. The actual wood will not be environmentally friendly enough to use due to its long life cycle. The search for more renewable alternatives such as wood that can grow fast and in a short period to harvest is extremely urgent.

Coconut wood is mostly made from coconut trees that are cut down after they finish their seed production. They actually have been used as a construction material for many years, mostly as a structural material. Yet the properties of Thai coconut wood have not been seriously studied. Coconut wood has a very high potential as an alternative structural material for commercial use because coconut trees are abundant in southern Thailand and are useless after their seed production has completed, when the trees are cut down to allow for a new line of young production. The ready availability of this material is a great opportunity for construction. Therefore, this research is conducted with the intention of endorsing the use of coconut wood as a viable structural material.

Understanding coconut

Coconut is a plant in the Palm family. While we call it coconut, it is actually an abbreviation of coconut palm and has the scientific name of Cocos Nucifera. Coconuts are grown abundantly throughout the tropics for seed consumption. Nearly one third of the world population is dependent on the consumption of coconut. They utilize four products from the coconut: the milk, meat, water, and oil. Coconut can produce seeds for many years. Beyond the life of seed production, coconut trees must come down for the new young ones to grow, rather than being left to stand free. For many hundreds of years, after being cut down, coconut trunks or logs have been sawn for local construction uses. It is known among local people for its hardness. Yet the study of coconut as a viable structural material is still limited.

Coconut can be grown in most tropical regions in the world. Southeast Asia is not only the main consumer of coconut, but also a major area of coconut production, including Thailand, the Philippines, Indonesia, Vietnam, India, etc. In Thailand, coconut trees are mostly grown in the South and the Southeast, such as Chumporn, Surathani, Chantaburi, and Trad. Thai people use coconuts as part of their diet too. Many famous Thai dishes have coconut milk in them. Coconut trees in Thailand are raised for seed production. There are many species of coconuts, like other plants, but it is obvious that there are two distinctive types of coconut trees: short and tall. The shorter species is more likely to be used for its juice and is consumed when it is young, due to the wonderful flavor and aroma in the juice. Taller coconut trees will produce seed with thicker meat inside. People extract the coconut meat to produce coconut milk. Tall trees are harvested when seeds are old and brown-looking.

It is clear that shorter coconut trees will have a shorter height but wider trunk. The difference between the top and bottom can be quite significant. The shorter species can reach up to a maximum of 12 meters. The taller coconut trees are longer and also with a thinner trunk. They can reach up to a maximum of 18 meters. The average diameter for most coconut trees is 30 centimeters. Coconut trees can first produce seed as early as 5 to 6 years, and can have a life span of 60-70 years for the taller species and about 30 years for the shorter species. A coconut tree can produce 75 seeds in a year (Aragon, 2000), and continue to produce until completing its life span. They are also cut down when their production is low, so new young ones can have room to grow.

Coconut tree trunks are cut down in tremendous quantities each year because they are so abundant. The character of clean small tree trunk allows the plantation to have many trees within the growing area compared to other trees. They are mostly cut down when their seed production is poor. That means there are lots of coconut tree trunks ready to be transformed into different materials. Many of them are sawn for construction use, and many for producing handicrafts because of their distinctive fiber. Similar to bamboo, coconut is a Monocotyledon or Monocot for short, so the cross section of the trunk indicates clearly the xylem and phloem. The coconut trunk is solid, unlike bamboo that is hollow, but the configuration of the fiber is quite similar. The strong fiber or harder wood is located near the outside perimeter of the trunk. This area is the strongest part of the trunk and the most appropriate for structural use. Thai locals call this portion *"Peek"* or *"Krapeeh"*. Towards the center, the wood has a lot less density and is not really good for structural use. When the section is cut, it is clear that this area has a lighter color and weight. Thai locals call this *"Sai"*.

There are lots of similarities between monocots like bamboo and coconut when looking at their vascular bundles. Bamboo is hollow and coconut is solid. It is obvious that bamboo has greater fiber because the vascular

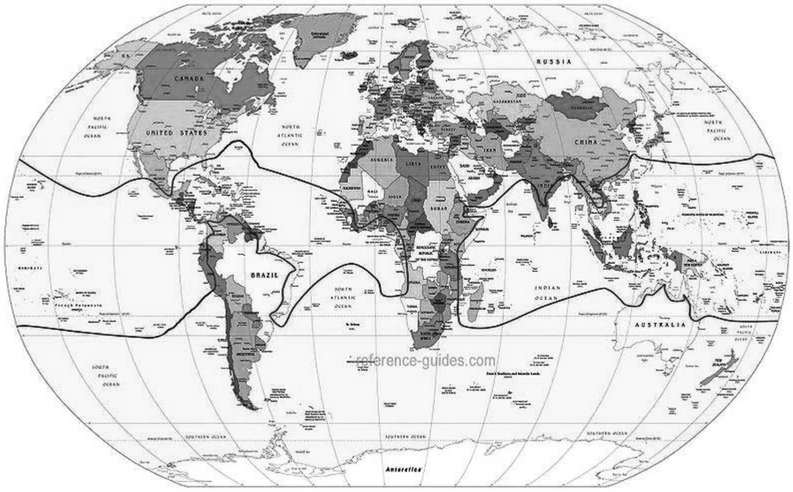


Figure 1. World map of coconut tree regions (image courtesy of Wikipedia).

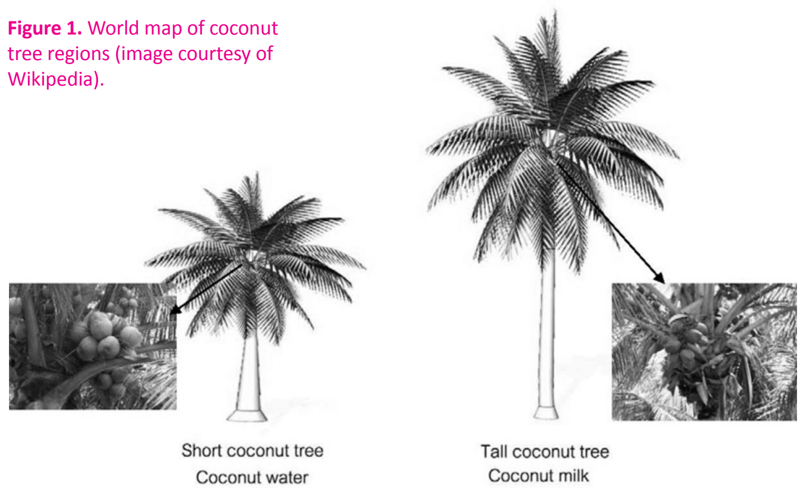


Figure 2. Comparison of Coconut tree characteristics of different species.

Figure 3. (left) Harvested coconut trees transformed into lumber on site; (right) Coconut wood used in construction in local coconut areas.

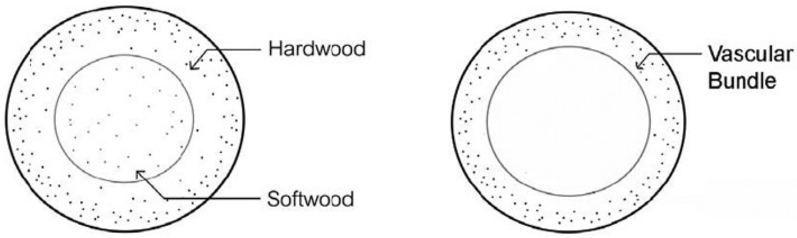


Figure 4. Cross section of coconut trunk, compared to Bamboo.

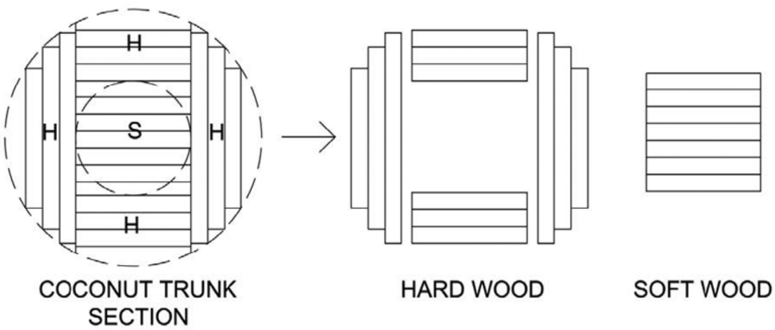


Figure 5. Classification of hard and soft wood on the coconut trunk's cross section.

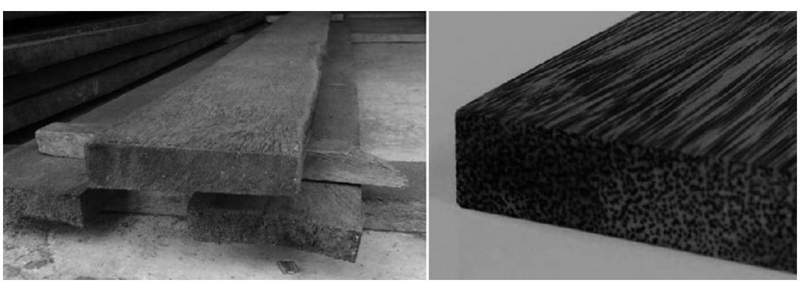


Figure 6. (left) Rough sawn coconut wood ready for structural application, (right) Sanded coconut for use in interior or product applications.

bundles are more condensed in the limited area of their trunk, while those of coconut are scattered all over the trunk. However, they are formed in similar ways, with more vascular bundles around the perimeter and less towards the center. That is why coconut's *Krapeeh* is a much harder wood than its *Sai*. Therefore, when people harvest the coconut, they classify different properties depending on its location in the trunk.

Test Experiment

The mechanical properties of coconut wood will be investigated through experimentation. The coconut wood will be tested in the engineering lab in the form of beams, a common bending structure. The specimen is purchased from sawn coconut wood from Chumporn, southern Thailand. Due to the size of the coconut tree trunk, the ready-sawn coconut lumber is cut into cross sections of 2x5" or 1 ½ x 4 ½". The length varies from 3 meters, 4 meters, and 6 meters. The beam selected for this experiment is 3 meters in length because the 2x5" section does not offer a deep section, and it is a common size that suppliers cut. If using short section and long beam as the test specimen, it will be too easy to collapse the beams, so the result will not be as accurate. A length of three meters offers an appropriate proportion to test. The total quantity is 4 beams. The selection is also intended to use the harder wood (from the outside ring) by measuring the density to be 300 kg/m^3 or higher. The core (inside ring) will not be used for structural purposes.

The setup for the beam testing is based on a four-pointed loading configuration, with two beam supports and two point loads. In this case, the beams will fail because of bending, instead of vertical shear if done in three points. The configuration is set as a simply supported beam, while one support is a pin connection and the other is a roller connection to make sure there are no horizontal loads. The beam's length is 3 meters. It is offset 5 centimeters on either side at the beam supports, so the m iddle section is divided into three equal sections of 97 centimeters for the point load's locations,

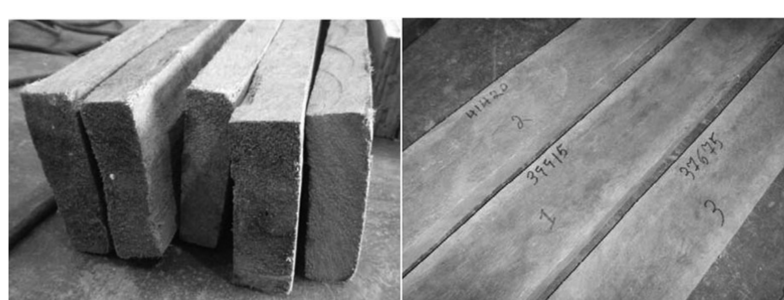


Figure 7. Coconut wood specimen, selected from the outside ring or *Krapeeh.*

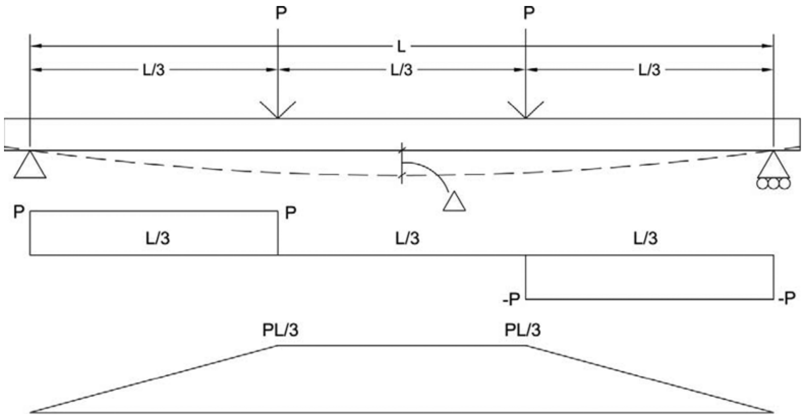


Figure 8. Loading diagram for test is selected to be a four-pointed simply supported beam.

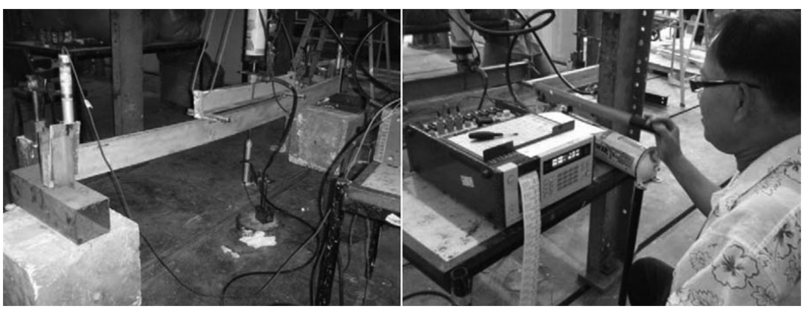


Figure 9. Images of beams while testing.

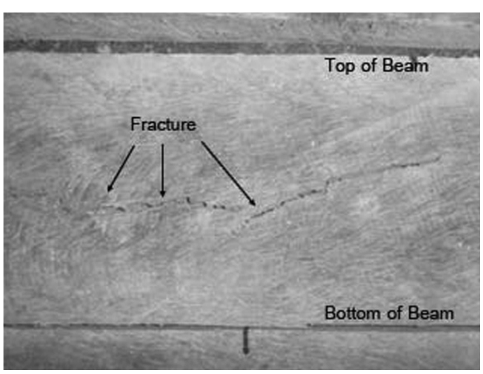


Figure 10. Fracture found in coconut wood when failed.

as shown in figure 8. The test will look into the maximum load to fail the beams, the loading behavior, and the deflection. The location of the test is at the Structural Engineering Laboratory, School of Engineering and Technology, Asian Institute of Technology (AIT), Thailand.

Test Results & Analysis

The loading tests were increased until the coconut wood beams failed to receive loads.All four specimens reacted the same way when they failed, cracking and springing out of the supports. The cracks appeared on the beams at the horizontal middle depth section, where the neutral axis is. It is obvious that the beams failed by the maximum horizontal shear, even though the test was designed for the beams to break through bending. This may suggest that the bending properties are higher, since the material failed by shear first. It is estimated that coconut wood is weaker in shear due to its horizontal grain.

The numerical analysis is further performed by comparing the results of the structural properties with the mechanical properties of the Thai woods. The criteria are set to investigate the density, loading behavior, maximum load, and deflections, in order to calculate the maximum stress, the allowable stress, and lastly the modulus of elasticity.

Specimens were purchased from coconut farm suppliers, and carefully selected by weight. The greatest weight signifies the hard outer ring portion of trunk, which is a stronger wood. Before testing, they were measured and their weight seemed to be relatively close. The density was calculated at an average of 344.6 Kg/m^3, which seems to be quite low when compared with other structural softwoods.

The test obviously shows that density has a proportionate effect on the ability to receive loads and the vulnerability to deflection. There was also some evidence that the beams moved while loading. This can cause

The maximum load and maximum deflection at center point

Specimen Number	Maximum Load (Kg)	Maximum Deflection (mm)	Density (Kg/m^3)
1	230	58.63	325.48
2	180	60.22	313.65
3	150	66.98	296.05
4	250	62.74	404.80

Table 1. Comparison of the specimens' maximum load, maximum deflection, and density.

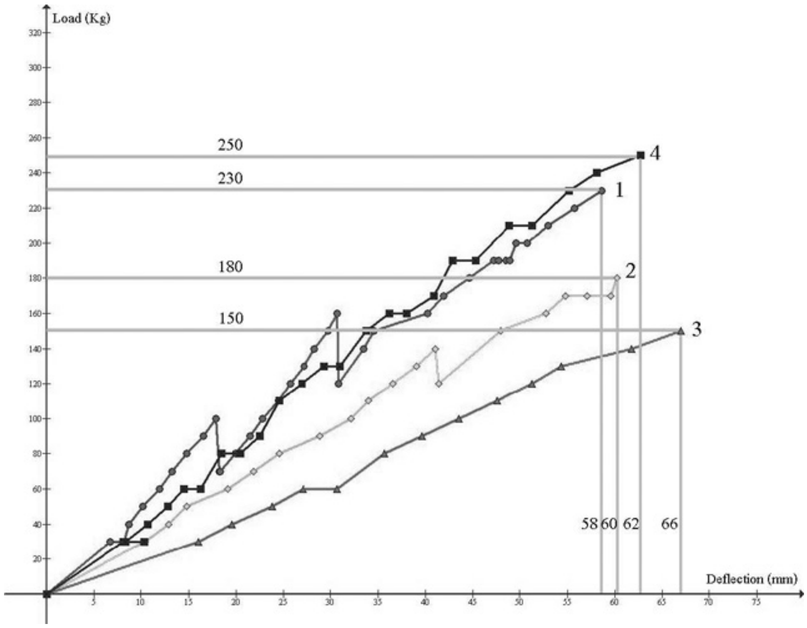


Figure 11. Comparison graph of specimens' plotted loads versus deflection.

Specimen Number	Maximum Load (Kg)	Maximum Bending Stress (Kg/cm$_2$)	Modulus of Elasticity (Kg/cm$_2$)
1	230	264.5	75,618
2	180	207	57,206
3	150	172.5	42,691
4	250	287.5	75,667
	Mean =	232.87	62,795.50

Table 2. Comparison of specimen's maximum bending stress and modulus of elasticity.

Comparison to hard wood beams in Thailand

Material	Wood Classification	Specific Gravity	Max. Bending Stress (Kg/cm$_2$)	Modulus of Elasticity (Kg/cm$_2$)
Coconut	Tested Specimen	0.34	232	62,795.50
Teak	Soft	0.62	641	81,536.51
Tabag	Medium	0.72	808	112,556.28
Teng	Hard	1.07	924	115,462.47
Daeng	Hard	1.05	1,193	153,130.78
Bunnag	Very Hard	1.12	1,519	230,690.40

Table 3. Comparison of important mechanical properties of coconut wood and other commercial woods in Thailand (Saengathit, 2009)

the stress calculation to be slightly varied. However, all graph projections demonstrate a similar behavior. It can be simply determined for this experiment that lower density wood can receive less loads, and likewise the other way around.

Maximum Stress and Modulus of Elasticity

Bending stress is a property created from the loading condition. It tells us how well a material can resist the bending condition due to the loads applied. It is calculated using the simple equation of the relationship between bending moment and section modulus. The modulus of elasticity is also calculated using the deflection equation of the four-pointed simple beam. The results for all the specimens are:

From the data tested, coconut has shown that its capacity for receiving bending is almost one third that of a softwood like teak, and 5 times less strong than the strongest wood in Thailand. The data shows that coconut beams are less strong, but the beams broke due to shear, so it is still positive that its capacity to receive bending continues, and perhaps is comparable to softwood. When looking at the modulus of elasticity, coconut wood has shown that it is still the least stiff. It is only 77% that of teak wood, which does not indicate is not significantly inferior. In summary, it is disappointing that the overall performance of coconut does not show the highest ability, but this research suggests a great deal of positive potential developments. Coconut beams can receive more bending stress, if they do not break due to the horizontal shear. Potentially, carefully selected coconut wood could have structural properties comparable to soft wood like teak. This finding is significant when taking into consideration sustainability.

Case Study

It is important to understand how these findings will be used in real applications. The research has found that coconut lumber is still vulnerable to higher loads, so application in beams, girders, and columns will still need further studies. However, the research proposes the joist application because they can clearly distribute small loads; in addition, joists are used in large quantities, therefore using an abundant construction material seems to be an appropriate proposal. An example of a joist design is put together to get an idea of how joist members are sized according to loads in residential projects. A criterion is set of 250 Kg/m^2 for the live load and 70 Kg/m^2 for the dead load.

The study is to understand how big the joist spacing (d) should be if coconut lumber is used for the joists at 3, 4, and 5 meters span with four typical sizes of dimensional lumber, 2x4", 2x6", 2x8", and 2x10". The maximum stress of the coconut is 232 Kg/cm_2, based on the loading test. Allowable stress (fb) for design is assumed to be 0.7 of the maximum data, which is 162 Kg/cm^2. The moment (M) of this loading condition is calculated by:

$$M = \frac{wl^2}{8}$$

d = Joist spacing in meter at 3-meter framing span

$$M = \frac{(d)(320)(3^2)}{8}$$

M = 360d Kg.m Find Section Modulus (S)

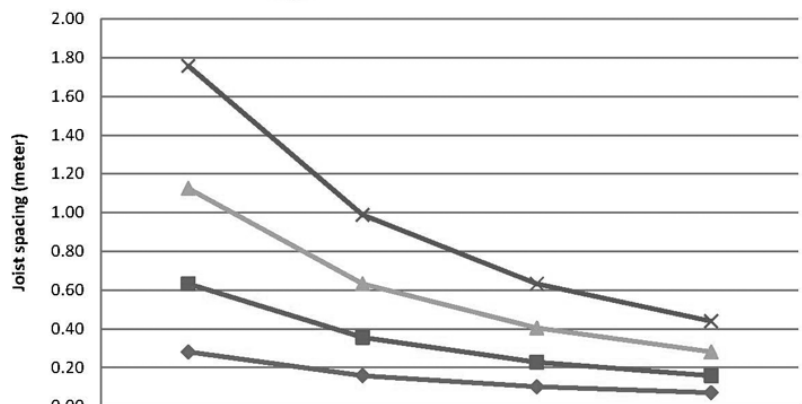
$$M = \frac{M}{fb} = \frac{360d}{162}\,m^3 = \frac{36000d}{162}\,cm^3$$

S2x4 =62.5cm^3, then d=0.28m
S2x6 = 140.6 cm^3, then d = 0.63 m
S2x8 = 250 cm^3, then d = 1.13 m
S2x10 = 390 cm^3, then d = 1.76 m

The simple calculation demonstrates that the joist spacing of a 3-meter span is 0.28m for 2x4", 0.63 m for 2x6", 1.13 m for 2x8", and 1.76 m for 2x10" respectively. The calculation is performed further for a larger span in typical residential framing at 4, 5, and 6 meters, and the joist spacing (d) results are shown in the figure below as guidelines.

This case study provides preliminary evidence that coconut lumber is still capable of receiving loads in residential framing with reasonable dimensions. This may encourage further uses.

Figure 12. Diagram of how to determine joist spacing using coconut lumber at predetermined spans.



	3m span	4m span	5m span	6m span
2x4	0.28	0.16	0.10	0.07
2x6	0.63	0.36	0.23	0.16
2x8	1.13	0.63	0.41	0.28
2x10	1.76	0.99	0.63	0.44

Figure 13. Coconut joist design guideline at different span, in order to get general idea on sizing.

Conclusion

It is obvious that coconut still retains considerable potential as an alternative construction material in terms of sustainability, due to its abundance, fast growth, and low energy production. In terms of its structural properties, coconut wood is still weak in shear because the vascular bundles are widespread in the trunk section. They do not offer the best structural capability, but it is nevertheless comparable. In this case, the actual bending property might not be found in this research, due to earlier failure by shear. It is predicted to be, in fact, a higher projection. However, the bending stress found in this research is still low when compared to structural woods in Thailand. It may be comparable to soft wood, which can create a simple lightweight structure, such as joist members.

Coconut is considered an exotic wood because of its grain and being an unconventional source. It can offer a special beauty through its texture. It may not give the highest structural capacity, but it is still a valid structural material. Therefore, the utilization of coconut wood is extremely viable as a sustainable and decent structural material. It could be used in simple small load structures, like local houses, resorts, or bungalows. It could also show off its exotic beauty if used in resorts where coconuts are abundant, so that foreign visitors can experience the Thai vernacular style. Even though its structural properties are somewhat disappointing, this research suggests that this material still has potential, especially within the current context of global warming. This research still fully supports the viability and sustainability of coconut wood as an alternative structural material. To develop further studies of this material, coconut could be transformed using engineering technology to increase its structural capacity, such as lamination technology and other material composites. This potential will be worth exploring in further investigations.

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