J. W. Gottstein Memorial Trust Fund

The National Educational Trust of the Australian Forest Products Industry

GOTTSTEIN
TRUST

USE OF PLANTATION HARDWOOD THINNINGS AS ROUNDWOOD IN CONSTRUCTION

AMANDA YEATES

1999 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organisation (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are,

1. Fellowships and Awards - each year applications are invited from eligible candidates to submit a study program in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their program. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

4. Study Tours - industry group study tours are arranged periodically and have been well supported.

Further information may be obtained by writing to,

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1. Executive Summary

Access to hardwood material for processing from native forests is being phased out under Regional Forest Agreements in Australia and conserved under environmental policies in most other countries. Plantations are expected to meet a growth in demand of approximately 4% (~100,000 hectares) annually and the total plantation estate is expected to reach 3 million hectares within two decades.

Critical to the success of any plantation hardwood development will be the ability for all players across the value chain to realise an economic return from their investment. This will mean a that not only will there be a requirement to find markets for high value end products from the final crop, maximising return to both the grower and the processor, but also economically viable markets for products from other components of the plantation, including the material thinned in the management of the plantation. While markets for high quality final crop resources will not present a problem in the context of current national and international utilisation trends, using thinnings material presents a considerable challenge as processing the material is difficult, and the value of and return on products from this resource is poor. If suitable markets for this material can be found, it provides a revenue stream during the life of the plantation, as opposed to having return only at final crop, and increases the overall viability of the plantation.

This report describes a study which addresses the utilisation potential of plantation hardwood thinnings as round wood in construction including:

- Economic benefits of using thinnings material as round wood in construction.
- Design characteristics of the material and possibilities for grading.
- Connection methods.

The study indicates enormous potential to improve the economics of the plantation hardwood industry through utilisation of small diameter thinnings material as roundwood in construction. A simple economic model which assumes diversion of 20 percent of the total national hardwood thinnings from wood chip to roundwood for construction indicates a potential doubling of the income from this resource.

Impediments to the development of this industry in Australia are the current lack of standardised grading systems, design guides and round wood connection techniques. Results from an international study (Ranta-Maunus 1992) indicate that the strength of thinnings kept in their round form can be up to double that of the equivalent material as sawn lumber. While these results suggest potential for use of thinnings in construction, and future supplies of resource for such an industry are set to increase, the single biggest impediment to the development of the industry is a successful jointing system.

In a similar way that the development of nail plating technology opened the opportunity for mass produced truss and frames, the success of an industry in using small diameter round wood for construction will depend on the development of an inexpensive, mass produced, universal jointing system. An opportunity exists for Australian research to capitalise on development of jointing systems available from the research to date, and to adapt the technology to suit commercial requirements. The development may incorporate other technologies such as kiln drying of the rounds to reduce differential movement caused by the in-service moisture content changes in the material, due to shrinkage and swelling with shifts in moisture content. Successful development of a jointing system has the potential to increase the commercial viability of plantation hardwood forestry in Australia, and increase returns to the grower, processor and end user.

2. Introduction

2.1 Background

Access to hardwood material for processing from native forests is being phased out under Regional Forest Agreements in Australia and conserved under environmental policies in most other countries. Plantations are expected to meet a growth in demand of approximately 4% (~100,000 hectares) annually and the total plantation estate is expected to reach 3 million hectares within two decades. In 1996 the Australian government introduced a Forest Industry Strategy and Vision 2020 aimed at trebling the plantation resource and effecting a saving of $2billion annually in import replacement. In 1999 Australia has an estimated 900,000 hectares of plantations of which 389,000 were eucalypt (National Plantation Inventory, March 2000). Extensive eucalypt plantations have also been established in China (2m ha), India (5m), Vietnam, and South America. Most of these plantations are initially targeted at the pulpwood market with sawlog an increasing consideration.

The current trend in forestry in Australia toward managed plantation resources has been driven by environmental concerns which focus on the cessation of native forest logging and replacing this industry with plantations for industrial wood production. Politically these concerns are being addressed through ‘Regional Forest Agreements’ (RFA), a process initiated in 1992 through the cooperation of Federal and State governments of the day. Such agreements have resulted in a significant reduction in future harvesting of wood from native forests and a commitment by government to plantation development and private investment in plantation hardwood forestry.

Plantation forestry provides new challenges in the effective use of resource, which were not seen in processing of native forests. Good management and high productivity in plantations cannot be achieved without proper thinning procedures. Thinning in forestry management is the removal of some trees at various times during the life of the plantation. The trees removed are generally those which are suppressed and do not exhibit good growth potential. Thinning allows the other trees to continue growing with reduced competition, and at the same time reduces the risk of insect and disease attack, and the risk of destruction of the plantation through fire, as the fuel load of the forest is reduced. The thinning process yields a surplus of small diameter round timber that currently has limited low value markets, particularly in the case of hardwoods.

Critical to the success of any plantation hardwood development will be the ability for all players across the value chain to realise an economic return from their investment. This will mean a that not only will there be a requirement to find markets for high value end products from the final crop, that maximise return to both the grower and the processor, but there must be economically viable markets found for other components of the plantation, including the material thinned in the management of the plantation. While markets for high quality final crop resources will not present a problem in the context of current national and international utilisation trends, using thinnings material presents a considerable challenge as processing the material is difficult, and value and return on products from this resource is poor. If suitable markets for this material can be found, it provides a revenue stream during the life of the plantation, as opposed to having return only at final crop, and increases the overall viability of the plantation.

2.2 Objectives

In the development of this Fellowship study, the original objective was to assess the use of small diameter material as roundwood for construction, both from hardwood and softwood resources. However, the current political and environmental focus on plantation hardwood forestry meant that a significant research focus has been the viable processing of plantation hardwood. In conducting this research, it quickly became apparent that the management practices associated with plantation hardwood forestry would yield large volumes of small diameter material that would be difficult to process using current technology, and that had limited product potential in economically viable markets.

Much of the discussion in this report relates directly to the use of small diameter hardwood material derived from the management of plantation hardwood forests. The issue of finding markets for this material is critical to the development of successful plantation hardwood forests for industrial lumber production both nationally and internationally.

While the focus for this study is hardwood, the principles of using roundwood in construction could apply equally to both hardwood and softwood.

In Australia, there have been limited studies into the use of small diameter roundwood in construction. While there are many domestic and small-scale industrial buildings that have used roundwood for structural members, information available for designers is limited, particularly in relation to connection systems.

In developing the itinerary for this Fellowship the objective was to visit selected international forest product research organisations which had been involved in research and development projects dealing with small diameter roundwood in construction. The itinerary is presented in Appendix A.

3. Current Practices for Use of Thinnings

3.1 Australia

Utilisation of small diameter material in Australia is mainly as pulpwood chips, firewood, fence posts and agricultural poles such as trellis stakes for grape production. These markets in most cases are currently adequately supplied through the softwood thinnings resource. Recently developed plantation hardwoods resulting from the shift from native forests for industrial wood production will yield high volumes of small diameter material from the thinning process. Attempts to move this small diameter hardwood resource into current markets could cause an oversupply, which has the potential to significantly lower the value of these markets. In order that plantation hardwood forestry be profitable and therefore attract the private investment required for its success, economically viable markets must be found for the thinnings material.

There are currently applications where roundwood is seen in construction in Australia, most notably in pole homes, which have enjoyed increasing popularity in Australia over recent years. The difficulty in promoting and increasing the use of small diameter roundwood in construction is the lack of technical support for designers wishing to utilise this resource.

Currently, there are inadequate systems for:

- Grading of small diameter roundwood to reliably predict the design characteristics of the material.
- Design guidance and standardised design procedures.
- Standardised, effective and inexpensive jointing systems.

While the use of small diameter roundwood from thinning of sustainably managed plantation hardwood forests would seem attractive to designers, the lack of technical support and design guides discourages many from using the material.

3.2 Processing Small Diameter Thinnings for Sawn Wood

Small diameter plantation hardwoods provide challenges in both sawing and drying due to reduced log size, growth stresses and juvenile wood. Consequently, the sawn recovery from plantation hardwood thinnings can be expected to be lower, and mechanical properties associated with the sawn material less than those experienced with traditional resources.

Juvenile Wood

Juvenile wood is the material laid down in the initial growth phase of the tree. The juvenile wood fibres have a tendency to be shorter and lower density. Juvenile wood often exhibits spiral grain which causes distortion during sawing and drying (Plate One). Juvenile wood is difficult to quantify, and is almost impossible to measure in a standing tree using currently available technology. It is hypothesised that juvenile wood in plantation hardwood material occurs in the first 15 to 18 years of growth. As many hardwood plantation management regimes have a commercial thin at an age between 10 to 15 years, it is expected that the majority of material coming from plantation hardwood thinning will be juvenile wood and thus will be difficult to process for sawn wood.

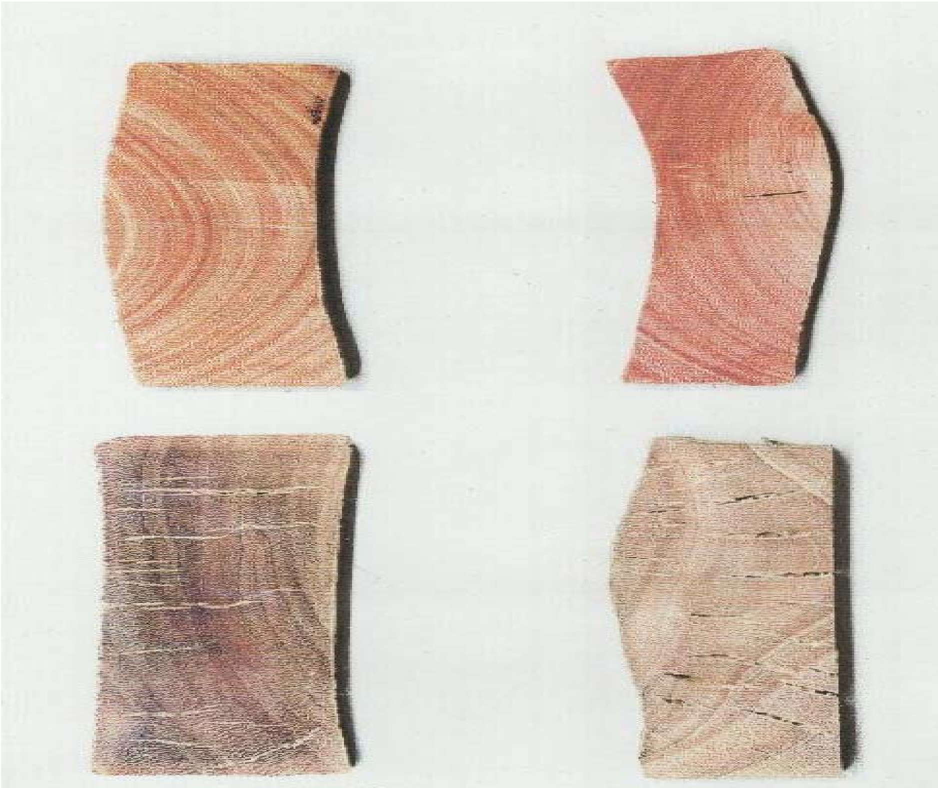


Plate 1: Examples of distortion of sawn boards during drying due to juvenile wood.

Growth Stress

Growth stresses are also the result of growth phases of a tree. In hardwoods, layers of cells added to the stem during growth are in a state of tension. Each layer added increases the tension forces and thus the tension forces in the outer part of the tree are constantly increasing (Malan 1987). To counterbalance the tension forces, compression forces develop in the central part of the tree. In the standing tree, these opposing forces are balanced, and thus have no effect on the macro structure of the wood. On cross cutting, this equilibrium is removed, causing the outer tensile cells to contract or shorten, and the inner compressive cells to expand (Malan 1987). This distortion is exhibited through the development of radial splits at the ends of the logs. Growth stresses can also cause splitting of sawn boards, and can also contribute to the distortion of timber during sawing and drying. The phenomenon tends to be worse in trees that have been subject to suppressed growth (Malan 1987). In the case of plantation hardwoods, most management practices prescribe high initial stocking. The material removed during the thinning process is often that with suppressed or poor growth, and the associated growth stresses may make it extremely difficult to process (Plate 2).

Plate 2: Cracking pattern in a tree caused by growth stresses after cross cutting (left) and the effect this can have on the sawn board (right).

Mechanical Properties

In addition to problems of juvenile wood and growth stresses described above, density and other defects such as knots can also affect the quality of recovered product from plantation hardwood thinnings. Studies in Queensland (Leggate *et al* 2000, Muneri *et al* 2001) have indicated that for some species, for example, the density of material of thinning age (between eight and twelve years) can be as low as sixty to seventy percent of the density of mature wood. In addition, the modulus of elasticity (MOE) for material of a similar age has been measured as low as seventy percent of that expected from mature trees. Similarly in studies of the modulus of rupture (MOR), values have been measured at eighty percent of the expected value for mature trees (Muneri *et al* 2001).

3.3 International Practice

Internationally, the need for improved utilisation of thinnings material from the management of forests is recognised. Table 1 below indicates approximate area under plantation hardwoods in a number of other countries (Klemarewski *et al* 2000).

Table 1: Examples of Area under Eucalypt Plantation

Country	Area Under Plantation (Hectares)
Brazil	2 921 000
India	2 670 000
South Africa	557 000
Portugal	550 000
Spain	550 000
Chile	300 000
China	274 000
Argentina	242 000
Vietnam	202 000
Uruguay	176 000

Growers of the resource have recognised the need to position thinnings resources into high value markets to ensure the economic viability of this resource and to increase the overall economic performance of the plantations.

In Europe, a major research project into the use of plantation thinnings material as roundwood in construction was completed in 1998 (Ranta-Maunus 1992). The project resulted in design guidelines for grading, design and jointing systems which were recommended for inclusion in Eurocode 5 for engineered structures. Design guidelines were also produced for simpler non-engineered structures.

While this project focussed on softwood plantation thinnings, the principles for development of design guidelines that were recommended for adoption in standardised engineering design could be used for the development of a viable industry in the use of small diameter roundwood from plantation hardwood thinnings in construction in Australia.

3.4 Economic Benefits of using Hardwood Thinnings as Roundwood in Construction

Consistent with the implied strategic goals outlined by the Federal Governments 2020 Vision Policy, hardwood plantations are estimated to increase from 389 000 hectares in 1999 (National Plantation Inventory, March 2000) to 873,000 hectares by 2020. This represents annual plantation growth of between 15,000 to 32,000 hectares (or 4 percent per annum) over the next 18 years assuming a straight-line growth percentage. The estimated plantation size also takes into account the assumed 20-year rotation and a commercial mean annual increment of 17.5 m^3. If it is also assumed that thinnings material will make up about forty-five percent of the plantation, the growth in this resource will be from 1 million m^3 in 2004 to 3.4 million m^3 in 2020 (Collins 2001).

Under the current market situation, the majority of this thinnings material would be sold as woodchip or pulp. Global woodchip prices are currently about \$90/ m^3 and expected to decline by 3% annually as supply exceeds demand (Collins 2001). If the plantation thinnings could be successfully sold into a woodchip market, revenue from thinnings would increase from \$82 million in 2004 to \$187 million in 2020.

If even a small percentage of this thinnings material can be utilised as roundwood for construction, the return to the investors in plantation hardwoods is large when compared with sale into woodchip markets only. For the purposes of this analysis, it is assumed that 80% of the thinnings material produced is used for traditional woodchip markets, twenty percent is used in round form for construction. The value of the product as a construction material is assumed to be \$200 per cubic metre, with an increase in value of 3 percent per annum. By applying these assumptions it is possible to conclude that:

- Revenue in woodchip from plantation hardwood thinnings will move from \$66 million in 2004 to \$150 million in 2020;

• Revenue in roundwood for construction from plantation hardwood thinnings will move from $36 million in 2004 to $217 million in 2020;

• Overall revenue from plantation hardwood thinnings will move from $103 million in 2004 to $368 million in 2020

This simple economic analysis represents the potential for increased return to the investor, through the development of a market for plantation hardwood thinnings as roundwood for construction. The increased revenue from diverting just 20 percent of the total thinnings material is illustrated in Figure 1.

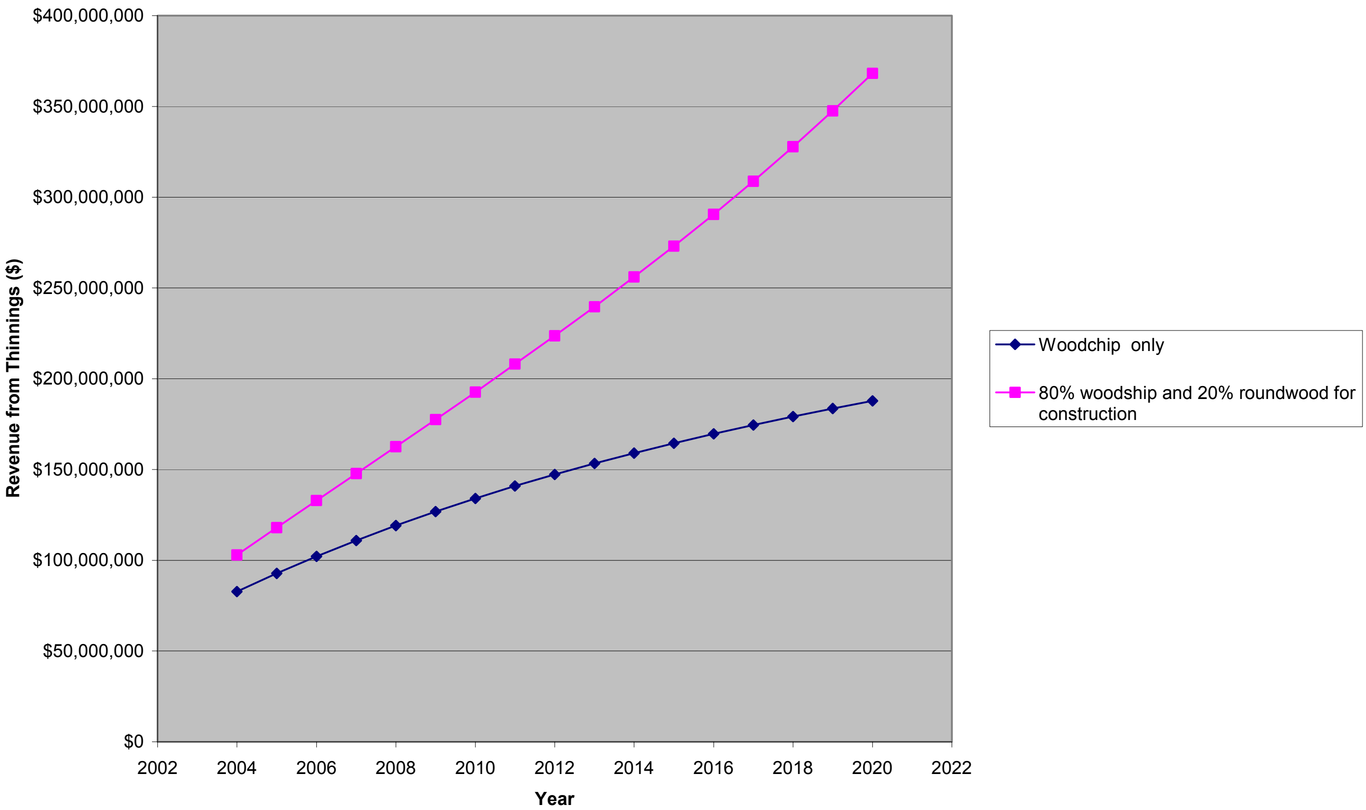


Figure 1: Revenue from thinnings into woodchip markets compared with utilising 20% of available thinnings from plantation hardwood for roundwood for construction.

4. Use of Small Diameter Roundwood in Construction

4.1 Geometric comparison with Sawn Timber

In keeping small diameter thinnings material in round form, not only are processing difficulties minimised, but the characteristic design properties are improved over equivalent sawn sections that could be recovered out of the same material. This is due to section geometry combined with tree physiology. (Wolfe 1999)

To illustrate this, the section properties of a round sample are compared with those that can be achieved from the largest square section achievable from the same section. The example compares the round section with the largest square section possible through pure geometry only. It does not take into account processing issues and natural characteristics such as sweep in the log, knots, insect damage, decay and other natural defects.

Table 2 below details the average cross sectional area, section modulus and second moment of area for a typical small diameter round section from thinnings. The round section has a butt diameter of 250mm with an average two percent taper along the length of the sample. The total length is 9 metres and the sample is debarked with no shaving or machining.

Table 2: Average Section Properties for Round Section

Property	**Value**
Butt diameter (D_{butt}) (mm)	250
Small end diameter (D_{SED}) (mm)	205
Average diameter (mm)	227.5
Area (mm)	40.7×10^3
Section Modulus (S_x, S_y) (mm^3)	1.2×10^6
Second moment of area (I_{xx},I_{yy}) (mm^4)	131×10^6

By comparison, Table 3 indicates sectional properties for a square section sawn from the same log. Tree physiology is such that taper is experienced along the length of the sample toward the top of the log. This taper limits the square section that can be cut from the log to the geometric constraints of the small end diameter. In this case the maximum cross sectional area that could be cut from the log would have a width of 145mm.

Table 3: Section Properties for Square Section

Property	**Value**
Width (B) (mm)	145
Area (mm)	21×10^3
Section Modulus (S_x, S_y) (mm^3)	0.5×10^6
Second moment of area (I_{xx},I_{yy}) (mm^4)	36.8×10^6

In this example cutting the square section from the round log would reduce the cross section area by fifty-two percent, the section modulus by forty-four percent and the second moment of area by twenty-eight percent. In addition the physiology of the tree is favourable to superior properties in round form. When left in the natural round form, the outer fibres of the section contribute greatly to the characteristic properties of the material. When sawn these fibres are cut and are no longer as significant in the strength and stiffness characteristics of the material. At the same time, knots and other strength reducing characteristics that were surrounded with continuous fibre in the round form are often on the face or the edge of a sawn section, causing them to become strength-limiting defects.

4.2 Design Characteristics

There has been limited published data on the characteristic properties of small diameter roundwood. Internationally there is also a lack of material-grading standards for small diameter round wood and design guidance for the use of this material in structural applications. Much of the information available for design is based on testing of small clear sawn timber and grading rules are often subjective and do not necessarily reflect the true characteristic properties of the material.

Critical to the success of encouraging the use of small diameter thinnings as roundwood in construction is having comprehensive design and grading standards to allow both producers and designers to maximise the utilisation potential of this material. Ideally, grading rules could be developed that could be used by producers with minimal capital outlay with reliability suitable for designers. In order to achieve this, a grading program must be developed which may include traditional visual grading principles together with practical inexpensive non-destructive grading methods such as acoustics. This grading information must then be calibrated against true structural properties through in grade testing principles that rely on the testing of full size sections of material.

4.3 Grading Methods

Visual Grading

Visual grading is a means of predicting design characteristics of timber based on known relationships between visual characteristics of the material and structural properties. Examples of the types of visual characteristics that could be measured are knots, insect damage, decay, sweep of the log and growth ring width. In sawn timber, visual grading is well practised internationally as a means of grading structural material. It is however recognised in sawn timber that the correlation between visual characteristics and structural properties is in many cases quite low, and it follows that the reliability of the structural properties is quite variable.

Non-Destructive Test Methods

Non-destructive evaluation (NDE) techniques have been used for grading of sawn timber since the mid 1960's, in the form of machine stress grading. NDE, as with visual grading, relies on the relationship between a property that can be measured and the structural characteristics of the material. The major advantage of NDE techniques is that they remove the subjective element that can be associated with visual grading, and therefore they have the potential to have better correlations with the structural properties of the material, and improve the reliability. There are a number of NDE methods that may be suitable for grading of small diameter roundwood as follows:

Acoustic

This method measures the dynamic MOE of the material by the excitation of a sound wave at one end of a sample. A measurement is then recorded of the time taken for this to reach the other end of the sample, and the velocity of the sound wave is used to determine the dynamic MOE of the material.

X-ray

Higher density wood attenuates more radiation than lower density wood. Variation in attenuation is detected by x-ray sensors as different x-ray shadows. These x-ray shadows can then be used to assign structural characteristics.

Microwave

Microwave grading techniques involve transmitting and receiving electromagnetic waves through the timber. The transmission of these waves through the material varies with the dielectric properties of the material, and this variation can be used to determine grading parameters.

4.4 Relationship between Grading and In-Grade Properties

In the EC project *"Round small diameter timber for construction"* a study was conducted where visual properties and properties measured through non-destructive techniques were measured for a sample of small diameter roundwood and compared with the characteristic properties derived from in-grade testing. The study was conducted on a number of European pine species from thinnings operations in normal forest management practices. The samples in this study were visually graded and also graded using acoustic and x-ray techniques. The samples were then destructively tested in bending to determine MOE and MOR. The results of this in-grade testing, along with density results, are given in Figure 2.

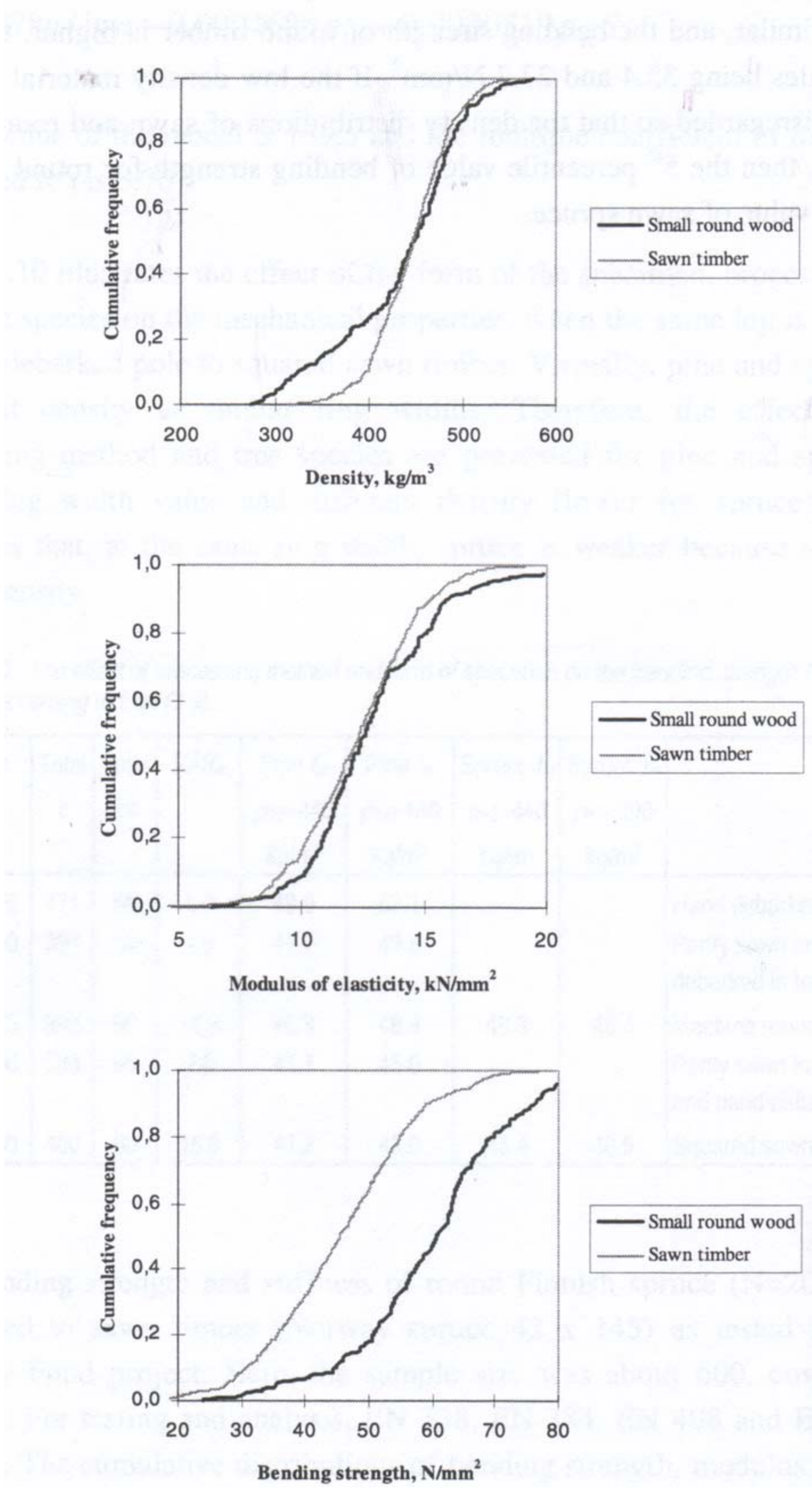


Figure 2: Density, MOE and MOR for Round Timber and Sawn Timber [Ranta-Maunus 1999]

As can be seen in Figure 2, the results from the round timber are compared with results for sawn timber from a similar resource. The density of the two populations is similar, with the round timber having slightly lower density on the bottom thirty percent of the population. The MOE of the two populations is also similar. Of most interest is the difference in MOR between the two populations. The MOR of the round material is double that of the sawn material, which reinforces the hypothesis that strength is enhanced by leaving the material in the round form.

In correlating the visual and non-destructive grading methods with the structural characteristics obtained from testing, it was found that the visual grading parameters had a low correlation coefficient (r^2=0.5), but this correlation is similar to than that exhibited for sawn timber on which well-established grading systems are based. The NDE techniques showed higher correlations than the visual methods, and the results indicate that the NDE systems are a promising grading alternative that could be used as an independent grading system, or in series with visual grading to improve reliability. In a model incorporating acoustic grading combined with information on knots and density, the correlation coefficient r^2 was 0.67.

The results from the European testing program reinforce the potential for use of hardwood thinnings as structural elements. With a well-designed research program, a grading method could be developed to correlate with in-grade testing results. The grading could be a combination of visual and NDE techniques to increase the reliability of results.

4.5 Connection Methods

Connecting round structural elements is perhaps the most challenging aspect of utilising thinnings as roundwood in construction. Part of the appeal of sawn timber is its relative uniformity, parallel flat surfaces and standard dimensions. These allow for fabrication of simple, inexpensive connectors such as nail plates that are used in the prefabricated truss and frame industry. Natural round timber with its varying dimensions and taper make not only prefabricated connections difficult but also add complications in other construction areas such as the fixing of cladding and flooring to round members. In addition, roundwood exhibits greater shrinkage in the tangential direction than in the radial and axial direction during drying (Figure 3). This differential shrinkage induces cracking along the length of the round material that may interfere with the effectiveness of the connection systems.

In all of the construction systems studied, unseasoned timber was used. The differential shrinkage that can compromise both jointing systems and structural capacity of members may be minimised if the members were installed seasoned. This would reduce the differential movement experienced with changes in the in-service environment.

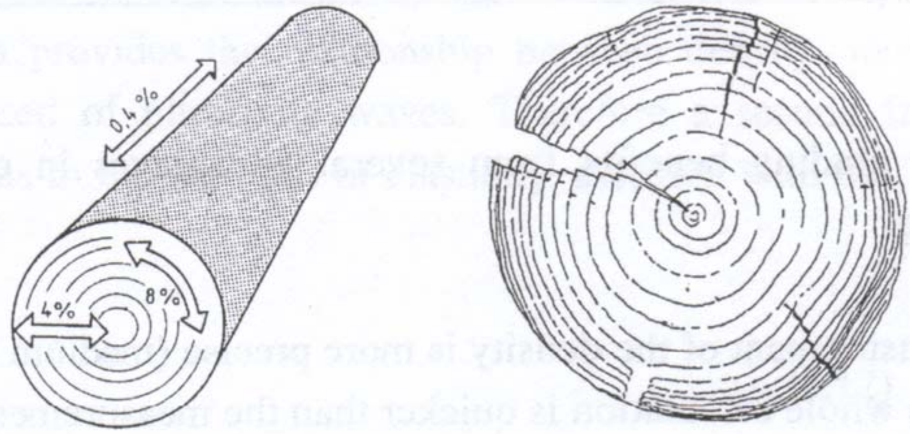


Figure 3: An example of cracking due to differential shrinkage

There are a number of schools of thought regarding the development of connectors for small diameter roundwood structural elements. There are those who believe that the resource requires simplistic, low technology engineering solutions. This type of jointing systems would allow for the provision of inexpensive kit type structures that can be premanufactured in the factory and arrive ready to assemble on site, with specialist tooling requirements kept to a minimum. The opposing view has seen the development of complex jointing systems designed to maximise the capacity of the joint while at the same time being an attractive feature of the construction.

A number of jointing systems were investigated during this Fellowship study as follows:

Wood-to-Wood Connections

Plates 3 and Figure 4 illustrate a typical wood-to-wood connection system. These types of jointing systems are based on traditional construction methods and are low technology simple jointing solutions. The round members are often notched or surfaces at the connection point are flattened to ensure contact is made between the members. The jointing system generally includes a bolt or dowel through the members to strengthen the connection, particularly where movement in the joint is expected through shrinkage of members.

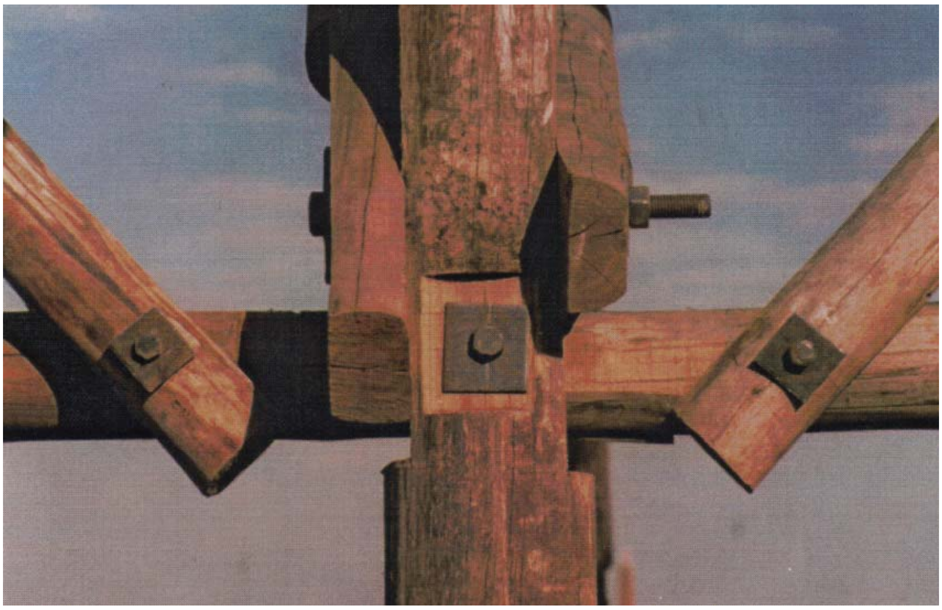


Plate 3: Wood-to-wood connection incorporating bolts

This type of jointing system has the advantage of being simple and easy to assemble. The disadvantage of the system is that its simplicity also limits its versatility in construction. The joints are often limited in the number of members that can be associated with each joint, and connecting members in more than two planes is difficult, thus limiting their design potential. There are also difficulties associated with maximising the design capacity of the joint, as the number of bolts that can be used in a joint is limited by the surface contact area between members, thus the full structural potential of the members is difficult to realise.

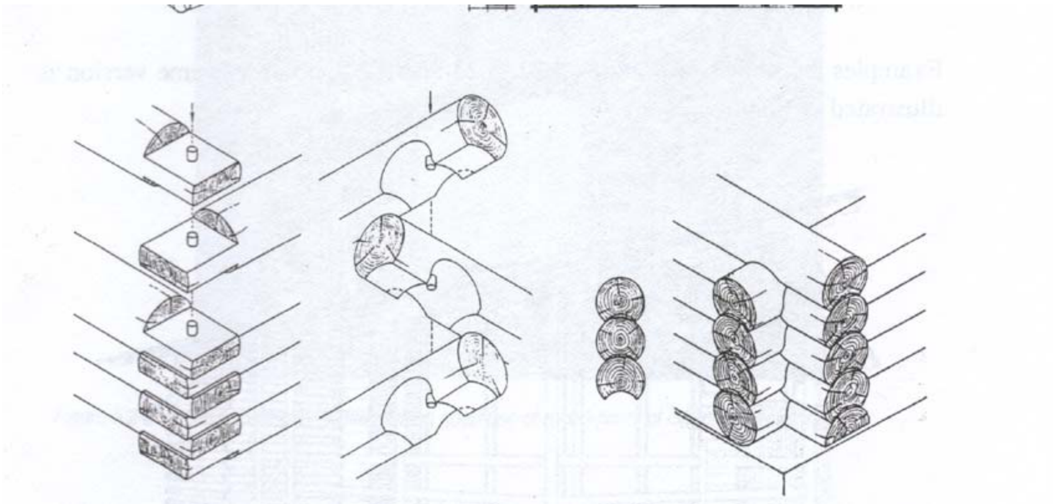


Figure 4: Wood-to-wood connection in traditional log framing

Epoxy Joint

A purpose-designed jointing system (Figure 5) was developed by Buro Happold Engineers for demonstration structures in England. The jointing system was developed to allow the jointing of tension members, which had been limited under traditional jointing systems, with minimal visible connection to improve the aesthetics of the connections. The joint involved a stepped hole in the end of a member. A steel rod is embedded into the hole using an epoxy resin. The use of an end-grain jointing system was chosen to maximise the efficiency of the joint in the small section. The epoxy resin was incorporated in the joint due to its gap filling properties.

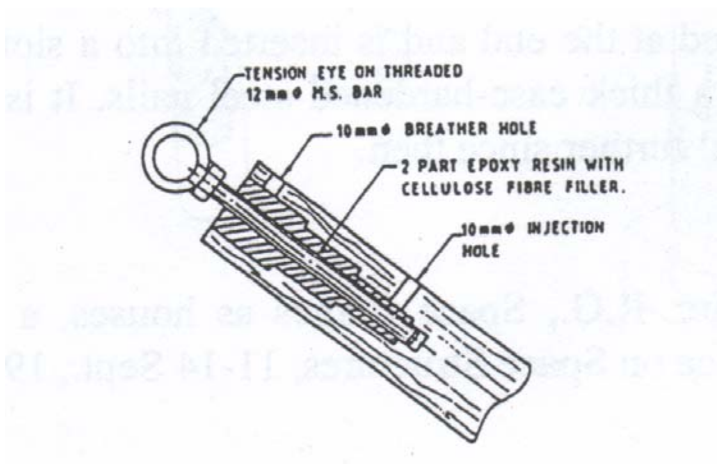


Figure 5: Buro Happold Tension Jointing System

Four joints of this type were tested at Bath University to determine their suitability for the design applications. The performance of these joints in the laboratory tests was adequate. However, the extent of testing, in particular the number of samples tested, was limited and there was no testing on duration of load effects and creep of the joints.

The jointing system has been incorporated into the demonstration structures, the first of which has been in service for over ten years. In that time the jointing system has performed to expectation. However, the joint was designed to carry tension loads under a design snow load that as yet has not been achieved and thus the joints have not had to perform under their full tension load in service.

Under Australian design conditions, the performance of this jointing system would be questionable as epoxy resin has a tendency to soften with heat and moisture, and the high humidity and heat experienced in Australia may compromise the integrity of the joint.

Nail Plates

The nail plating system (Figure 6, Plate 4) is based on the system used for the highly successful prefabricated truss and frame industry in sawn timber. Plates are manufactured from light gauge steel that is shaped to suit round timber. The plates are predrilled for nailing of standard nails into the members.

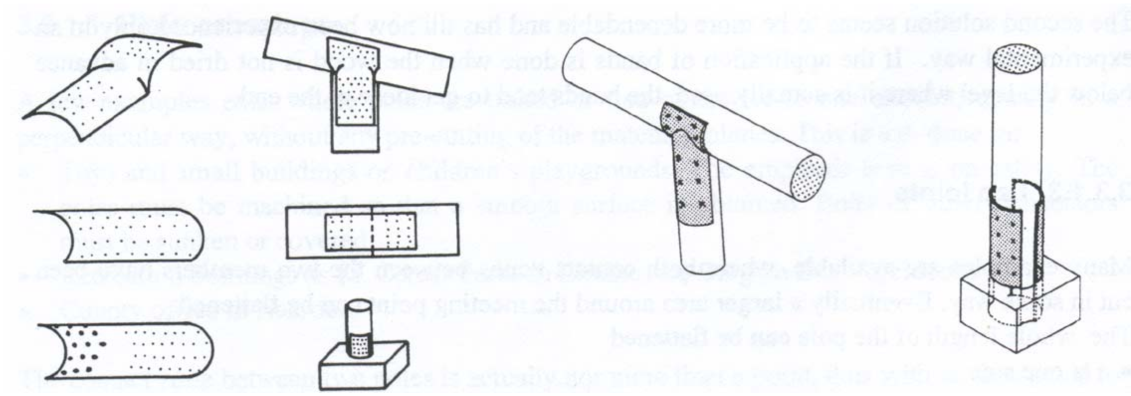


Figure 6: Examples of Nail Plating Systems for Roundwood

In order for the system to be successful, the plates would need to be inexpensive and cater for the diameter and form variation between members. It may be possible to achieve this if the plates can be manipulated on site to fit snugly around the section without compromising the structural integrity of the plate.

Plate 4: Nail Plate Application

Laced Connections

Laced connections were developed specifically for use with small diameter roundwood. The member is slotted at the end along the diameter and a steel plate is inserted. Dowels or bolts are then inserted perpendicular to the steel plate through the member (Figure 7). The use of the steel plate allows a number of load transfer bolts or dowels to be used thus maximising the design capacity of the joint. Once the bolts are in place, steel or wire lacing is applied around the member to minimise movement and cracking and maintain the strength of the joint.

The laced connection system has been used successfully in a number of small diameter roundwood constructions in Europe. The advantage of the system is that the plates can be inserted either on site or prior to delivery, and the steel plates can then be used into standard connection systems. The major drawback of the system is that the strength is heavily reliant on the lacing being fixed tightly around the member. In normal service, many of these systems have not been as effective as expected as shrinkage in the members has caused the lacing to slacken so that it is no longer an effective part of the jointing system. In addition, the system has had some negative feedback for aesthetic reasons.

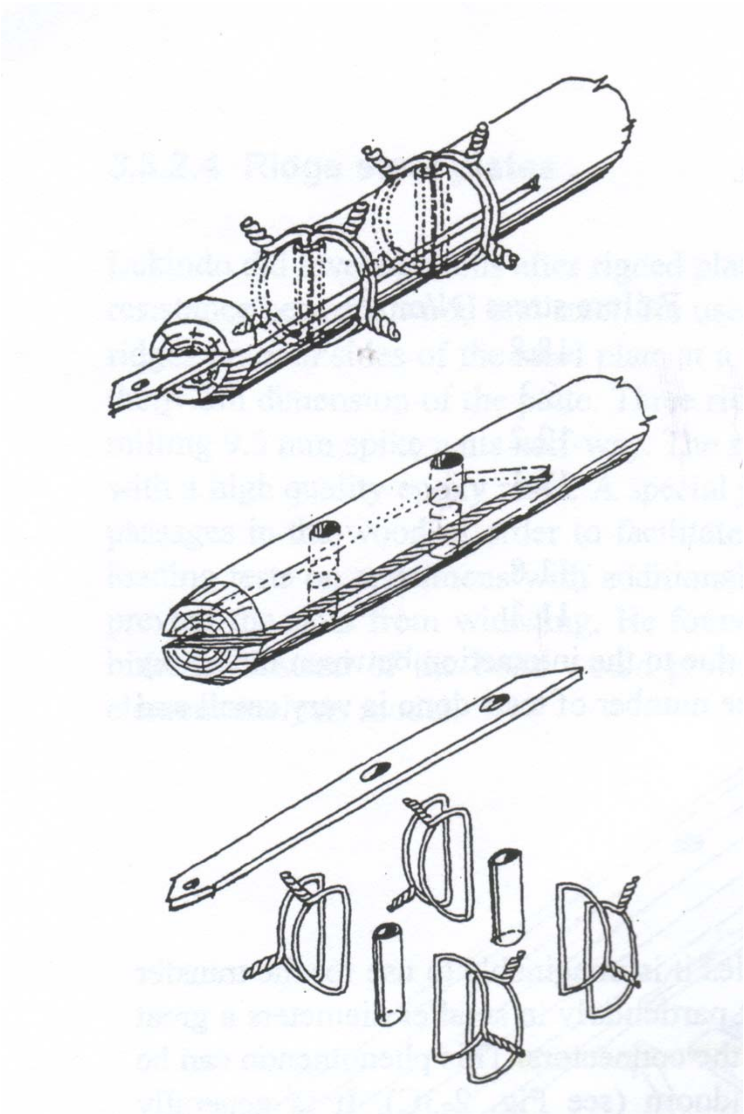


Figure 7: The Laced Connection System

The four jointing systems discussed above were the focus of this study tour. There are other jointing systems that have been trialed for use in connecting small diameter roundwood for construction, with varying success. While many of the jointing systems studied have some aspects which are advantageous in connection small roundwood, none have completely addressed the issues associated with using this material as structural members while being inexpensive, universal, easy to use and aesthetically pleasing.

Other Systems

In the US, a number of high technology systems have been developed and patented to address the use of thinnings material in construction. One such system is called 'Light Prestressed Segment Arch (LPSA) Structural Technology'. The system uses mild steel connector 'sleeves' that the small diameter round wood slide-fit into, to form frames which are compressed using tensioning wire strands (LPSA Structural Technology, www.avalon.net). The advantage of the system is that the sleeved jointing system carries load in compression, avoiding issues associated with other failure modes that are seen in some of the other jointing systems.

The LPSA system was patented through EMIR Limited, a British research, development, design and engineering innovation corporation, and the technology later passed onto the American Institute of Sustainable Science and Technology (AISST). The system was originally developed through innovation funding from the European Union, and in the 1990 Toshiba Year of Invention Competition, won the top Small Business Invention Award.

Potential for Adaptation of Systems for Australia

In the jointing systems studied in this Fellowship, none had yet allowed for the development of a commercial industry based on the use of small diameter thinnings material in construction. While many of the systems proved successful in their initial load-carrying capacity, their long- term performance was not always consistent with requirements. In most cases, the biggest single impediment to the use of these systems was that they could not be mass produced for universal jointing systems, and had to be designed and manufactured on an individual job basis.

In a similar way that the development of nail plating technology opened the opportunity for mass produced truss and frames, the success of an industry in small diameter round wood for construction will depend on the development of an inexpensive, mass produced, universal jointing system. An opportunity exists to work with prototype jointing systems available from the research to date, and adapt the technology to suit commercial requirements. The development may incorporate other technologies such as kiln drying of the rounds to reduce differential movement caused by the in-service moisture content changes in the material due to shrinkage and swelling with shifts in moisture content.

5. Concluding Remarks

There is enormous potential to improve the economics of the plantation hardwood industry through utilisation of small diameter thinnings material as roundwood in construction. A simple economic model which assumes diversion of 20 percent of the total national hardwood thinnings from wood chip to roundwood for construction has the potential to double the income from this resource.

Use of the thinnings resource in its round form in construction diverts it from a low value thinnings resource to a higher value product without adding major processing requirements. This eliminates issues associated with trying to divert the thinnings into sawn products, where recovery can be low due to splitting, collapsing and other degrade experienced during sawing and drying.

The results of testing in Europe would indicate that leaving this resource in its round form could have major benefits for the strength of the material. In tests conducted in the project, the MOR of roundwood was approximately double that experienced for sawn material from a similar resource.

The most difficult aspect of developing a successful roundwood construction industry based on the use of hardwood plantation thinnings is the connection systems. While much work has been conducted worldwide, there is still no system which can be used that is inexpensive, easy to install, applicable to a variety of design situations and attractive enough to use as a design feature rather than simply a jointing system.

Australia has made a major commitment to the development of commercially viable plantation hardwood forestry. In order to see this industry succeed, there needs to be markets not only for the end product, but also for other materials including thinnings. The development of an industry utilising plantation hardwood thinnings in construction would see the material moved out of low value commodity markets such as wood chip and into higher value more viable markets.

While the potential to develop use of plantation hardwood thinnings as roundwood in construction is high, there would need to be research into the development of grading and design standards for the resource. The work on grading in the European project “Round Small Diameter Timber for Construction” showed potential for the development of non-destructive grading technology. In particular acoustic methods showed potential for incorporation with visual grading systems to improve the reliability of design properties and reduce the subjectivity associated with visual grading only.

In addition, commercially-viable jointing systems would be vital to the development of an industry using small diameter hardwood thinnings in construction. Concepts developed in research to date could be adapted towards this end. The jointing system would need to be inexpensive to produce, have the ability to be mass produced, and to be used as a universal jointing system to avoid the need for individual design and manufacture of joints for each design situation. While there is potential for use of thinnings in construction, and future supplies of resource for such an industry are set to increase, the single biggest impediment to the development of the industry is a successful jointing system. An opportunity exists for Australia to develop a jointing system to overcome this. The systems developed by TUDelft in the European project “Round Small Diameter Timber for Construction” exhibit good potential for further work and could be used as a basis for development of commercially viable connection systems.

Finally, the successful development of such an industry will depend on the perception of designers and their willingness to accept the concepts and new technologies. There would need to be some effort devoted to the education of designers in the use of this material, and marketing efforts in promoting its use as a sustainably-managed plantation product.

APPENDIX A: Travel Itinerary

Tuesday December 14 1999

TRADA (UK)

Dr Lionel Jayanetti

Discussions centred around a United Nations project TRADA in which twelve year old plantation Eucalyptus grandis *had been used for the construction of a community and education centre in the central African country of Malawi. The project focussed on low technology solutions that could be easily constructed by the local community.*

Wednesday December 15 to Friday December 17 1999

Buro Happold Engineers and site visit to Hooke Park (UK)

Buro Happold Engineers were responsible for three demonstration buildings including a prototype house, training centre and student lodge using small diameter roundwood timber. The timber was sourced from local forests around the site and the construction used innovative systems of design and jointing.

Monday December 20 1999

VTT Technical Research Centre of Finland

Dr Alpo Ranta-Maunus

VTT was the coordinator of a project commissioned by the European Commission entitled "Round small-diameter timber for construction". The project was a comprehensive study of availability of material, dimensions, quality, cost of harvesting, drying methods, durability, strength, potential types of structures that could be constructed from round timber and new mechanical jointing systems.

Wednesday December 22 1999

TU Delft, Netherlands and site visits to prototype buildings

Dr Casper Groot, Dr Pieter Huybers

TU Delft was also a participant in the EC project "Round small-diameter timber for construction". The university focussed on the research areas of connection systems, and developed a number of prototype buildings.

Monday January 10 to Wednesday January 12 2000

USDA Forest Service, Forest Products Laboratory, Madison WI

Dr Ron Wolfe

FPL has conducted research into the use of small diameter roundwood from the management of forests for use in construction. The focus has been on options for use, including agricultural or and higher value end use applications and jointing systems.

Monday January 17 to Friday January 21 2000

University of Sao Paulo, Brazil

Dr Akimi Ino

The university has been involved in a number of projects utilising small diameter roundwood from management of plantation eucalypt forests, primarily using traditional building methods to provide low cost housing and agricultural structures.

The study tour included exposure to a variety of solutions to the issues associated with use of small diameter round wood in construction, from low technology traditional round timber construction usage suitable for agricultural construction such as farm sheds, through to highly engineered structures with complex connection systems aimed at high value markets.

APPENDIX B: Case Studies

B1- Hooke Park

LOCATION AND BACKGROUND

Hooke Park Forest is located in north east Dorset, United Kingdom. The development was initiated by the Parnham Trust, Beaminister, Dorset UK. This group was founded by John Makepeace in 1977 as a non-profit-making educational charity. Its primary objective is to develop skills in students necessary to establish new enterprises using timber as a primary material. The site is in the heart of the 330 acre (132 hectare) woodland, consisting primarily of Norway Spruce.

DESIGNER

Architect: ABK Architects
7 Chalcot Road
London, NW1 8LH, UK
E-mail: 100045.3147@compuserve.com

Engineer: Buro Happold Engineers
Camden Mill
Lower Bristol Road
Bath, BA2 3DQ, UK
E-mail: richard.harris@burohappold.com

PROJECT DESCRIPTION (Burton, Dickson and Harris 1998)

The project brief was to develop a school for thirty students and staff, accommodation, workshops and visitor centre. Where possible, these were to be constructed from the forest thinnings, the intention being to demonstrate that these forest thinnings that traditionally had little value could have commercial uses. Stage one of the project consisted of a prototype house and a workshop.

The prototype house uses curved roof members in tension from Norwegian spruce thinnings material of 60 to 90mm diameter. The house is 11.2 m long by 8.5 m wide, and roof members are spaced at 460mm and span a maximum distance of 5.5m. These members form a catenary shape between the central A frame of the building and the external walls (See Figure B1.2). Over time, the change in moisture content of these members is expected to change as the members air dry. In this process, the stresses induced by the initial deflection of the members under the self-weight load will relax (as the stiffness of members increases with reducing moisture content). This reduced deflection over time allows superimposed environmental loads (most importantly snow) to be accounted for in the design (as the snow load can be superimposed on the relaxed initial stresses) with minimal additional deflection. In addition, the roof structure is a flexible membrane to allow for the movement in the members.

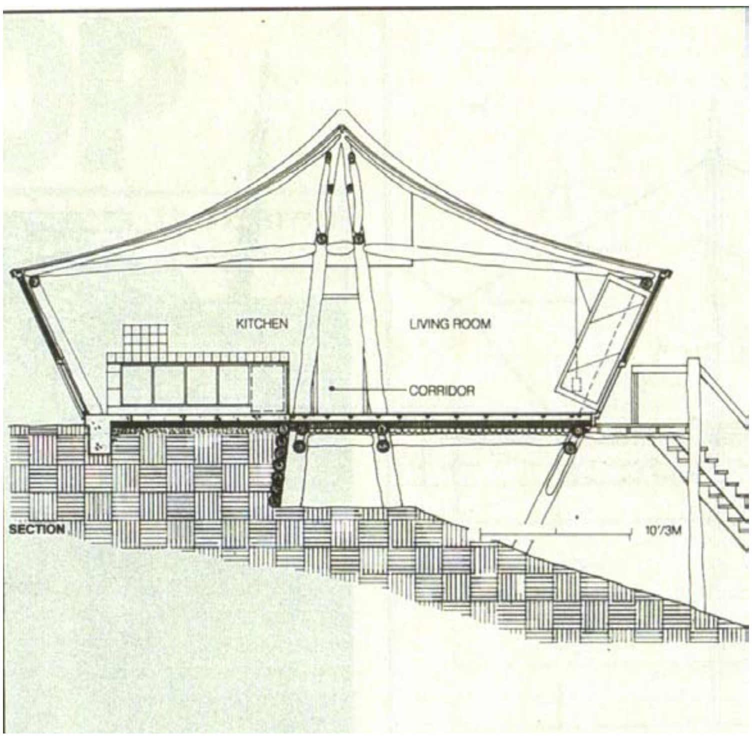


Figure B1.1: Section Through the Prototype House

Figure B1.2: Completed Prototype House

The workshop building has three shells, each spanning 15m, to form a structure 42.5m long and 7m high. The shells have a rigid laminated crown arch member, and thinnings of small end diameter 65mm and butt diameter of 155mm from the shape. The thinnings were bent in a cantilever when still green by pulling down with a rope to prestress, and were then connected to the central crown. In the construction of the first shell, 60% of this material failed during prestressing that required replacement with new timber. During this phase of construction, the thinnings were bent using gradual slow bending to the required shape. In further stages the wastage was reduced by overbending the members and then releasing the over stress. In doing this, member failures were reduced to ten percent. The roof structure is a flexible membrane as with the prototype house, to allow for movement in the structure, and to account for the uneven geometry due to the non-uniformity of the members.

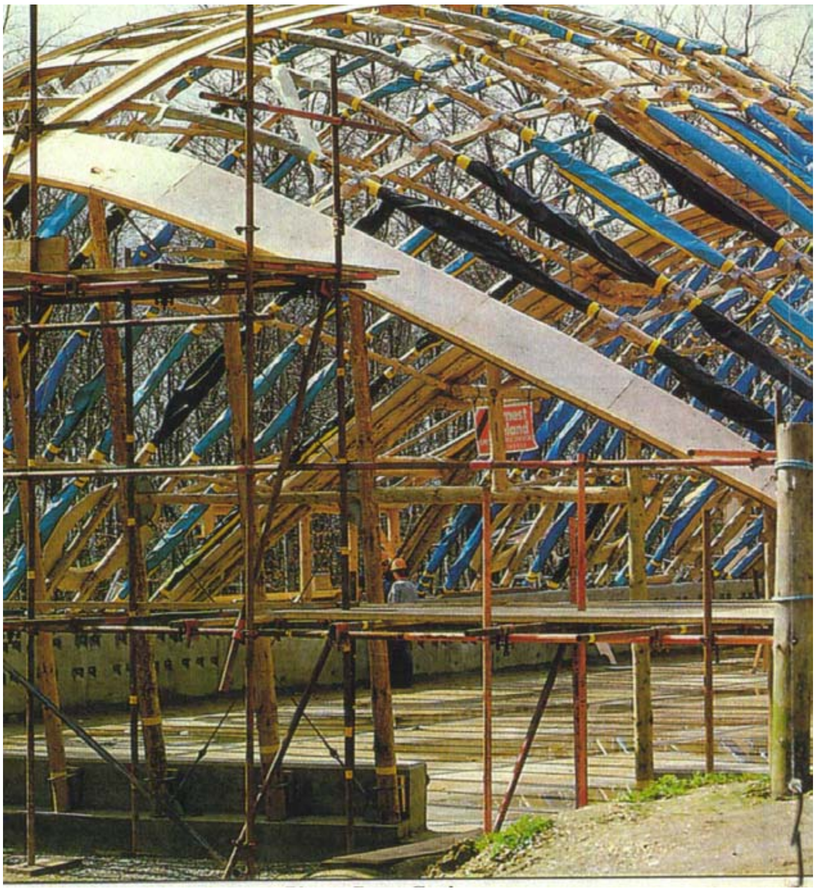


Figure B1.3: Workshop Under Construction

Figure B1.4: Completed Workshop

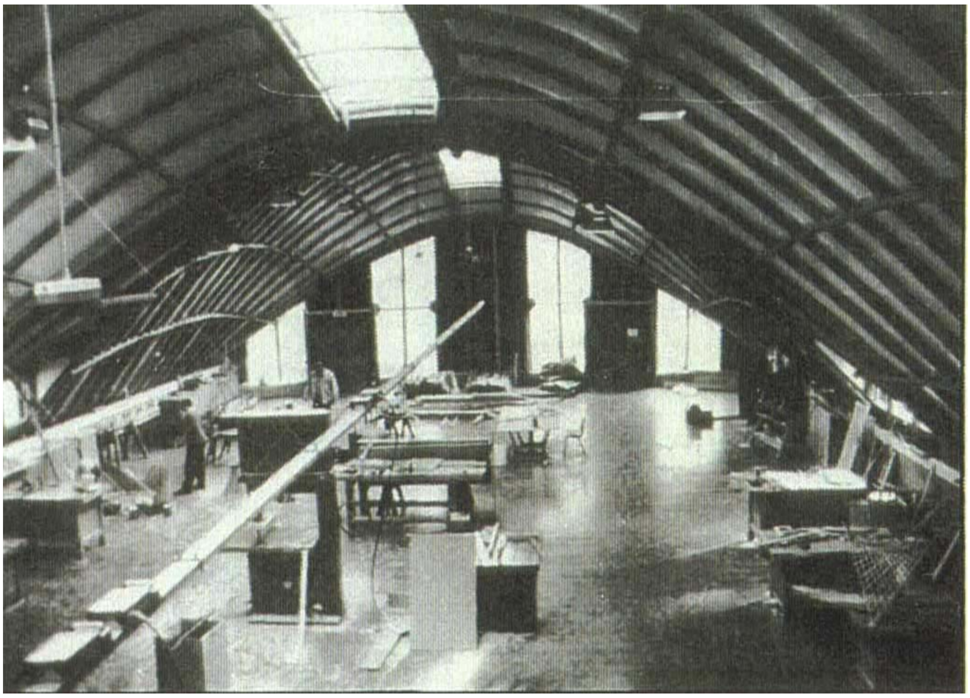


Figure B1.5: Interior View

JOINTING METHOD

Construction used the epoxy jointing system described in Section 4.5. The joint was purpose designed for this project, and was intended to act in tension. In initial testing of the jointing system at Bath University, joint failure occurred at 30kN and failure was initiated with the bar pulling out of the resin cone. To improve the gap filling properties and therefore increase the elasticity of the joint, cellulose microfibre filler was added. Four joints were tested with the 'improved' resin, with results ranging from 24.2 kN, 43.5 kN, 47 kN and 62 kN. The first result was discounted due to apparent poor workmanship, and while the laboratory testing was limited, the remaining three results were considered adequate to pursue this jointing method. In 1999, the design snow load to the structure had not yet been reached due to mild winter conditions, so the joints had not had full tension load, and therefore could not be fully verified for in-service performance in tension.

B2: Observation Tower, Apeldorn, The Netherlands

LOCATION AND BACKGROUND

The observation tower is located within the state owned forest in Apeldorn. The tower was constructed as a demonstration structure as part of the project "Round Small-Diameter Timber for Construction" FAIR CT 95-0091. The tower was designed by Dr P. Huybers (TUDelft) and constructed by Mulder, Apeldorn in May 1995.

PROJECT DESCRIPTION (Huybers 1996)

The tower is a space frame structure 27m high and has a base of offset space grids with an 8.1m x 8.1m floor plan. The tower was constructed using debarked larch poles of varying dimensions- usually 12, 15 and 20cm diameter and 2.5m of 3.6m long. The design incorporates angle systems that allow for up to 18 members meeting at a single node.

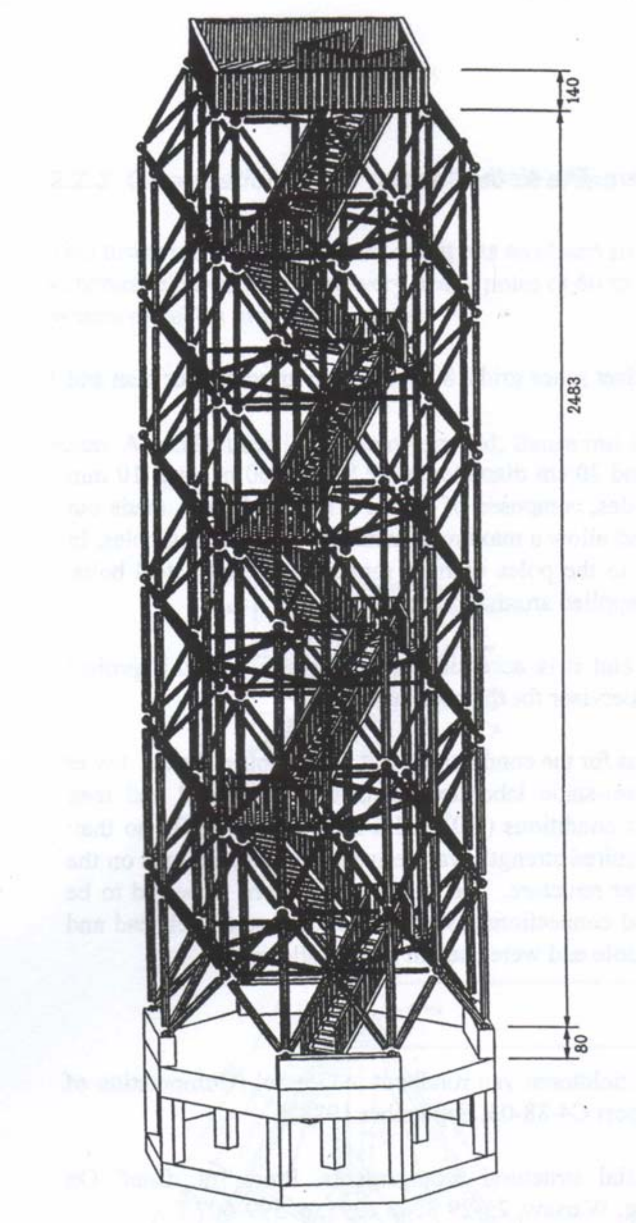


Figure B2.1: Observation Tower Design Sketch

The round timbers were installed in an unseasoned condition, and differential shrinkage during drying in service has caused that round members to crack longitudinally. This is perhaps heightened by the extremes of environmental conditions that the materials been subjected to during the in-service seasoning process. The longitudinal cracks may have been lessened had the members been seasoned prior to installation.

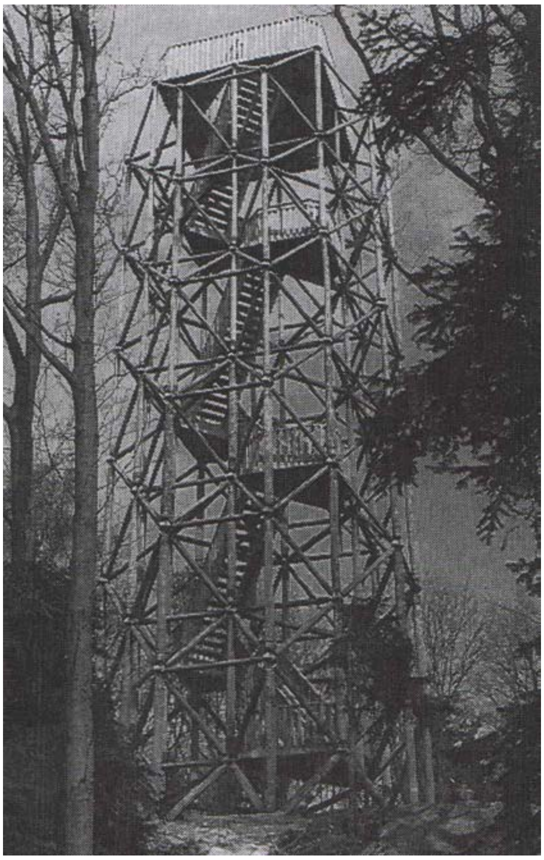
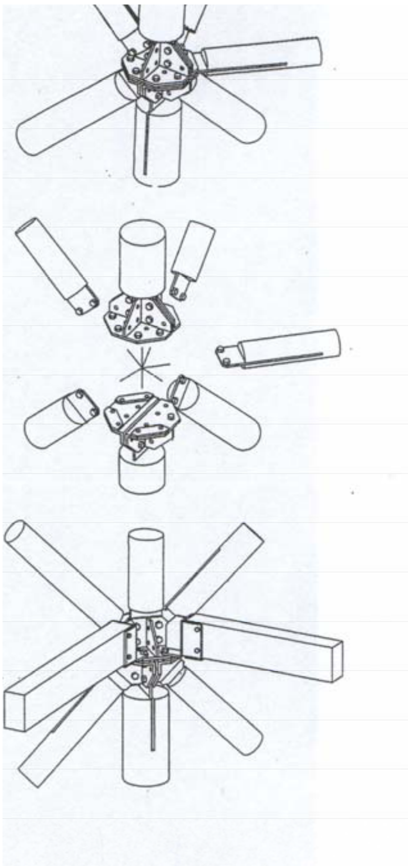


Figure B2.2: Completed Structure

JOINTING METHOD

The tower has incorporated slotted end members with 10mm steel plates inserted in conjunction with the wire laced jointing system discussed in Section 4.5. The tower has been in service since 1995, and on inspection, the wire lacing was loose and thus not contributing to the effectiveness of the jointing system. This may also have been due to the members being installed unseasoned. The movement due to change in moisture content would be lessened of the members were installed seasoned, and thus the lacing system would remain tight to the pole and the jointing system could achieve its full design potential.

For an agricultural use, the wire lacing system has the potential to be an effective jointing method, however, its lack of aesthetic appeal makes it less likely to be used in high quality interior and feature jointing systems. In addressing this, TUDelft has proposed a number of modifications to the jointing system that would make it more attractive for these types of application.



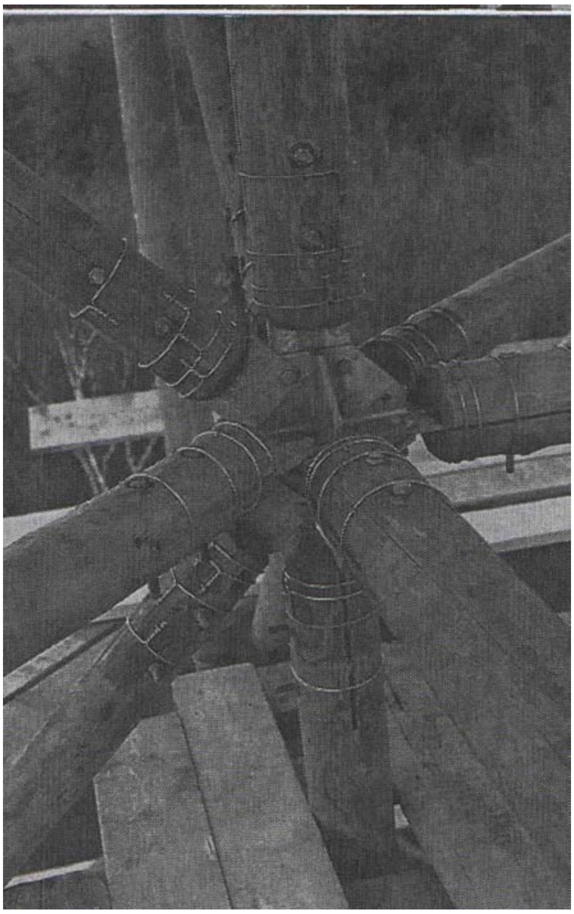


Figure B2.3: Tower Jointing System

B3: Sao Carlos Forest Office, State of Sao Paulo, Brazil

LOCATION AND BACKGROUND

Brazil has large areas under plantation eucalypts, mainly rose gum (E*ucalyptus grandis)*. Plantation eucalypts were first established in the early 1900’s as a source of fuel wood. Much of the plantation eucalypt resource is now used for pulp, generally harvested at a rotation age of approximately ten years. There are increasing moves towards extending the rotation age of these plantations to reposition them into high value sawn timber markets. The Sao Carlos Forest Office was a demonstration building to exhibit the potential of thinnings material in construction.

PROJECT DESCRIPTION

The Sao Paulo Forest Office is designed and built in the tradition of log homes. It is a different approach to the utilisation of thinnings than many of the other demonstration structures that adopt high technology innovative solutions. By contrast, this structure was constructed to demonstrate the ability to use this resource for low cost construction, for applications such as low cost housing.

JOINTING METHOD

Jointing methods adopted in this structure is a traditional method used in typical log frame construction. This is in line with the objective to provide low technology and low cost solutions to the use of plantation hardwood thinnings.

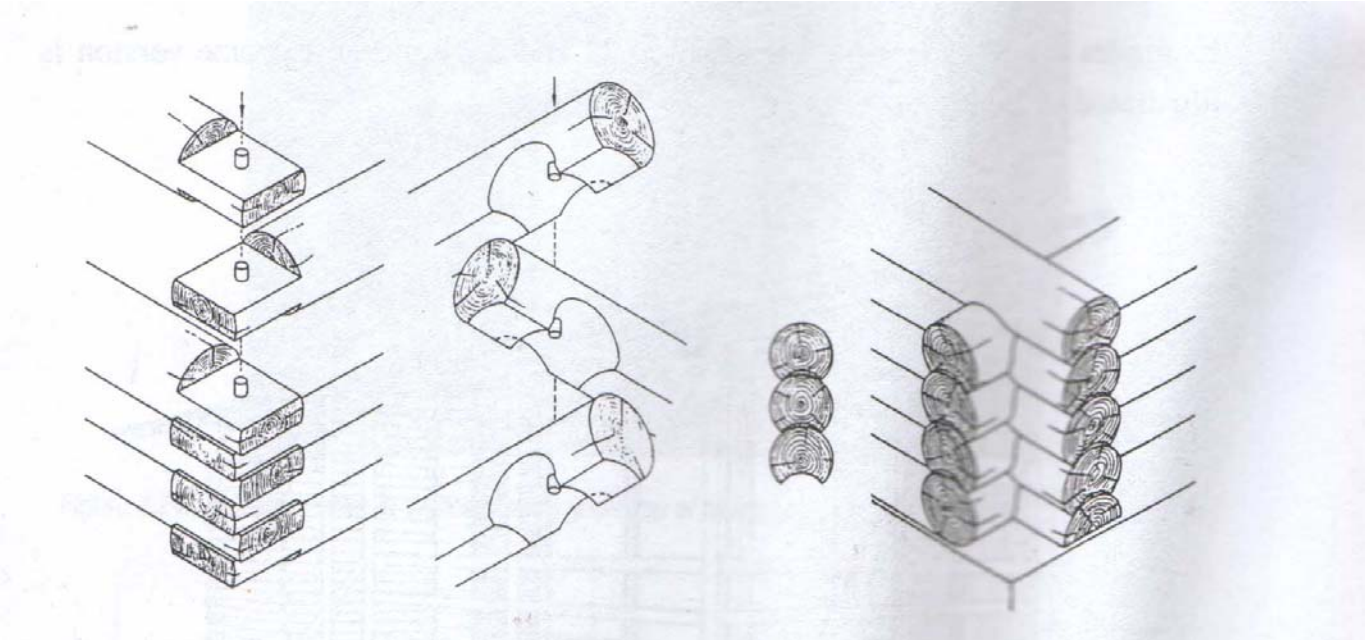


Figure B3.1: Traditional Jointing Method Adopted

B4: Malawi Community Schools Project

LOCATION AND BACKGROUND

The UK Department of International Development funded the construction of 100 new primary schools in Malawi, Central Africa. TRADA Technology Limited undertook a project in 1996 to demonstrate and promote the use of local plantation eucalypt thinnings in this community development program through the construction of a pole framed classroom building near the capital, Lilongwe.

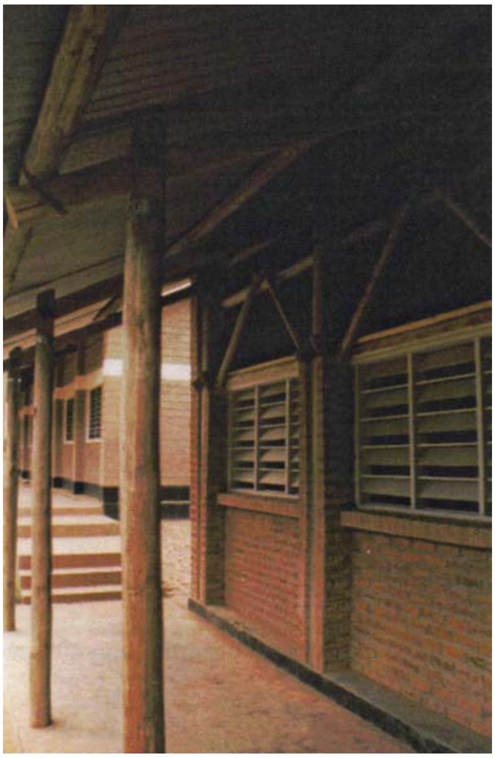


Figure B4.1: Completed Classroom

DESCRIPTION (Jayanetti 1996)

A location plantation of 7 to 14 year old *Eucalyptus grandis* was sourced for the thinnings material for the project. The thinnings material used for the project was of diameters between 50mm and 150mm. The project was designed to encourage community participation and develop skills in these communities. The project used low technology construction solutions to allow low cost construction with minimal tooling requirements. The project was designed in this way to allow the use of local materials to boosting the local economy.

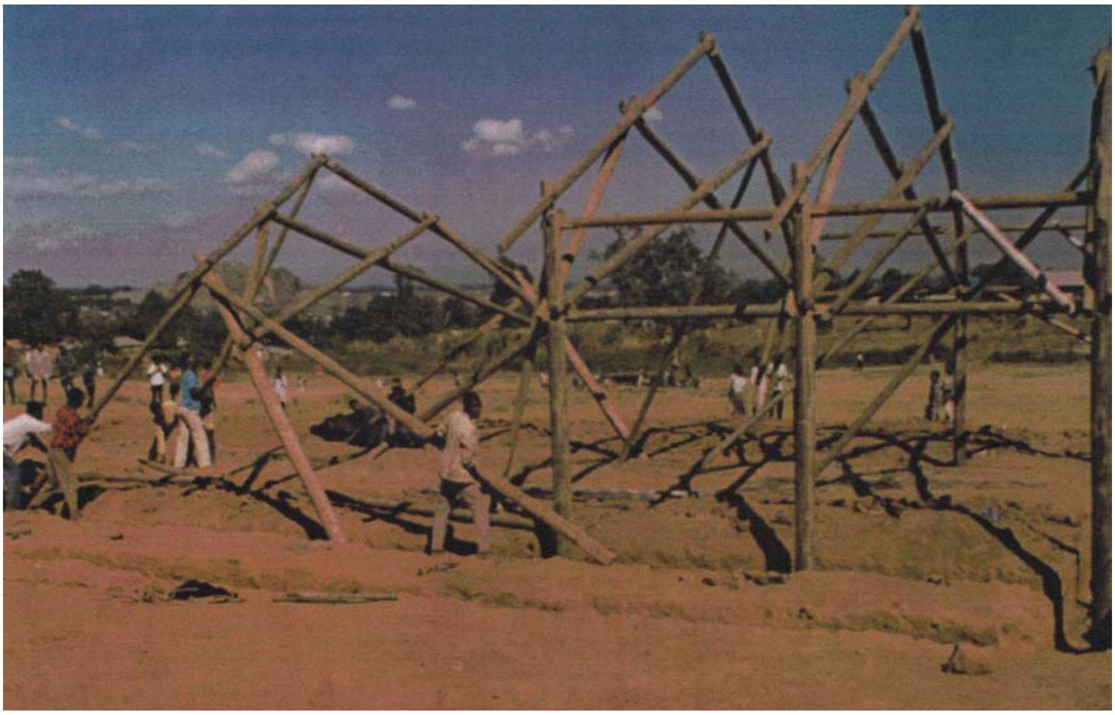


Figure B4.2: School Building Under Construction

Figure B4.3: Interior of Classroom

JOINTING (Technical Guidance Note TGN 2, TRADA Technology)

The Malawi school building followed the traditional construction methods through to the jointing systems. In keeping with the brief to have the local community involved in the construction, the jointing method was developed to allow the local workers to prefabricate the joints and assemble these on site using simple hand tools.

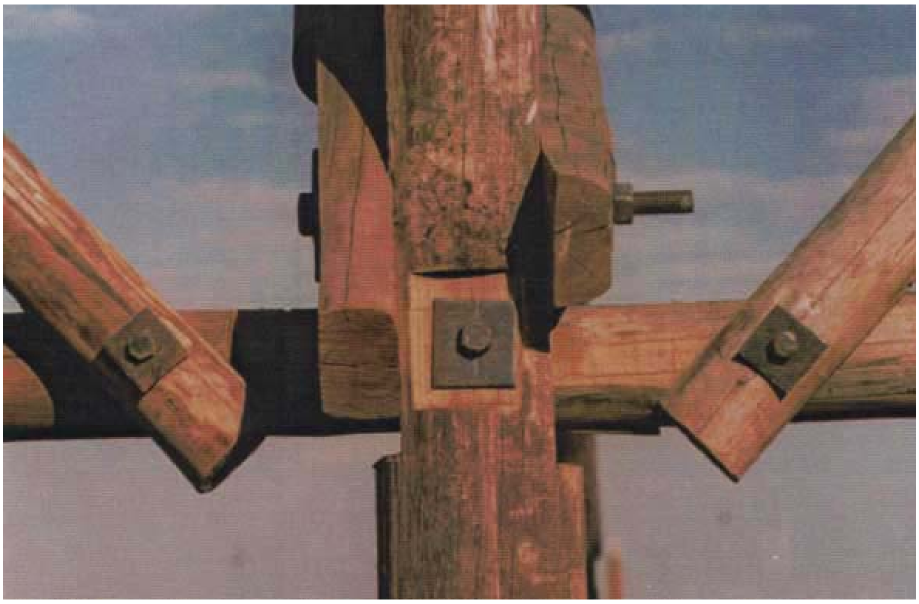


Figure B4.4: Jointing System

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