Chapman, Mr, John

Presenter: John Chapman

School of Architecture, University of Auckland

Private Bag 92019
Auckland, 1
New Zealand
Ph 0064 9 3737 999 Fax 0064 9 3737 694
Email: jb.chapman@auckland.ac.nz

Title of paper: **Timber, a truly sustainable resource, can be used to replace steel and concrete structures in multi-storey building.**

Intended Category: Sustainable infrastructure and buildings

ABSTRACT

This paper describes and summarises the recent research at the School of Architecture, University of Auckland, into utilising pinus radiata timber for the main structural elements in commercial and industrial building. This research is in response to the advantages of timber as an environmentally sustainable material. Timber is a reducer of the greenhouse gas, CO_2 and requires low amounts of energy for manufacture. Also, it is an efficient material for structural elements and is cost effective. The initial three studies were concerned with radiata poles as the columns for multi-storey building; comparing various types of timber floors for commercial applications; and poles as industrial truss elements. The fourth and main project, informed by the previous studies, researched the potential of radiata poles as the main structural elements in medium storey apartment building.

INTRODUCTION

At the beginning of 2000, study in timber engineering was commenced at the University of Auckland, School of Architecture. The main thrust of the work was investigating the possibility of utilising timber poles as the main structural elements in commercial and residential building. Over the following 3 years, four facets of study were completed. The 4th research project incorporated the conclusions of the previous three studies. Also, it addressed the perceived problems and risks associated with radiata poles as structural elements. As a consequence, the 4th project is reported more fully.

The reasons for initiating this research were:

1) Pinus radiata stems are a renewable resource, require little energy during manufacture; and absorb carbon from the atmosphere, thus reducing green house gases. A pole building structure will store more carbon within its timber than is released into the atmosphere during manufacture. This suggests these buildings may provide carbon credits for the developer.

2) There is an increasing number of NZ radiata stems becoming mature and requiring felling over the next 20 years. (NZMAF, 2002) It is important to consider new ways of utilising and adding value to this resource.
3) Over the last 35 years pinus radiata poles have been used extensively as columns, foundation piles and as the vertical cantilever members of retaining walls. They exist under a continual and often a reasonably high state of compressive or bending stress. Due to a minimum of in-service problems radiata poles have gained the reputation as a competent structural product.
4) Before reinforced concrete gained prominence in the 1930s New Zealand had a tradition of using timber, mainly Australian hardwoods, for the construction of railway and road bridges which supported truck loadings of up to 90 tonne.
5) For NZ softwoods, round timbers (i.e. poles) have higher failure stresses and better stiffness properties than sawn lumber.
6) Pinus radiata poles are a cheap source of timber at NZ$350 per cu.m. When sawn into lumber, radiata becomes NZ$850 per cu.m.; and glulam costs around NZ$2000 per cu.m..

Study 1: RADIATA POLES AS THE COLUMNS IN MULTI-STOREY TIMBER BUILDING

In 2000 an undergraduate student studied the possibility of using radiata poles as the main load bearing columns in 14 storied multi-storey timber building. His study was limited to considering gravity loads only in the columns.

The columns were located, in plan, on square grids. The grid spacings used were typical for commercial building - 7.2m; 9.0m; and 10.6m. The student calculated the required pole diameters, according the appropriate NZ codes. The maximum pole diameters required were 300mm dia; 400mm dia; and 525mm dia. respectively for the 3 above column spacings.

The results of the study showed that, according to the relevant NZ codes, readily available poles can be used to support the gravity loads in commercial multi-storey timber building up to 14 stories. However, the question arises – how would additional compression loads in the columns due to wind and earthquake loads affect the pole diameter required.

Study 2: COMPARING POSSIBLE TIMBER FLOOR STRUCTURES FOR MULTI-STOREY BUILDING

In 2001 and 2002, the student who helped with the above study into timber pole columns completed a Masters degree on the topic of comparing various types of timber floor structures for multi-storey building. The challenge was to design efficient beams in timber for spans and loads used in commercial building. The floor structure types considered were:

- timber trusses (using gauged timber and roof truss fabrication equipment)
- glulam
- LVL (linear veneer lumber)

The column locations were the same as used in 'Study 1' above – at the intersections of square grids in plan. The grid spacings are thus 7.2m; 9.0m; and 10.8m.

The arrangements of floor structure that proved to be the most economic and practical were as follows:

- pairs of primary floor beams spanning across the building from column to column. Thus, the spans and spacings of the primary beam pairs were the same as the grid spacings. – i.e. 7.2m; 9.0m; and 10.8m
- secondary beams spanning along the building between the primary beams. Their spacings were one sixth of the grid spacing – i.e. 1.2m, 1.5m, 1.8m
- gauged timber joists at 400 centre spacings spanning between the secondary beams

The floor live load was considered to be 3 Kpa which is suitable for commercial office loading. Calculations were completed for the member sections and joints to comply with the appropriate NZ codes. The resulting members for the three types of timber floor were compared for cost and volumes of timber.

The results showed that timber trusses as the main floor structure elements, when constructed using equipment commonly available in a timber roof truss factory, resulted in complicated arrangements with multiple trusses required for the primary beams. The glulam floor beams were, as expected, capable of providing support for residential floors in multi-storey timber building. However, the volume of timber required is more than for the other 2 options. The LVL member study concluded that the LVL could be arranged with 'box' and 'I' beam sections to significantly reduce timber volumes.

All joints were designed using bolts. The bolted joints proved to be relatively expensive. It would appear that a mixture of bolts to hold the joints together and steel shear pins to carry most of the shear loads would be a significant improvement.

The study pushed boundaries as all the studies we could trace for multi-storey timber building only used glulam for larger span timber members.

Study 3: LARGE INDUSRIAL TRUSS STRUCURES USING PINUS RADIATA POLES

The project looked at the possibility of utilising trusses made predominantly with radiata pole members for industrial and commercial building. This study was assisted by a Masters student.

This research was partly informed by the large timber truss bridges, built in NZ for road and rail traffic, during the 19^{th} and early 20^{th} centuries. The trusses for these bridges were made up of timber top and bottom chords; inclined timber web members in compression; and vertical tension web members made of mild steel rods. This arrangement of the truss members avoided the difficulty of joining two timber members in tension. The vertical mild steel rods had threaded ends and penetrated the top and bottom chords. Their end attachments were simple with a nut and washers to avoid excessive bearing pressures against the face grain of the chords.

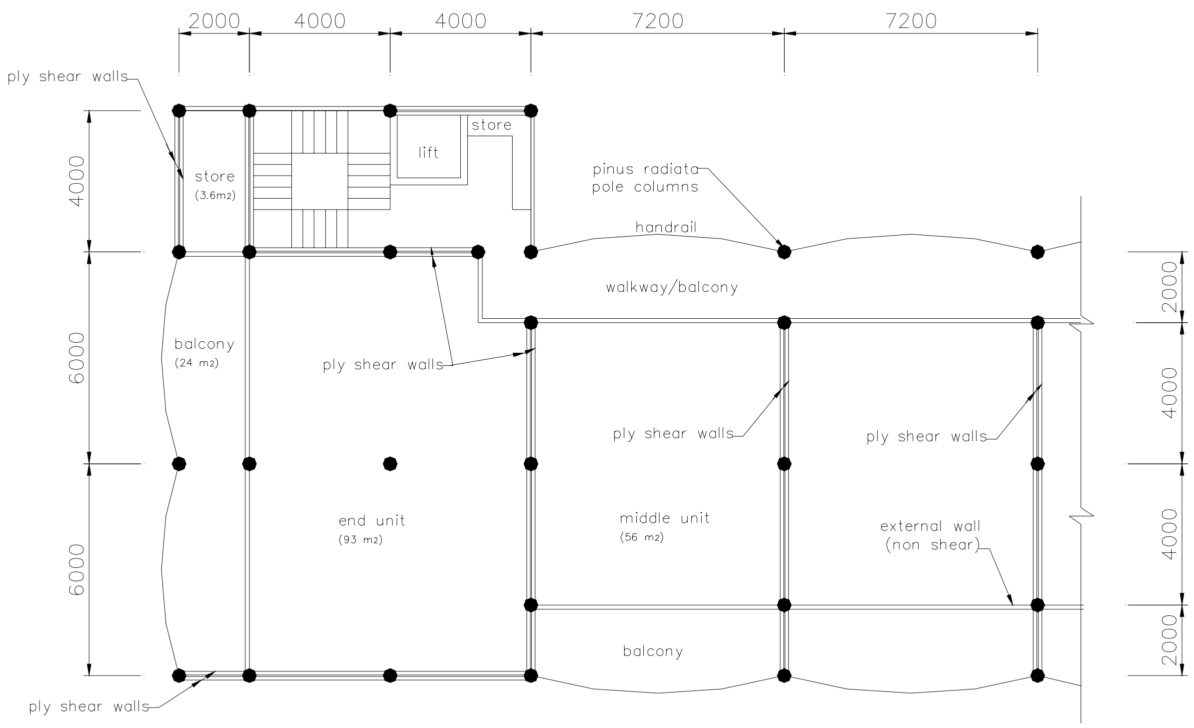
The study considered 5 bay, 7 bay and 9 bay trusses. The truss members were arranged similarly to those of the old wooden bridges and had radiata poles as top and bottom chords; pole web members inclined at 45^{o} in compression; and the vertical webs as m.s. rods in tension. The spans and loadings were the same as for the primary beams in the previous study into timber floor beams for multi-storey commercial building. This allowed the resulting trusses to be compared to equivalent timber systems in glulam, trusses of gauged lumber, and LVL.

This study fused historic experience with currently available materials to seek a viable alternative to using glulam in commercial/ industrial building. Because of the relatively low cost of radiata poles, the trusses in this study proved to be less than half the price of the equivalent glulam beam. The pole trusses were deeper than the glulam beams but were considerably stiffer.

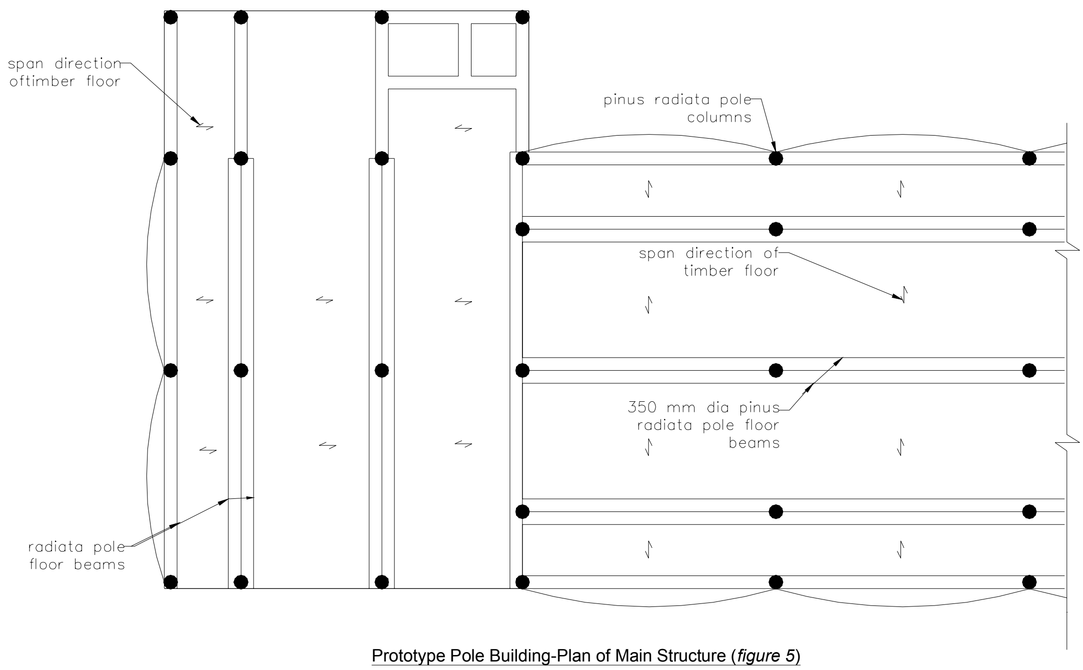
Study 4: SIX STOREY APARTMENT BUILDING USING RADIATA POLES FOR THE BEAM AND COLUMN STRUCTURAL ELEMENTS

The results of the above research projects led us to speculate that timber poles were very suited to the structural elements in medium storey apartment building because they could be arranged as simple posts and beams and not require complex jointing. The resistance to horizontal loads would be supplied by the frequent party walls. This idea became the basis of the 4^{th} and final project.

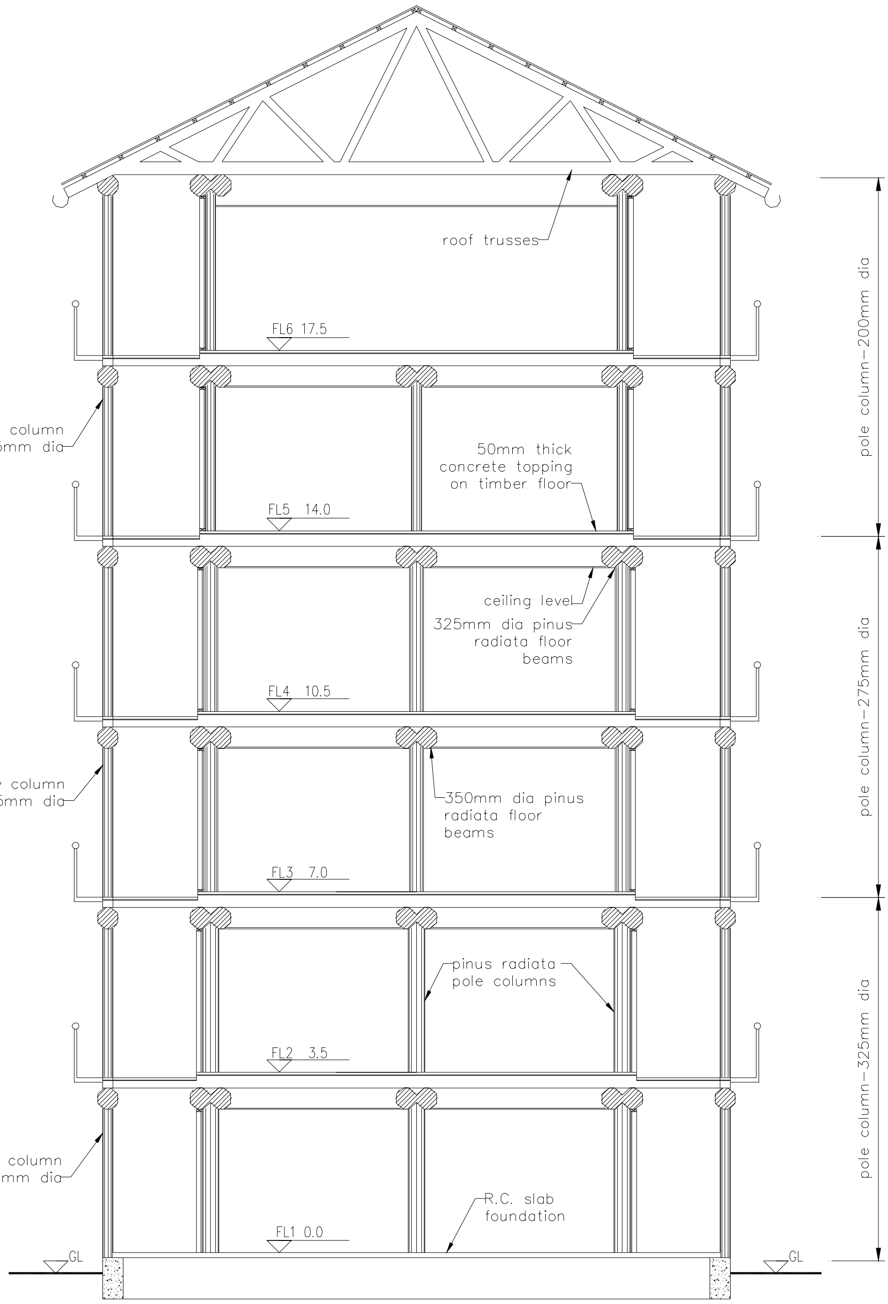
Plans were drawn up for an apartment building with 2 and 3 bedroom units and basement car parking. The plans informed the locations of the columns. This 6 storey apartment building is referred to in the details and tables as the 'Prototype Pole Building' or 'P.P.B.'



Prototype Pole Building-Plan of Units (*figure 1*)



Prototype Pole Building-Plan of Main Structure (*figure 5*)



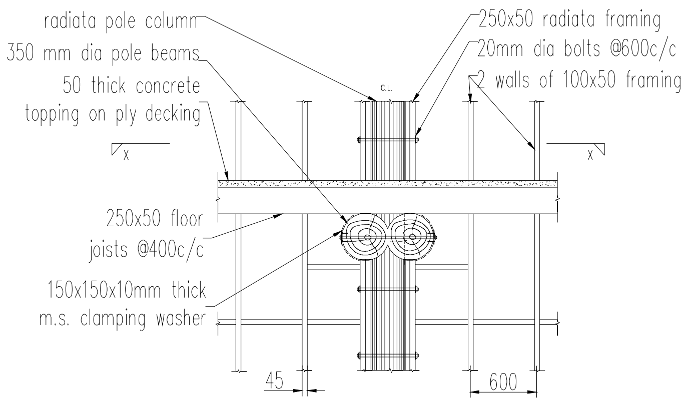
Prototype Pole Building-Transverse Section Through Middle Unit (*figure 3*)

The main structural elements were radiata pole floor beams, radiata pole columns, timber floors, and plywood wall diaphragms. The pole elements formed a simple post-beam system. The party walls were designed as plywood sheathed diaphragms to resist wind and earthquake loads.

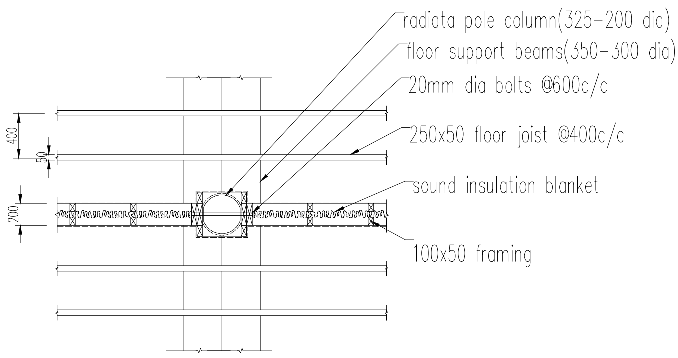
Each floor beam was typically 2 parallel and adjacent radiata poles. This arrangement made the joints to the columns neat because they were contained within the party walls. Also, there is increased safety because the likelihood of the 2 poles having a weakness at the same location along their lengths is unlikely.

The floor is similar to one which was recently constructed for a South Auckland commercial building (Davison, 2001). It is comprised of timber floor joists spanning between floor beams; 12 mm thick plywood flooring; and a 50mm concrete topping to assist a suitable sound insulating rating. Research is currently being carried out at the Faculty of Creative Arts and Industries, University of Auckland, into timber floor systems that are suitably sound proof for multi-storey timber building. Hopefully, solutions can be found which avoid concrete floor topping.

The columns were located in the party walls and sized to support the vertical compression loads. Additional column strength was provided by 2 no. 250mm * 50mm lumber studs bolted to opposite sides of each column. These studs were also part of the beam to column attachment and were associated with the party wall framing. The 5 elements that effectively made up each column reduced the problem due to a weakness in any one of them.



P.P.B.-DETAIL OF COLUMN TO FLOOR BEAM JOINT (*figure 4*)



P.P.B.-DETAIL(X-X) PARTY(SHEAR)WALLS (*figure 5*)

The study considered seven aspects of the prototype pole building:

1 dimensional stability of the timber
2 environmental impact
3 building strength
4 non destructive testing of poles
5 economics
6 fire resistance
7 sound insulation

DISCUSSION OF THE ISSUES

Dimensional Stability. This subject is often associated with multi-storey timber building. Dimensional instability occurs due to timber shrinking and expanding with drying and varying moisture content. These effects result in variations in building dimensions and affect claddings etc. When wood moisture content alters, considerably more dimensional changes occur across the grain than along the grain. The P.P.B. has 20m high columns that consist of 3 no. 7m approx long poles end on end. Because the timber grain is parallel over the entire height of the column, changes in building height are reduced to a minimum.

Experience at the BRE house 2000 project has shown that the moisture content of the timber framing stabilised around 12.5% and then remained relatively constant in the residential environment (Enjily, 1999). The maximum variation in moisture content observed during building use was 1%. If the pole members for a multi-storey building are kiln dried before manufacturing to match the expected in-use moisture content, then only small dimensional variations would be expected.

Environmental Impact. Currently, in NZ, pinus radiata, when used under dry conditions is not treated chemically and remains disease and borer free. However, for use in countries where termites exist, this topic may require further investigation.

The typical form of construction for medium rise residential units is R.C. (reinforced concrete) with reinforced concrete block masonry party walls and pre-stressed concrete floor units spanning between these walls.

With respect to helping the environment there are criteria we can consider. These include carbon dioxide released into the atmosphere and energy required during production.

Table 1 compares the energy for manufacture for the main structural elements of the P.P.B. and a typical similar R.C. building. The table also compares the weight of carbon released into the atmosphere as CO_2. (Buchanan,1993) The negative value of carbon released for the P.P.B. of -27.4 Kg/sq.m. means that the carbon released into the atmosphere during manufacture is less than the quantity permanently stored in the timber structure. The estimated amount of carbon released into the atmosphere by the R.C. building is 52.5 Kg/sq.m.

The energy required for manufacture of the P.P.B. is 22% that used by the R.C. alternative.

It is conclusive that buildings with pole structural elements will assist the environment significantly better than R.C. buildings.

Table 1

ENERGY USED IN MANUFACTURE & CARBON DIOXIDE EMISSIONS

(per square metre of floor area)

PROTOTYPE POLE RESIDENTIAL BUILDING –

RADIATA POLE COLUMNS & BEAMS / PLY SHEAR WALLS ON TIMBER FRAMING / TIMBER FLOORS (+CONC. TOPPING)

			ENERGY USED		CARBON EMITTED	
Structural Element	Material	volume /sq.m *(cu.m/sq.m.)*	Energy / vol. *(Gj/cu.m.)*	Energy Used *(Gj/sq.m.)*	Net C. / vol *(kg/cu.m.)*	Emission *(kg/sq.m)*
Columns	timber pole	0.0600	0.8	0.05	-245	-14.70
Beams	timber pole	0.0550	0.8	0.04	-245	-13.48
Floor Slab	concrete	0.0500	7.3	0.37	182	9.10
	12mm ply	0.0120	1.2	0.01	-220	-2.64
	joists	0.0310	1	0.03	-235	-7.29
Shear Walls	framing	0.0130	1	0.01	-235	-3.06
	12mm ply	0.0120	1.2	0.01	-220	-2.64
PROTOTYPE POLE BUILDING – ENERGY USED / CO_2 EMISSIONS			**Energy *Gi/sq.m* =**	**0.50**	**CO^2 emissions *kg/sq.m* =**	**-27.41**

TYPICAL REINFORCED CONCRETE RESIDENTIAL BUILDING –

200 BLOCK SHEAR WALLS / REINFORCED CONCRETE SLAB

			ENERGY USED		CARBON EMITTED	
Structural Element	Material	volume /sq.m *(cu.m/sq.m.)*	Energy / vol. *(Gj/cu.m.)*	Energy Used *(Gj/sq.m.)*	Net C. / vol *(kg/cu.m.)*	Emission *(kg/sq.m)*
Shear Walls	conc. Blocks	0.0897	7.3	0.65	182	16.33
	reinforcing	0.0003	0.8	0.00	-245	-0.06
Floor Slab	steel	0.0011	448	0.49	8117	8.93
	concrete	0.1500	7.3	1.10	182	27.30
REINFORCED CONCRETE BUILDING – ENERGY USED / C O_2 EMISSIONS			**Energy *Gi/sq.m* =**	**2.24**	**CO_2 emissions *kg/sq.m* =**	**52.50**

Building Strength. The loads considered on the P.P.B. are from the NZ standards (NZS 4203, 1993). The building dead load is 1.9kn per square metre of floor area. The floor live loads are 1.5Kpa and 2Kpa for domestic floors and balconies respectively. The roof snow load has a maximum value of 2Kpa which covers all areas of NZ up to an altitude of 600m.

The wind loads assumed on the P.P.B. is for all locations in NZ that are relatively flat but exposed and without obstructions to wind. The resulting basic wind speed is 48m/s.

A major advantage of a timber building is the reduced seismic mass and the associated decrease in earthquake loads. The earthquake load applied was for a plan with three middle units between the end units. The horizontal loads were deduced assuming the ply shear walls having limited ductility, a medium earthquake zone (zone factor = 0.6), and 'intermediate' type soils. The resulting lateral force coefficient, C is 0.14.

For major earthquake zones, as exist in areas of California and New Zealand, where the 'zone factor' becomes 1.2 only the columns supporting floor and deck loads are affected. The poles for levels 1 and 2 increase from 325mm to 375 mm dia; those supporting levels 3 and 4 change from 275mm to 300mm dia; and the poles of levels 5 and 6 remain at 200mm dia.

Calculations for pinus radiata pole member section sizes were carried out. An abbreviated form of these calculations accompanies this article (Table 2). The calculations are for the members for the ‘middle units’ because they are slightly more loaded than those of the ‘end units’.

As expected, the required pole column diameters reduce with height. The maximum diameter for the pole columns is 350mm and the minimum is 175mm.

The floor beams supporting floor only are typically a pair of 350mm diameter radiata poles that form a combined section with the timber floor. The beams supporting floor plus balcony are similar except that 2 no. 325mm dia. stems are required. The beams carrying balcony only can be 1 no.300mm dia. The ends of the floor beams are shaped to fit around the pole columns and are supported on 2 no. 250*50 radiata studs which are usually part of a shear wall. The floor load in the 2 no. 250*50 studs is transferred into the pole columns via M20 bolts at 600 centres.

Radiata poles of the above diameters and at the required lengths are readily available.

The shear walls are illustrated in figures 1, 4 & 5. They consist of 2 no. 100*50 framed walls with a 50mm gap between them. Each outer wall face is lined with a layer of 9mm thick plywood to provide shear resistance. The maximum shear force in the walls is 28Kn/m (increasing to 62Kn/m for major earthquake zone loading). This can be supported by the proposed 2 layers of 9mm thick plywood which together have a strength capacity of 90.2Kn/m. The ply shear walls could be replaced with diagonal steel bracing if required.

STRENGTH CALCULATIONS SUMMARY FOR PROTOTYPE POLE BUILDING *table 2* *(for middle units which have critical loads and spans)*									
PINUS RADIATA POLE COLUMNS *Column design strengths are for poles with a minimum outer density of 350 kg/cu.m*									
Location in middle units	Supporting floor only			Supporting floor & deck			Supporting deck only		
Floor level	1&2	3&4	5&6	1&2	3&4	5&6	1&2	3&4	5&6
Pole diameter (mm)	325	275	200	325	275	200	250	225	175
Max. limit state axial compression, N*c (kN)	858	566	272	835	485	208	412	269	125
Column design strength, ϕN (kN)	858	590	293	858	590	293	486	379	180
PINUS RADIATA POLE BEAMS – combined section with timber floor *Beam design strengths are for poles with a minimum outer density of 450 kg/cu.m*									
Location in middle units	Supporting floor only			Supporting floor & deck			Supporting deck only		
No. of poles in beam	2			2			1		
Pole diameter (mm)	350			325			300		
Max deflection+ creep (mm)	28			27			29		
Max limit state bending moment, M (kN.m)	123			100			51		
Beam design strength, ϕMn (kN.m	221			177			63		

Non-destructive Testing of Poles. Testing by Walford showed that failure stresses for NZ grown softwoods are dependent on the dry density of the timber existing at the outer 20% of the pole radius (Walford, 1994). Thus, when the density of this outside layer is established, the timber strength can be calculated.

During the last decade considerable development has occurred for the measurement of stem density using Acousto-ultrasonic (AUS) based methods. (Sandoz, 2000). These methods of testing relate propagation velocity of the longitudinal ultrasound wave with wood density and modulus of elasticity. There are two types – stress wave propagation and natural frequency vibration. The accuracy range is 4%. This type of non-destructive testing is also useful for detecting pole defects.

The '4-point strength test' could, also, be used to non-destructively test the poles for stiffness and strength. It is a recognized method of testing in NZ and Australia and is often used for timber power transmission poles before they are exported. In this test, the pole is supported at each end and the deflection is monitored while two jacks place loads along the length of the stem (Horrigan, 1998).

Economics. Table 3 compares costs of the main structure for the P.P.B. and a similar R.C. building. It concludes that the pole/timber structure is 89% the cost of the R.C. structure.

Timber poles are a relatively cheap form of timber at NZ$240 (US$160) per cu.m. The cost of sawn lumber is NZ$800(US$540) per cu.m and glulam is NZ$2000(US$1330) per cu.m. When estimating the manufacture and erection costs of the pole structural elements in table 3 we have been conservative at NZ$620(US$420) per cu.m. This cost covers strength testing, assessing straightness, trimming flat faces, and drilling boltholes etc. The cost of pole element fabrication would decrease with production output because investment in automated procedures would be justified.

A timber pole type building is significantly lighter than the R.C. alternative and, as a consequence, would have reductions in foundation costs. The table 3 analysis does not include this difference in foundation costs.

Table 3

MAIN STRUCTURE COSTS in NZ$ & US$ (per square metre of floor area)

NZ$1.0 = US$0.67

PROTOTYPE POLE RESIDENTIAL BUILDING –
RADIATA POLE COLUMNS & BEAMS / PLY SHEAR WALLS ON TIMBER FRAMING / TIMBER FLOORS (+CONC. TOPPING)

Structural Element	Material	Vol./sq.m *(cu.m/sq.m.)*	COST NZ$ Material Cost *(NZ$/cu.m.)*	Building cost *(NZ$/sq.m)*	COST US$ Material Cost. *(US$/cu.m.)*	Building cost *(US$/sq.m)*
Columns	timber pole	0.0600	620	37.20	415.4	24.92
Beams	timber pole	0.0550	620	34.10	415.4	22.85
Floor Slab	concrete	0.0500	300	15.00	201	10.05
	12mm ply	0.0120	3000	36.00	2010	24.12
	joists	0.0310	1440	44.64	964.8	29.91
Shear Walls	framing	0.0130	1440	18.72	964.8	12.54
	9mm ply	0.0120	3000	36.00	2010	24.12
PROTOTYPE POLE BUILDING COST			**NZ$/sq.m =**	**185.66**	**US$/sq.m =**	**124.39**

TYPICAL REINFORCED CONCRETE RESIDENTIAL BUILDING –
200 BLOCK SHEAR WALLS / REINFORCED CONCRETE SLAB

Structural Element	Material	Vol./sq.m *(cu.m/sq.m.)*	COST NZ$ Material Cost *(NZ$/cu.m.)*	Building cost *(NZ$/sq.m)*	COST US$ Material Cost *(US$/cu.m.)*	Building cost *(US$/sq.m)*
Shear Walls	reinforced conc. blocks	0.0897	1100	98.67	737	66.11
Floor Slab	prestressed units+topping	0.1000	1100	110.00	737	73.70
REINFORCED CONC. BUILDING COST			**NZ$/sq.m =**	**208.67**	**US$/sq.m =**	**139.81**

Fire Resistance. Good fireproofing would be very important to avoid a conflagration with possible loss of life and a resulting drop of public confidence in timber multi-storey building.

In the P.P.B. each residential unit is an independent fire cell. The pole columns and party walls are lined with plasterboard of suitable thickness. The pole floor beams are protected by a fire rated suspended ceiling below and a concrete topping above. Fire protection could be increased further, if local codes require, by the use of sprinklers.

The relevant NZ code considers the charring rate of radiata pine as 0.65mm per minute (NZS 3603:1993). Thus, the amount of surface charring expected in a 1hour fire is 39mm. This leads to a reduction of the diameter of a round section by 78mm. Theoretically, in a 1-hour fire a 350mm dia. beam becomes 272mm dia. and a 325mm dia. column changes to 247 mm dia.

The 350mm dia beam moment strength, after a 1 hour fire reduces, for brief loadings as would be expected during and after a fire, to 130kN.m. The beam is still completely safe because the maximum occurring bending moment for the dead load (self weight) plus live load condition is 123kN.m. The apparent beam ‘over-strength’ is because the deflection criteria determined the beam section size.

The 325mm dia column axial strength, after a 1 hour fire reduces, for brief loadings, to 620kN. The column dead load is 427kN. and the column, with reduced section, can support a live load which is 89% of the total live load.

Should anything go wrong with the plasterboard linings, the pole members would appear to have reasonable strength after a 1-hour fire event.

Sound Insulation. We have explained above that concrete floor toppings were chosen to ensure a good level of protection from vertical noise transference. A sound insulation blanket would also be located on the ceilings below the R.C. floors.

The resistance to footfall noise increases as the natural frequency of the floor system increases. Typical timber floors have natural frequencies well below that of concrete floors. Timber floors have been constructed with concrete toppings to increase mass and improve acoustic performance. The toppings have gone someway to emulating the properties of concrete floors but their relatively high cost has proven to be a problem (Dunn,2000).

Hopefully, economically viable timber floor systems will eventually be developed with suitable acoustic properties and they will replace concrete floor systems.

At the party walls, sound insulation is assisted by sound absorbing fibreglass blanket between the 2 lots of timber framing. *(figure 5).* This arrangement, in association with plasterboard linings of sufficient thickness, has been found to supply adequate insulation against horizontal sound transference.

CONCLUSIONS

The 4th and final topic of the research into timber as the main structural elements in commercial and industrial building was the 6 storey apartment building. It evolved as a consequence of the conclusions of the previous studies and was the most complete project. Also, it was the most significant because it considered and reconciled the perceived problems and risks associated with radiata poles as structural elements.

Eleven aspects for the 6 storey apartment building were considered and none showed up any impediments to utilising radiata poles as the main structural members.

However, an important issue for the use of radiata poles as structural elements has not yet been researched. This is the possibility of radial cracking within the poles under the consistently dry conditions of an enclosed building and the consequent impacts on strength and stiffness. Other issues which would require further investigation are connections to the round and uneven surfaces of the poles; and the weakening effects of notches in the poles which are likely to occur at joints.

The choice now is to commit to more research to overcome the unknown aspects of softwood poles as the main structural elements in multi-storey timber building or to keep exclusively using glulam which is an excellent but relatively expensive product.

At present in NZ, there is no apparent interest and thus a lack of funding for carrying out research in this field. From the viewpoint of the environment, this is unfortunate. However, as the world's energy supplies become scarce, further research into this low energy, sustainable, and readily available building product is likely to take place.

BIBLIOGRAPHY

NZMAF - New Zealand Ministry of Agriculture and Forestry.2002.*A national exotic forest description as at 1 April 2001,18th edition.*
Buchanan A , Honey B. *Energy and carbon impacts of building construction*. Proceedings of Institute of Professional Engineers Conference 1993,pp354 – 365
Davison Ross. *Timber Construction – Concrete Feel.* NZ Timber Design Society Journal issue 4 vol 10, pp 19-24, 2001
Dunn A H. *Investigation into reducing foot fall noise in timber framed apartment buildings*. Pacific Timber Engineering Conference 2000
Enjily V, Palmer S. *The current status of timber frame 2000(TF2000) project*. Pacific Timber Engineering Conference 1999,vol 1.
Horrigan A, Crews K, Boughton G. *In-Grade Testing of Utility Poles in Australia*. NZ Timber Design Society Journal issue 2 vol 9, pp 15-20, 1998
Nicholls S. *Timber construction in NZ utilising effective sound insulation*. NZ Timber Design Society Journal issue 1 vol 10, pp 13-24
NZS 3605:1993, *Specifications for timber piles and poles for use in building.* Standards Association of New Zealand.
NZS 4203:1992. *Code of practice for general structural design and design loadings for buildings.* Standards Association of New Zealand.
Walford G B. *Strength of New Zealand grown softwood poles*. Proceedings of Pacific Timber Engineering Conference 1994,vol 2,pp434 – 444
Sandoz,J.L.,Benoit,Y.Demay,L. *Wood Testing using Acousto-ultrasonic*. Pacific Timber Engineering Conference 2000.
NZS 3603: 1993.*Timber structures standard.* Standards Association of New Zealand.