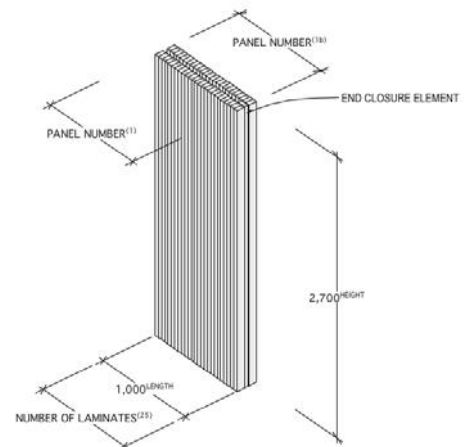
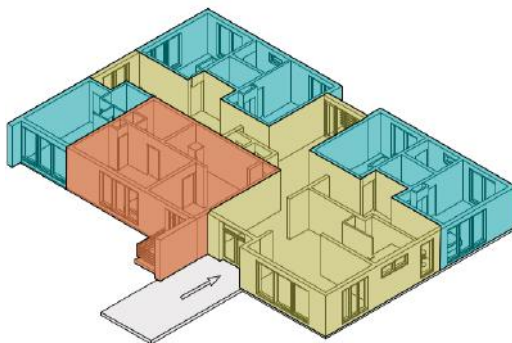


A COMPARATIVE STUDY OF THE SWEDISH AND AUSTRALIAN TIMBER CONSTRUCTION SECTORS LEADING TO THE DEVELOPMENT OF A PREFABRICATED PARALLEL LAMINATED TIMBER WALL SYSTEM



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The Old Man And His Sons

Aesop (1620 - 564 BC)

Fable LXII

An old man had several sons who were constantly quarreling with each other. When the father had exerted his authority and used all possible means to reconcile them to no purpose, he at last had recourse to this expedient.

He ordered his sons to be called before him and a bundle of sticks to be brought; and then commanded them, one by one, to try if, with all their might and strength, they could any of them break it. They all tried but to no purpose; for the sticks being closely and compactly bound up together, it was impossible for the force of a man to break them.

After this, the father ordered the bundle to be untied, and gave a single stick to each of his sons, at the same time bidding him to try to break it; which, when each did with all imaginable ease, the father addressed himself to them to this effect:

"O my sons, behold the power of unity! ..."

Solid laminated wood panels are:

'... the concrete of the 21st century.'

Michael Green
Architect (2012)

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INTRODUCTION

The Swedish timber construction industry's vibrant, interdisciplinary timber building culture, rationalised approach to construction and expanding market share, have resulted in a unique set of attributes, influences and drivers contributing to a broadening cultural acceptance of engineered timber as a viable alternative to steel and concrete.

For some time, Australia's timber and off site construction sectors have been considering a range of significant developments that have revolutionised timber based construction in Sweden, broader Scandinavia and the German speaking countries of Central Europe. Advances in new timber construction systems such as Cross Laminated Timber panels and prefabricated three dimensional volumetric construction methodologies are being studied with interest by Australia's architects, engineers, builders, regulatory bodies, timber processors and developers. Despite this, the vast majority of the Australian construction sector continues to design and build conservatively using steel, masonry and concrete in the traditional on-site, sequential approach to construction.

This thesis explores Australia's potential to continue expanding its engineered timber and modern off-site construction industry through a comparative discussion of the Swedish and Australian timber based building sectors and their related industries. This discussion is followed by the introduction of a new prefabricated engineered laminated timber structural wall system, using readily available skills, equipment and materials, and its application to a theoretical three storey residential building.

The objective of this thesis can be expressed in the following questions:

Can a simple engineered timber panelised wall system using low grade plantation timber be developed for the Australian building industry, and what lessons can the modern Swedish timber construction sector provide to assist Australia's timber producers to expand into modern, vertically integrated, off-site construction?

This research explores these questions over six chapters.

Chapter One explores issues pertaining to Sweden and Australia's historical and cultural relationships to timber; the respective economic environments that have informed the development of timber as an accepted modern building material, and the exploration of significant emerging factors that could inform new opportunities for timber in Australia. In addition, a comparative study is undertaken investigating a range of established and emerging prefabrication and engineered timber building methodologies currently being used in Sweden and Australia which provide context and identify significant commercially available technologies.

Chapter Two investigates the development of a relatively simple 'low tech' engineered timber panelised wall system that uses low grade Australian plantation timber, readily available fabrication skills and manufacturing techniques. The intent is to identify readily available Australian materials, products and skills that would be required to develop a prefabricated engineered timber structural solution that is specifically suited to the Australian context.

Chapter Three presents a theoretical design exploration of a three storey residential building using the panelised wall system explored in Chapter Two.

Chapter Four presents the architectural drawings for the building introduced in Chapter Three

Chapters Five and Six provide the conclusions and propose areas for further research.

1.0 - TIMBER IN SWEDEN AND AUSTRALIA

This chapter introduces both the historical context of timber as a versatile building material and the current 'state of the art' of engineered timber products in Sweden and Australia by exploring a wide range of pertinent issues such as the cultural perception of timber, the economic context that influences the development of new construction, technological advances in timber based off-site building methodologies and the varieties and availability of the timber grown in each country.

Examples from eleven timber based business in Sweden and eight timber based business in Australia are included to provide a cross section of each country's timber industry. A study of the Australian context follows with a discussion of the broader issues it faces and its capacity to develop new products and markets.

1.1 - Sweden and Timber - Past and Present

Sweden has enjoyed a lengthy, rich and on occasion, vicissitudinous association with timber. An abundant natural resource, timber exists ubiquitously in almost all aspects of Swedish life and culture. As one of Scandinavia's most quintessentially recognisable materials, timber has helped define the essence of the Swedish built environment. As a country and aspects a representative of the nordic region, it is renowned for producing high quality timbers that feature prominently in construction, boat building, furniture manufacture and handicrafts. Early examples of this can be found in the infamous Viking longboats and expansive Viking common houses, circa 1,000 AD, such as the reconstructed Viking stronghold at Trelleborg on the island of Zeeland.

In the 17th and 18th centuries, Sweden emerged as a world economic and military power (Frost 2000), projecting its authority throughout the Baltic region through the construction of massive tall ships. It was their knowledge of timber, engineering and construction that enabled them to establish and maintain this position for over a century. One of Sweden's most notorious examples of its deep seated and long held ambition to push the limits of timber engineering and construction is the well preserved but ill-fated Swedish timber war ship the Vasa.

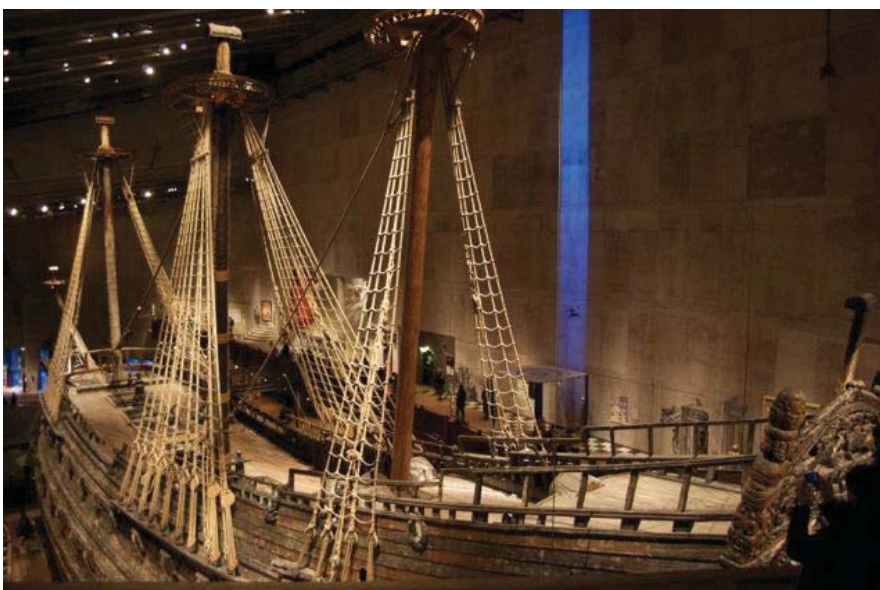
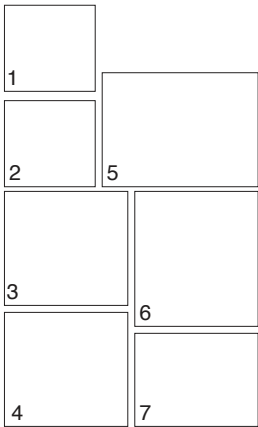
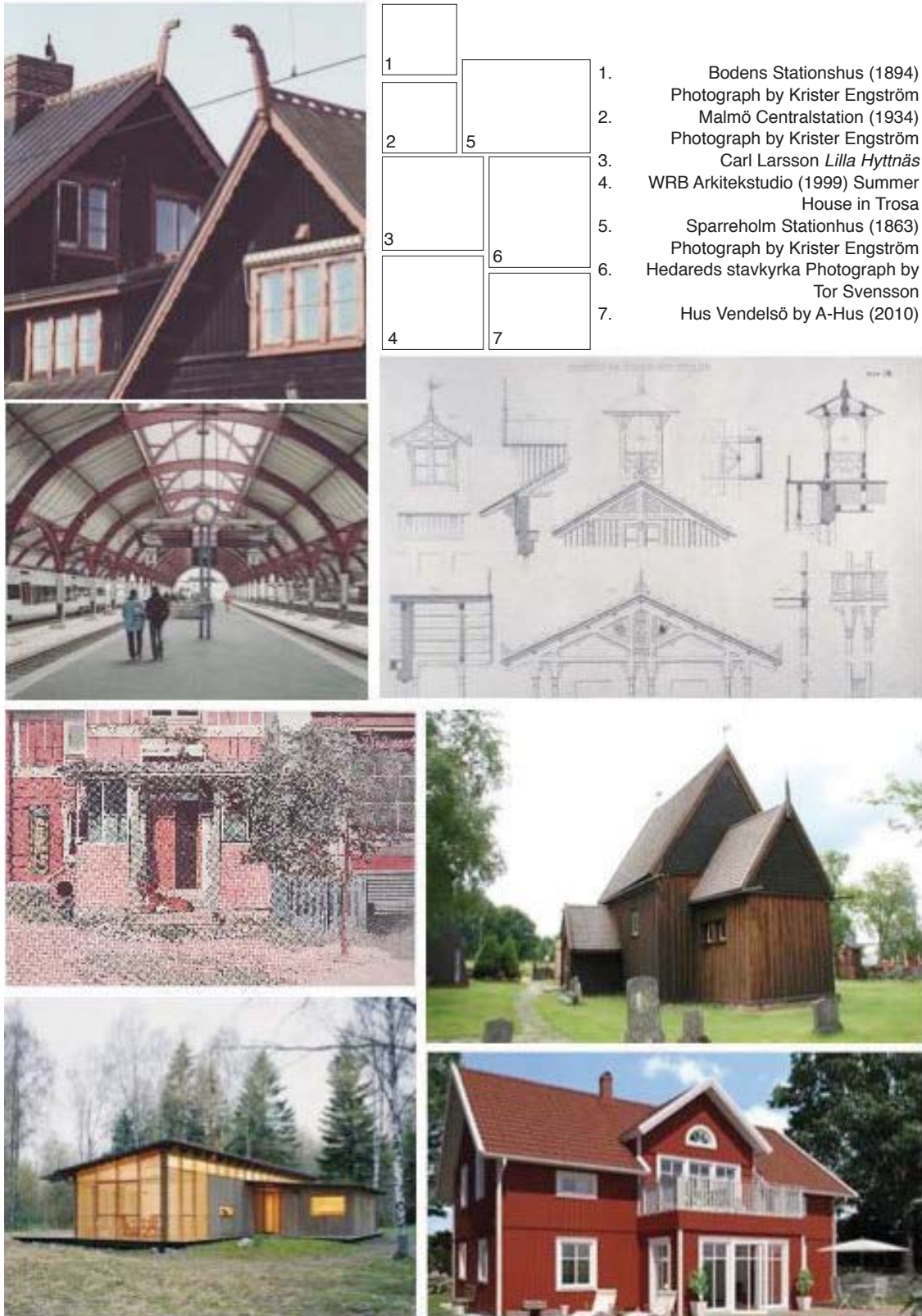


Figure 1.1 - The Vasa. Restored, preserved and on display in Stockholm. Image - D.Bylund

The Vasa was commissioned by the Swedish king Gustavus Adolphus (1594-1632) and built from 1626 to 1628, but this powerful albeit disastrous attempt to project their military might was soon to become a national disgrace. While the Vasa was not the largest timber war ship built by the Swedes, she was to hold a significant position in the Swedish naval military might of the day as the King himself had taken effective charge of her design by sacking the naval engineers. Within hours of being launched in Stockholm harbour she was to sink, thanks to an over ambitious design and an inopportune gust of wind. Despite numerous attempts to recover her, she remained on the harbour floor with only the top of her mast protruding above the water line for many years. Due to the preserving effect of the silt in the Baltic Sea, she was eventually relocated in the 1950s and found to be largely intact and subsequently raised to the surface in 1961 (Vasa Muset 2010). She now sits conserved in one of Stockholm's most popular museums as a spectacular testament to both their passion to succeed at the highest level using the best available technology of the day and as a silent warning of the risks involved.

Sweden has, of course, a lengthy association with timber beyond tall ships. Its long affiliation with its immediate neighbours has resulted in a recognisable commonality in all things timber that is often perceived as simply 'Scandinavian' or 'Nordic'. Cristoph Affentranger, in his book, *New Wood Architecture in Scandinavia*, comments on the historical connection Sweden and its timber has within the Nordic region where he states that traditionally, the use of timber in Sweden has much in common with its neighbour Norway (Affentranger 1997). It is reasonable to extend this link to Denmark, Iceland and Finland as these five countries comprise the collective known as the Nordic Co-operation* and even beyond this co-operative to other northern European countries such as Estonia and Russia.

* Nordic Co-operation - The political co-operation which is built on common values and a willingness to achieve results that contribute to a dynamic development and increase Nordic competencies and competitiveness (Norden 2012).



1. Bodens Stationshus (1894)
Photograph by Krister Engström
2. Malmö Centralstation (1934)
Photograph by Krister Engström
3. Carl Larsson *Lilla Hyttnäs*
4. WRB Arkitektstudio (1999) Summer House in Trosa
5. Sparreholm Stationhus (1863)
Photograph by Krister Engström
6. Hedareds stavkyrka Photograph by Tor Svensson
7. Hus Vendelsö by A-Hus (2010)

Figure 1.2. Examples of traditional and contemporary Swedish timber construction across a range of disciplines.

Affentranger proposed that Norway's early post and beam stave churches, the freer form 'Swiss Style' buildings of the 19th and 20th century's organic architecture that

was derived from the landscape, typify the historical development of timber construction also seen in Sweden.

This commonality in architectural design and materiality has also been identified by celebrated Swedish architectural photographer Åke E:son Lindman. In a recent interview, Lindman stated that ‘...Swedish design is characterized by pure lines and clarity, however in terms of diversity, I find it is hard to define any unique Swedish design. I believe there is a Nordic solidarity’ (Barup 2013).

This strong association with timber and the development of engineered timber solutions throughout the nordic region continues to this day as exemplified in the proposed new High North Centre for the Barents Secretariat. In 2009, the Norwegian architectural firm Reiulf Ramsrad Architects was commissioned to design the High North Centre for the Barents Secretariat in the arctic town of Kirkenes, Norway, which has been described as the ‘... *world’s highest building ever constructed in wood*’ (Reiulfra Ramstad Arkitekter 2009). It is proposed to be 16 or 17 storeys high and has been inspired by ‘... traditional architecture from Russia, Sweden, Finland and Norway’ (Timber & Sustainable Building 2009). As of publication, the project remains in its development phase.

Numerous Swedish timber buildings dating as far back as the 15th century remain in use to this day. Many have been restored and relocated to Sweden’s outdoor museums and are conserved for future generations to enjoy. For example, Skansen in Stockholm (Skansen 2012) along with Kulturen in the city of Lund in southern Sweden (Kulturen 2012) feature an eclectic mix of authentic timber buildings arranged in traditional villages. These living outdoor museums feature timber structures that range from churches to schools to farm buildings and bell towers.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage registered church village of Gammelstad in Luleå (UNESCO Church Village of Gammelstad 1996) and the church village in Skellefteå are examples of historical log cabins that remain in use to this day.

These examples of early Swedish timber construction are noteworthy as they represent authentic 15th century timber construction, reflecting the domestic construction style of the time in its original context, which now forms part of the national built environment and historical identity.

Throughout the 19th and early 20th centuries, it was common practice to construct Sweden's provincial and suburban train stations entirely of wood and many of these structures continue to be functional civic buildings. Architecturally, they are examples of typical Scandinavian timber construction techniques expressing stylistic sentiments representative of their era. These can be in the form of log cabins, expressed post and beam structures, timber stud frames clad in weather boards with ornate stylised trim detailing and even some of the modern era's first laminated beam structures. Examples of these can be seen in Figure 1.2 such as Bodens Stationshus built in 1894, Malmö Stationshus in 1924, with glue laminated beams manufactured by Töreboda Limträ, and the original Sparreholm Stationshus from 1863 (Linde Bjur 2010).

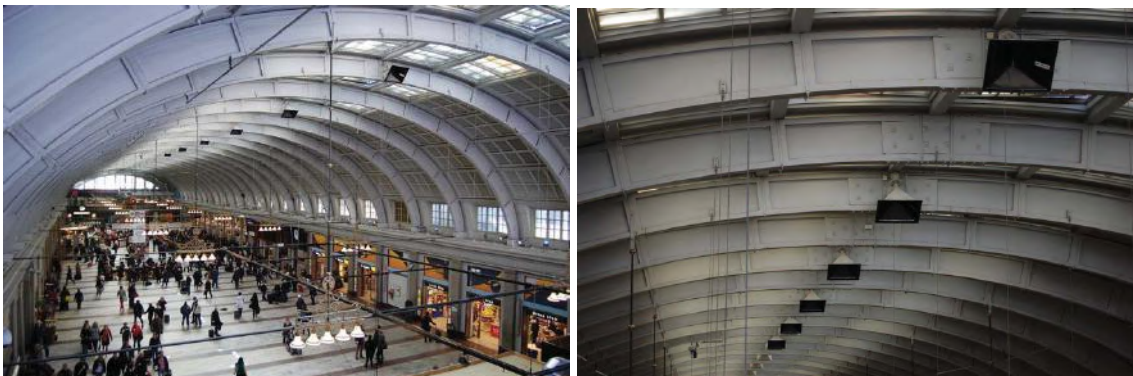


Figure 1.3 Stockholm's centralstation. Photo:D.Bylund

It is also worth noting that the timber roof structure in the main hall of Stockholm's central train station (Figure 1.3), *Stockholm centralstation*, built from 1925 to 1928 and designed by Folke Zettervall, features a series of expressed, impressively curved, laminated timber roof beams which are '... the main architectural feature (of a) generous, light filled central hall ... (that is) carried by elliptically-arched glue-laminated wood beams that spring powerfully from granite columns' (Hultin 2009).

The main hall is 119 metres long, 23 metres wide and 13 metres high; its arched timber beams dominate the interior and are a prime example of one of the world's first modern curved, laminated timber roof structures. Manufactured by Töreboda Limträ in the small southern Swedish town of Töreboda, the arches are a testament to the early 20th century progressive technical developments in glue laminated timber structures.

The Töreboda Limträ glulam factory, established in 1919 and purchased by Moelven in 1982, continues to manufacture glue laminated beams and is Scandinavia's only glue laminated curved beam manufacturer. The Töreboda glue lamination facility is also the world's oldest, continuously operating, laminated timber beam manufacturer.

Beyond the sphere of civic, institutional and multi-residential building, a significant body of preserved, expressed timber freestanding houses exist and are highly prized by their owners. Many Swedes own summer houses in the heavily forested areas outside the main towns and cities that often date back several hundred years. The deeply held Swedish desire for a simple timber cottage deep in the forest can, in part, be traced back to the 1870's when the painter Carl Larsson published a book called *Ett Hem* (Affentranger 1997). Larsson's water colours feature his own house *Lilla Hyttnäs*, located two and a half hours north of Stockholm in Sundborn. *Lilla Hyttnäs* is a classic Swedish post and beam timber cottage typical of the era. His paintings feature both interior and exterior views of the cottage with many architectural details and timber furniture items that express an optimistic craftsman's touch. The qualities of the wood complement the stylistic charms prized by many Swedes wishing to establish contact with nature in an approach that aspired to '... the beautiful and ideal (that) anticipates modernism in many aspects (of its) technical realisation' (ibid).

The preservation of these houses could also be attributed, albeit unintentionally, to Sweden's history of wealth taxes that can impose significant ongoing financial burdens onto property owners who upgrade older houses when carrying out renovations/modernisations. 'Improvements' such as replacing timber floors or adding a

spa increased the value of a property and therefore, until it was abolished in 2008, resulted in a higher annual tax liability.

In recent times, Sweden's highly successful timber cottage industry, along with its furniture manufacturing industry, has continued to celebrate timber by allowing its physiognomy to be expressed prominently in almost all aspects of life.

While timber has held a highly regarded position within Sweden's long residential construction history, with the exception of the examples previously referred to, relatively few civic or institutional all-timber buildings constructed throughout Sweden's periods of intense civic, institutional and religious building activity still exist.

Over the last 400 years relatively few timber buildings have survived the fires, war, neglect and of course, the modernist wave of concrete, steel and glass. Over 100 years of prescriptive building regulations and successive steel and masonry based architectural movements have dominated, not just Scandinavian cities, but much of European, North American and Australian architecture. These 'modern' construction methods have all but excluded timber. Until recent times, timber as an identifiable structural material in public buildings has been conspicuously absent apart from its use as flooring or wall cladding.

Other countries with a history of the structural use of timber such as Japan, Germany, Austria and Switzerland, despite being similarly subject to wars, fires and invasive town planning schemes, still feature restored or reconstructed significant historical timber buildings, often in their original location. Examples of these are Kyoto's Kinkaku-ji or Golden Pavilion, originally built in 1397; the Buddhist Higashi-Honganji Temple, established in 1602, also in Kyoto; Germany's half timber, gothic and renaissance guild halls such as the recently restored Knochenhauer Hildesheim from 1529 and England's half timbered buildings such as Little Moreton Hall, Cheshire, built in 1550.

Over the centuries, Sweden's towns and cities have been built and re-built many times yet relatively few large scale historical timber buildings remain. Noteworthy

expressions of early timber construction in public buildings that have survived are predominantly limited to internal and often hidden structural components such as roof members. Stockholm's Royal Palace is a good example of this. Rebuilt and remodeled in 1754 following extensive fire damage to the previous palace in the 16th century, it has a structural timber roof that is completely hidden from public view by parapet walls, but is considered to be a significant example of how larger spans were achieved with timber prior to lamination using medieval roof truss techniques and large scale members.

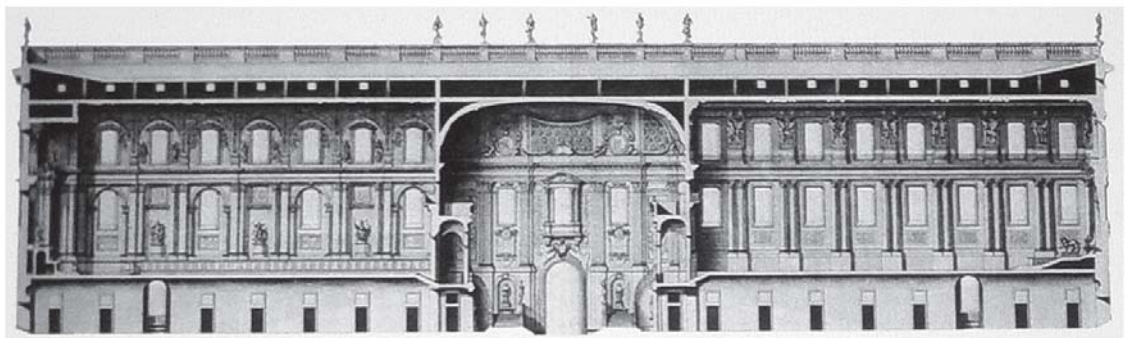
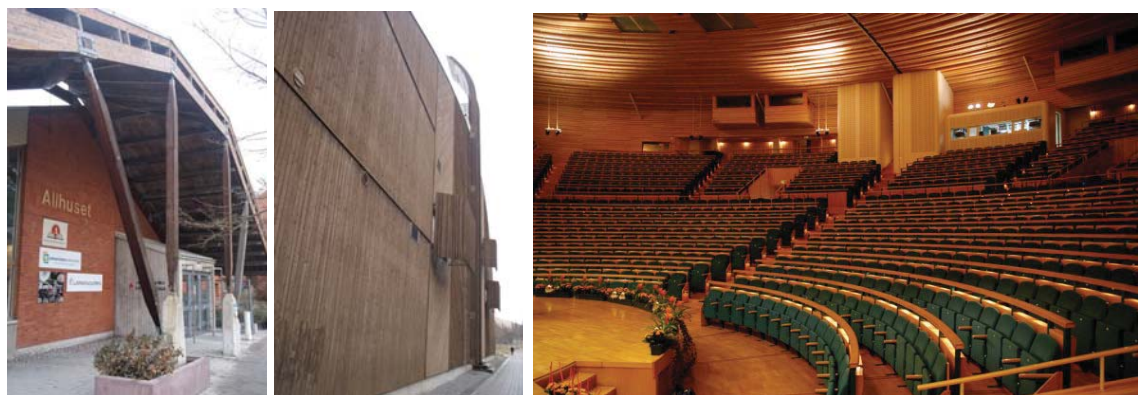


Figure 1.4 Long section of Stockholm Palace showing the regular truss arrangement and large spans. Source - Wikimedia Commons. Author unknown

In more recent times, a significant exception to the absence of timber in notable civic buildings is Ralph Erskine's Stockholm University Frescati Campus additions. These later buildings contrast with the six original 1970s multi-storey concrete 'slabs' which were viewed '... as a symbol for the era's despised large-scale approach to building' (Olof Hultin; Bengt OH Johansson; Johan Mårtelius; Rasmus Wærn 2009).



1. Allhuset (1982). Photograph by A.Falk
2. Frescatihallen (1983). Photograph by A.Falk
3. Aula Magna (1996-1997). © Wikipedia



Figure 1.5 Ralph Erskine's Frescati Campus additions

Erskine's buildings feature timber prominently both structurally and aesthetically, and collectively they '... complemented in a refined way ... (the) ... originally sterile environment ...' (ibid). These include the student union building, *Allhuset* (1981) which was awarded the Kasper Salin Prize of that year, the *Aula Magna Auditorium* (1996-97) and the distinctive all-timber sporting facility, *Frescatihallen* (1983).

As previously discussed, surviving civic and institutional timber structures have been conspicuously absent from many Swedish cities and their relatively recent built environments. This can be primarily attributed to Sweden's prescriptive building regulations, enacted in 1888, limiting the use of structural timber in buildings over two storeys. This prescriptive approach to building materials created industry path dependencies reliant primarily on concrete and steel construction (K. Mahapatra; L. Gustavsson 2008). These controls were the result of a moratorium placed on the use of structural timbers following numerous disastrous fires in Swedish cities such as Uppsala in 1702, Växjö in 1843, Sundsvall in 1888, and Umeå also in 1888. A combination of tightly packed buildings and overcrowded medieval town layouts inevitably meant fires often had a catastrophically devastating effect. Restrictions on the use of structural timber from this period extended well into the modern era, only being repealed in 1994. The effect has been to artificially constrain the technical development of timber in modern multi-storey construction. Internal interest in emergent timber technologies and membership of the European Union (Andrén 2010) along with aspirations to develop more environmentally conscious building practices have played an important role in replacing what had become an antiquated, 19th century timber building code.

Once new performance based codes were enacted in 1994, intense activity in the field of timber construction fast tracked technical developments in high rise timber building. An increasing number of architects, academics, engineers and developers have begun to utilise and rapidly progress new engineered timber construction techniques now seen in increasing numbers of Sweden's contemporary multi-storey

buildings. One in seven new multi-storey buildings in Sweden is now built with an engineered structural timber frame ‘... where 80% to 90% of the construction process is outsourced to a quality-assured factory environment’ (Svensson 2010).



Figure 1.6 Timber multi-storey apartment developments in Växjö (2010). Photo D.Bylund

While this new multi-storey timber construction industry could still be considered to be in a formative phase as it competes with concrete and steel, it is experiencing unparalleled growth as Sweden’s towns and cities create new developments that mandate timber-only construction supplanting traditional heavyweight high rise construction methods. During the last 15 years, Sweden has established a number of highly developed timber building technologies that utilise industrialised production building methodologies to produce all-timber buildings up to eight storeys high (SP Technical Research Institute of Sweden 2009).

To promote the ongoing development and continued use of wood as an integral part of Sweden’s cultural and sustainable development mandates, every four years the Swedish Forest Industries Federation (Skogsindustrierna), hereafter referred to as the SFIF, hosts Träpriset or ‘The Wood Award’. This award is ‘... for exemplary Swedish architecture that makes use of wood and that captures the essence of our time’ (Skogsindustrierna 2011).

In 2008 the winning entry was Östra Kvarnsbogen, a development of 40 houses situated in a nature reserve in Sollentuna, just north of Stockholm, designed by Brunnberg & Forshed Arkitekton AB. According to the competition website, this project was the award winning nominee as:

‘Östra Kvarnskogen has been constructed within a large nature reserve with sharply sloping terrain. Here, nature holds sway, and there are houses which stand partially-supported by 7m-high steel pillars as a result of the mountain’s steep slope. The man-made and the natural appear to co-exist peacefully here. Its uniqueness leads heart and mind to a tranquil state.’



Figure 1.7 Träpriset

The expansive use of timber construction in developments such as this reflect the almost ubiquitous Swedish desire to settle deeply in their lush forest environment and have structures that complement their natural surroundings. This is not just an example of an alternative lifestyle, but rather as a symbiotic expression of the deep tie that exists between the people, the forest and the land. In a recent interview in the Swedish design and culture publication *Mr Wolf*, Malmö based architect Mats Edström from Barup & Edström states that Swedish architecture is informed by ‘our common values; being very equal, orderly, believing in trust ... and ... most importantly, (through) nature worship ... thus ... nature is often a strong consideration in Swedish architecture’ (Barup 2013).

The Australian timber industry also features an annual industry award for exemplary timber design to improve its profile called *The Australian Timber Design Awards*.



1

2

1. Saffire (2011), Interior view, Circa Morris - Nunn Walker - Image source - Australian Timber Design Awards
2. Saffire (2011), Bird's eye view, Circa Morris - Nunn Walker - Image source - Australian Timber Design Awards

Figure 1.8 The Australian Timber Design Awards

Inaugurated in 2000 by *Forest and Wood Products Australia's* timber promotional body *WoodSolutions*, it is now in its 14th year.

The Australian Timber Design Awards attract numerous submissions competing for recognition in a number of categories such as:

- | | |
|--|---------------------------------------|
| Residential Class 1 – New Buildings | Residential Class 1 – Best Renovation |
| Multi-Residential – New Building | Public or Commercial Building |
| Interior Fit-out | Treated Pine Structures |
| Outdoor Timber – Stand-alone Structures. | Furniture and Joinery Award |

The overall winner of the 2011 Australian Timber Design Award was the Saffire Resort project in Tasmania by Circa Morris Nunn Architects. Images from the winning

entry can be seen in Figure 1.8. According to the The Australian Timber Design Awards website the judging panel was ‘... wowed above all by the manner in which the Saffire resort responds to its bushland surroundings.’ The judges also noted how ‘... the organic curves of the resort roofs rise gradually above the bush like small hills, reminiscent of the gentle peaks of the nearby Hazard Ranges’. The point was made that ‘... these complex curves could not have been achieved without the design flexibility of pre-fabricated structural timber – a fact that ultimately gave Saffire the edge over other timber-rich finalists’.



Figure 1.9 Australian Timber Design Awards 2012. Candlebark School Library. Photo Australian Timber Design Awards 2012

As with the 2011 scheme, prefabricated timber featured predominantly in the 2012 overall winning design, Paul Haar Architect’s Candlebark School Library (Figure 1.9). The *Australian Timber Design Awards* website gives special mention to the ‘expert use of engineered timber’ as a significant factor in their decision and ‘The judging panel was greatly impressed by ... the broad-span timber roof of the library supports a 500-600 mm layer of earth--a significant engineering challenge--and is made of LVL billets and massive exposed portal frames’ (Australian Timber Design Awards 2012).

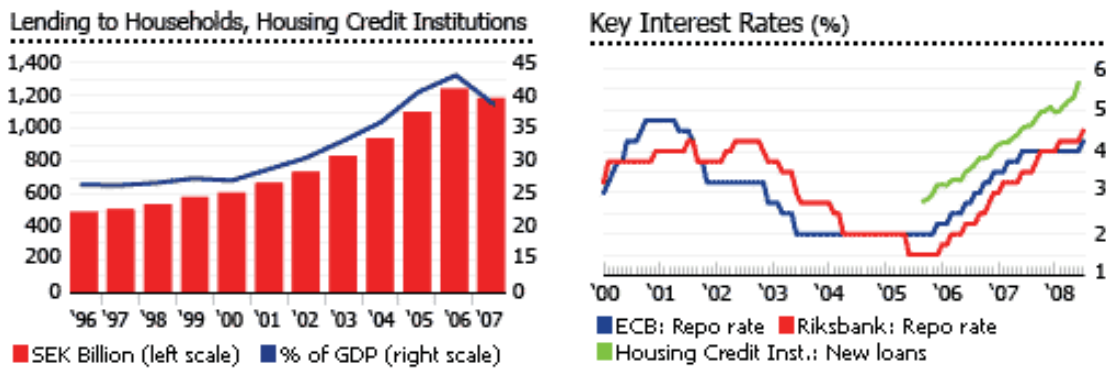
This trend in awarding projects with larger span engineered timber structures differs significantly from Sweden’s Träpriset (The Wood Award) award winners who

express timber for timber's sake regardless of the engineering achievements of the structure itself. This difference could reflect a more inclusive approach to timber in Sweden that does not feel the need to emphasize timber's capacity to compete with steel or concrete.

1.2 - Timber in Sweden's Economic and Industrial Context

Gaining an insight into Sweden's economic and industrial setting relative to its timber construction industry can inform how the Australian timber industry could expand into new value-adding opportunities and beyond. Australia can learn valuable lessons from Sweden's experience and the context in which it operates. Some of these lessons are how timber processors have vertically integrated into construction, the direct relationship to the economy and building activity, regulatory compliance and increasing customer expectations of building performance. Also of relevance are private and government R&D (Research and Development), and innovation transfer to commercialisation.

Sweden's residential construction sector is dominated by off-site construction that is now considered to be of such high quality it is often described as a 'manufactured product' (Schipper Meyers Kelly 1985). Sweden's approach to the construction of both free standing cottages and mid rise multi-residential apartments represents a new standard in economic and construction rationalism that has been tempered by a craftsman's approach to industrial production. The domestic residential market for Swedish housing is less driven by the speculative factors that are often a major influence in the Australian housing market. The Swedes '... tend to look on the purchase of a house, not as speculation in real estate or as a step towards the next house, ... but as a relatively permanent investment' (ibid). This is reinforced by government policy that discourages speculation in real estate through high taxes on short term gains (ibid).



Source: Sverige Riksbank

Table 1.1 Swedish lending trends 1996 to 2007 and interest rates 2000 to 2008.

As with the Australian Bureau of Statistics, the Swedish Statistiska centralbyrån (Statistics Sweden) provides a range of statistical data derived from the Swedish construction industry including building price index data on multi-dwelling buildings and collectively-built one or two room dwellings.

In Sweden, the number of rooms used to classify a residential building or apartment's size only refers to the number of actual bedrooms it contains. Other rooms, such as kitchens or bathrooms, are not considered. Thus, a one bedroom dwelling is referred to simply as a one room dwelling regardless of the actual number of rooms the dwelling may contain. Additional rooms such as bathrooms and kitchens are assumed to be included and may or may not be actual separate rooms. Collectively-built dwellings are defined as '... such buildings that are intended for rental or tenant-owned dwellings or built to be sold'. Further clarification of the items included in the calculations are as follows: 'Useful floor space of dwellings (with certain limitations) includes space above ground in a dwelling (and is) '... limited to the finished inside walls that enclose each dwelling, and includes kitchen cupboards, wardrobes and the like' (ibid). Useful floor space is defined as '... the sum of useful floor space of dwellings and non-residential floor space' (ibid). Individually constructed dwellings are not included.

The 2008 Statistiska centralbyrån statistics, for the purposes of differentiating urban and country data, divide the country into two regions: 'Metropolitan Areas' and 'Rest of Country'. Combined data is also provided and is collectively referred to as

'Whole Country'. Information is divided into 'Number of dwellings', 'Production cost per dwelling' (SEK/dwelling) and 'Production cost per square metre' (SEK/square metre). The figures include 25% VAT general sales tax that is applicable to all construction costs in Sweden.

The Statistiska centralbyrån website defines the Building Price Index (BPI) as measuring the '... cost (of) development after deducting differences in quality etc' (ibid). According to the 2008 Swedish Building Price Index (BPI) the construction cost for multi-dwelling buildings increased by 3%. The least expensive multi-dwelling buildings were built in Northern Sweden where production costs were SEK 18,070m² (\$2,877 AUD) while costs were highest in the greater Stockholm area at SEK 27,653m² (\$4,150 AUD) (ibid). 2008 also saw the metropolitan areas of Sweden increase by 6,433 multi-dwelling buildings constructed at an average cost of SEK 2,482,000 per dwelling (\$380,000 AUD). This equated to SEK 34,101/m² (\$5,220/m² AUD). This calculates to an average dwelling size being approximately 73m² which can be interpreted as typical for the higher density, multi-storey apartments that are commonly found across Sweden's major cities. In 2008, 1,384 one or two dwelling buildings were built at a cost of SEK 3,719,400 (\$568,715 AUD) each and equate to SEK 27,469/m² (\$4,200/m² AUD). Thus an average dwelling size is approximately 135m² which is considerably smaller than the Australian average house size of 245.3m² (Statistics 2010). This large variation in size makes it difficult to compare the Australian and Swedish BPIs, especially when considering other relevant factors such as designing for climate, differences in construction methods, standards of finish, material and labour costs.

The Swedish National Institute of Economic Research's December 2009 press release reported that despite a 4.4% drop in GDP in 2009, it was expected that higher exports and rising consumption in 2010 would improve the situation and that 2010 would see 2.7% growth followed by 3.3% in 2011. It is expected that in line with improvements in the international economy, increases in domestic consumption,

continuing low interest rates and reductions in taxation, Sweden will continue to experience growth (Konjunkturstutet 2009).

Construction of dwellings fell dramatically in the mid 1990s to early 2000 but experienced a moderate increase in the number of dwellings constructed leading up to 2010 despite some recent contraction in housing values. Notwithstanding this, some Swedish sawmill companies have begun developing plans to open new sawmill facilities to expand their production capacity. Holmen Timber is currently constructing a sawmill in Braviken that will produce structural timber from spruce (Holmen 2010) and Södra has also recently announced its intention to purchase a fully operational sawmill from Germany and install it in Sweden to supplement its existing sawmill operations.

The Swedish industrial environment is an example of a modern, advanced, industrialised economy that utilizes and often develops leading industrial techniques. The timber industry itself has many large timber processors operating as vertically integrated supply, design and construct companies whose operations extend from silviculture to sawmilling to generating their own energy requirements and even engaging in the production of biofuels such as second generation biodiesel and ethanol production from their timber waste (Preem 2008).

In this highly industrialised country, the timber industry operates in an environment that is increasingly focused, albeit as only a relatively small percentage of gross production, on producing value-added timber products and is now extending its operations into building life cycle management and end of use recycling.

A report by Roos, Flinkman, Jäppinen and Warensjö on the adoption of value-adding processes in Swedish sawmills found that Swedish ‘... mills organise their value-adding operations in a rational structure, concentrating their efforts in related operations where they can utilise machines and skills for several products and markets.’ (Roos Flinkman Jäppinen Warensjö 2000). Value-adding becomes another step in the traditional sequence of events that is required to get wood from the forest to

the market process i.e. logging-felling/transport/milling/drying/grading/sales. The value-adding process itself can start as early as the milling stage with lower grade timber being identified early in the process. The high level of computer based technical processing in modern mills is capable of identifying lumber that has a lower density or a greater number of knots. This material is electronically tagged to allow it to be isolated at the appropriate time for use as a source material in a value-added product. Despite the existence of numerous large scale off-site construction facilities, Roos, Flinkman, Jäppinen and Warensjö found that in terms of overall production, mills still only engaged in value-adding to a small percentage of their total production, as standard graded lumber volumes far out weigh the amount of timber currently required for use in engineered and value-added products. This could, in part, be attributed to ongoing conservative traditions within the sawmill industry and also because of the risk associated with investment required for further processing (ibid). Milling companies such as Derome, Martinsons and Moelven are notable exceptions to this with significant investments in industrialised house production or the manufacture of value-added timber building components that utilise sawn material from their own milling operations.

Sweden's timber industry operates within the context of a heavily unionised work force in a politically socialist environment and consequently, employees' benefits are considered high relative to other developed countries. Sweden, known as a model welfare state, taxes heavily to fund many community and institutional services. Despite this, Watkins points out that because Swedish industry must compete in international markets, the welfare state is limited in the level of restraint it can impose such that '... Swedish industry has successfully competed, despite the rise in wage rates, the shorter workday and increasing vacation time mandated for Swedish labor' (Watkins 2007).

A high level of mechanised processes combined with the need to constantly improve efficiencies to remain both nationally and internationally competitive has seen

an overall decline in the number of sawmill operational staff, many of whom are now required to be multi-skilled. By its very nature, prefabricated timber buildings require a high degree of industrialised production and rely on economy of scale production models to be profitable. As high production volumes are one of the key elements of prefabricated construction, the Swedish prefabrication industry must continually strive towards large production outputs to offset the high capital costs associated with the development and maintenance of its technically advanced facilities.

As a point of comparison, several large scale Australian sawmills have also developed a range of value-added timber products to complement their standard sawn timber range. For example, the Hyne sawmilling company, operating predominantly on the eastern seaboard, produces a range of LVL and glue laminated posts and beams and also operates a residential construction timber framing plant. Carter Holt Harvey Wood Products, also based on Australia's eastern seaboard, produce, in addition to standard sawn products, a range of engineered timber joists and bearers, structural plywood products and a complete, small scale panelised building system.

In Western Australia, the small number of timber wall frame and roof truss manufacturers face some significant challenges in a residential market dominated by traditional on-site stick roof construction and double brick walls. Two timber processing companies deserve specific mention: Wespine, WA's largest softwood timber mill and Wesbeam, WA's only engineered Laminated Veneer Lumber (LVL) manufacturer. Both Wespine and Wesbeam are separate companies although both originated from Cullity Timbers. Wesbeam manufactures a range of engineered LVL products, primarily for residential and light commercial construction. Wespine also views their sawn timber as an 'engineered product' because of the high level of testing they carry out to ensure its reliability in accordance with the Machine Grade Pine (MGP) standard for sawn lumber. Wespine has developed its suite of sawn products to specifically cater for the 'stick' roof construction industry so prevalent in Western Australia, as the unique attributes of Western Australia's Radiata pine such as knot size and spacings suits the production of

the large range of sawn lumber sizes required for stick roof construction. Wespine and Wesbeam are discussed in greater detail in the review of Selected Australian Sawmills and Timber Construction Companies in Section 1.14 of this chapter.

1.3 - Sweden's Tree Varieties

Silviculture in Sweden incorporates three tree varieties. These are:

- **Norway Spruce** (*Picea abies*) - The most common in Sweden at 40% of total standing volume.
- **Scots Pine** (*Pinus sylvestris*) - The second most populous at 39%.
- **Swedish Birch** (*Betula pendula Dalecarlica*) - The third most populous at 12%.

The remainder consists of other deciduous trees at 6% and standing dead trees at 3%.

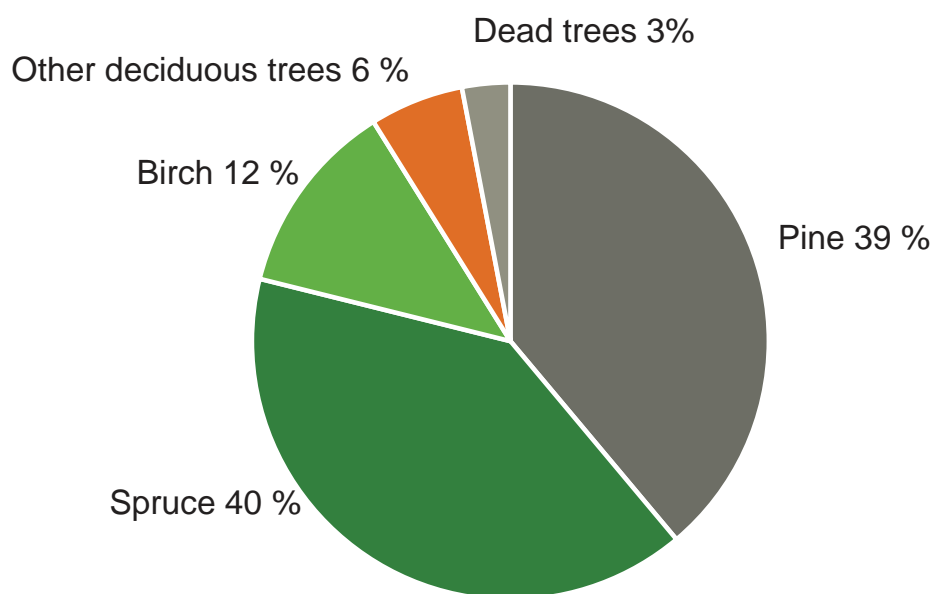


Table 1.2 Swedish Forests Standing Volume by Tree Varieties. Source - Skogsindustrierna National Forest Survey

The following is a brief overview of the characteristics of each species:

1.3.1 - Norway Spruce

The *Norway spruce* (*Picea abies*) also known as *Gran* or *White Wood* is a softwood, evergreen coniferous tree that typically grows 30m to 35m tall and has a trunk diameter up to 580mm when harvested, but can grow up to 1.5m in diameter. It tolerates acidic soils well, but does not flourish in dry or deficient soils. It is used for

both timber and paper production and is also popularly used as Christmas trees. Umeå University in the north of Sweden recently announced that it had discovered the world's oldest recorded living spruce tree in the Dalarna province of Sweden, estimated to be 9,550 years old (Kullman 2008). Prior to this announcement, according to Professor Kullman, it had been generally thought that the spruce tree was a 'relative newcomer' to Sweden.

1.3.2 - Scots Pine

The *Scots pine* (*Pinus sylvestris*) also known as *Tall* or *Red Wood* (so called because it has a reddish coloured sap wood), is a softwood evergreen conifer that typically grows from 25m to 40m tall with a trunk diameter that can grow up to one metre. The bark is thick, scaly, dark grey-brown on the lower trunk, and thin, flaky and orange on the upper trunk and branches. The mature tree is distinctive due to its long, bare, straight trunk with a rounded or flat-topped mass of foliage. The Scots pine's lifespan ranges from 150 to 300 years and the oldest recorded Swedish specimen is just over 700 years (The Gymnosperm Database 2011). The Scots pine is used for lumber and pulp wood. Harvesting requirements and growth periods are similar for both the Norway spruce and Scots pine. Both require 60 to 80 year growth periods and are commonly harvested at around that time subject to customer requirements and a mill's maximum log diameter processing ability. Commonly, harvesting occurs when the top of the trunk reaches a minimum diameter of 120mm but can range between 180mm to 420mm. The typical mean width is 240mm with some mills having the capacity to process up to 580mm. The harvesting machinery optimises each individual tree trunk when felling by sawing the log into lengths subject to its trunk diameter as the tree is felled. The section of the trunk which is less than the minimum width is used for pulp production. The harvesting process is discussed in more detail in Swedish Timber Harvesting and Silviculture in Section 1.8 of this chapter.

1.3.3 - Swedish Birch

The *Swedish birch* (*Betula Pendula Dalecarlica*) is the national tree of Sweden. There are several varieties known locally as the *Björk* (*Betula sp*), the *Glasbjörk* (*Betula pubescens*) and the *Vårtjörk* (*Betula alba*). It is a broad leaf, deciduous hardwood and is a variety of the *European White* or *Silver birch*. The tree commonly has coloured, paper-like peeling bark, dissecting leaves and a pendulous form. It grows well on cold, exposed sites with light, sandy soil and can reach a height of ten to 15 metres. Its trunk can grow up to 500mm in diameter but it is not used for the production of large sawn products as it is harvested well before it reaches this size. It is used predominantly for pulp wood, tongue and groove flooring and as residential fire wood.



1. Swedish birch in summer
2. Swedish birch in winter
3. Norway spruce
4. Scots pine



Figure 1.10. Swedish birch, Norway spruce and Scots pine. Photos. D.Bylund

1.4 - Australia's Tree Varieties - Native and Introduced

Like Sweden, both softwood and hardwood trees are farmed in plantations or as sustainably managed native forests in Australia with the most common farmed or managed tree varieties being pine and eucalyptus. These are outlined below:

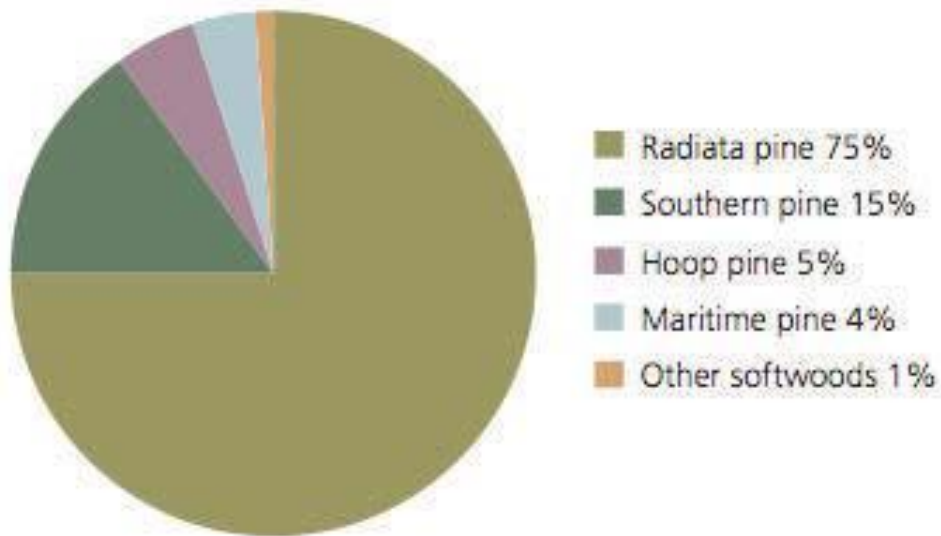
Hardwood Species			
Mangium <i>Acacia mangium</i>	Blackwood <i>Acacia melanoxylon</i>	Lemon Scented Gum <i>Corymbia citriodora</i>	Spotted Gum <i>Corymbia maculata & Corymbia variegata</i>
White Gum <i>Eucalyptus (E.) argophloia</i>	River Red Gum <i>E. camaldulensis</i>	Gympie Messmate <i>E. cloeziana</i>	Flooded Gum <i>E. grandis</i>
Blackbutt <i>E. pilularis</i>	Mountain Ash <i>E. regnans</i>	Sydney Blue Gum <i>E. saligna</i>	Karri <i>E. diversicolor</i>
Tasmanian Blue Gum <i>E. globulus</i>	Shining Gum <i>E. nitens</i>	Jarrah <i>E. marginata</i>	
Softwood Species			
Radiata pine <i>Pinus radiata</i>	Hoop pine <i>Araucaria cunninghamii</i>	Caribbean pine <i>Pinus caribaea</i> <i>var. hondurensis;</i> <i>Pinus caribaea</i> <i>var. caribaea</i>	Slash pine <i>Pinus elliotti</i>
Maritime pine <i>Pinus pinaster</i>			

Table 1.3. Common trees farmed in Australia. Source - Australian Bureau of Rural Science 2009

According to the Australian Government's Department of Agriculture, Fisheries and Forestry Bureau of Rural Science's publication *Australia's Forests at a Glance 2009*, a plantation is '... an intensively managed stand of trees, of native or exotic species, created by the regular placement of seedlings or seeds.' (Australian Bureau of Rural Sciences 2009). Australia's plantations feature both soft and hardwoods.

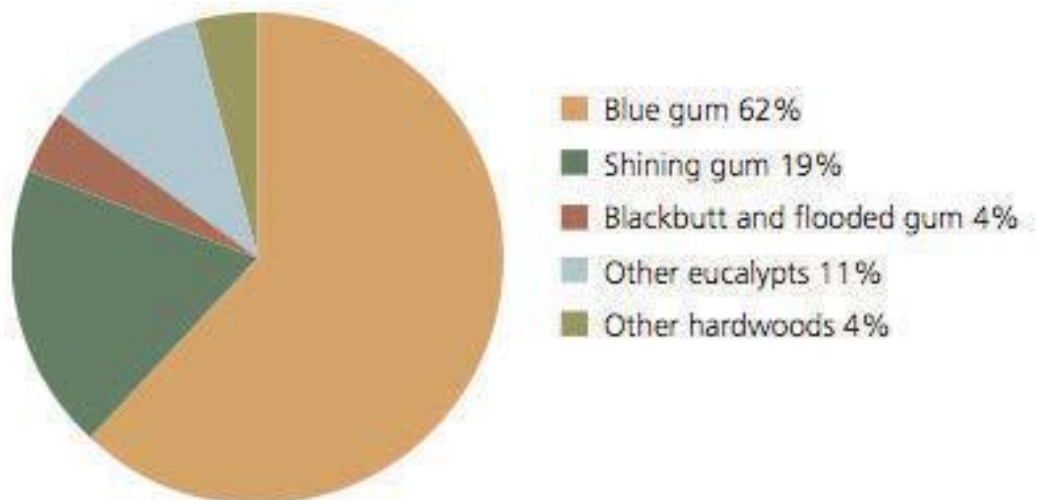
As can be seen in the following graphs, Radiata pine (*Pinus radiata*) dominates the softwood plantations (72%) and Blue gum (*Eucalyptus globulus*) dominates the hardwood plantations (62%).

Softwoods



Distribution of softwood trees as a percentage. *Source - Australia's Forests At A Glance 2010*

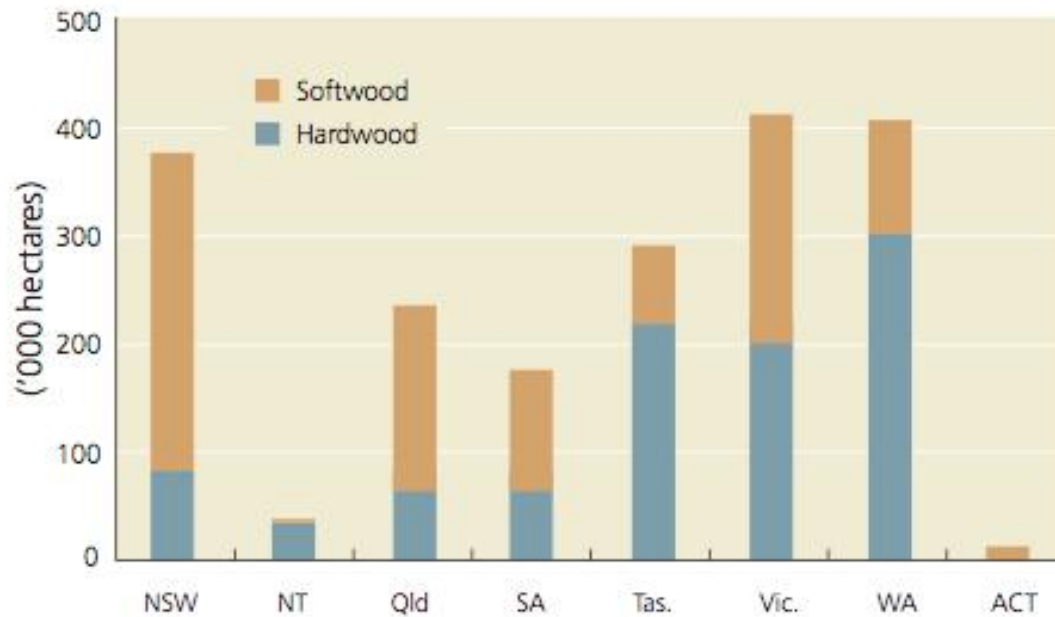
Hardwoods



Distribution of hardwood trees as a percentage. *Source - Australia's Forests At A Glance 2010*

Table 1.4. Distribution of hardwood and softwood trees by percentage in Australia

Nationally, Australia currently has over 2.0 million hectares of plantation timber of which 49% are hardwoods and 51% are softwoods. Victoria has the largest area of plantation, followed closely by Western Australia and New South Wales.



Source - Australia's Forests at a Glance 2010

Table 1.5 Australian state by state distribution of softwood and hardwood trees

As the blue gum tree (*Eucalyptus globulus*) is farmed for paper and pulp and does not appear to be suitable for structural applications, this report will focus on the potential for Radiata pine as the primary plantation timber that suits value-adding through engineering and prefabrication and is the most readily available.

The following overview of Radiata pine has been supplied by the Forest Products Commission of Western Australia (FPC WA 2013).

1.4.1 - Pinus Radiata

Radiata pine, formerly referred to as Monterey pine or Insignis pine, is a large softwood native to a very limited area of the west coast of North America but planted widely in the world's southern temperate zones, especially in South Africa, Chile, New Zealand and Australia. In Western Australia, major plantations have been established in the south-west on fertile soil and in rainfall areas greater than 700mm

• Wood description

The heartwood is pale yellow-brown, and sapwood pale yellow-white. The

texture is fine, with the grain usually straight except for the central core of juvenile wood that often has pronounced spiral grain in the first few years.



Figure 1.11. Radiata pine plantation and detail of trunk showing distinctive raised bark pattern. Photos - D.Bylund

- **Wood density**

Green density (the mean density of the timber unseasoned) is approximately 1000 kg/m³, air-dry density about 590 kg/m³ in 30 to 40 year old trees and about 480 kg/m³ in 10 to 20 year old trees. Basic density (oven dry mass over green volume) is about 490 kg/m³ in 30-40 year old and about 405 kg/m³ in 10-20 year old trees.

- **Shrinkage**

Tangential and radial shrinkage from green to 12% moisture content before steam reconditioning are 5.1 and 3.4 per cent respectively, and after steam reconditioning 5.1 and 3.5 per cent respectively. Steam reconditioning is essential for restoring the shape of collapsed timber which may have resulted from the drying process and is intended to equalize the moisture content (EMC) within the wood to prevent stresses developing that can cause bowing or springing.

- **Workability**

The wood is relatively easy to work, but knots and resin pockets are common.

- **Durability**

Timber's natural durability is classified according to standards outlined in the Australian Standard AS 5604. Timbers are rated on a scale of 1 through 4. In its natural state, Radiata pine does not rate highly according to this scale as it receives only Class 4 for both decay and for decay + termites. Treated pine performs

significantly better and a range of treatments are available for both indoor and outdoor applications.

Class	Standard
1	Timbers of the highest natural durability
2	Timbers of high natural durability
3	Timbers of only moderate durability
4	Timbers of low durability. These timbers have about the same durability as untreated sapwood, which is generally regarded as Class 4, irrespective of species

Table 1.6 Australian Timber Durability Classes

- **Strength group and properties**

Green and dry strength groups are S6 and SD6 respectively. The more important strength properties are given in the table below.

Property	Units	Green	Dry
Modulus of Rupture	MPa	42	81
Modulus of Elasticity	MPa	8100	10000
Maximum Crushing Strength	MPa	19	42
Hardness	KN	2.1	3.3

Table 1.7 Radiata pine strength group and properties

- **Uses**

Radiata pine is used for general construction, house framing, molding architraves, doors, shelves, joinery and turnery, decorative panelling, furniture, construction plywood, sliced veneer as a facing for particleboard, pulp and paper and reconstituted products e.g. particleboard and Medium Density Fibreboard (MDF). If preservative treated, Radiata pine can also be used for posts, poles, sleepers, retaining walls, decking, cooling towers and mining timber.

- **Commercial Availability**

The timber is readily available in all Australian states and territories.

1.5 - Selected Australian and Swedish Tree Varieties - A Properties Comparison

Apart from tangential and radial shrinkage, Radiata pine has many similar properties to both Scots pine and Norway spruce. This would indicate that it could perform comparably well if used in modern timber building design. The primary point of difference is the tangential shrinkage (5.1mm) and radial shrinkage (3.0mm to 4.0mm) that Radiata pine exhibits compared to both Scots pine and Norway spruce. This could have a significant impact on its use where dimensional stability is important. The incorporation of control joints and architectural detailing to accommodate the potential dimensional variation that could occur would need to be considered when using Radiata pine for products/systems such as CLT and mid rise apartments. The following table compares Radiata pine, Scots pine and Norway spruce. Where available, information on Tasmanian blue gum has also been included because of its abundance as a plantation timber in Western Australia, should it be considered for use in engineered timber construction in the future.

Tree Variety/Property	Radiata Pine (Pinus radiata)	Scots Pine (Pinus sylvestris)	Norway Spruce (Picea abies or Picea excelsa)	Tasmanian Blue Gum (Eucalyptus globulus)
Shrinkage				
Tangential (mm)	5.1 (Medium)	0 (Very Low)	0 (Very Low)	7.7 (High)
Radial (mm)	3.0-4.0 (Medium)	0-2 (Very Low)	0-2 (Very Low)	4-5 (High)
Unit Movement	0.27%			0.40%
Strength Group				
Unseasoned	S6 (Reasonably Low)	S6 (Reasonably Low)	S6 (Reasonably Low)	S3 (Reasonably High)
Seasoned	SD6 (Reasonably Low)	SD6 (Reasonably Low)	SD6 (Reasonably Low)	SD2 (High)
Stress Grade				
Unseasoned	NA			F8-F17
Seasoned	F5-F14			F8-F34
Density Per Standard				
Unseasoned (kg/m ³)				1100
Seasoned (kg/m ³)			460	980
Joint Group				
Unseasoned	J4 (Medium)	J4 (Medium)	J6 (Very low)	J2 (High)
Seasoned	JD4 (Medium)	JD4 (Medium)	JD6 (Very Low)	JD2 (High)
Colour	Straw /light brown	Straw /light brown	Straw /light brown	Straw /light brown
Mechanical Properties				
Modulus of Rupture - Unseasoned	42			78
Modulus of Rupture - Seasoned	81			146
Modulus of Elasticity - Unseasoned	8.1			11
Modulus of Elasticity - Seasoned	10			20
Maximum Crushing Strength - Unseasoned	19			40
Maximum Crushing Strength - Seasoned	42			83
Impact - Unseasoned	12			16

Tree Variety/Property	Radiata Pine (Pinus radiata)	Scots Pine (Pinus sylvestris)	Norway Spruce (Picea abies or Picea excelsa)	Tasmanian Blue Gum (Eucalyptus globulus)
Impact - Seasoned	6.9			23
Toughness - Unseasoned (Nm)	Medium - 15 - 25			Medium - 15 - 25
Toughness - Seasoned (Nm)	Low - up to 15			High - 25 Nm & above
Hardness - Unseasoned	2.1			7.3
Hardness - Seasoned	3.3			12
Durability				
In-Ground	Low (0-5 years)	Low (0-5 years)	Low (0-5 years)	Moderate (5-15 years)
Above Ground	Low (0-7 years)			Reasonably High (15-40yrs)
Marine Borer Susceptibility	Yes	Yes	Yes	Yes
Lyctid Bore Resistance	Yes	Yes	Yes	No
Termite Resistance	Not resistant			Not Resistant
Fire properties				
EFH Ignitability	14			
EFH Spread-of- Flame Index	8			
Critical Smoke-Developed Index	3			
Critical Radiance Flux - Lower (kW/m2)	>2.2 - <4.5			>2.2 - <4.5
Critical Radiance Flux - Higher:	>2.2 - <4.5			≥4.5 [kW/m2])
Smoke Development Rate:	<750			<750
Fire Properties Group Number:	3-Slightly combustable	3-Slightly combustable	3-Slightly combustable	3-Slightly combustable
Average Specific Extinction Area	<250	<250	<250	<250
Bush Resistance (AS3959)	BAL 12.5 and 19	Not tested	Not tested	BAL 12.5 and 19

Table 1.8 Swedish and Australian commercial tree comparison.

Data compiled from *Wood Solutions* species (www.woodsolutions.com.au) and *Timber Building in Australia* (www.oak.arch.utas.edu.au). Note: Blank spaces indicate that author was unable to identify or source any reliable data in these categories.

1.6 - Forest Ownership and Management in Australia

According to *Australia's Forests at a Glance 2012*, 'In 2010–11 the proportion of plantations owned by institutional investors (for example, superannuation funds) increased by three per cent since 2009–10 to 31% of all plantations. Public ownership now stands at 24%; farm foresters and other private growers own 8%; and timber industry companies own about 13%. Historically, managed investment schemes funded most of the expansion in private plantations, but ownership by these schemes decreased from 36% in 2008–09 to 24% in 2010–11'. These ratios are indicated in the the following graph.

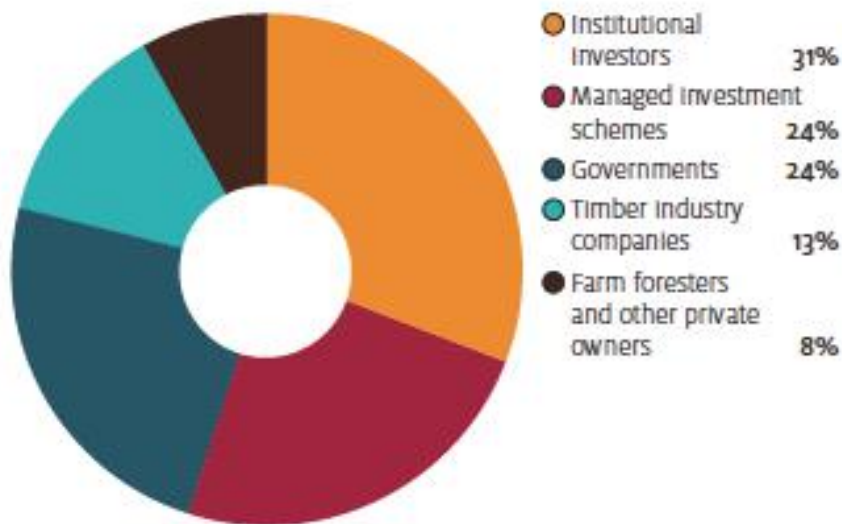


Table 1.9 Australian Plantation Forest ownership distribution

In southern Western Australia, a significant number of Tasmanian blue gum (*Eucalyptus globulus*) tree farms have been created as Managed Investment Schemes (MIS). Many of these schemes, such as Timbercorp and Great Southern, failed to meet their projected profits, and combined with a sharp drop in pulp exports to Japan, have collapsed resulting in investors losing the bulk of their investment. The farmers who leased their land to these schemes have also been negatively affected through lost income and access to their land for other farming purposes. Many of the trees remain

in the ground but have not been maintained, and without a market have become a significant cost to the farming community.

Australian Senator Bill Heffernan's comments on the Australian Broadcasting Commission's (ABC) *Landline* report, *The Future of Managed Investment Schemes* (25/02/2007) are a telling indictment of just how much damage failed MISs have inflicted on the tree farming industry and to the investors who have lost money following their collapse:

'The facts are that MISs are the greatest tax rort that's confronted Australia in a long while, and there are going to be a lot of people in the long run getting burnt'.

On the same program, Robert Belcher, the Managing Director, Chairman and Public Officer of Sustainable Agriculture Communities Australia (SACA) stated that MISs are:

'... tax-avoidance driven. They're not market-based. They're anti-competitive and, when you put all of those things in a mix, you've got bad news.'

and that

'... it doesn't matter what happens to that venture, because the person who's going to lose is the investor not the managed investment company. What they're not doing is looking down the track and seeing where the brakes are going to go on, where the market signals are going to come in. There are none. There is no reason why an MIS scheme will stop because they're oversupplying. As long as people continue to invest it will keep going, because the real money for the promoter is made from the investor not from the end product.'

The issue that Robert Belcher refers to above is the apparent practice of MIS tree farms primarily being established for reasons other than producing timber for their intended purpose. Failed managed timber investment schemes such as Timbercorp and Great Southern may have an effect on private investors' willingness to consider planting other types of trees such as soft and hardwoods for structural purposes. How this will affect the private structural timber plantation industry is yet to be seen.

Government plantations of structural timber remain unaffected by the negative MIS situation.

The sawlog/pulpwood plantation output distribution trend has been identified in the *Australia's Forests at a Glance 2010* publication in the following graph.

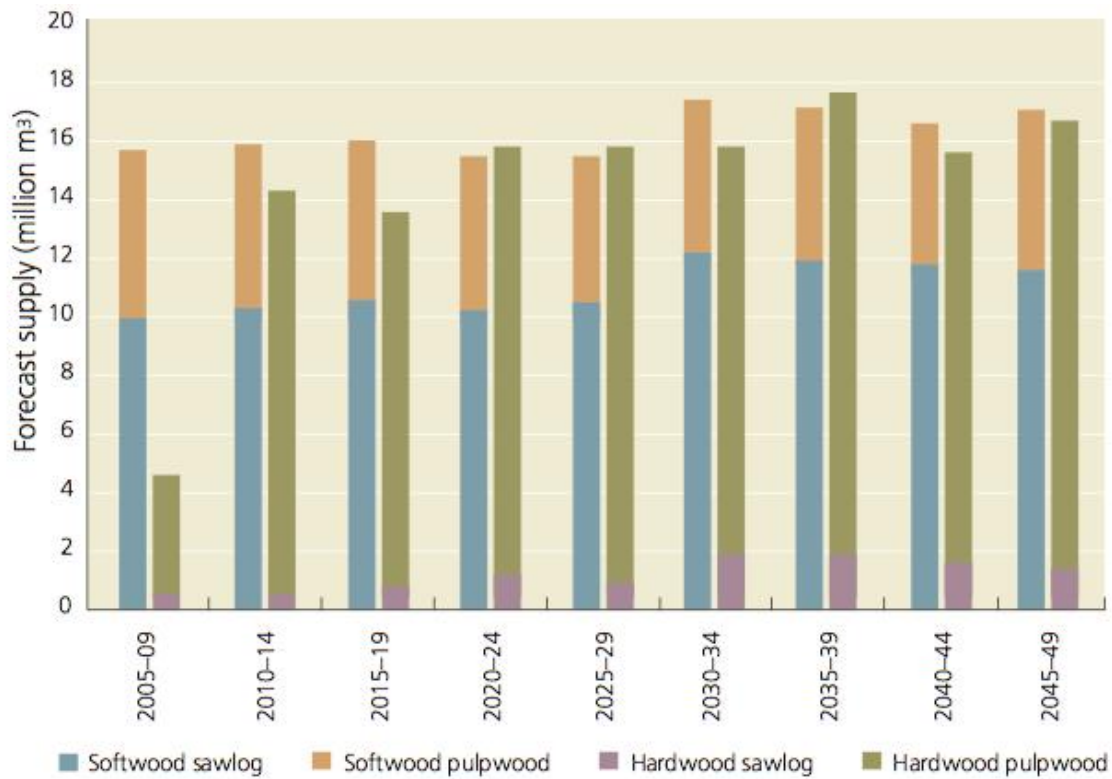


Table 1.10 Projected Australian sawlog/pulpwood plantation output distribution trend 2005 to 2045. Source - Australian Forests at a Glance 2010

The same report states that:

‘The potential supply of softwood plantation sawlogs and pulpwood is not expected to change significantly from now to 2050. The potential log supply from hardwood plantations will rise rapidly because the large areas established from the mid-1990s are reaching rotation age. The vast majority of those plantations are managed to produce pulpwood for paper making. Hardwood sawlog supply from plantations is estimated to rise slowly to 2030 then stabilise at a low level or decline to 2050’.

Further to issues such as difficulties currently being experienced within the private sector’s primary vehicle for establishing financially viable plantations (e.g. failed Managed Investment Schemes), negative community sentiment toward tree farms

within older farming districts is also becoming apparent. Anecdotally, the author has encountered rural communities in the south west of Western Australia (WA) expressing concern over large, multi-national corporations purchasing farm land to plant trees for carbon offset purposes and to ensure pulp supplies. The change in the landscape's appearance, as increasing numbers of plantations grow on cleared land that had previously been used as pasture land, has some farming districts concerned about their ability to maintain land for large scale cropping.

The July 2011 issue of the *Countryman* reports that several of WA's south west shires are limiting the area in which farmers can plant trees for the purposes of acting as a 'carbon sink' and being able to claim a tax deduction via the Australian Government's *Department of Climate Change and Energy Efficiency's Subdivision 40-J of the Income Tax Assessment Act 1997*, which came into effect in July 2007. The DCCEE website states that the '... introduction of this deduction is intended to encourage the establishment of forests for the dedicated purpose of absorbing carbon dioxide from the atmosphere' (Department of Climate Change and Energy Efficiency 2011).

According to the article in the *Countryman*, the intent of the shires is to maintain food production as a district's main use rather than, as Plantagenet's chief executive Mr Rob Stewart describes, '... wall-to-wall carbon plantings' (Matthews 2011). Further to this, he states that the shire does not want to be known as a 'carbon denier', presumably to conform to the widely held view of the need to increase carbon stores by planting trees, as a '... carbon sink monoculture ... wouldn't be good for the district' and that the '... issue with carbon sinks is that you are potentially giving away good agricultural land for something you cannot eat, you cannot cut down and cannot dig up' (ibid).

One of the emerging issues in Australia relating to the use of trees as a carbon sink stems from the potential stifling of the carbon economy through restricting tree harvesting due to the permanence obligations required to remain eligible for the

scheme. This obligation states that the trees cannot be removed for a period of 100 years which could equate to a significant disincentive to establishing a cyclical approach to carbon capture through continual planting, harvesting and replanting. Harvesting a tree for uses that do not destroy the wood allows, subject to the land's capacity to support re-planting, a cyclical approach to the natural absorption of carbon from the atmosphere. Carbon continues to remain 'locked up' in the timber for its life time, regardless if it is retained in a plantation or built into a house. By allowing trees to be harvested and replanted, the carbon store equation grows exponentially as more plantations are managed through a cyclical 'plant, grow, harvest, plant, grow, harvest' model. The societal benefit of adopting a longer term view toward the ongoing use of timber as a significant part of managing the planet's resources and environment can only be determined through hindsight, but if the climate change projections are correct, then any material that stores carbon efficiently and also performs a valuable function in a modern economy should be embraced.

1.7 - Swedish and Australian Forests - A Brief Comparison

Gaining an understanding of the significant differences between Sweden and Australia's forestry resources becomes an important foundation for assessing Australia's potential to develop its own prefabrication and engineered timber industry beyond that which is currently in operation.

For the most part, Sweden's forests are owned by private entities who, apart from their legislative obligations to perpetuate the industry, have significant cultural and entrepreneurial imperatives that drive them to expand their forest resources for future generations. This is a significant difference between Australia and Sweden and one that should not be discounted. While large tracts of land with timber plantations on them are privately owned in Australia, many by Managed Investment Schemes, the majority of plantation timber remains government controlled and thus lacks the cultural and entrepreneurial forces that often drive innovation.

Sweden is approximately one-seventeenth the size of Australia with a total land mass of approximately 45 million hectares (ha).

Despite its relatively small size, approximately half of Sweden’s land (22.5 million ha [55.63%]) is considered ‘productive forest land’ (Skogsstyrelsen 2012). This equates to approximately 18.5 times more plantation timber producing land than is currently available in Australia.

Sweden’s ‘forest land’ is defined as ‘... land which is suitable for forestry and not significantly used for other purposes with a potential yield capacity of at least 1m³ sk (stem volume over bark) per hectare per year’ (Skogsindustrierna 2008).

The balance of Sweden’s land (18.2 million ha) comprises 4.6 million ha (11.2%) of swamp, 0.9 million ha (2.2%) of rock surface, 3.6 million ha (8.82%) of high mountains and subalpine coniferous woodland, 3.4 million ha (8.3%) of arable land and pasture land, 4.0 million ha (9.8%) of national parks, nature reserves or areas protected by nature conservation agreements and 1.7 million ha (4.15%) classified as ‘old growth forest’. Old growth forest in Sweden is officially defined as ‘... being over 140 years in northern Sweden (Norrland, Dalarna, Värmland and Örebro counties), and over 120 years in the rest of the country’ (Skogsstyrelsen 2009).

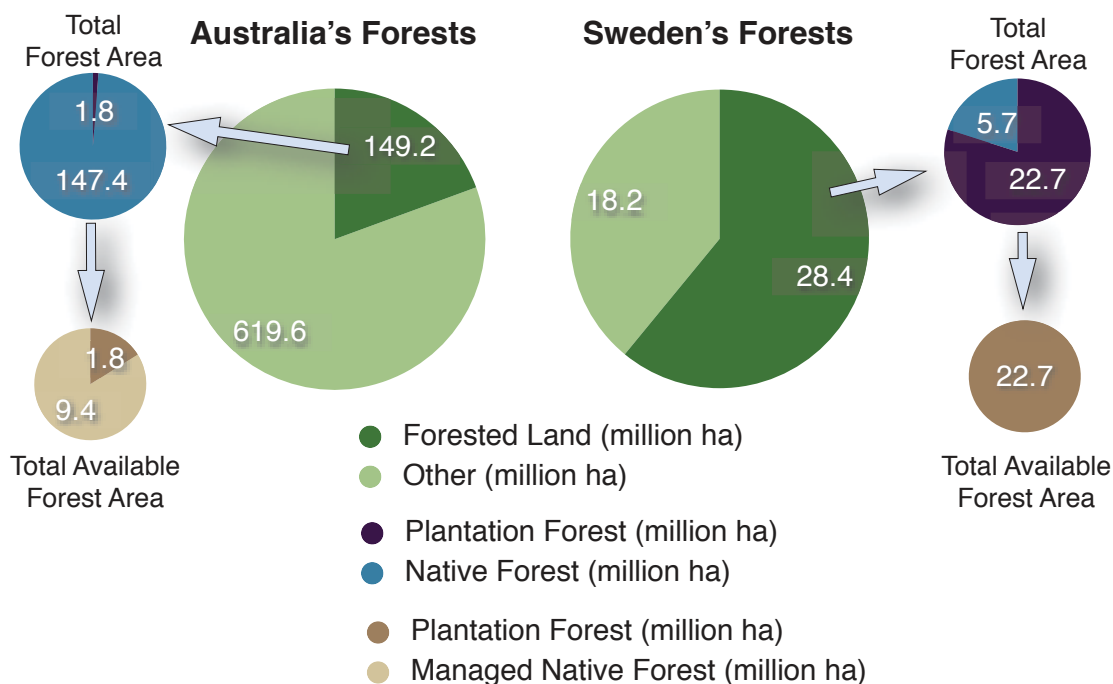


Table 1.11 Comparison between Australian and Swedish Forest Typologies

According to the Australian Bureau of Statistics, Australia's land area is approximately 768.8 million ha of which 149.2 million ha (19%) is 'forest land' (Australian Bureau of Statistics 2012).

Australian forests are classified as '... land with trees with an actual or potential height greater than two metres and 20% crown cover' (ibid). Of this 149.2 million ha, native forests account for 147.4 million ha (19.1%) and plantation forests, defined as 'Intensively managed stands of trees of either native or exotic species, created by the regular replacement of seedlings or seeds' (Australian Bureau of Rural Sciences 2009), cover 1.8 million ha (0.23%).

The area of native Australian forest that is available for harvesting is 9.4 million ha (ibid). Combining the native forests that are available for logging (9.4 million ha) with the plantation (1.8 million ha) forest area equals 11.2 million ha which is roughly half the area of Sweden's managed plantation/native forest area that is comparatively available for forestry. This is a noteworthy difference, especially given that Australia is significantly larger than Sweden yet has a population that is only approximately 2.4 times greater.

Both countries enjoy a high standard of living and feature highly developed urban environments, but Sweden's increasing level of dependence on timber relative to its available resource demonstrates the widening gulf that exists between the two countries in this aspect.

While Sweden increases its reliance on its timber resources as improvements in timber processing technologies further its ability to compete with steel and concrete, such initiatives in Australia remain, with some notable exceptions, on the periphery of the building industry as it perpetuates its reliance on steel and concrete as the number of timber processors diminish. This is not surprising considering the ratio of land currently available for managed plantation timber compared to other natural resources.

Sweden's definition states that 'forest land' is land that is '... suitable for forestry and not significantly used for other purposes' (Skogsstyrelsen 2012) whereas Australia

simply states that 'forest land' is '... land with trees with an actual or potential height greater than two metres and 20% crown cover' (Australian Bureau of Rural Sciences 2009). Based on such disparate definitions, direct comparison between the two countries, beyond that which is given here, would require a more in depth comparative analysis to allow more detailed conclusions to be drawn. It must also be noted that the differences in official definitions of 'forested land' between Australia and Sweden should be taken into account when drawing these conclusions.

The total value of the Australian forestry industry is \$21.4 billion AUD (144.7 billion Swedish Krona [SEK]) or 0.6% of GDP (ibid). The total value of Sweden's forestry industry (in 2009) was 195 billion SEK (\$29 billion AUD) or 2.2% of GDP (Skogsstyrelsen 2013). This is a very interesting comparison relative to the land available for managed timber production. While Sweden has twice the area of land under timber production than Australia, the total annual value generated by its industry is only 1.3 times that of Australia (\$21 billion AUD). In part, this could be attributed to the relatively slower speed at which Sweden's forests grow and can be harvested. Typically this might be 80 to 90 years. In Australia, native forests also have a similar regrowth cycle, but Radiata pine is often harvested within 20 to 25 years.

As of 2006, 23.58 million ha or 16% of Australia's 147.6 million ha of native forest has formal protection in nature conservation reserves (ibid). While the the total forest area per person in Australia is about 7 ha, the area of plantation forest land in Australia per capita only equals 0.08 ha whereas Sweden has 2.42 ha/per capita. The differences between the two demonstrate a number of interesting variances and should be assessed contextually relative to differing geographical, environmental, climatic, historical and economic conditions. According to the ABS, it is estimated that when the English settled Australia in 1788, forests covered one-third (33%) of the continent and by 2006 this area had fallen to less than one-fifth (19%).

From the late 18th century, Sweden's natural forests were subject to a sustained period of extensive land clearing to supply the nation's demand for wood and grazing

lands. As the population expanded and progressed into the industrial age, the demand for construction materials and fuel for heating rapidly intensified. Sweden's relatively slow growing forests were unable to regenerate naturally resulting in a serious shortage of timber in many parts of Sweden right up until the 1920s .

This widespread and often unchecked capitalisation of Sweden's forests in the 19th century led to the introduction of regulations requiring that clear felled forests be replanted and prescribed restrictions on livestock grazing in young stands.

Subsequent to the two previous centuries' unregulated use of forest resources in Sweden (and in other parts of Europe), the 20th century saw numerous attempts at forestry regulation via successive Forestry Acts (1903, 1923, 1946, 1979 and 1993) in an ongoing attempt to provide legislative protection to ensure controlled management of forests. Further to these legislative frameworks, politically motivated, counter recessive unemployment programs in the forest industry and '... extensive subsidies establishing areas to be ditched and the establishment of a forest road network ...' were utilised to further assist the establishment of a viable, long term forest and timber industry (Riksskogstaxeringen 2010).

The legacy of this systematic establishment of a national forest industry has resulted in an economically secure, functional timber industry with managed mixed species farmed forests now covering over 55% of the country. According to the Riksskogstaxeringen (the Swedish National Forest Inventory), the proportion of broad-leaved trees is now at the same level as in the 1920s (ibid).

While 9.8% of Sweden's forested area has some form of protection and 4.15% of its forests are classified as 'old growth', the Swedish conservation organisation Skyda Skogen (*Protect The Forests*) has raised concerns over the commercial processes that have transformed Sweden's modern timber industry, describing the commercialisation of the natural landscape as having undergone a '... large ongoing ecosystem change (that) is reaching its final phase (where) diversified natural forests and old "peasant forests" have been transformed into industrial plots often managed

with insufficient nature consideration' (Skyda Skogen 2010). They have likened this process to being '... similar to agriculture and cultural landscapes, where small-scale, diversified meadows, pasturelands and fields have been replaced by large-scale agriculture' (ibid).

Anecdotally, logging companies have only conceded the retention of many 'old growth' forests because of harvesting difficulties associated with their remote or rugged locations. Finding a balance between effective forestry practices and the protection of bio diversified ecosystems in Sweden is becoming a politically challenging issue as the timber industry currently employs over 100,000 people and contributes 11% of its export income (Skogsindustrierna 2008). According to the SFA, major investments in silviculture, forest regeneration, the replacement of low yielding forests and the reforestation of underutilised grazing land are part of Sweden's vision to maintain a sustainable timber supply into the 21st century.

1.8 - Swedish Timber Harvesting and Silviculture

As with most modern forest producing countries, Sweden utilises several stages in the tree farming process. These are known as Cleaning, Thinning and Regenerative Felling.

Most timber is harvested using sophisticated mechanical harvesting heads attached via a boom to a multi-wheeled, all terrain forestry machine capable of operating on steep slopes. The hydraulically operated boom allows the operator to remotely harvest the tree from the safety of the vehicle's cabin. The harvesting head grips the stem at its base, a fully integrated hydraulic chainsaw arm cuts the tree and as it undergoes a controlled fall, the trunk is pulled through the head to be de-branched and cut into specified lengths. The whole process takes about 15 to 20 seconds depending on the size of the tree, and an operator can cut many hundreds of trees a day.

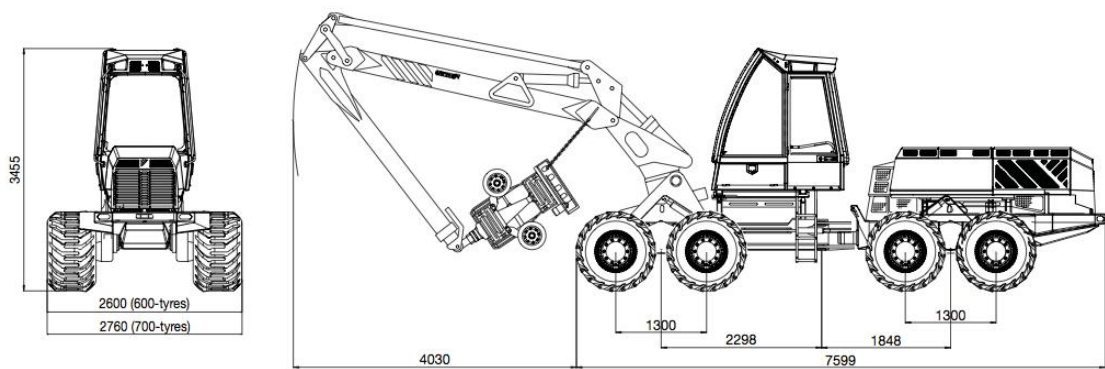


Figure 1.12. Swedish built *Gremo 1050H* Harvester. Image - gremo.se

The Forestry Research Institute of Sweden (Skogforsk), based in Uppsala, hereafter referred to as the FRIS, has recently released research by Björn Löfgren into the automation of forestry machines. In this report, Löfgren identifies future developments in automation and remote control direction in ‘... entire operations (from) knuckle boom manipulation ... (to) ... the collection, transmission and reporting of information ...’ as the next area of forestry to undergo massive technical development.

The results of the report have been utilised by forestry group Södra and machine manufacturer Gremo AB to develop and test a driverless tree harvester called the Besten (The Beast) ‘... that is remotely controlled from two wood carriers and has lower harvesting costs and fuel consumption than existing harvester-forwarder systems’ (Södra 2010). This driverless system is currently undergoing a two year trial in the Snapphanebygden forestry district in Södra Forest’s southern region. Also being developed is a remotely controlled stump harvester. According to an ElmiaWood International Forest Fair 2003 press release, Gremo AB is also testing a stump harvester to work in conjunction with the Besten to extract the stump after felling. The report claims that 20% of the forest’s energy lies in the tree stumps. According to the report, the harvester has performed successfully in trials, but the space taken up by the harvested stumps in a truck load is making the process economically unviable (ElmiaWood 2010).



1. Detail of Harvesting Head
2. Forestry Machine
3. Harvesting Head and Boom

Figure 1.13. Harvesting Head

Photographs by SP maskiner AB

Stump harvesting has a number of issues to address and will require additional research investigating its viability as there are concerns that it can have unintended negative effects on both a future plantation’s productivity and the environment. A report published by the Canadian Journal of Soil Science has found that in areas that have undergone stump harvesting, the ‘... short-term benefits of intensive site disturbance with possible long-term loss of soil productivity’ (Page-Dumroese Harvey 1997) can impact negatively on root structures and seedling growth rates due to the severe compaction resulting from the stump removal machinery. According to discussions between the author and representatives from Södra, stump harvesting also possesses a number of potential economic disincentives as the soil and stone content in the stumps make processing expensive and difficult to optimise.

Silviculture in Sweden utilises Cleaning, Thinning and Regenerative Felling in a three stage process. The following descriptions of these processes have been adapted from information provided by the Swedish Forest Agency (Skogsstyrelsen), hereafter referred to as the SFA:

1.8.1 - Cleaning

This first stage is performed, depending on the variety, when the young trees have reached a height of two to four metres. During this phase, decisions are made on which variety (when multiple varieties are present in a stand) and which individual trees

are left unharvested to allow continued development of the stand. In Sweden, about 200,000 ha are 'cleaned' annually.

1.8.2 - Thinning

Thinning is carried out during the stand's vigorous growth period and is done for two reasons. Firstly, an income is created as a result of the felled trees being used for pulp and as a fuel in the generation of bioenergy. Secondly, thinning assists in the future development of the stand as the remaining trees are provided with better growth conditions resulting from less competition for nutrients. Improved access to sunlight and water resultant from the removal of the lower branches encourages straighter growth with fewer knots.

A stand is normally thinned two to four times during its growth cycle. In Sweden, approximately 270,000 ha are thinned annually which results in an annual timber yield of about 15 million m³ standing volume.

While the thinning of forests produces income opportunities progressively throughout the life of the stand, there is evidence from research carried out in New Zealand by Mr John Chapman, Senior Lecture at the University of Auckland's School of Architecture and Planning, that amongst certain tree varieties, it could actually result in a reduction in the overall strength of the timber.

Chapman's study on the comparative strength of Radiata pine poles farmed using contemporary thinning techniques found that the bending and compressive strength had reduced by 40% and 39% respectively when compared to previous testing carried out on trees harvested in 1993 (Chapman 2009). It is possible to infer from Chapman's conclusions that trees farmed under less intensive cleaning and thinning regimes have resulted in lumber that meets higher strength grades. It should be noted that according to Södra at this time, neither significant decreases nor increases in timber strength have been identified in the Swedish grown Norwegian spruce or Scots pine resulting from the thinning process. As with Australian grown Radiata pine, New Zealand's Radiata pine can be harvested much sooner than Sweden's farmed

softwoods. Reasons for decrease in strength properties will be the inherent differences between the varieties and the significantly longer growth periods required for Swedish grown timbers compared to New Zealand grown Radiata pine. It could also be stated that the lack of comparable data from 60 to 80 years ago, when the current stock was first planted, does not allow comparative testing to the same degree as was possible in the New Zealand study. It also could be argued that standards and strength testing technologies were less developed when the current stock of Swedish trees was originally planted.

Notwithstanding this, increased volumes of milled timber that fail to meet recognized structural standards for residential frame construction has been one of the primary factors driving the development of new engineered timber products as sawmills attempt to find markets by creating value-added products from forest thinnings.

1.8.3 - Regenerative Felling

In Sweden, regenerative felling is the term used to describe the process of clear felling a forest stand and replanting within three years as per the mandated Swedish forestry regulations. Regenerative felling is undertaken when a stand reaches the harvesting variety's targeted trunk height and diameter as the incremental growth rate of trees decreases when they reach a certain size. Several factors can affect the tree growth period such as soil fertility, climate and stand management during the growth cycle. Regenerative felling is carried out on about 200,000 ha annually which is less than one percent of Sweden's total forest area. Annually, the timber yield is about 50 million m³ of the standing volume.

As previously mentioned, regenerative felling is controlled by the *Skogsstyrelsen* (Swedish Forest Agency - SFA) and before the process can be carried out, the forest owner is required to submit an application to the SFA requesting permission to begin harvesting, describing the measures that will be enacted to preserve and safeguard any special environmental and cultural values that may be present on the site.

As an alternative to regenerative felling, there have been attempts in Sweden by various forest owners to practice successive felling. Successive felling allows the forest to maintain trees that are representative of all ages being present with the aim of encouraging greater biodiversity within the stand. The intent is to allow greater ecological balance within the forest environment. On moist and wet land, the SFA requires successive felling silvicultural methods to be used, but according to discussions between the author and representatives from Södra, in practice, the successive felling technique has generally not proven to be either commercially or environmentally viable.

The relevance of the various harvesting techniques to engineered timber and prefabrication is through the perceived benefits to the industry of sourcing lumber from best practice forestry methods that both optimise production and minimise ecological disturbance. This issue is less prevalent in monocultural tree farming such as Radiata pine, but carries significant cultural and emotional relevance as forestry and environmental groups struggle to find common ground in developing the use of timber in lieu of steel or concrete.

1.9 - Cumulative Energy Demands in Sweden's Forestry Industry

As with most other industrialised processes, the forestry, sawmill and paper and pulp industries in Sweden are becoming the focus of more concerted environmental pressures to reduce their cumulative energy demands. The cumulative energy demands resultant from the production and use of construction materials refers to the embodied energy that a product has consumed. Collectively this includes its production (or growth), manufacture/processing, transportation and installation into the building during construction.

According to the *Centre for Design* at the *Royal Melbourne Institute of Technology University* (RMIT) the embodied energy in construction materials ‘... represents the sum of all the energy inputs into a product system, from all stages of the

life cycle ...' (RMIT 2009). This can be defined for construction as '... extraction of materials, processing, transport and manufacture, and sometimes including capital equipment and services supplied to the product system in question. For a full product system or service the use and disposal phase may be included in the value ...' (ibid).

When considering the cumulative energy demands of timber as a building material in Sweden, the historical relevance of sawmill locations relative to available transport methods and markets is significant. The Swedish timber and forestry industry response to this issue is to address ways to optimise the energy available from sawmill waste and by improving transport efficiencies by reducing distances that timber and wood products must travel from the forest via the mill to the warehouse and where possible, to the building site through logistical efficiencies resultant from their vertical integration into the construction sector.

During the 19th century, Sweden developed into a modern industrialised economy that '... roughly coincided with the secular changes experienced in European secular society ...' (Soderlund 1953) and thus industrialised development '... coincided with a very rapid development of Swedish economic life in general' (ibid). One of the main implications of this development and subsequent improvement in economic conditions meant that as society increased in wealth, towns and cities became larger and more established. For example the town of Sundsvall, in Västernorrland in the centre of Sweden '... was one of the world's largest sawmill districts ... (and) ... at its zenith during the 1890s the district had over forty steam-driven saws'. At its peak in 1895 it '... exported 700,000m³ of wood, an incredible 19% of the total Swedish export' (ibid).

At the beginning of the 20th century, the location of Sweden's sawmill operations and booming timber industry was largely determined, as previously stated, by the location of forests and the ability to efficiently transport sawn products to markets. In the northern part of Sweden, sawmills were usually located near the coast alongside rivers that were capable of transporting logs which were tied together and floated as

'rafts' to the coast. These logs could then be processed and directly loaded onto ships. In the south and central parts of Sweden, sawmills tended to be located near the source of the timber and then transported to markets via road and rail as, unlike northern Sweden, viable river transport was not available.



1. Floating log rafts at Husum on Sweden's Eastern Coast (circa 1970).
2. Husum Pulp Mill. Source image from *Husums Fabriker 1919 - 1994*

Figure 1.14 Logs transported on rivers to mills in Sweden

During the first half of the 20th century, the transportation of timber on rivers in the north was a cost effective means of transport as can be seen in the following table.

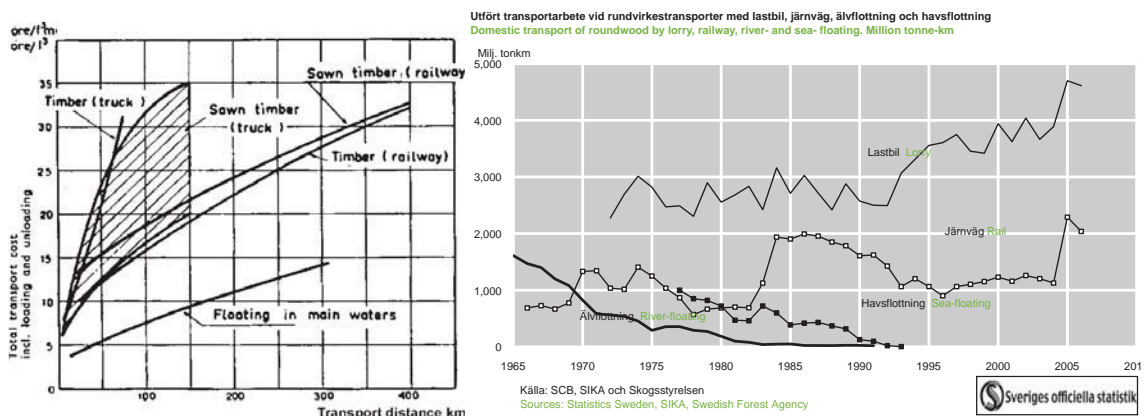


Table 1.12 Swedish log transport methods in the 20th century. Source B Thurnell, 1955

River transport, by default, allowed for very low embedded energy inputs. As road and rail have now replaced rivers as a form of transport in northern Sweden, haulage has become a significant aspect of the cumulative energy demands pertaining to timber building. As demonstrated in the above graph on the right, most building materials are now transported via the road networks and where connections allow, via the rail network.



Figure 1.15 Logs being loaded on a train in Bräcke, Sweden. Photo by Bosse Ångström

Waterborne transportation ceased completely in the early 1990s and according to Carlsson and Rönqvist's report on backhauling in forest transportation, land based transport in the Swedish forestry industry now '... accounts for more than 25% of the total land-based transportation work. One half, roughly, is attributable to the wood flow (roundwood and chips) and the other half to the distribution of finished products. About 90% of the wood is transported by truck and the rest by rail and ship' (Carlsson Rönqvist 2005). As the locations of many of Sweden's sawmill towns were reliant on available transport methods (i.e. a river flowing to the sea with a suitable harbour), deep seated historical connections often maintain sawmilling in these locations.

Several innovative developments aimed at reducing the financial and environmental cost of timber transport in Sweden are being investigated. Carlsson and Rönqvist's report on backhauling discusses one such method that attempts to address the cumulative energy cost of timber production. This report describes backhauling as the practice of improving transport logistics with the aim of ensuring logging trucks travel loaded both to and from the mill where possible. The intention is for the trucks to carry payloads in two directions in lieu of the standard one way payload cycle that they have traditionally travelled. One of the difficulties to be overcome with this concept is finding suitable commercial loads that logging trucks can carry other than the logs themselves as the unique design of the logging trailer restricts its capacity to carry other materials (Page-Dumroese Harvey Jurgensen Amaranthus 1997).

Another innovative development is the burgeoning potential presented by the production of biodiesel from sawdust. Sawdust contains considerable energy in the

form of the natural oil that exists in pine. Sweden's sawmill industry is already amongst the world's leaders in minimising waste resultant from timber production processes by generating electrical energy to operate both sawmills and often the surrounding industry and towns. A press release by SunPine (2008) announced the construction of Sweden's first Tall Olja biodiesel plant in conjunction with Preem, Sweden's largest oil producer, Sveaskog, Sweden's largest collective forest owner and Södra. Tall Olja biodiesel is produced from '... pine oil, a by-product of pulp and paper production, (and) will be converted to environmentally friendly biodiesel. Between 65 and 70 per cent of the raw material is turned into diesel. The remainder becomes pine tar pitch ... (which) ... the forest industry buys back as fuel for lime kilns' (Sveaskog 2009). Production per annum is projected to be 100 million litres. By producing fuel from a waste product, the timber industry can further demonstrate its environmental credentials in all aspects of its production when compared with alternative construction material.

1.10 - The Swedish Timber Processing Industry

Swedish sawmills can be categorised into two production sectors depending on the industry they serve. These are the paper and pulp mills and the sawn timber mills.

Since the 1980's, both sectors have experienced a dramatic decrease in the total number of mills. According to the *Skogsindustrierna (Swedish Forest Industries Federation - SFIF)*, the total number of sawn timber mills decreased from 283 to 170 and the board industry mills contracted from 32 to 8. The paper industry mills also contracted from 62 in 1980 to 43 in 2005 and the pulp industry contracted from 72 to 43. Notwithstanding these decreases, each sector simultaneously experienced a steady increase in its gross output. One explanation is that despite a large number of smaller sawmills closing or being sold to larger companies, improved technological efficiencies and increasing market demands have resulted in an increase in each successive decade's production.

The structure of the Swedish sawmill industry has changed dramatically over the last 50 years. As previously mentioned, the reduction in the total number of sawmills has not resulted in a decrease in the output volumes. There has been a transition from a labour intensive industry intent on producing as large an output capacity as possible through the utilisation of traditional manufacturing methods to a modern, market based strategy that avoids bulk production and instead aims to produce products on demand (Heikerö 1996).

There are three types of ownership structures amongst Sweden's sawmills: fully integrated, partially integrated and non-integrated (Månsson 2004). The largest category is the fully integrated structure. Sawmills in this category are privately owned and operate to maximise the profits from the mill itself. The second largest category, usually owned by forest companies, is the partially integrated structure. These companies also own the forests themselves and therefore operate to maximise profits for the company as a whole; the aim being to make both the mills and the forest production profitable entities. The third type is the non-integrated sawmill that is owned and operated by forest owners with the aim of maximising profits from the forest operation depending on the prices at any give time by increasing the inputs into the sawmill (ibid).

Another factor that has influenced Sweden's reduction in mills could be the increase in imported timber for paper and pulp production from neighbouring countries.

The following charts, sourced from the SFIF's *Facts and Figures 2008* publication, demonstrate this decline in the number of production facilities and also demonstrate simultaneous increases in production for sawn and board timber mills.

Sawn Timber	1980	1990	2000	2005	2008
SFIF					
Number of saw mills >10,000 m ³ /year	283	260	207	175	170
Production per saw mill, 1,000 m ³ (approx.)	40	45	80	100	110
Total production, million m ³	11,2	11,7	16,3	17,6	17,5
Exports, million m ³	5,9	6,5	11,1	12,2	12,0
Export value, SEK billion	5,4	11	19,4	21,7	22,8
Main markets, 1,000 m³					
Great Britain	1 000	1 200	2 460	2 835	2 620
Germany	900	1 200	1 170	800	1 010
Denmark	600	700	1 300	1 425	1 110
Board Timber					
SFIF					
Number of mills		32	18	12	8
Production					
Particle board, 1,000 m ³		1 193	843	640	628
Plywood, fibreboard and MDF, 1,000 m ³				293	217
Export volumes					
Particle board, 1,000 m ³		463	183	98	32
Plywood, fibreboard and MDF, 1,000 m ³				122	50
Export value, SEK million*		937	539	622	264

Table 1.13 Swedish sawmill to production output ratios between 1980 and 2008. Source - SFIF's Facts and Figures 2008



Figure 1.16 - One of Södra's modern flow sawmills. - Photo - D.Bylund

Milling in Sweden is a highly mechanised and technologically advanced

process. Much of the processing is fully automated and operates as ‘flow sawmills’, where high processing speeds with a minimum of downtime allows for reduced lead times and minimises the creation of stock piles. In order to maximise flexibility, mills operate systems that allow straightforward saw changes from one batch to another. This flexibility provides the capacity to quickly modify both the input and output sizes of the lumber.

1.11 - The Australian Timber Processing Industry

Australia has a number of large scale, modern sawmills which produce a range of sawn products with a high degree of structural testing and certification according to Australian standards. Some provide value-added engineered timber products while others focus on ensuring a highly reliable engineered standard is achieved within their sawn lumber range.



Figure 1.17 - Wespine’s Dardanup Sawmill. Photo - D.Bylund

Australian sawmills operate in a very conservative construction environment that has a heavy reliance on other building materials such as steel, concrete and masonry. Unlike other sectors of the Australian construction industry, the wood based construction sector, with some notable exceptions, demonstrates very little vertical integration into actual construction. Unlike their Swedish counterparts, Australian

sawmills generally continue to operate within a fairly conservative business culture that is yet to realise the potential to expand beyond the milling of timber.

Notwithstanding this, most larger scale sawmills recognise the need to differentiate themselves from their competitors via the development of new engineered timber products and investigate expanding their business model to compete with steel and concrete.

The Australian engineered timber products and companies that are outlined in Section 1.14 of this chapter entitled *Australian Timber Processors and Timber Construction Companies*, were considered for their potential to expand into larger scale prefabrication facilities that could create second and third tier value-added building systems with the intent of escalating into larger scale building products and vertical integration. Whilst some have made attempts to expand into combining vertical integration with timber value-adding in a similar way to the Swedish, significant in-roads are yet to be achieved or maintained.

While the Australian timber processing sector may have the potential to expand into more sophisticated engineered products and systems or even vertically integrate into building construction, the conservative approach to risk that exists within the culture of the Australian sawmill industry influences investment in tooling and skills training when clear market prospects do not exist. The emerging trend in Scandinavia and central Europe for timber supply companies to be vertically integrated into the building industry through material supply, value-adding and in some cases, on-site construction, does not seem to be reflected in Australian sawmill companies, albeit with some notable exceptions as already discussed.

In the past, some Australian sawmills have operated under a vertically integrated model. According to the Australian architect and timber design specialist Associate Professor Greg Nolan, '...in the past, some Australian sawmills were heavily involved in timber production, various types of fabrication and even construction' (Nolan 2010). Currently, Nolan now defines most Australian sawmills as simply '... commodity

manufacturers and suppliers ...’ and that ‘... major timber producers did not know how their products were being used ...’ (ibid). One of the key components of successful vertical integration in the building sector is understanding where and how construction materials are utilised. If Australian sawmills see themselves as primarily commodity manufacturers, then significant effort will be required in gaining adequate construction industry knowledge partnered with a willingness to manage their timber beyond their gates and through to a completed building. Without this insight, a sawmill’s ability to accurately inform and manage the transition into vertical integration becomes haphazard at best.

The importance of considering vertical integration into the development of a timber based new construction methodology becomes even more apparent when the commercial success of Swedish and European companies such as Martinsons, Moelven, Stora Enso and KLH are considered. Each company is either a traditional or relatively new sawmilling company that has expanded into large scale value-adding to their sawn timber products and most have also established some level of vertical integration into the construction chain. Refer to Section 1.15 for more information on how these companies have expanded into vertical integration or are using it as a key element of their business model. The ability to both fully understand the intended use and be intimately involved in supply, manufacture and construction of a structure that relies on the core production material positions timber processing companies at the forefront of the industry, but also exposes them to greater risk. Notwithstanding this, significant expansion of the existing engineered timber sector beyond current levels is unlikely to occur in the near to medium term. Reports such as the FWPA’s *Emerging Technologies and Timber Products in Construction* (2007) and its 2012 review and update by Associate Professor Perry Forsythe (PhD) indicate that the timber industry is at least starting to consider some of the emerging technologies.

With this in mind, engineered timber based structural systems that require a minimum of plant and specialised training and equipment were identified in this

research as having the most potential to be adopted by the sawmill industry as a first step to value-adding if the Swedish experience was to be emulated in Australia. A key element of many of the new Swedish and European timber based systems was their ability to utilise low grade timber in a structural capacity, thus creating a market for lumber that would otherwise be stockpiled or sold at a loss by the sawmill. This, in conjunction with a system that did not impose significant infrastructure and retooling costs, became the primary factor used to inform the solution investigated in this thesis as detailed in Chapters Two and Three. Developing new products and timber based building systems that can improve a sawmill's return on the timber that falls outside the requirements for structural grade pine is an important issue that many Australian mills are considering as they strive to improve their return per log processed. According to Nolan, producers now '... stockpile this material or on-sell at a discount' (Nolan 2010). This effectively results in a 'significant minority' (ibid) of sawn timber that is available for value-adding and has the potential to become an asset rather than a liability.

In an interview between the author and Johannes Habenbacher of *KLH Austria*, Mr Habenbacher stated that solid timber panel systems have a number of benefits. Solid timber panels have: '...high load stabilisation, climatic performance advantages, lower risk of structural damage over frame construction from unintentional water ingress, high quality of construction, and (are) a flexible, non closed method of construction'. The properties/characteristics of load stabilisation, climatic performance, capacity to withstand some degree of water ingress and a flexible open system of construction form a second tier of desirable traits that a new solid timber panel system should aspire to for the Australian construction industry.

1.12 - Current Methods of Australian Residential Construction

Australia's cities are dominated by the single storey free standing suburban bungalow. These buildings are predominantly constructed of either double clay brick or

brick veneer. Any other wall construction system seeking to gain market acceptance will need to compete directly with brick and its associated attributes if it is to succeed.

One of the main perceptions of brick is that it is a strong and resilient method of construction. New materials and construction systems will find it very difficult to establish themselves if they do not directly address the perceived strength and permanence associated with masonry construction.

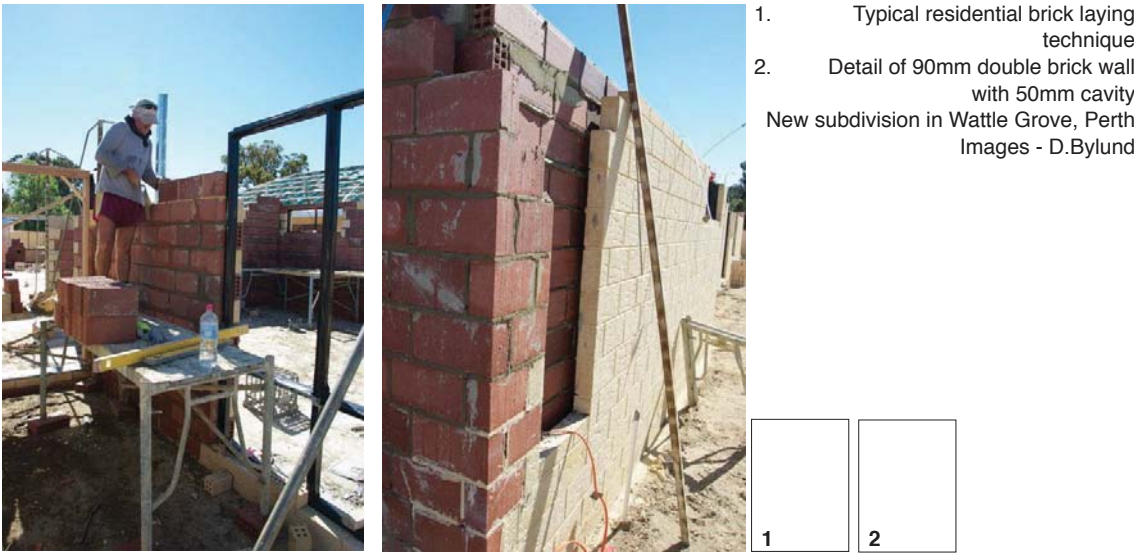


Figure 1.18 Typical cavity brick construction

The various contexts and region specific building methods exhibited in the Australian building sector, along with the expectations of the markets they supply, will play a significant role in the acceptance and uptake of any new developments in this field.

To further understand the context that new engineered timber building will face in Australia, it is worth briefly exploring the history in which the current brick method of construction came to exist. In Perth, Western Australia, the double clay brick wall is the the dominant residential construction method.

This came about as a result of the ready availability of high quality clay and a very effective marketing campaign in the 1970s and 1980s that leveraged the solid nature of brick by promoting the ‘knock test’ as a perceived determiner of strength, solidity and permanence and therefore assumed superiority over light weight construction. The ‘knock test’ was a term coined by a marketing campaign that

attempted to convince potential home owners that the solid nature of double brick was superior to frame construction. By knocking on a wall and listening to the resultant solid or hollow sound would be a way to differentiate between the two. On Australia's east coast in cities such as Sydney and Melbourne, brick veneer dominates primarily because of conservative municipalities, speed of construction and its cost effectiveness (Dean 1987).

New methods of construction intending to compete with the solid, heavy weight nature of brick will either provide an alternative heavy weight structural solution such as concrete or solid timber or will attempt to provide a light weight construction with superior technical solutions such as improvements on cost, acoustic and/or thermal performance. Both approaches will find it difficult to overcome the entrenched brick based mentality and as such, will take time to establish. Other masonry systems attempting to establish themselves, such as Hebel's light weight reinforced concrete block system, acknowledge this. In a recent Hebel publication entitled Houses Product and Range Guide, they specifically make reference to their Hebel Power Panel product as passing the 'critical "knock test" for consumers' (Hebel 2011).

1.13 - Timber and Prefabricated Construction in Australia

In early 2013, Lend Lease completed the design and construction of the ten storey Forté Building in Melbourne's Docklands district. This building is now considered one of the most significant modern engineered timber structures in Australia, having won the 2013 National Timber Design Award. According to the Australian Timber Design Award judging panel, 'Forté is a superlative example of what can be achieved using the latest generation of engineered timber products. The judging panel was particularly impressed by the use of cross-laminated timber (CLT) in the building frame. They expect that Forté will serve as a demonstration to the Australian market of how this revolutionary technology permits the rapid construction of strong, lightweight



Figure 1.19 - Forté Building. - Photo - D.Bylund

buildings that may be both tall and wide' (Australian Timber Design Awards 2013). Built with Cross Laminated Timber imported from KLH in Austria, it is claimed to be the world's tallest modern all-timber residential structure (ibid). Lend Lease has led Australia in establishing a commercial relationship with one of Europe's leading CLT manufacturers. Subsequent to Lend Lease's efforts to test imported spruce based CLT into Australia for use in its

building program, two Australian timber suppliers are now also promoting the supply of imported CLT. The Le Messurier Timber Company Pty Ltd recently announced its OPTIM CLT product which it imports from Stora Enso, and Tilling's new SmartStruct commercial division promotes itself as Australia's official importer of KLH's CLT and as a provider of collaborative timber building solutions. Research by Carter Holt Harvey has indicated that Australian grown Radiata pine is well suited to CLT and could outperform the imported spruce products. As imported CLT establishes itself as a viable structural product in Australia, locally produced alternatives are likely to emerge to compete with the imported product.

On the east coast of Australia, Carter Holt Harvey's Panelised Building System (PBS) and Timberbuilt Solutions are two examples of locally developed, engineered timber products, suitable for light weight residential modular construction and engineered bespoke timber structures respectively. These systems are commercially available, but have yet to gain any significant traction in the market. Forestry Tasmania's new Hardlam LVL product is another example of more recent Australian innovation in this area, but is in its formative stage and is yet to be made widely

available. Refer to Section 1.14, *Australian Timber Processors and Timber Construction Companies* for further discussion on these systems.

The School of Engineering at Queensland's Griffith University in conjunction with Salisbury Research Centre, the Department of Agriculture, Fisheries and Forestry Australia and the Queensland College of Art, has recently published a two part paper presenting a new Veneer Based Composite (VBC) suite of structural products that have been designed to utilise waste native hardwood material in the form of Rectangular Hollow Sections (RHS), 'C' sections and I shapes. This suite of engineered timber products shows much promise, but is relying on attracting an industry partner to be commercialized and researched further to demonstrate its potential performance in design and to provide industry with guidelines for their application and safe use.



Figure 1.20 - Structural Veneer Based Composite (VBC) Products From hardwood thinnings - Part 1: Background and Manufacturing, Griffiths University (2013)

In 2011, a new company called panelBuild commenced trading in Queensland, possibly as Australia's first timber based full scale off-site prefabrication facility. panelBuild manufactured preassembled floor cassettes, fully serviced wall and closed wall panels and skillion roof planes for residential and other light construction buildings. Despite a promising start, panelBuild closed in 2013 as it struggling to secure projects due to its inability to gain significant market share and difficulty in producing buildings to a high enough standard. This, in part, could have been due to their use of 90mm x 45mm timber wall studs in accordance with Australian standards instead of the much larger scale timber member sizes used in Scandinavia and Germany. In the author's opinion, the use of relatively small gauge timbers by panelBuild resulted in structures that lacked the more solid feel and sense of permanence that Swedish prefabricated



Figure 1.21 - panelBuild's Queensland factory.
Photo - D.Bylund

timber structures possess. For example, Lindbäck Bygg AB typically uses 170mm x 45mm wall studs in their volume module construction. The larger studs provide a large cavity space for insulation and give the structure a more solid feel. panelBuild's failure suggests that timber prefabrication on the scale it is

undertaken in Scandinavia is still some time away in Australia.

Juxtaposed with the Scandinavian prefabrication and off-site operations, Australian prefabrication companies, with the exception of panelBuild's approach, generally build according to traditional sequential construction order, mirroring the build process of on-site construction.

In Western Australia there is a range of the more common engineered timber products currently being manufactured or fabricated. These are Particle Board manufactured by The Laminex Group in Dardanup; Laminated Veneer Lumber (LVL) posts and beams for low rise residential use by Wesbeam in Neerabup; residential wall frames, timber roof and floor trusses by World Wide Timber Traders in the southern Perth suburb of Bibra Lake, and Structurally Insulated Panels (SIPS) using imported Oriented Strand Board (OSB) skins in conjunction with an Expanded Polystyrene (EPS) core by SIPS Industries, also in Bibra Lake. An addition to this list is the yet-to-be-realised Lignor's Engineered Strand Lumber (ESL®), Engineered Strand Board (ESB®) and Cross Laminated Strand Timber (CLST™) at the proposed Albany based manufacturing plant in the south west of Western Australia. The vast majority of residential construction undertaken in Perth, Western Australia, does not use these engineered timber products and systems in any significant way and instead, uses a concrete 'floating slab on ground', double brick walls and a pitched 'stick' roof.

Commercial construction predominantly utilises tilt up and precast concrete and structural steel. Large scale high level timber prefabrication plants such as those found in Sweden do not exist. There are no turn-key volume module timber systems being built on the scale of Linbäcks's Piteå factory, no Cross Laminated Timber (CLT) plants such as Martinsons in Bygdsiljum and no large scale glue laminated plants creating glue laminated beams of a comparable scale to Moelven's factory in Töreboda.

Swedish engineered timber developments have almost exclusively involved the use of softwoods. In Australia, attempts have been made to develop various engineered timber products from plantation blue gum hardwoods. The majority of these initiatives have failed to be commercially successful, in part because of the low timber properties inherent in native plantation hardwoods such as blue gum. The other significant contributing factor is the difficulty in raising venture capital for new and untested developments in timber products in the Australian market. Examples of this are the Scrimber project, as noted below, and Lignor's Engineered Strand Lumber (ESL®), Engineered Strand Board (ESB®) and Cross Laminated Strand Timber (CLST™).

Forestry Tasmania has recently announced a new LVL product called *Hardlam*. Manufactured in China from Tasmanian forest thinnings, it is produced from rotary peeled, pulp-grade, small diameter or low grade eucalyptus logs. The product is a combination of regrowth and plantation timbers such as Shining gum (*Eucalyptus nitens*) and Tasmanian blue gum (*Eucalyptus globulus*). The manufacturers claim that the combination of regrowth and plantation timbers ensures maximum strength and stiffness with the appearance of premium Tasmanian oak (*Eucalyptus delegatensis*, E.



Figure 1.22 - Hardlam furniture piece.
Photo - hardlam.com.au

obliqua & E. Regnant). Forestry Tasmania claims *Hardlam* will be certified in accordance with the requirements of AS/NZ 4357.0:2005 Structural Laminated Veneer Lumber (Forestry Tasmania 2012).

One example of an Australian timber based product and construction system that did not reach its predicted potential was Scrimber, which was to be produced in Mt Gambier, South Australia in the late 1980s. Scrimber was developed by CSIRO researcher John Coleman. According to an entry in the Encyclopedia of Australian Sciences by Rossana Walker, Scrimber uses ‘... small logs, such as Radiata pine thinnings, (which) are crushed between rollers to form long inter-connected strands, dried and then reconstituted as long sections after addition of a binding resin and hot pressing’ (Walker 2001).

While Australia does have a range of modern engineered timber products that are comparable to some of the advances seen in Scandinavia and Central Europe over the last decade, Australia’s commercially available prefabricated timber systems are not as well established and are generally failing to keep pace with Europe in terms of technical solutions, automated production or market exposure. Those that do exist, with some notable exceptions, predominantly use imported technologies or relatively simple methods of production that do not rely on advanced automation. Australia’s innovative timber construction industry continues to be eclipsed by steel, masonry and concrete construction methods.

1.14 - Australian Timber Processors and Timber Construction Companies

The following company overviews represent an interdisciplinary exploration of current practice across both Australian sawmills and the prefabricated engineered timber construction sector.

Each company has been chosen as it is broadly representative of current Australian practice or offers a unique approach, relative to standard Australian building practices, to timber construction. The companies considered demonstrate a variety of approaches and differing degrees of development and some have the beginnings of vertically integrating into the Australian construction industry. This overview gauges the current level of practice and construction focused innovation within the Australian sawmill and prefabricated timber construction industry.

The selected companies considered are:

- Wespine
- Hyne Timber
- Carter Holt Harvey
- Wesbeam
- Lend Lease
- Nordic Homes
- Timberbuilt Solutions
- panelBuild

1.14.1 - Wespine

Company Description:

Wespine was started in 1985 and operates a modern softwood sawmill in Dardanup, in the south west of Western Australia. It is owned jointly owned by the Australian company Wesfarmers Limited and New Zealand's Fletcher Building Limited. It mills Radiata pine, primarily sourced from state owned plantations. Wespine has a contract to purchase logs from the Western Australian State Government until approximately 2032, supplying timber throughout Australia and to countries in the Pacific Rim. In full production, the sawmill's capacity is approximately 200,000m³ output per annum. Depending on building activity and the prevailing economic context, up to 90% of Wespine's production is used by the Western Australian market (Kiddle 2013).

Products:

Wespine specialises in kiln dried sawn timber products including dressed, stress graded and preservative treated timber. Its structural products are specifically suited to the on-site 'stick roof' method of construction that predominates in the Western Australian housing sector. It also supplies timber for the furniture and home handyman sectors via Bunnings which is owned by Wesfarmers. Sawmill waste is sold under contract to the Laminex Group who operate an MDF plant, also situated in Dardanup. Laminex is owned by Fletcher Building Limited.



Figure 1.23 Wespine sawmill facility. Image:D.Bylund

Information sourced from the author's interviews with Wespine management, wespine.com.au and fletcherbuilding.com.

1.14.2 - Hyne Timber

Company Description:

Hyne Timber has been in operation on the eastern seaboard of Australia since 1882. It operates softwood sawmills in Maryborough and Tuan in Queensland and in Tumbarumba in New South Wales, with a total sawn timber output exceeding 1,600,000m³ per annum.

Hyne Timber mills significant volumes of plantation Araucaria and Radiata pine and it supplies timber and timber products to the Australian, Southeast Asian, Middle East and New Zealand markets. In addition to sawn timber, structural and decorative products, Hyne also produces a large range of engineered structural timber products and timber trusses and frames.

Hyne Timber is Australia's largest privately owned timber company and it actively supports undergraduate and postgraduate research on developments in engineered timber products, specifically in the application of Cross Laminated Timber plate products using Australian grown plantation softwoods.

Products:

Sawn Wood Products

Hyne produces a range of structural timber products for the residential and light commercial markets.

Hyne Frame, which is available in MGP10, MGP12 and MGP15 strength grades.

Hyne T2 Blue timber products are designed to provide termite protected structural timber products for areas south of the Tropic of Capricorn. As with Hyne Frame, Hyne T2 Blue is produced in MGP10, MGP12 and MGP15 strength grades.

Hyne T2 Red timber products are designed to provide tropical termite (*mastotermes darwinensis*) protected structural timber products for areas north of

the Tropic of Capricorn. As with Hyne Frame and Hyne T2 Blue, Hyne T2 Red is produced in MGP10, MGP12 and MGP15 strength grades.

Hyne T3 Green is produced for use in external, above ground structural applications in MGP10 and MGP12 strength grades.

Engineered Wood Products

Hyne also produces a range of Engineered Wood Products (EWP) such as Laminated Glue Lumber (LGL) and Laminated Veneer Lumber (LVL) posts and beams.

Hyne LGL and LVL

Manufactured from Australian grown plantation softwood, these laminated post and beam products are produced in a range of widths with 45mm and 65mm depths in incremental lengths between 3.6m to 9.9m. The LGL products are treated with LOSP (Light Organic Solvent Preservatives) H3.

Glue Laminated Beams

Hyne Beam 17 (plantation softwood), Hyne Beam 18 (Tasmanian oak) and Hyne Beam 21 (Queensland mixed hardwood or in select grade spotted gum) are produced for a wide variety of structural applications. Hyne's range of glue laminated timber beams come in a wide variety of strength and visual grades in lengths up to 15.6 metres and with several preservative treatments.



Figure 1.24 Observation platform, material supplied by Hyne Timber and detail of beam products. Information and images sourced from the authors's interviews with Hyne management and hyne.com.au.

1.14.3 - Carter Holt Harvey

Company Description:

Carter Holt Harvey (CHH) was founded in 1900 in New Zealand by Francis Carter, Robert Holt and Alexander Harvey as a sawmilling company. Over the last century, it has grown and diversified substantially, now employing approximately 2,500 people across Australasia. It was purchased in 2006 by New Zealand businessman Graeme Hart for NZ\$3.2bn. CHH now forms a group of companies that produce timber building products, pulp and paper and packaging across Australia and New Zealand.

CHH's Australian operations, all based on the eastern seaboard, include eight sawmills, an LVL plant, particle board, MDF moldings, corrugated card packaging, cartons and food packaging factories. The Australian operation has also diversified into the prefabricated construction sector, manufacturing affordable housing via a panelised building system. CHH represent one of the few timber processors that has attempted to vertically integrate its timber processing with construction.

The New Zealand operations include three sawmills, plywood, particle board, LVL, pulp, corrugated packaging and carton factories.

Products:

Structural Building Products

CHH manufactures a range of stick and panel products for the residential and light commercial markets. Its stick based products are: *LASERframe* untreated, *LASERframe TERMINATOR Red* and *LASERframe TERMINATOR Blue* which are sawn timber products suitable for light frame construction across Australia.



Figure 1.25 Carter Holt Harvey residential truss products. Images sourced from CHH

Plywood products such as *ECOply*, *PLYfloor*, *PLYgroove*, and *SHADOWclad* are CHH's range of structural and non-structural panelised plywood flooring and cladding products. *STRUCTAflor* is CHH's particleboard tongue and groove flooring system. It also produces a termite resistant product called *STRUCTAflor TERMINATOR* along with an energy efficient suspended floor system designed to comply with energy efficient design requirements marketed as *R-Flor*.

Engineered Products

CHH's engineered structural beams include LVL products marketed under the names *hySPAN*, *hyJOIST*, *hyCHORD* and *hyPLANK*.



Figure 1.26 Large scale nail plate trusses. Image supplied by Carter Holt Harvey

Outdoor and Landscaping

CHH manufactures a large range of CCA treated sleepers, fencing, decking and round wood.

Panelised Building System (PBS)

In an attempt to address the length of time that standard on-site residential construction typically takes in Australia, CHH have devised an economical, light weight modular panelised system of wall and floor construction. Wall elements are manufactured in 2.7m x 1.2m and 2.7 x 6.0m, and floor panels are 2.4m x 10m.

As with most Swedish prefabricated timber systems, CHH recommend that they be consulted during the early stages of design to ensure that the benefits of their PBS are optimised. The system features an integrated engineering and tie-down load path, suitable for use in Australia's northern cyclonic regions. CHH have partnered with housing prefabricators, Podtrading and Nomad Building Solutions, to provide a design and construct service for both flat pack construction and volume module systems.



Figure 1.27 Podtrading building system details

Information sourced from the author's interviews with Carter Holt Harvey management and chhwoodproducts.com.au. Images sourced from chhwoodproducts.com.au and podtrading.net

1.14.4 - Wesbeam

Company Description:

Wesbeam is a Western Australian Laminated Veneer Lumbar (LVL) manufacturer situated in Neerabup, north of Perth. The Wesbeam sawmill and manufacturing plant was completed in 2004. Wesbeam has a 25 year agreement with the State Government of Western Australia to harvest the state owned Pinus pinaster trees from the plantations in Gnangara and Yanchep. Wesbeam's primary market is Western Australia, but attempts are being made to gain a foothold in the competitive eastern seaboard construction sector.

Products:

Laminated Veneer Lumbar

Wesbeam manufactures a suite of treated and non treated LVL products for the residential and light commercial sectors. These include, but are not limited to, the e-splay, e-beam, e-purlin, e-strut, e-garage, e-joist, e-lintel and e-stick, each product being engineered to a particular task or role.

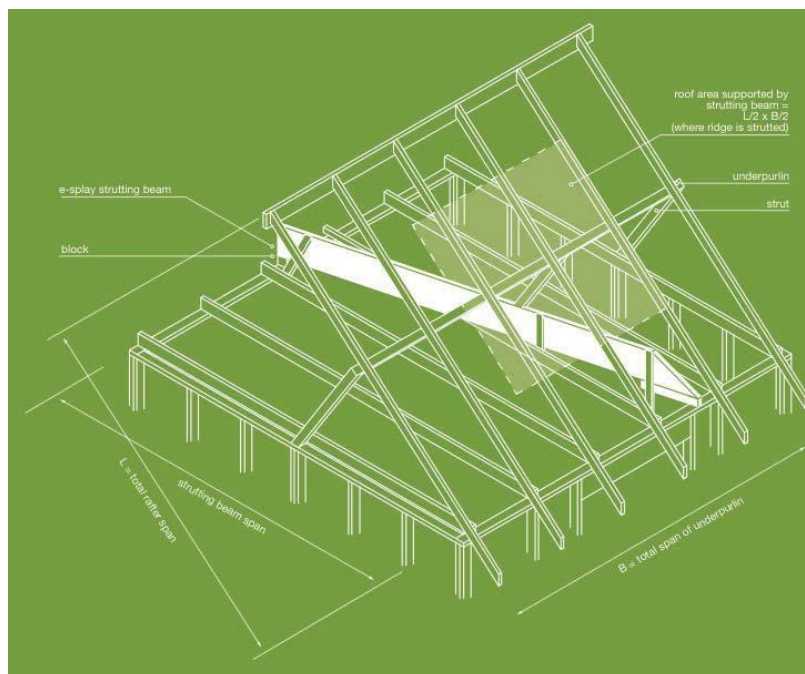


Figure 1.28 Diagrammatic view of stick roofing members.

Information and image sourced from wesbeam.com

1.14.5 - Lend Lease

Company Description:

Lend Lease is a large builder and project developer. It has been included in this section to highlight the role it has played in the development of CLT construction in Australia.

Lend Lease was founded by GJ Dick (Duss) Dusseldorp in 1958. Mr Dusseldorp first arrived in Australia from Holland in 1951 to build 200 prefabricated workers' houses, with a 'handful of Dutch workers' for the Snowy Hydro-Electric scheme. Lend Lease is now a multinational property and infrastructure company that has completed over 10,000 projects and employs over 18,000 employees world wide.

Lend Lease has recently completed what is claimed to be the world's tallest CLT building in Melbourne's docklands district. The Forté building, designed by Sheppard Robson Architects, was built with panels imported from the Austrian CLT manufacturer KLH and is based on the planar method of construction where planar elements such as walls, floors and roofs are prefabricated off site, in this case Austria, and then erected on site in a sequential manner similar to tilt up precast concrete panels.

The Forté apartment project is Australia's first commercially produced CLT building. Following on from the industry wide interest generated by the promotion of the United Kingdom Stadhaus Murray Grove project, designed by Waugh Thistleton Architects and using KLH's CLT system in 2008, Lend Lease determined to design and construct a significant project in Australia using CLT. This project has received broad industry, media and public interest because it represents the beginning of a new era in engineered timber design and construction and is the first tangible evidence of CLT's potential in this country. As

a pioneering project, it will inform debate about the viability of a heavy timber manufacturing and construction industry in Australia.

At the 2012 Frame Australia Melbourne conference, Andrew Nieland, Lend Lease Australia's Business Manager, gave a talk entitled *Utilising Wood Construction Systems in Tall Buildings*. In this talk, Nieland outlined Lend Lease Australia's plans for CLT and its use in future developments. According to Nieland, Lend Lease sees CLT as being a step change rather than a quantum leap in construction processes in Australia and that it has the potential to comprise up to 30% to 50% of all Lend Lease mid rise apartment projects.



Figure 1.29 Forté Apartments artist impression and under construction.

Information sourced from lendlease.com, forteliving.com.au, Andrew Nieland's Frame Australia 2012 presentation and Dr Alastair Wood.

1.14.6 - Nordic Homes

Company Description:

Nordic Homes, situated in Navel Base to the south of Perth in Western Australia, build prefabricated, architect designed timber homes that loosely draw their inspiration from the Nordic region's 'timber weekend lake house'. They claim their off-site built homes are Scandinavian 'contemporary re-interpretations (that) are appropriate to local conditions and create a point of difference from other transportable solutions' (Coniglio Ainsworth 2012).

Despite being prefabricated and having a Scandinavian influence, their build processes remain tied to established, standard sequential on-site methods, albeit creating three dimensional volumetric modules in a factory yard setting which are then transported to the site. Notwithstanding this, they claim significant build time advantages over masonry construction and build good quality houses with a higher than average standard of finish than comparable Australian transportable houses, remaining relatively unique in Western Australia for their use of timber frame construction.

Nordic Homes' sister company, Nordic North, specialises in prefabricated construction for Western Australia's northern mining industry. Industry directives, driven by BHP and Rio Tinto, now only specify steel frames for all mining applications in West Australia's far north. This has effectively forced Nordic North to adopt steel construction for all buildings in this market.

Nordic Homes' timber frame to double brick cost comparisons for single storey standard residential homes indicate that double brick construction in the Perth metropolitan area is approximately 15% cheaper than either on-site or off-site timber frame. Mark Nylund of Nordic Homes attributed this to higher material and labour costs for all non brick aligned trades. Mr Nylund's analysis of this competitive divergence between the trades sees this as a result of the dominance and subsequent cost controlling power of the large established project home companies. Notwithstanding this, Mr Nylund predicts that the large project home

building companies will lose a significant part of their competitive advantage in the coming years as the quality control, Australian standards compliance and technical solutions of prefabricated light weight steel construction from China improve. He is of the opinion that Western Australia and specifically Perth's ingrained preference for masonry construction is waning as new generations of home buyers enter the market without the apparent bias of previous generations. This shift in preferences has the potential to advantage both heavy and light weight timber construction, but Mr Nylund's prediction of the imported modular steel products may override any benefit this may give to the domestic timber industry.

Products:

Prefabricated Timber Homes

Nordic Homes build a range of designs that are aimed at a variety of markets. Their '*Contemporary Homes*' range include The Voss 2x1, The Holmen 2x2 and The Oslo 3x2. The *Northwest Homes* are suited to Australia's hot northern climatic areas, are cyclonic rated and can be constructed to have up to 8 star energy efficiency ratings. These include The Bergan 3x2, The Helsinki 4x2 and The Stockholm 4x4.



Figure 1.30 - Prefabricated houses by Nordic Homes

Information and images sourced from the author's discussions with Mark Nylund of Nordic Homes, nordichomes.com.au and from nordicnorth.com.au

1.14.7 - Timberbuilt Solutions

Company Description:

Timberbuilt Solutions has been in operation for over 20 years and is owned by engineer Bruce Hutchings. Based in Melbourne, Timberbuilt offers a unique service in Australia that is more akin to European bespoke timber supply and construct companies than any other Australian engineered timber fabricator. Specialising in large span, LVL, box beam portal frame construction and complex carpentry, Timberbuilt design, engineer and prefabricate timber structures with spans up to 40m.

Products:

Prefabricated, Engineered Timber Construction

Timberbuilt operates a *Hundegger K2* CNC precision carpentry machine capable of machining widths of up to 600mm, depths up to 320mm and lengths up to 20 metres. Timberbuilt bespoke timber services are complemented by their *ecoBarn* series of prefabricated engineered LVL portal frame barns, sheds and storage facilities.



Figure 1.31 Timberbuilt bespoke and boxed post and boxed beams

Information sourced from the author's interviews with Timberbuilt Solutions management and timberbuilt.com.au

1.14.8 - panelBuild

Company Description:

The now defunct Australian company, panelBuild was a relatively new manufacturer of pre-assembled and fully lined timber floor, wall and roof elements for low rise housing and light construction. The *panelBuild* manufacturing facility was based in Darra, Queensland and operated a large indoor factory using German made Weinmann woodworking machinery such as assembly and butterfly tables, CNC cutting and trimming machines and automated nailing equipment.

In 2012, panelBuild won the Queensland Timber Industry Award for Best Timber Manufacturing Operations. Despite their high level of commitment to modern prefabrication, as previously discussed in Section 1.13 of this chapter, panelBuild struggled to establish itself in the Australian construction sector and was forced to close in 2013.

Products:

panelBuild manufactured their building elements as planar components and transported them to site in a flat packed format. On site, a crane was used to lift and position each element in an ordered installation sequence.



Figure 1.32 panelBuild manufacturing plant, on site installation and completed houses
Information and images sourced from panelbuild.com.au and a factory visit by the author.

1.15 - Selected Swedish Timber Processors and Timber Construction Companies

A notable difference between the Swedish and Australian approaches to timber construction is the volume of residential construction that is being built off site. In Sweden, some 90% of all low rise residential construction is undertaken using a range of off-site prefabrication methodologies.

As has been demonstrated, Australia's engineered timber and off-site construction sector has failed to keep pace with the recent significant developments that are revolutionizing construction in Scandinavia and German speaking Europe.

This section focuses on Sweden's modern engineered timber and off-site construction industry. Its energized, interdisciplinary timber building culture, rationalised approach to construction and expanding market share have resulted in a set of unique attributes and drivers that have contributed to a broad cultural acceptance of timber as a viable alternative to steel and concrete. Australia's potential to expand its own engineered timber and modern off-site construction industry in the light of the Swedish context will be explored through a comparison of their respective timber supply, regulatory framework, wood processing and construction industry cultures.

The three timber construction methodologies briefly presented here reflect a fundamental shift from the traditional on-site methods of construction still practiced widely in Australia. The off-site method of construction is now the common method in which housing is procured in Sweden and as such, has earned respect amongst architects, builders and developers and this is reflected in the standing the industry in general now holds.

The prefabrication construction that does occur in Australia is not generally well regarded and is often seen to be inferior to on-site construction, primarily due to the lower quality construction associated with prefabricated mining buildings or 'dongas'. The negative connotations associated with prefabrication and its light weight construction have been compounded by the common use of low quality fittings, doors, windows and minimal insulation. Dongas are often built to a price rather than to an

exacting standard. Even in instances where higher quality, large scale projects are to be built off site, such as the now mothballed \$160 million six storey residential project for BHP in Port Hedland by the recently liquidated Port Village Accommodation, there remains a culture of low tech, and even flimsy association. This is evidenced by Michael Argyrou, joint Managing Director of Hickory Construction group's comments when describing how his company might take over the construction of the Port Village project. In a recent interview with The Sydney Morning Herald, Argyrou states:

'The plan was ... to send our people up there to put together the parts like in Lego to create the hotel' (SMH 2013).

Argyrou's reference to the project as '...being like lego...' infers a certain disregard for construction that does not fall into the standard typology, even when it is worth \$160 million.

The issue of prefabrication and its negative perceptions as it relates to construction is examined by builder and innovator, Ted Benson. Benson's comments are drawn from his experience in North America, but also have significant relevance in Australia. Benson has written a number of books on reviving timber frame construction such as *The Timber Frame Home: Design, Construction, Finishing* (Taunton Press; 2nd Revised edition (March 20, 1997) and *Building the Timber Frame House: The Revival of a Forgotten Art* (Touchstone; Reprint edition September 1, 1981). He has also been heavily influenced by Sweden's off-site timber construction industry and his reflections can provide a valuable insight into the public's perceptions of prefabricated construction in Australia. He regularly contributes to a blog on issues pertaining to timber construction and in a recent post entitled *Montage Homebuilding*, he expresses significant concern regarding North American society's impressions of buildings built off site that are known as prefabricated or modular. He states '... (we are) ... uncomfortable with the terms used for off-site building fabrication methods. It's usually either "modular" or "prefab," and both have muddy meaning because of the diversity in practice, and both come with some negative baggage. Modular refers to the built

volumes that are trucked on the highway like carcasses of beached whales, and prefab mostly connotes a modernist style, with an indeterminate percentage of value-added in off-site value actually accomplished in the prefabrication process' (Benson 2013).

In response to this issue, he is attempting to adopt the Swedish term for off-site construction which is 'Montage'. Benson reasons that this is a more suitable term to describe the process of off-site construction that does not contain the negative connotations associated with the terms 'prefab' or 'modular'. Benson's argument is that since the Swedish term "montage", which can be translated as "assemble" in English, does not have any significant negative connotations, it is therefore '... a good description of our building process ...' that is a '... combination of disparate elements that forms a unified whole'. Benson explains that '... In Sweden, an off-site built home is called a *montagehus* which directly translates to assembly house (ibid). As previously discussed, Australian prefabrication also suffers from negative associations that are now entrenched and the establishment of higher quality construction through modern prefabricated construction methods will need to address this.

Three distinct constructional methodologies have emerged within Swedish timber prefabrication and construction or *montage träbyggande*. The most common technique is the prefabrication of engineered wall and floor frames and trussed or flat roof structures where the underlying structural typology can resemble traditional framed construction. Standard timber profiles and lengths are replaced with the use of interlocking, spliced timber studs, Laminated Veneer Lumber (LVL) and glue laminated elements (refer Figure 1.35, image 7).

Engineered beams and girders, from wood composite structures using Orientated Strand Lumber (OSL), that resemble traditional steel sections in three dimensional form are also available and promoted as an alternative to standard lumber (refer Figure 1.37). These components can be transported to site and combined in the traditional construction processes or assembled in a factory to make volume elements which are then transported and stacked or 'montaged' to make the completed building.

The second technique is 'massivträ' or massive timber. Massive timber is solid, cross-laminated timber panels designed to act as floors, walls and roof elements (refer Figure 1.35, Images 8,9 & 10). This method of timber building bears a closer resemblance to prefabricated tilt-up concrete panel construction than traditional timber construction. The timber elements are transported to the site with openings pre-cut and then assembled on site to form the completed structure. The building is then fitted out with services, doors, windows and wall, floor and ceiling finishes. Martinsons is currently Sweden's only massive cross-laminated timber producer although Moelven does import some Norwegian manufactured cross-laminated timber panels. The Austrian cross-laminated timber manufacturer KLH (Kreuzlagenholz Massivholz GmbH) has built a production facility in northern Sweden although it is not currently operational.

The third construction methodology type is a timber post and beam structural system called Trä8 (Timber 8) designed for larger buildings typically spanning an 8m x 8m grid produced by Moelven (refer Figure 1.34). Massive glue laminated posts and beams are arranged in a gridded format with vertical stabilising elements at various locations subject to the individual design of the structure. This system is typically used for buildings up to four storeys but can potentially be used for up to 10 storeys. The level of prefabrication and the percentage of off-site prefabrication or on-site assembly/construction differs between systems and between projects and is also subject to transport availability, relative economies of scale and site accessibility.

The following case studies explore each of these three approaches to timber based prefabrication methodologies. Each company has been chosen for its unique method of timber construction, significant sectorial influence and distinctive approach to its specific market(s). The companies considered demonstrate varying approaches and degrees of development and vertical integration within the timber construction industry in Sweden and greater Scandinavia. They are all held in high esteem, providing high quality construction that would be difficult to achieve through traditional on-site

construction methods. Each optimises the benefit of building in a controlled environment and by utilising integrated Building Information Management (BIM) technologies to translate the design directly to the construction of elements and by significantly improved construction times resulting from a non lineal approach to construction.

The companies considered are:

- Derome
- Moelven and Ekologi Byggarna
- Setra
- Newbeam Sweden AB
- Lindbäck Bygg AB
- Randek BauTech AB
- Masonite Beams AB
- Södra
- Solid Wood Scandinavia KLH
- X-HOUSE
- Martinsons

1.15.1 - Derome

Company Description:

The Derome group ‘... work(s) across the entire chain – from forest to finished houses (where) wood is “the green link” ...’ and as such, they are fully vertically integrated into forestry, sawmill, timber construction and project development. The Derome family owned company was established in the small town of Derome, south of Göteborg, in 1947 by carpenter Karl Andersson. In 1968, Karl’s four sons, Erling, Bernt-Göran, Ingemar and Karl-Erik became partners in the company. The following is a brief outline of Derome’s subsidiaries with production that is relevant to this research.

Products and Subsidiaries:

Derome Skog

With the stated aim of ‘full service for effective forestry’, Derome Skog (forest) purchases timber from wood-suppliers as well as private forest owners in western Sweden, from upper Skåne to the Norwegian border, with the aim of sourcing wood from forests close to their sawmills. They have an in-house procurement organisation with specialised forestry purchasers. Derome claims that resulting from their extensive refinement of wood products for high-quality saw logs, forest-owners normally receive a higher net price than they would from delivering to the pulp industry. Derome own and manage their own forests as well as partner with other independent forest owners to supply a full range of forestry and advisory services. They also promote their ‘green’ credentials by operating an ‘... ecological forestry operation using modern methods, including PEFC (Program for the Endorsement of Forest Certification) certification’ (Derome 2013)

Derome Skog processes approximately 1,000,000m³ of wood annually. They provide a comprehensive range of forestry services for 3,000 forestry owners with properties from 15ha to 3,000ha. These services are divided into wood deliveries (15%) and harvesting on a commission basis (85%). Their forestry planning also includes the supply of seedlings and planting, clearing, thinning, final harvesting, biofuel, ground preparation, road maintenance and ditching, consulting and management agreements.

Derome Timber

Timber from Derome sawmills is marketed under the brand Derome Timber. They operate specialist mills to produce a range of high-quality wood products. Their Kinnared mill in the south of Sweden produces sawn and processed spruce products and their Anneberg sawmill, also in southern Sweden, specialises in sawn pine and pressure-treated timber. Derome Timber supplies from Skåne to the Mälars valley near Stockholm, their range includes 1,300 environmentally and quality-certified products, including PEFC-certified timber. Operating a logistics enterprise in conjunction with a large central warehouse, they coordinate with builders' merchants, DIY stores, house and roof truss manufacturers as well as pallet and other wood industries.

Derome Timber has a sawing capacity of 400,000 m³ annually. Their planing capacity is 400,000m³ annually, pressure-treatment capacity is 300,000m³ annually and they maintain central warehouse capacity for 10,000m³ timber products. Derome Timber has ISO 9001 quality assurance, ISO 14001 environmental assurance and is PEFC certified. Their timber products include sawn and planed timber, machine graded and stress tested timber, pressure-treated timber, wall studs and external paneling, primed paneling, tongue and groove boards, machined finger-jointed structural timber, lathe and formwork timber.

A-Hus (House)

A-hus is Derome's modern factory based production facility that produces typical Swedish timber houses in a range of floor plans and architectural styles as can be seen below. The houses are built using CAD technology via an automated production line which produces house components in Anneberg in the south of Sweden. A-hus develops, constructs and sells approximately 350 houses annually and produce almost one house per day. In addition to supplying to the domestic market, they export to Holland, Denmark, Belgium, and Germany.



Figure 1.33 A-Hus homes by Derome. Images from derome.se

Derome also has the following subsidiary companies:

- *Derome Bioenergi* uses the by-products from the harvesting and sawmill production to produce their own pellets and briquettes to provide fuel for boilers that can generate enough energy for 120,000 homes.
- *Derome Byggvaror* supplies solid timber building materials and products to building companies.
- *Derome Träteknik* produces customised components and roof trusses for the building industry.
- *Andersson Haus & Dach* produces roof trusses in Germany for their domestic market.
- *Derome Förvaltning* is an environmentally focused property management, building administration and leasing department within Derome that manages Derome's portfolio of managed residential buildings.

1.15.2 - Moelven and Ekologi Byggarna

Moelven Company Description:

Moelven is a Norwegian based company that delivers wood products to the construction industry throughout Scandinavia with production facilities in Norway and Sweden and, as with Derome, is also vertically integrated from the forest to project development.

Moelven operates three divisions: Timber, Wood and Building Systems. They employ 3,200 people with a revenue of 91 million SEK (\$17.5 million AUD). The corporation is owned by Glommen Skog BA 25.08%, Eidsiva MI2 AS 23.78%, Agri MI AS 15.85%, Viken Skog BA 11.87%, Mjøsen Skog BA 11.75%, AT Skog BA 7.29%, Havass Skog BA 4.02% and Allskog Holding AS 0.08%. Individual investors own the remaining 0.36%.

Ekologi Byggarna Company Description:

Ekologi Byggarna is a small building company based in Östergötland in the south of Sweden. They specialise in building with 'krysslammade massivträelement' or cross-laminated massive timber elements produced by Moelven MassivTre AS in Krødsherad municipality in Buskerud, Norway.

Ekologi Byggarna and Moelven MassivTre Products:

Moelven MassivTre AS's cross-laminated timber panels are produced on an automated High Frequency Press that provides short curing times and high flexibility. The timber planks are then cut into the required profiles using a Computer Numerical Controlled (CNC) processing machine. As with other cross-laminated timber panels or 'Lamellas', Moelven MassivTre are cross-bonded in three, five, seven or nine layers that are combined into a solid element. They can be used for floors, walls and ceilings in all types of buildings and can also be

used for balconies. Depending on the context, they can be left raw, lacquered, oiled or painted.

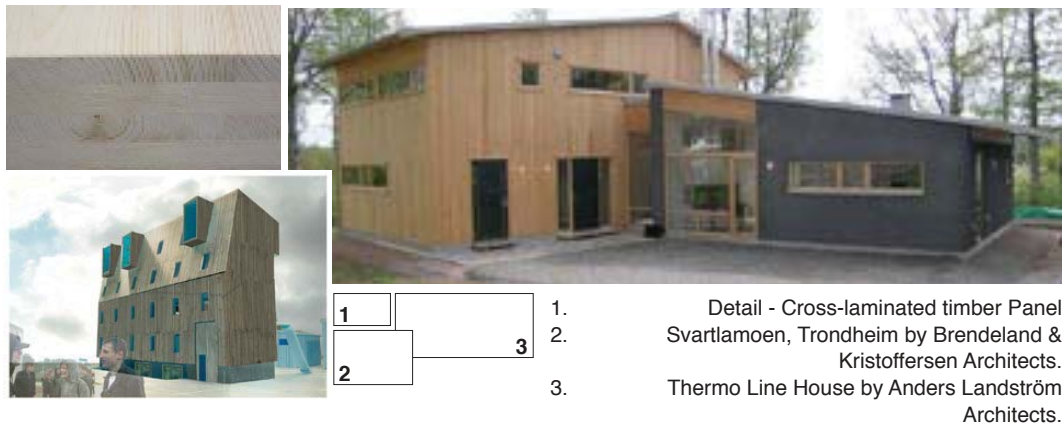


Figure 1.34 Ekologi Byggarna CLT detail and projects. Images supplied by Ekologi Byggarna

Moelven MassivTre can be used in single and multi-storey buildings. Moelven claims that their products are an environmentally efficient construction system that uses large elements which can be constructed or ‘montaged’ on site quickly and efficiently. They utilise suitable lower quality timbers that would not otherwise be used by removing weakness through a finger jointing process. As with other CLT products, Moelven MassivTre product is relatively simple to work with on site and can be modified to suit a variety of services, fixtures and fittings. It is relatively easy to combine with other building materials. MassivTre’s cross-laminated timber can potentially allow for thinner floor elements relative to concrete. An example of MassivTre’s potential flexibility is its popular use as an alternative when replacing concrete balconies on existing structures.

Moelven Products:

Moelven Timber

Moelven Timber uses pine and spruce trees harvested in south-east Norway and middle Sweden. The timber is harvested close to the company’s sawmills and all of the sawmills are PEFC certified. The company manufactures a wide variety of wood-based products such as furniture,

flooring, molding, panels, glulam, windows and packaging material. Moelven Timber's production can be customised to comply with customer specifications for dryness, quality and dimensions.

Moelven Construction Wood

Moelven Construction Wood supplies planed sawn wood to manufacturers of roof trusses, housing and modular buildings utilising the same timber sources as Moelven Timber.

Moelven Glulam

Moelven Glulam is made of spruce which is sourced from suppliers in south-east Norway and mid-Sweden.

Moelven Kerto

Moelven Kerto is a glued veneer beam with high strength and stiffness. It is designed for use in advanced load-bearing wooden structures. Kerto is an environmentally certified product that can be recycled and is manufactured using recyclable raw materials. In Australia, Kerto is known as Laminated Veneer Lumber or LVL.

Moelven Wood Sheets

Moelven Wood Sheets in Sweden and Moelven Wood Sheets in Denmark produce some of Scandinavia's largest range of wood sheet products for industrial applications.

Building Systems and Modular Buildings

Moelven develops and manufactures custom tailored building modules, interior layout systems and engineered glulam structures and beams for applications such as bridges and major construction projects. In 2009, Moelven launched a new multi-storey structural timber building system called Trä8 (Timber 8) developed in conjunction with Luleå University. The components consist of glulam pillars at 8m centres, beams, cross bracing/shear elements and Kerto floor and tie beams. It has been designed for simple

installation and achieves rapid weather protection during construction. It can be used for buildings up to four storeys high and features an 8m x 8m grid assembly. The Trä8 system allows structural arrangements using timber that has previously only been possible with steel or concrete column and beam construction. Structural columns are located in an orthogonal grid allowing dividing walls to be freely positioned anywhere within the gridded arrangement. Moelven also has its own proprietary modular building system which it claims offers high quality construction, design flexibility and short delivery periods. Moelven modules are available for homes and apartments, schools, service buildings, offices and temporary housing. Several residential projects, a detail of the post and beam connection and a model of the structural elements can be seen below.



Figure 1.35 Trä8 building system. Photographs and images by Moelven

1.15.3 - Setra

Company Description:

Setra is one of Sweden's largest wood products companies and a leading timber company in Europe producing eco-certified wood products for interiors and construction. They have approximately 1,200 employees and annual sales of almost SEK 4 billion (\$600 million AUD). Approximately 55% of sales comprise exports to Europe, North Africa, the Middle East and Japan with the balance being sold to the domestic market. Setra has approximately 2,200 shareholders, the three largest being Sveaskog (50%), Mellanskog (27%) and LRF (22%). As with both Derome and Moelven, Setra is a vertically integrated company that provides services from timber supply, milling and timber processing to value-adding and construction.

Products:

Setra Raw Material

The Raw Material division is responsible for purchases of sawlogs and sales of bioproducts such as chips, sawdust and bark. Setra's largest raw material suppliers are Sveaskog and Mellanskog. A large part of the raw material is certified according to FSC and PEFC. The business conducts direct purchasing operations from private forest owners for its sawmills in Vimmerby, Malå and Rolfs.

Setra Redwood

The Setra Redwood division is responsible for sales of sawn Redwood products (*Pinus sylvester*) to industrial customers primarily in Scandinavia, the United Kingdom and North Africa. The business operates five specialised redwood sawmills in Horndal, Kastet, Nyby, Skinnskatteberg and Vimmerby

with a combined annual production of approximately 850,000 m³ of sawn product.

Setra Whitewood

The Setra Whitewood division is responsible for sales of sawn whitewood (*Picea abies*) products to industrial customers primarily in Sweden and northern Europe. The business has three specialised whitewood sawmills in Hasselfors, Heby and Färila with a combined annual production of approximately 650,000 m³ of sawn product.

Setra North

The Setra North division is responsible for sales of sawn and planed wood products from Setra's northern units, primarily to customers in Scandinavia and the Mediterranean. The Rolfs and Malå facilities have an integrated sawmill and a planing mill with an annual sawn production of 320,000m³. Their Kvarnåsen facility produces value-added painted surface-treated moldings.

Setra Wood Products

The Setra Wood products division is responsible for Setra's co-ordinated sales to the Swedish and Norwegian building materials trade. They manufacture joists, panels, moldings, flooring, glulam, pressure treated wood, joinery and board materials. Production takes place at five locations: Långshyttan, Valbo and Skutskär in Sweden as well as Helgeroa and Skien in Norway. A distribution centre is located in Katrineholm, Sweden.

Setra Plusshus

Plusshus supplies customised timber homes and buildings made with a high level of prefabrication. They utilise a closed system called Trälyftet for multi-storey construction, producing commercial buildings in Sweden and Norway. Plusshus operates two factories: one in Arvidsjaur manufacturing box

units, and one in Kristinehamn manufacturing complete volumes. Examples of Setra Plusshus projects can be seen below.



1	2	3	4
	6		
5		7	
8		9	
		10	

1. Vestre Voksen Bobstad - Oslo
2. Vetenskapsstaden - Stockholm
3. Vetenskapsstaden Detail - Stockholm
4. Vetenskapsstaden Under Construction - Stockholm
5. Bosch Vaitoudden Factory Under Construction
6. Plusshus Factory Floor
7. Bosch Vaitoudden Detail
8. Skellefteå Multi-storey Car Park Concept
9. Skellefteå Multi-storey Car Park Interior
10. Skellefteå Multi-storey Car Park Exterior

Figure 1.36 Selected Setra projects. Photographs and image by Setra

1.15.4 - Newbeam Sweden AB

Company Description:

Newbeam Sweden AB has developed and patented a method based on the Orientated Strand Board (OSB) wood composite material to press wood-composite girders and beams with a variety of typical construction profiles in three dimensions. The resultant beams have a high strength and a slender cross section similar to steel girders and are integrated into a newly developed structural system in which the components are designed to key into each other.

Products:

Newbeam Sweden AB manufactures floor and roof beams, external wall studs, internal and partition wall studs and 'H' beams. They also manufacture a variety of products for furniture and interior fitting manufacturers and the installation and packaging industry. The Newbeam C section and H beam profiles are unique homogeneous timber products in the classic web and flange arrangement.

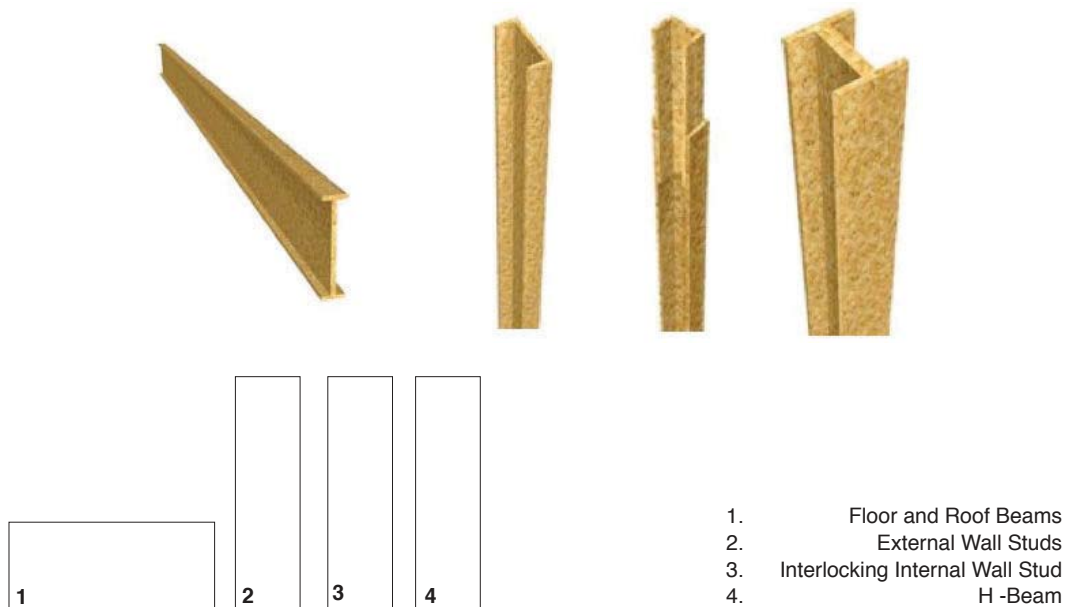


Figure 1.37 Newbeam structural products. Images supplied by Newbeam Sweden AB

1.15.5 - Masonite Beams AB

Company Description:

Masonite Beams AB is a subsidiary of the building material supplier The Byggma Group which has an approximate annual turnover of SEK 2.15 Billion (\$332.5 Million AUD). With headquarters in Norway, the Byggma Group is one of Scandinavia's largest suppliers of building materials and construction systems. The majority of The Byggma Group's sales activity is in Norway, Sweden, Finland, Denmark, the Netherlands, Germany and the UK.

Products:

Masonite Beams AB manufacture hybrid Masonite and pine I-Joists and I-Beams in their production facilities located at Rundvik in the county of Västerbotten, northern Sweden. The joists and beams are used as structural components designed for engineered timber floor, wall and roof construction. The Masonite structural products can be combined with solid beams as an alternative to conventional timber products in residential and commercial buildings. Masonite engineered timber comprises slow-grown, solid timber, stress graded flanges combined with Masonite K40 structural board for the web. First manufactured in 1974, Masonite I-Joists now have both British Board of Agément (BBA), European Technical Approval (ETA) certification and Conformité Européenne (CE) marking, together with Forest Stewardship Council (FSC) chain of custody certification. They are manufactured in accordance with the International Organisation for Standardisation requirement, ISO 9001:2000, and the environmental standard ISO 14001. With high strength and consistent structural integrity, they can accommodate clear spans up to ten metres. Masonite I-Joists are manufactured in standard 220mm, 240mm, 300mm, 350mm and 400mm depths and are also manufactured in a variety of widths and lengths to

accommodate a range of structural demands. The Masonite Separating Floor System allows the majority of the floor system fabrication to be done off site utilising a patented dry system allowing the completed floor to be transported to site and craned into place. Masonite I-Joists and beams can also be used to create internal spaces within the roof void as self supporting truss components using Masonite K40 boards as connectors. Examples of Masonite building products can be seen below.



Figure 1.38 Masonite beams products by Masonite Building Products.
Images by Masonite Beams AB

1.15.6 - Södra

Company Description:

Södra (South) is an economic association owned by over 51,000 forest owners in southern Sweden that operates ten sawmills and has an annual turnover of SEK 18 billion (\$2.8 Billion AUD). They employ approximately 4,000 people in areas that range from forestry management and environmental conservation to accounting, sales and product development. The Group's four business areas produce sawn and planed timber goods, interior products, paper pulp and biofuel. Södra also generates electricity from waste derived from its milling processes and now produces more electricity than it uses.

Södra was formed in 1938 under the name Sydöstra Sveriges Skogsägareföreningars Förbund as an economic association of local communities and forest owners in Småland to promote the interests of the local forest industry. During World War Two, they provided much of the biofuel used in Sweden's wood-gas generators that powered cars, buses and other vehicles. Following the war, Södra expanded into pulp mills to provide further economic opportunities for Sweden's southern forestry sector. The Group's various business areas produce sawn and planed timber goods, interior products, paper pulp and biofuel. Södra's five business entities are:

- Södra Skog – Timber raw products, forestry services
- Södra Timber – Wood products
- Södra Cell – Paper pulp
- Södra Interiör – Interior wood products
- Södra Windpower AB - Electricity

Products:

Södra Timber's construction systems and timber advances have been developed by Södra Building Systems AB with the stated goal '... to develop, manufacture and market timber-based building components and building systems.' (FORDAQ 2001). Its intended aim is '... to establish these and other timber components and building systems as competitive alternatives on the European market'. Södra views the Nordic countries and Europe as expanding markets where multi-storey timber building is increasing and it sees its products as making '... an important contribution to the building market for faster and simpler building' (ibid). The systems developed by Södra Building Systems AB that will be addressed in this report are SödraSmart, SödraSinus, SödraSemi and SödraSolid. Currently, only SödraSmart is being produced commercially.

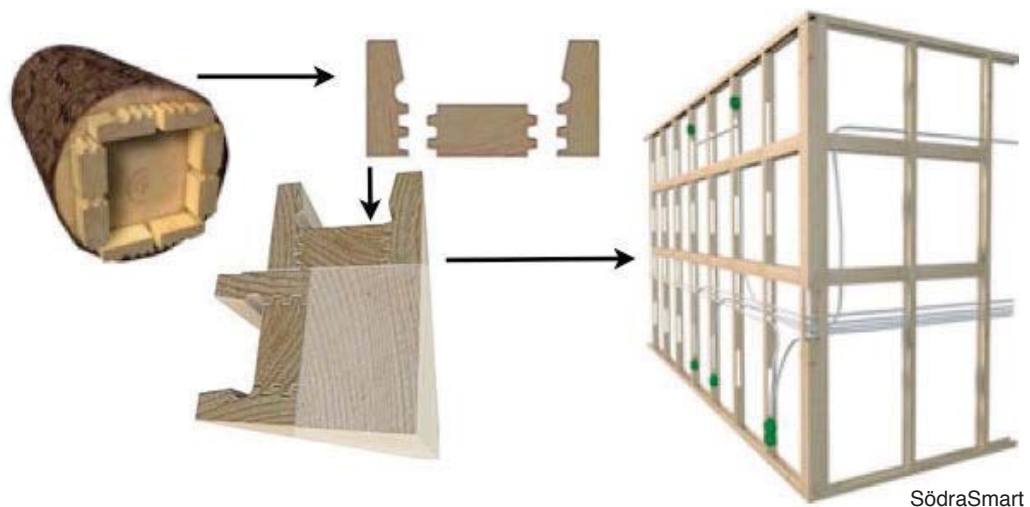


Figure 1.39 SödraSmart milling method, products and application. Images supplied by Södra

The SödraSmart stud system is made from side boards milled from Norway spruce. The stud is made of three laminated parts: two side pieces joined with 300mm spines positioned at 200mm centres to create longitudinal openings for services. This segmented format prevents tension in the spine affecting the stud and causing it to warp and is designed for use in non-load bearing wall partitions.

SödraSinus

SödraSinus are timber studs which incorporate longitudinal slots. The slots are formed by passing the studs on the flat through a machine with pairs of vertically oscillating saw blades that are positioned about 30mm apart. The intent is to extend the path sound waves must travel to pass through the timber from narrow face to narrow face. It is claimed that in lieu of building two separate 100mm walls with a 30mm gap for inter-tenancy acoustic insulation, one wall using 150mm SödraSinus studs can be used (Walford 2010).

SödraSemi

SödraSemi is a prefabricated timber construction for inter-tenancy floors. It uses solid timber SödraSinus joists spaced about 100mm apart with batts filling the space. Joists that support the ceiling below are set lower than the other joists so that they do not support the flooring above. Exceptionally good sound insulation is claimed for this construction along with a shallower profile than standard I-beam construction (Walford 2010).

SödraSolid

SödraSolid is a solid timber slab for walls or floors, made by mechanically laminating dimension lumber. Long steel rods provide the laminating force. It is intended that SödraSolid be manufactured up to 12 metres lengths, widths up to 2.4 metres, and thicknesses of 70mm, 95mm, 120mm, 145mm, 170mm, 195mm and 220mm using box grade timber (Walford 2010).

1.15.7 - Solid Wood Scandinavia KLH AB

Company Description:

Solid Wood Scandinavia KLH AB is a relatively new company in Sweden with a factory located in the Dalarna region. It is a subsidiary of the Austrian company, KLH Massivholz GmbH. Its cross-laminated timber (CLT) panels have European Technical Approval and technical approvals in Germany, France, Spain, Russia and the United Kingdom along with several other European countries. It undertakes internal and external quality checks to assure a high quality product which is PEFC-certified from sustainable farmed forests. The parent company, KLH Massivholz GmbH, claims to be a leader in the European production of cross-laminated solid timber and supplies 16 European countries, from Greece to Iceland and from Spain to Russia.

At the time the research was undertaken for this thesis, the global financial crisis and staffing issues resulted in Solid Wood Scandinavia KLH AB temporarily halting its production facility. Notwithstanding this, the Austrian parent company KLH states that it remains committed to its Scandinavian operation and hopes to activate the production of CLT in Sweden as soon as possible.

Products:

Solid Wood Scandinavia KLH AB cross-laminated timber panels are produced from spruce strips that are stacked crosswise on top of each other and glued together to form panels that can be up to 16.5 metres in length and 2.95 metres in height. The cross aligned arrangement of the longitudinal lamellas reduces swelling and shrinkage in the board plane to an insignificant minimum. In the cross-laminated configuration, static strength and shape retention increase considerably. Solid Wood Scandinavia AB claims that compared to conventional timber construction products, cross-laminated timber allows for building load transfer that is not available in traditional frame timber construction. Loads can be

transferred on all sides and are considered to be in a genuine wall plate and shear wall plate action.



Figure 1.40 CLT projects and exploded panel view. Images supplied by KLH

The timber is dried to moisture content of 12% (+/- 2%) to enhance stability and minimise attacks from fungus and insects, although it is recommended to seek Solid Wood Scandinavia KLH's advice when considering the use of the product in areas prone to Termite and European Borer to ensure adequate protection is in place. Through the manufacturing process, the boards are subject to both visual and mechanical quality sorting procedures. The gluing takes place using solvent-free and formaldehyde-free, Polyurethane (PUR) adhesive from Purbond (HB 110, HB 530). This adhesive is tested according to the Deutsches Institut für Normung standard DIN 68141 and other strict criteria according to Materialprüfungsanstalt Universität Stuttgart (the MPA Baden

Württemberg Otto Graf Institute in Stuttgart). Solid Wood Scandinavia KLH also manufactures internal and external supporting timber components and uses special construction methods in accordance with DIN 1052 and EN 301. The glue is applied automatically over the whole surface and a high level of adhesion is achieved as the lamination press applies a pressure of approximately 6kg/cm². The factory cutting of solid cross-laminated timber panels takes place using state-of-the-art CNC technology. Each panel cutout is based on the required wall, floor and roof elements for each building.

1.15.8 - Lindbäck Bygg AB

Company Description:

The Lindbäck Bygg construction company builds turn-key, multi-storey apartments from two to six storeys high, by utilising timber framed three dimensional volumetric elements manufactured by an industrialised building methodology, and combined on site to create the complete building as a turn-key project. They construct a range of accommodation types such as hotels, condominiums, student and rental apartments and retirement homes. The three dimensional volumetric elements are manufactured in a 17,400 m² facility in Piteå, in northern Sweden. The company's two primary market areas are in the north of Sweden and in the Stockholm/Mälardalen region. Lindbäck started volumetric element construction in 1994 and has produced over 5,000 apartments in this manner. They are one of Sweden's largest, industrially-produced, timber based, residential apartment builders. They invest three percent of their turnover on research and development and maintain an ongoing partnership with Luleå University of Technology by providing their production facility as a test bed for the ongoing exploration of Lean principles in the industrial production of buildings.

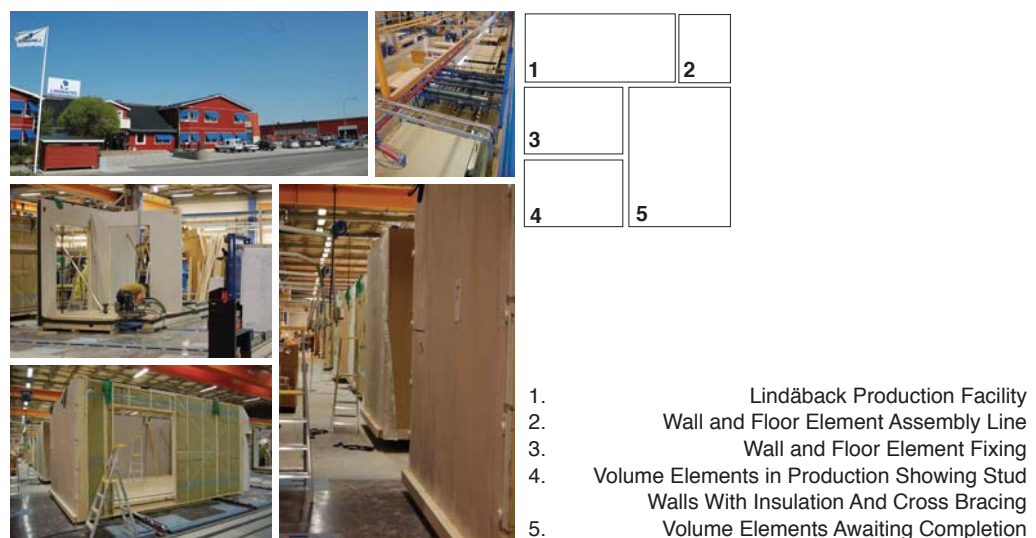


Figure 1.41 Lindbäck Bygg off-site production facility. Images: D.Bylund

Products:



Figure 1.42 Four storey student accommodation building. Photograph supplied by Lindbäck Bygg

Project: Kv Marksjön; **Client:** Asplund Property; **Architect:** Lennart Carlsson;

Category: Student Apartments; **Number of Rooms / Apartments:** 143; **Number**

of floors: Four; **Completed:** 2008; **Address:** Universitetsgatan 1,3,5,7,9.

Architect's Comment:

“These type of apartments have relatively small structural dimensions, and fairly early on in the project we introduced Lindbäck construction into the picture. Despite this, as an architect, the challenge was to design within the dimensions of the road transport parameters to allow transport of the modules through Sweden. An additional challenge was to manage each apartment's access and egress nodes when working within the module units, all of which needed to be accessible from the stairway. Cooperation with Lindbäck construction went smoothly allowing us to provide detailed solutions via our CAD drawings, which in turn were used in Lindbäck production planning in Piteå.”

Summarised from the original Swedish by the author.

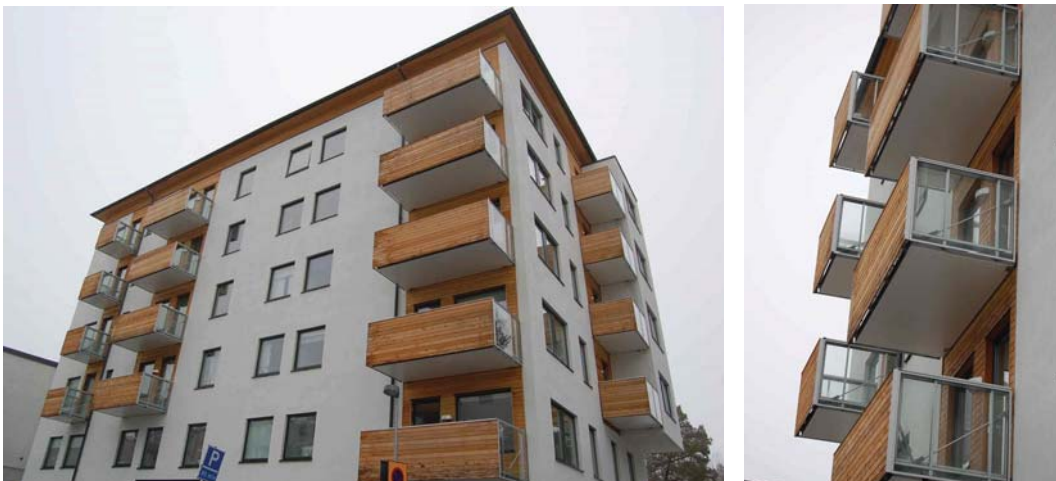


Figure 1.43 Vällingby Apartment project. Photograph. D. Bylund

Project: Kv Marksjön; **Client:** Sundsvall AB Real Estate; **Architect:** Kri Bennström, Bergkrantz Arkitekter; **Category:** Condominiums; **Number of Rooms / Apartments:** 62; **Number of floors:** Five/Six; **Completed:** 2009; **Address:** Björketorpsvägen 11-15,Vällingby.

Builder's Comment:

“The project is part of the rejuvenation of the suburb of Råcksta in Stockholm. In the first phase, developer Långskeppet AB converted the existing 60 year old houses on the block by renovating the interiors and building new facades. Three new buildings were then designed with the intention of harmonizing with the existing houses and to also express themselves as an independent part of the district. Externally, they were treated with the same white color to complement the existing buildings but were permitted to also maintain their own individual expressions with projecting eaves, larger balconies, protruding volumes and wood-paneled balcony railings that unite the facade in vertical bands. The roof elements are separated from the facade with the same material as the balconies, providing the building with an additional architectural exterior feature. All stairwells are accessible by an elevator directly from the garage which is constructed with concrete at ground level. The building has a total of 62 apartments of which just over half are three bedroom, varying in size from 65 m² to 80 m². The remaining apartments are distributed in equal shares by small, two-bedroom apartments of 43 m² and larger, four-bedroom apartments of 96 m² each.”

*Summarised from Swedish by author. Original Swedish text source from lindbacks.se/bygg/page139.php?newsid=31

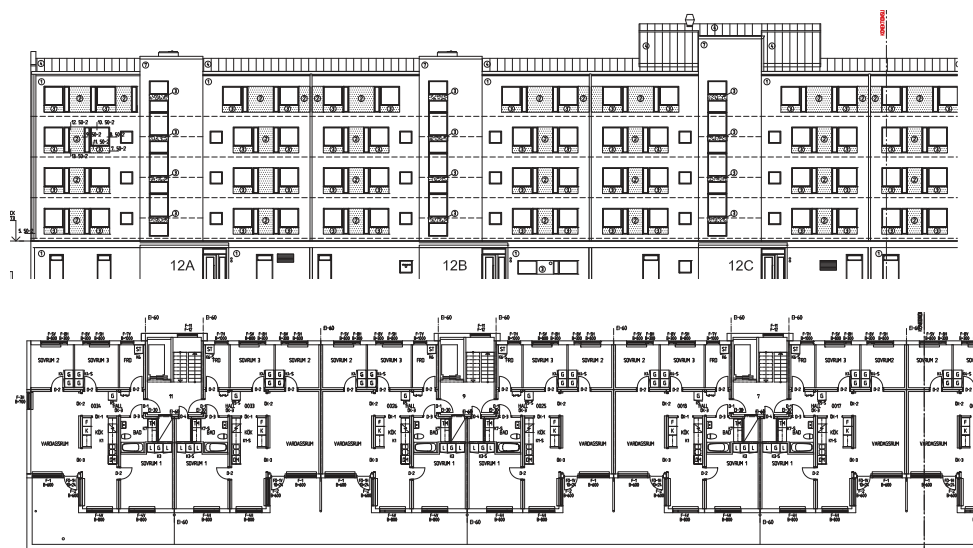


Figure 1.44 Plans and elevation from a Lindbäck Bygg multi-storey residential project. Used by permission from Lindbäck Bygg.

1.15.9 - X-House

Company Description:

X-House build low rise residential cottage homes using prefabricated large scale, horizontally glue laminated, single skin timber elements that are interconnected on site with a tongue and groove assembly. They liken their building methodology to a modern interpretation of the log home. Since their inception in 2010, X-House has built up a suite of contemporary Scandinavian designs by architects such as PeGe Hillinge from Göteborg (Gothenburg), Per-Eddie Bjuggstam from Örnsköldsvik and August Wiklund from Umeå. X-House's relevance to this study is its use of large scale lamellas to create wall subsections that interconnect to form whole wall lengths. This method of construction reflects a contemporary Swedish representation of parallel laminated solid timber construction and as such, is an interesting variant of the laminated timber panel construction explored in this thesis. Such systems provide unique opportunities to combine simple elements in a relatively 'low tech' manner.



Figure 1.45 X-House projects and detail. Information sourced from xhouse.se. Images: D. Bylund and xhouse.se

1.15.10 - Martinsons

Company Description:

Martinsons was established in 1929 by Karl Martinson in Bygdsiljum, a small town in Skellefteå Municipality in Västerbotten County and is now one of Sweden's largest family-owned wood processing companies, that, as with the other larger companies presented in this thesis, has established itself as a vertically integrated timber processing company. In addition to an extensive production of sawn wood goods, Martinsons is now Sweden's largest producer of glulam and is a leading Nordic provider of wooden bridges and building systems made from glulam and solid wood.

In 1954 a limited company was established in which all of the Martinson children became part-owners. Sales at that time were approximately SEK 500,000 (\$74,000 AUD). In 1963, Karl's sons Nils and Åke Martinson took over the company's operations. Glulam manufacture began in 1965 and five years later the first specialised glulam factory was built. In 1975, a sawmill was built at Bygdsiljum which at the time was the most modern in Europe.



Bygdsiljum Sawmill (2010) and Plant Operator. Photograph by Martinsons

Figure 1.46 Martinsons' modern sawmill facility.

In 1989, Martinsons built its first wooden bridge. The company purchased a 50% share in the Svenska Träbroar (Swedish Timber Bridge) company at the end of the 1990s. Sales of glulam to Japan began in 1992, which is now the company's largest export market. Production of Martinsons Cross Laminated Timber (CLT) also began in 2003. In 2005 a new sawmill was built in

Bygdsiljum at a cost of SEK 225 million (\$33,433,000 AUD). Martinsons represents a typical modern family owned Swedish sawmill operation that has diversified from producing a range of sawn products to investments in a significant glue lamination production, CLT manufacturing and the construction of timber buildings and structures.

Products:

Weather Board Panels

Martinsons' weather board products are manufactured in both horizontal and vertical glue laminated panels with rebated profile produced from split glue laminated beams allowing for a predominantly vertical grain orientation. The timber is dried to 12% moisture content which, when combined with the vertical grain orientation, minimises shrinking and splitting. A variety of sizes is manufactured with lengths up to six metres; each panel is 300mm wide.

Timber and Processed Products

Martinsons produce a complete range of sawn timber products and their sawmills, located near the lumber source, are in Bygdsiljum Hällnäs and Kroksjön.

Construction Timber Girders and Posts

Construction timber is available in the Swedish construction classes Bygg C12, C18, C24 and C30. Tongued and grooved boards and laths can also be manufactured with end-tongues and grooves.

Finger-jointed Construction Timber

Martinsons' finger-jointed construction timber is classified, based on strength, into the categories C12 to C30 and can be supplied in lengths of up to 12 metres. Panels can be finger-jointed up to a length of six metres with a permissible variation of 0/-2mm.

Interior Panels

Martinsons' interior panels are manufactured from both pine and spruce and can be treated, end-jointed, laminated and cut to length.

Exterior Panels

Martinsons' exterior panels are manufactured from spruce using rough sawn timbers. Panels can range from 50mm to 22mm thick and are glue laminated as a block and sawn to create weather boards.



Figure 1.47 Martinsons' projects and construction details. Photographs and images by martinson.se

Glulam Timber for Housing

Martinsons use the durable core* of the wood for its external surface and their glulam products can be customised according to the type of wood, quality of lamina and length desired and are available in dimensions of up to 200mm x 200mm square.

* The slow growth and small gauge of the logs, used by Martinsons for their Glulam product, results in the log's core having significantly different structural properties to those normally associated with the core of Australian softwoods. Extensive use of the core in engineered structural applications is also evident in companies such as the Canadian based CLT manufacturer Nordic with their Black Spruce product, *X-Lam*.

Ready-to-use components

Martinsons manufacture high quality and prefabricated custom components such as windows, doors and bed componentry.

Impregnated Timber

In compliance with the relevant environmental requirements, Martinsons offer products free from arsenic and chromium in the wood-preservation classes NTR-A, NTR-AB and NTR-B.

Cross Laminated Timber

Martinsons also manufacture solid wood cross laminated timber building elements consisting of ready-to-use planar building components such as floors, walls and roofs. As with Solid Wood Scandinavia KLH, Martinsons' CLT is manufactured off site in a dedicated plant. The components can also be prepared with pre-fitted electrical, hydraulic and acoustic materials.

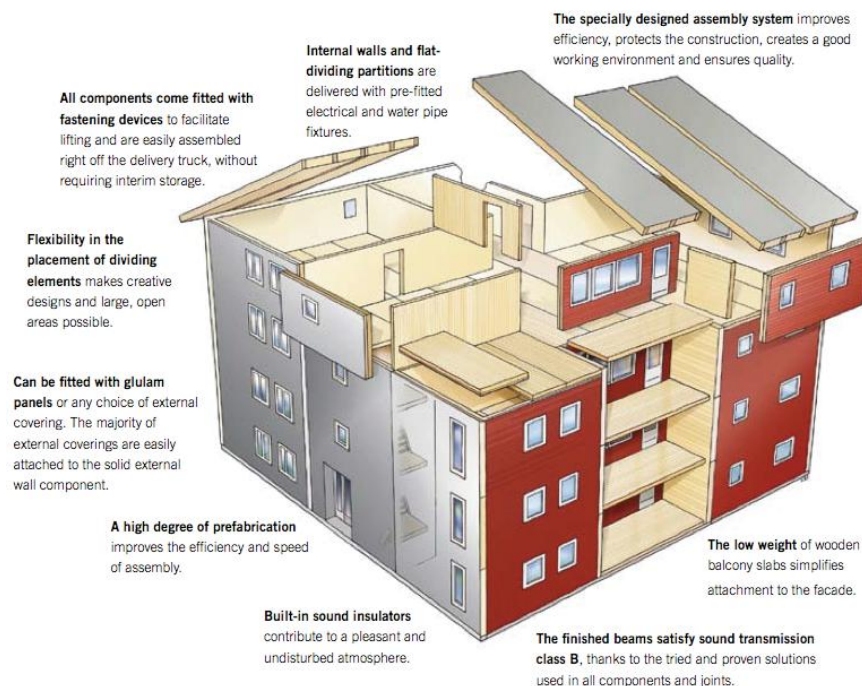


Figure 1.48 Exploded CLT project. Image supplied by Martinsons

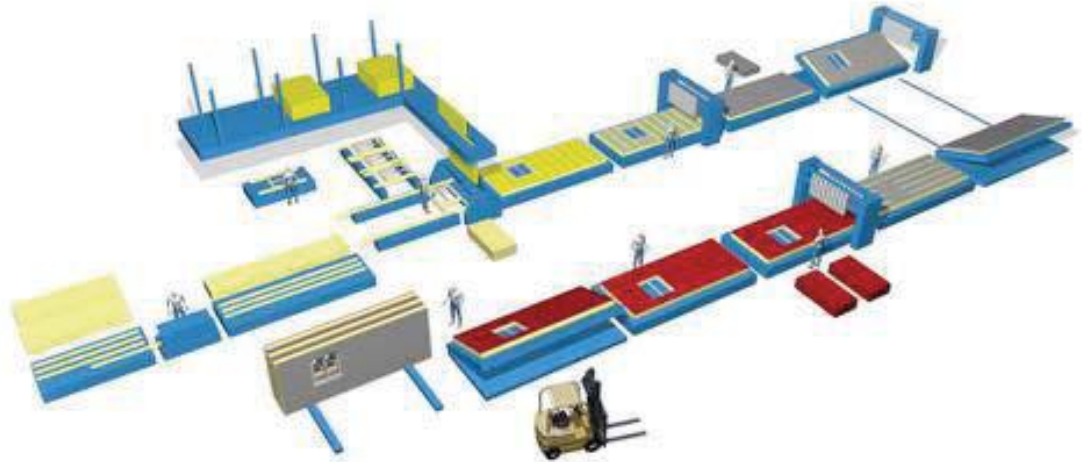
1.15.11 - Randek BauTech AB

Company Description:

Randek BauTech AB develops, manufactures and supplies mechanical equipment and software for house production management applications. The company manufactures production equipment for wall and floor panels, roof panels, interior and exterior walls, insulated wall elements and mobile home manufacturing equipment along with roof truss production systems. It also provides butterfly tables, inner and outer window frame machines, crosscut and notching saws, roof board machines, beam insulating machines, working tables with angle transfer as well as systems for automatic application of stucco on wall elements. Randek BauTech offers its products to housing manufacturers in Sweden, Norway, Finland, Denmark, the United Kingdom, France, the Netherlands, Germany, Austria, Switzerland, Ireland, Russia, China, Turkey, Algeria, the United States, Canada and Japan. The company is based in Falkenberg, Sweden. Randek BauTech AB operates as a subsidiary of Nordiska Truss Ab.

Products:

- Automated lines for prefabricated wall elements in wood or steel for up to 6000 houses annually.
- Lightweight working and turning tables for the manufacture of prefabricated walls made of wood or steel.
- Heavy working and turning tables for the manufacture of prefabricated walls made of wood or light weight steel.
- Equipment for windows, sub-components and roof trusses assembly.
- Computer guided vertical and horizontal milling machines.
- Computerised frame nailing station for wall elements up to 12 metres in length.
- Universal working bridges with saw, milling machine, nail gun or drilling unit.
- Transport equipment.



1	2
3	
4	5

1. Butterfly Table and operator
 2. Butterfly table flipping wall over
 3. Complete system production line schematic SF002
 4. Detail of automated wall framer
 5. Martinsons' Randek wall framing line
- Images sourced from randek.se and D.Bylund

Figure 1.49 Off-site timber prefabrication equipment. Images supplied by Randek BauTech AB

1.16 - Industrialised Timber Construction Philosophies - Lean and CoPS

The use of prefabrication and the adoption of a factory based approach to construction requires careful consideration on a range of different levels. The experience of the Swedish prefabricated timber construction industry has demonstrated that the types of building materials that best suit prefabrication, the cost of establishing and maintaining a facility with equipment and trained staff are key issues that will influence success or failure. In addition to these considerations, Professor Lars Stehn of Luleå Technical University points out that ‘... there is the risk that you can get so involved in making critical and good engineering solutions, that you can lose market perspective’. To demonstrate, he provides an example of a Finnish company that he has been working with and how adopting an optimised approach to prefabrication in construction and maintaining a customer focus can be difficult:

‘(I am working with) ... a Finnish sawmilling company which is one of the largest sawmill companies in the world. The first thing I said to them was to be careful not to fall into the technology and factory design trap, yet despite this, they are doing exactly that right now’.

When evaluating the technical aspects of creating a prefabrication system, design, build quality, cost and construction-time must be considered to avoid becoming entrapped in the technical solutions that Professor Stehn refers to. Once these issues are established, then the underlying prefabrication rationale should be addressed to inform and optimise the production processes. Significant research and experimentation must also be undertaken to ensure optimised factory based manufacturing processes.

One of the most widely studied and adapted production line systems is the Lean method pioneered by the Toyota Motor Corporation. As Toyota began producing cars in greater volumes throughout the 1950s, 60s and 70s, it refined and developed its production line approach to manufacturing of cars by developing the Toyota Production System (TPS). The TPS system was ‘... established based on two concepts. The first

is called "jidoka" (which can be loosely translated as "automation with a human touch") which means that when a problem occurs, the equipment stops immediately, preventing the production of defective products. The second is the concept of "Just-in-Time," in which each process produces only what is needed by the next process in a continuous flow' (Toyota 1995-2010). A key component of the TPS is to acknowledge and optimise integrated socio-technical systems that result from the interaction of people and technology in the work place. The underlying philosophy of the TPS system has been adapted to suit the production of many types of mass production and is now more widely known as 'Lean manufacturing'. The term 'Lean manufacturing' is credited to John Krafcik following an article he wrote in 1988 entitled, "Triumph of the Lean Production System," which was based on his master's thesis undertaken at Massachusetts Institute of Technology's *Sloan School of Management* following work he undertook for Toyota in its Californian operation.

The Lean approach is now being applied to off-site construction in Scandinavia and North America. According to Howell and Ballard of the American based *Lean Construction Institute (LCI)*, the Lean approach to construction can be summarised in the following four points:

1. The facility and its delivery process are designed together to better reveal and support customer purposes. Positive iteration within the process is supported and negative iteration reduced.
2. Work is structured throughout the process to maximize value and to reduce waste at the project delivery level.
3. Efforts to manage and improve performance are aimed at improving total project performance because that is more important than reducing the cost or increasing the speed of any one activity.
4. "Control" is redefined from "monitoring results" to "making things happen." The performance of the planning and control systems are measured and improved.

(Lean Construction Institute 2007)

When applying the Lean approach to the production of buildings, LCI's Howell and Ballard claim that '... Lean Construction is particularly useful on complex, uncertain

and quick projects ... (and) ... it challenges the belief that there must always be a trade between time, cost, and quality' (ibid). As a manufacturing philosophy, its application to industrialised construction '... is a production management-based approach to project delivery ...', that, when employed in construction, '... changes the way work is done throughout the delivery process' (ibid).

This change in 'the way work is done' involves rationalisation of the existing building methodologies. Traditionally, buildings are built in a sequential manner, literally from the ground up. Once a building has been designed, the process starts with various materials being delivered to a building site and a variety of contracted tradesmen undertake a series of tasks in a sequential manner to complete the building as directed by the builder's on-site supervisor. This typically involves preparation of the site for the services, compacting the ground and pouring footings and a slab or installing piles or stumps to create a stable level platform from which to build the structure. Walls, doors and windows are installed on the ground level, followed by any upper floors, walls, columns and beams and finally the roof. Internal fit outs include the services equipment, often in a multistage process, along with the cabinets and floor and wall finishes which are undertaken last.

Prefabrication in conjunction with a Lean approach to building, especially when applied to off-site construction, has reinvented this process by breaking down large structures into smaller components that can be built or manufactured in parallel and by rationalizing the actual work flow of each trade into a series of predetermined tasks. The various tasks are often undertaken by semi-skilled labourers working under close supervision of a tradesman. The personnel employed by the building company are usually employed full time rather than as independent contractors and work in a clean, dry and controlled factory environment.

For a building that is to be constructed by an off-site factory operating under the Lean philosophy, it is crucial that the design team involve the building company at an early stage to ensure that they optimise the benefits of Lean, off-site construction. For

example, a multi-storey residential building will often have similar floor layouts across each level. The construction requirements of the repetitive elements can be analysed to ensure the most efficient method of constructing and incorporated into the bespoke elements of the design.

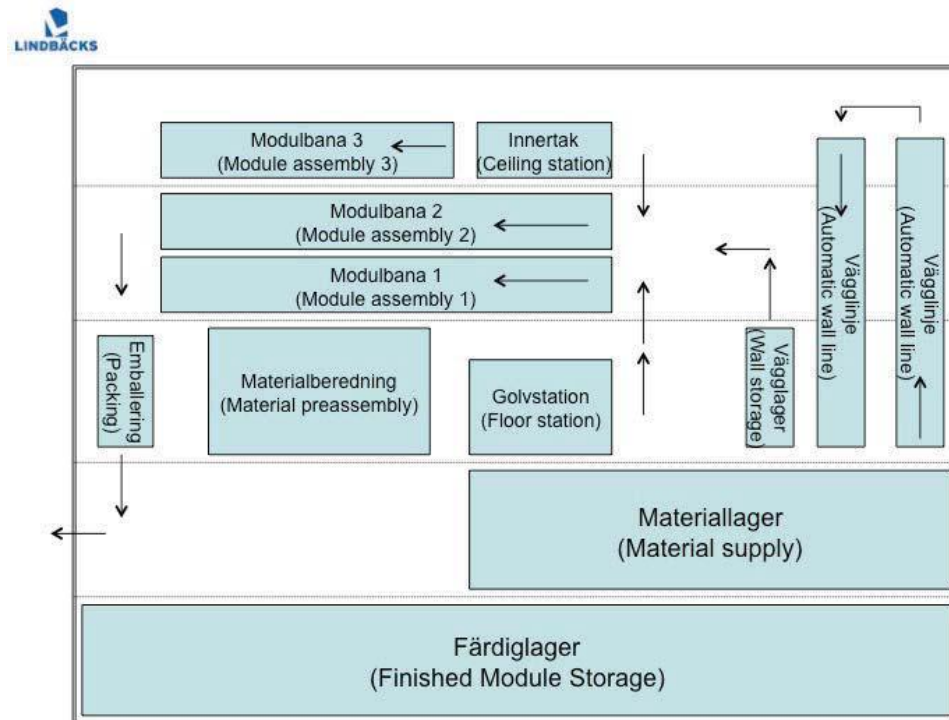


Figure 1.50 Lindbäck's Bygg's Lean factory floor layout showing the production flow and below, a tradesman working on a module. Flow diagram supplied by Lindbäck's Bygg. Photograph by D.Bylund

A Lean based off-site prefabrication approach aims to optimise the process of construction. The structure and fit-out of each floor is broken down into smaller

elements and built simultaneously, often right down to the internal finishes and fittings. Typically, in large scale, off-site Lean based construction, building materials are stored in an adjacent warehouse and teams of workers supply the exact quantities to the main construction floor production line according to pre-determined take-off lists and programmed schedules. Through this process, the bulk of a structure itself does not come together as a whole until each individual element is finally 'montaged' on the building site.

As a significant influence in most forms of mass production, it is not surprising that Lean has also had a significant influence on Sweden's 'montage' method of construction. With the introduction of off-site, factory based construction for large scale buildings in Sweden during the mid 1980's, research also began on adapting Lean production philosophies to construction. According to Höök and Stehn, simply employing Lean principles in the construction of buildings does not create a true Lean environment as pre-existing cultural imperatives within the construction industry can be in conflict with the aspirations of the Lean approach. They claim that the cultivation and establishment of a Lean culture within the employees of a company attempting to implement Lean principles is critical to its success.

In defining the culture that exists in the Swedish construction industry, Höök and Stehn state that, 'Culture is a concept that generally refers to "... the way things are done around here"' (Höök Stehn 2008). They also claim that in order to successfully instigate Lean methods into industrialised construction, the work environment or 'culture' that exists in both management and employees must first be understood. This key point is where resistance to change can occur when 'outsiders' are engaged to introduce a Lean approach who do not first spend time getting to know and evaluate the specific work culture that exists within a company or locality. They further argue that when approaching the introduction and ongoing management of Lean into a company, it is fundamental to manage the culture within the work environment. This claim is lent support by G.L Pepper's *Communications in Organisations: A Cultural Approach*.

According to Pepper, 'A cultural approach is argued to increase the understanding of an organization both from a philosophic and practical view point' (Pepper 1994). In addition, Höök and Stehn claim that, 'The key message is that it is not enough to just apply a Lean principle or tool without a simultaneous strive for a Lean culture. What is also needed is a balanced whole system view emphasizing improved performance through a focus on the persons delivering value to customers' (Höök Stehn 2008).

Based on their research outcomes, a cultural approach to the instigation of Lean, '... first shows the necessity of clear top management strategies, and secondly, the importance of changed work practices as facilitators of a change in culture' (ibid). Furthermore, '... there is a need for a simultaneous top-down and bottom-up approach diffused to workers' (ibid). To summarise, 'A Lean culture can not merely be obtained by (the) management proposing a strategy. Instead a culture is achieved when people find a strategy (or principles, practices and tools) to be working' (Höök Stehn 2008).

In contrast to the work of Swedish academics and industrialists such as Höök and Stehn promoting Lean in industrialised construction, some commentators have raised concerns that the burgeoning Swedish prefabrication industry is overly focusing on improving efficiencies in the production process to the detriment of the end product and the needs/concerns of the client. In an interview conducted by the author with Mr Johan Åhlén, the Project & Development Manager at Moelven's Töreboda laminated timber production facility in southern Sweden in May 2010, Mr Åhlén highlighted this issue when referring to Sweden's drive towards greater efficiencies in the housing construction sector:

'In Sweden, you cannot talk about modern timber construction without discussing the topic of how to manufacture it. All of the suppliers, and even more so, *Skogsindustrierna*, our umbrella organisation, are talking about modern production techniques, Lean production and the automotive industry. I have come from the automotive industry and I think we are being a bit over ambitious because what the consumer wants is not a building that is produced in a specific way. I would argue that they don't care what level of automation is used to produce it in the factory or whether it was built by a machine or not.'

Furthermore,

‘A house is not like a car. We know that a car has four seats, and a steering wheel, and where the engine sits is more or less determined. A house is an expression of who you are and what you stand for. You create a very specific environment that is intended to make you feel good and which suits you. I think that it is simpleminded to think that you can produce a house like a car. I’m not alone in this thinking, but there are also a lot of people who disagree. I agree that we need to be a lot more efficient in the way we produce buildings, but not to the extent where everything is built as a catalogue product because I don’t think that is what the market wants.’

Industrialised construction presents unique opportunities to apply advanced production techniques and methodologies that would not generally be considered when building in the traditional on-site manner. The opportunity to develop innovative organisational operational structures that have an off-site procurement focus can develop a competitive advantage and which can be perceived as a resource (Nord 2008). The key to off-site construction is finding the balance between efficiency and remaining focused on designing and constructing a building that fulfills the clients’s requirements and budget, and that contribute positively to the built environment.

In addition to the research and the practical application of Lean techniques in construction processes, investigations into *Complex Products and Systems* or CoPS as it relates to the nature of buildings and by extension, their construction in an industrialised process, have also been undertaken as an offshoot of general CoPS research. Research into CoPS can be defined as undertaking to ‘... improve understanding and the management of innovation in complex high value capital goods, industrial products, systems, constructs and net-works’ (CoPS Innovation Centre 2004).

At first appearance, the relationship between a building and CoPS may not be obvious. The following broad definition of CoPS, as defined by Graham Winch of the Bartlett School of Graduate Studies at University College London, states that a CoPS product or system has:

- Many interconnected and customized elements organized in an hierarchical way
- Non-linear and continuously emerging properties where small changes to one element of the system can lead to large changes elsewhere in the system
- A high degree of user involvement in the innovation process.

(Winch 1998a)

Further to this, according to Hobday, Rush and Tidd, in their paper entitled, *Innovation in Complex Products and Systems*, CoPS can be defined thus:

‘As high technology customised capital goods, CoPS tend to be produced in one-off projects or small-batches. The key production capabilities are systems design, project management, systems engineering and integration, rather than the volume manufacturing processes critical to competitiveness in consumer goods, such as camcorders and bicycles. Perhaps the simplest way of illustrating the defining characteristics of CoPS is to distinguish them from mass produced goods. There are at least three significant differences:

- First, they are comprised of many customised, interconnected elements including control units, sub-systems and components; these are organised in an hierarchical manner and tailored for specific customers and/or markets. Often their sub-systems e.g. the fan blade system for aircraft, are themselves complex, customised and high cost.
- Second, they tend to exhibit emergent properties during production, as unpredictable and unexpected events and interactions often occur during design, systems engineering and integration (Boardman,1990 & Shenhar, 1994). Emerging properties also occur from generation to generation, as small changes in one part of a system’s design can call for large alterations in other parts, requiring new control systems and, sometimes, new materials e.g. in jet engines.
- Third, they tend to be produced in projects or in small batches which allow for a high degree of direct user involvement, enabling business users to engage directly in the innovation process, rather than through arms-length market transactions, as is normally the case in commodity goods’ (Hobday Rush Tidd 2000).

A building, being the product of construction, is complex in nature, is a product (being commissioned and produced) and contains systems (structural, hydraulic,

electrical etc). Notwithstanding this, Winch points out that buildings also have distinct features that set them apart from other CoPS. He states that:

‘(an) Examination of the analysis of the principal features of the constructed product by Nam and Tatum (1988) strongly supports the contention that the constructed product is a complex product system, and that construction is, therefore, a complex systems industry. However, it has a number of distinctive features which also set it apart from the model of the complex systems industry developed by Miller and his colleagues:

First, the systems integrator role is shared between the principal architect/engineer and the principal contractor. Thus construction typically has two separate systems integrators - one at the design stage and one at the construction stage. Secondly, the fragmentation of the professional bodies in construction has weakened their ability to act as honest brokers of innovations as they typically threaten the interests of one or other amongst them. Thirdly, trade contractors (specialised suppliers) are rarely given full technical authority, and are often subject to separate specialist consultants’ (Winch 1998b).

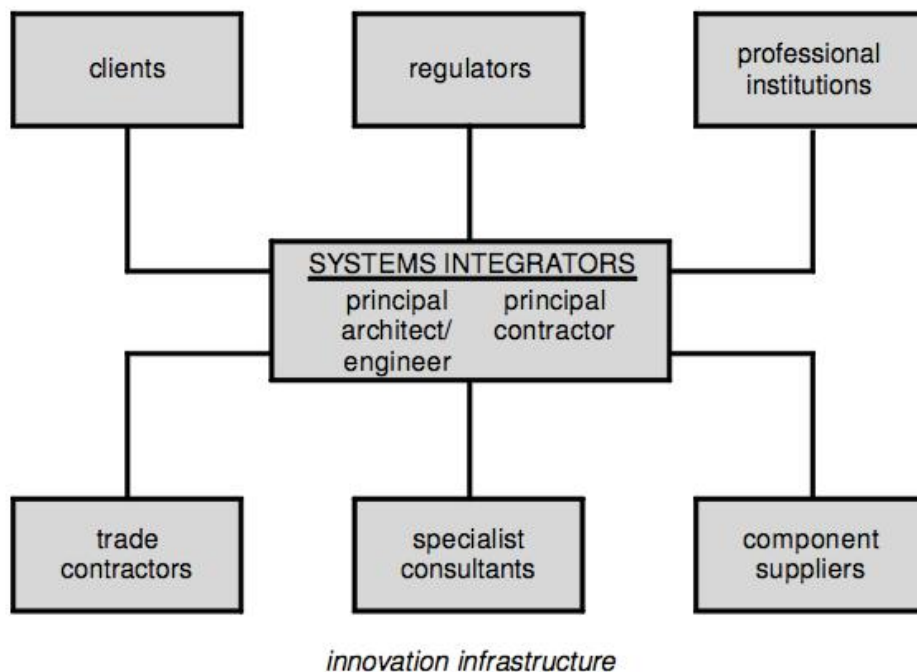


Table 1.14 Building System Integrators, Winch 1998

The vertical integration that has occurred in many of Sweden’s larger timber producing companies as they seek to explore Lean and CoPS production philosophies

in conjunction with their attempts to continue their growth through prefabrication has blurred the roles traditionally held by the architect, builder, material supplier and client. Without sufficient competition, this phenomena could have the potential to increase the end cost of construction as the opportunity for cost transparencies diminish.

The expansion of 'turn key' style projects procured, managed, constructed and delivered by large, vertically integrated single entities is a phenomena that is already affecting Australia's construction industry. Vertically integrated construction companies such as Perth based BGC, whilst not openly advocating Lean or CoPS philosophies, now provide goods and services spanning residential and commercial building, the manufacture of building and construction products, deliver mining, civil engineering construction and maintenance services, operate quarries and road transport businesses and provide property ownership and management and insurance.

The recent formation of the *Australian Lean Construction Institute*, jointly chaired by Marton Marosszeky of *Evans & Peck*, Mark Andrew of the *New South Wales Roads and Maritime Services*, Claudelle Taylor of *Leighton Holdings* and Ed Rogers of *AECOM* in 2012, indicates that Lean construction is starting to gain industry attention.

As companies such as BGC and Lend Lease increase their volume of off-site construction, philosophies such as Lean and CoPS will begin to influence their approach to building procurement as they investigate ways to continue optimising the value of their investment. Currently, light weight steel is the most common material used by Australian construction prefabricators and the benefits of new engineered timber solutions allowing larger buildings to be constructed off site are yet to be realised in Australia. Sweden's advances in this area have been assisted by their willingness to develop new engineered timber based construction systems allowing larger buildings to be built off site which in turn has engendered an environment of increased technical advancement requiring new approaches to construction such as Lean and CoPS.

1.17 - Opportunities and Constraints For Prefabrication and Engineered Timber in Australia

Despite being a modern western democratic country, Sweden clearly differs from Australia in its cultural, economic, geographic, climatic and environmental contexts. Notwithstanding this, many similarities exist between the two countries that can inform new approaches to construction. The Australian timber industry can benefit from gaining an understanding into some of the relevant conditions that influenced Sweden's development into large scale, off-site timber construction, or have come about following its commercialised applications. This opportunity, in conjunction with the optimisation of Australia's domestic timber resources through engineering processes and techniques, has the potential to guide the Australian path as it proceeds toward developing its own off-site and engineered timber methodologies within the context of a modern construction industry that, as with Sweden, has been dominated by steel and concrete throughout the 20th century.

A piecemeal approach to providing an alternative to existing construction techniques must be avoided. In an increasingly sophisticated built environment, new building systems must be capable of providing broad based solutions capable of addressing a project's brief at a lower cost than existing built solutions. It must also provide opportunities for waste minimisation, improving delivery times to reduce a client's holding costs, provide a safe working environment and provide for higher levels of quality control.

Dr Tomas Nord, in his Doctoral Thesis, *Prefabrication Strategies in the Timber Housing Industry, A comparison of Swedish and Austrian Markets*, points out that in Sweden's move towards an industrialised construction process and strategy, total solution requirements were necessary when developing an engineered timber building solution. This 'total solution' equates to architects and engineers being trained to take the particular constraints of off-site building into account when designing a new structure. Simply applying traditional design methods associated with steel or concrete construction to a prefabricated timber building will often cause

conflict. As new technologies such as CLT emerge and become more common, education in how to design structures featuring them is paramount. Simply designing a building assuming span, loads and tolerance of a steel structure but attempting to then construct the building as a CLT or a volume module structure will not work. This may seem self evident, but interviews with Swedish building companies such as Martinsons and Lindbäck Bygg have demonstrated the need to explain this to organisations and individuals new to prefabricated timber construction.

According to Nord, the Swedish timber companies have now begun to ‘... cut across the specialised value chain by incorporating design, procurement and production from in-house or established relations, to a pool of competencies needed to meet client requirements and market conditions’ (Nord 2008). Nord’s ‘specialised value chain’ are the mainstream architects and engineers who have much experience in traditional construction, but who are yet to appreciate or understand prefabrication’s unique set of constraints and opportunities. This need to communicate with the ‘specialised value chain’ concept is also inferred by Professor Lars Stehn where, when discussing the recent developments in Sweden’s timber prefabrication industry focusing on refining a system or structural design solution, he states that:

‘If you look at the individual companies that have developed timber, all of them are prefabricating and are developing integrated building solutions where the technical and engineering solutions are integral. Once they have a solution from an engineering point of view, they stick to it. If they have a jointing detail that works for them, they don’t need five different jointing techniques. They only use one joint solution and then they develop their value-adding by building as much as possible indoors, right down to installing the kitchen and hanging the wallpaper. The answer is not to have a multitude of timber engineering solutions, but to have one and a selling organisation that communicates with architects and clients explaining how to use their prefabricated solution’

This ability to communicate and promote a particular system with architects and engineers is critical to gaining traction in an established industry. The gradual adoption of Building Information Modelling (BIM) into a 2D based CAD environment has also had to address similar hurdles. The emergence of BIM into design is as a big leap forward as these new modern methods of construction are to traditional construction. As previously discussed, prefabrication on the scale now common in Scandinavia and German speaking D.A.CH countries is yet to be established in Australia. This is not to say that Australia lacks potential markets for such an approach. Identification of viable markets is a key element to attracting investment in new construction systems. One of the most significant potential markets for Australia's off-site construction industry is the provision of entire towns to service the mining industry along with the expansion of existing towns such as Port Hedland and Karratha in Western Australia, Gladstone in northern Queensland and Roxby Downs in South Australia. Developers such as Stockland, Lend Lease, and Mirvac are already considering the potential of these types of projects (Carter 2010) and several multi-storey buildings have been completed or are planned in areas where residential rents can be as high as \$3,000 per week.

Despite the environmental advantages of timber, significant emphasis is being given to lightweight steel's perceived durability benefits for the new northern mining company towns and villages. As referred to previously, discussions with Perth based *Nordic Home's* Managing Director, Mark Nylund, highlighted a relatively recent policy adopted by BHP and Rio Tinto that will affect timber's ability to compete in this market. This policy actively prescribes the use of steel and excludes timber for all prefabricated buildings purchased for their new mining camps. As these are the two largest mining companies in Australia, their refusal to consider timber alternatives has effectively shut the door on a significant market for any timber based building solution in Australia's north west. This will have significant implications for companies wishing to develop engineered, off-site solutions although not all mining companies are automatically excluding timber. Discussions between the author and

Fortescue Metals Group's (FMG) Infrastructure Manager, Mr Mark Tazewell, indicate that factors such as cost, scheduling and build and delivery time are significant factors in determining the type of structure that is selected for both the operations villages and construction camps. FMG sources some steel frame Single Person Quarters (SPQs) from China and Thailand under reciprocal supply agreements, but in the main part, prefer locally produced buildings (Tazewell 2012).

Mining camps are becoming increasingly sophisticated with a higher standard of amenity being provided through their built environment. Companies such as FMG recognise that in order to retain staff, higher standards of accommodation and amenity are required. Established Australian prefabricated building manufacturers, according to Mr Tazewell, can be reluctant to explore new initiatives and build to higher standards of construction, preferring to maintain their traditional methodologies. This presents an opportunity for new systems to compete as the gap that has previously existed between standards of construction for on-site based projects in Australia's southern cities and towns and the northern mining sector is diminishing, and companies such as FMG are prepared to pay more for higher quality products. Further to this, Section 4 of FMG's *Standard Specification for Permanent Villages*, General Design Philosophy states that all projects '... should include innovative features that result in a reduced carbon footprint, greater energy efficiency and improved environmental sustainability ...' (Fortescue 2011). This preference for building materials that have a 'reduced carbon footprint' and 'improved environmental sustainability' is further emphasised in Appendix 4 '*Fortescue Sustainability Design Checklist*' of the same document where their stated aim is to:

'... select materials and finishes that have low embodied energy ... and that have been certified under a recognised environmental rating system (wherever appropriate)' (ibid).

If companies such as FMG actually do use this criteria when assessing proposals for their mining town sites, then engineered timber proposals that utilise documented, sustainably managed timber have, as demonstrated by research published by the Canadian Wood Council, the clear advantage over steel as shown in the following graph:

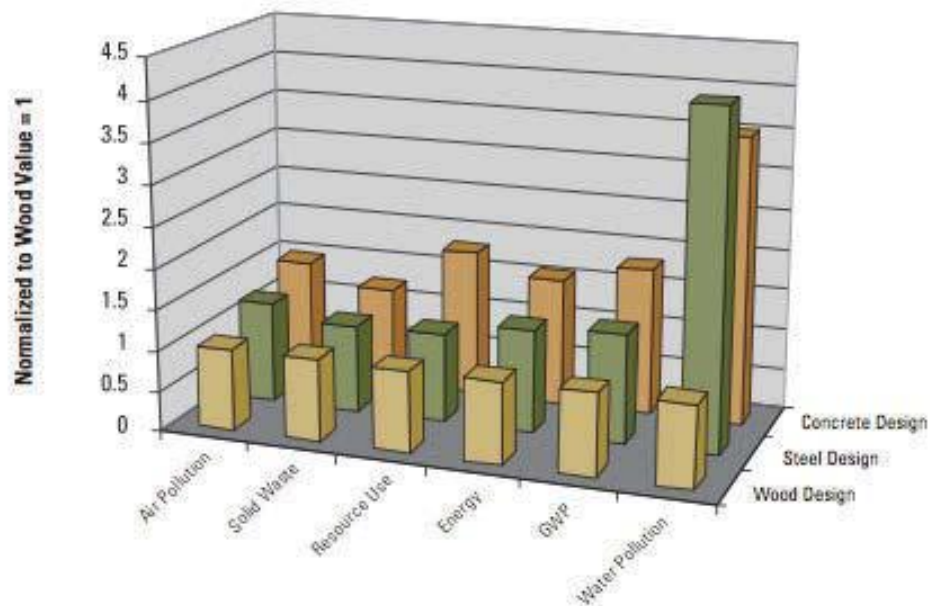


Table 1.15 Embodied Effects Relative to Timber Design across all Measures from Energy and the Environment in Residential Construction. Image supplied by the Canadian Wood Council.

As can be seen from the above graph, constructing with timber has significant environmental advantages over steel and concrete. Notwithstanding this, publicised environmental policies such as FMG’s do appear somewhat mitigated when considering the primary product of FMG’s mining in north Western Australia is iron ore.

A significant factor that will affect both off-site and on-site builders in Australia will be the influx of prefabricated, modular building systems from Asia. The author’s discussions with Mark Nylund of Perth based Nordic Homes presented a rather dire prediction that, as the build quality of the Asian prefabrication sector improves, many Australian builders will find it increasingly difficult to compete. In part, this sentiment

is supported by a recent article published in the WA Business News by Tim Treadgold, whilst reporting on a new residential development in an upmarket suburb of Perth. A Swiss couple with an appreciation for the modular and an economic model that considers not just the cost of construction but the associated holding costs as well, have found it more economical to purchase a prefabricated, two storey home from Victoria, have it transported almost 3,300 kilometres across the Australian continent on seven semi-trailers and erected on site under the supervision of a local, Perth based builder. According to the article, they claim a total cost saving of 30 per cent over a comparable local site-built masonry home, and construction time of 12 weeks in lieu of the 12 to 18 months typically experienced. According to Treadgold, this is because (construction) costs in Western Australia have skyrocketed to be amongst the highest in the world; interstate firms, benefiting from lower costs, are finding ways to crack the lucrative WA market, and WA buyers are learning how to bypass high-priced local service providers (Treadgold 2012). Mr Nylund's analysis, at least for Perth based construction costs, are that the dominant building companies ensure that the primary residential typology of single storey suburban masonry construction is the most affordable and that subsequently, their client base for timber framed homes is made up of those who are purchasing a house for environmental reasons over economic. The supply of brick based dwellings in Perth has become a self perpetuating cycle that has created a market that demands brick construction and an industry that is optimised to deliver it with very little attention paid to alternatives. Factors such as these will play a significant role in the establishment of off-site, engineered timber construction in Australia, albeit with the relevant issue being that which is applicable to each region's structural typology ie, double brick, brick veneer, light steel frame, etc.

The introduction of engineered timber into the northern mining facilities building sector will also be tempered by the significant influence that the mining companies have on the prefabricated construction industry. The current use of light

weight steel will present a significant challenge to the timber industry if it wants to compete in this market.

The potential for very high returns on investment in Australia's northern mining areas is attracting some of the larger development companies, but not without significant risk regardless of the structural material used. The Herald Sun newspaper recently reported that the Port Village Accommodation company was recently placed into receivership by BHP Billiton (Phillips 2012). Port Village Accommodation was attempting to build a \$150 million resort style prefabricated six storey hotel and apartments in Port Hedland for the mining and tourism industries (The Landing 2010). The project was to be constructed of prefabricated modules using imported components from Melbourne and transported over 4,300 kilometres to the construction site. While this project has failed to be realised, others, using standard on-site steel and concrete construction such as Finbar's Pelago West ten storey, 114 apartment complex in Karratha have been successfully completed.



Figure 1.51 Pelago Apartments in Karratha, in Western Australia's Pilbara region. Image supplied by pelago.com.au

Amanda O'Brian, in a newspaper report in *The Australian* entitled 'Pilbara dreams of being Little Dubai', discusses the opportunities that exist in this region for developers. She states that, 'A Little Dubai is to bloom in the Pilbara, with crown land to be given away free to property developers to build luxury high-rise apartments in the remote region as Western Australia gears up for a massive

expansion of its mining boom' (O'Brian 2011). With free land being made available in the context of government driven regional expansion, it is clear that developers presenting affordable, sustainable built solutions have a unique opportunity to facilitate new built solutions and utilise engineered timber and off-site construction techniques that respond to Australia's unique context.

The Western Australian government department charged with the task of providing opportunities in Western Australia's north west is the Pilbara Development Commission. Its stated mission, working under the title *Pilbara Cities*, is to '... build the population of Karratha and Port Hedland into cities of 50,000 people, and Newman to 15,000 people by 2035, with other Pilbara towns growing into more attractive, sustainable local communities' (Pilbara Development Commission 2012). Given the difficulties associated with building on site in Australia's north west, these developments clearly signal an opportunity for multi-storey, off-site construction methodologies.

1.18 - Solid Timber Construction in Australia - Past and Present

Residential construction techniques in Australia have been informed by a variety of influences such as climate, available building materials and by successive migration waves importing building techniques and adapting them to local conditions. On the eastern seaboard, timber frame and brick veneer have emerged as the dominant method of residential construction, while on the west coast, double clay brick is firmly established in Perth.

Commercial construction is less governed by regional influences, resulting in a relatively homogeneous spread of construction techniques that have responded to various developments in construction technologies. Typically, steel frame, precast or in-situ concrete and masonry or a combination of all are used.

The uptake of solid timber construction will be governed by many of the same factors that have influenced the acceptance of previously unknown construction

materials entering the Australian construction sector. Cost will be a significant factor that will inform its ability to compete. Notwithstanding this, solid timber construction does have some precedence in Australia's early history. In Justin Gare's treaty on colonial slab huts of Australia, solid timber construction or 'slab construction' was used '... mostly out of the barest necessity rather than as a preference' (Gare 1999). The early solid timber 'slab huts' were '... of heavy and rustic construction, manifest with no artifice of pretension, and provided the barest comfort and protection from the elements' (ibid). These first huts were either horizontally laid timbers acting as cladding infill between posts or vertically placed heavy timber 'slabs'.

One of Australia's definitive books on early timber construction by Philip Cox and John Freeland, describes the construction method of these early timber huts thus:

The horizontal slab construction required a groove or channel to be cut along the length of the posts. The posts were then set in the ground, about three feet apart, according to the desired layout. The slabs of timber were then dropped into the slots. A top plate was then run across the top of the posts to tie the posts together and support the roof. The vertical slab method allowed for more variations of technique. The vertical slabs could be either propped straight into the ground or into a grooved bottom plate, then held by a groove in the top, or simply nailed to the top plate. (Cox & Freeland 1969)



Figure 1.52 London Bridge Homestead. Circa 1870 by McNamara. Image by Justin Gare, from *Colonial Slab Huts*, 1999.

Another historical example of the use of solid timber as a response to necessity that is still standing and continues to be used to this day is the Koonalda Homestead in South Australia. Located in the Nullarbor National Park, the homestead's external walls were built with solid railway sleepers from the Trans Australian Railway, measuring approximately 225mm x 125mm x 2.1m. The sleepers are laid edge onto each other in a running bond and key into each other on the corners. Whilst this structure has stood the test of time and remains serviceable to this day, it is ironic that such a well built, solid timber structure should exist in a vast treeless plain that gets its name from the Latin 'nullus' (no) and 'arbour' (tree).



Figure 1.53 Koonalda Homestead. Photograph by John Bylund

This structure is a rare example of outback Australian construction from the late 1930s and early 1940s and few such structures remain today.

Construction methods of necessity, such as Koonalda Homestead, feature innovative, practical yet simple solutions as a response to limited building material and were gradually overtaken by today's standard method of construction using timber frame, then progressively by stone and masonry as these materials became increasingly readily available.

Perhaps necessity will again play a role in the emergence of solid timber construction in Australia. The escalation in environmental consciousness has the potential to positively differentiate engineered solid timber building solutions from other building materials which in turn could provide a competitive advantage; although the

argument about a particular building material's environmental credentials risks becoming an exercise in marketing and box ticking regulatory compliance and could become bogged down in green tape and dubious marketing. Along with other consumable items, construction materials are increasingly becoming subject to a certain amount of 'green marketing' in an attempt to tap into increasing consumer and governmental concerns regarding the environmental impact of construction. A recent blog by *Wood Solutions* entitled *Call to Action: Architecture of Necessity*, identified this issue whilst describing an exhibition entitled *Wood 2010* at the Swedish Virserum Art Museum. Here they noted that ... 'During the planning process for Sweden's Virserum Art Museum's third major exhibition, *WOOD 2010*, it became evident that social, economical and ecological sustainability issues had to be considered. However, when they looked behind much of the popular dialogue about sustainability, green architecture and green city planning, they discovered more posture than substance and more claims than credibility. The evidence suggested that the terms had been largely hijacked by marketing campaigns and were often more about greenwashing than actual sustainability.' (Wood Solutions 2012)

The Australian Competition and Consumer Commission has released a guide entitled 'Green Marketing and the Australian Consumer Law' in an attempt to provide some guidance to manufacturers and consumers about such claims. Associations such as the Cement Concrete & Aggregates Australia attempt to direct the environmental argument by claiming that, while concrete does have '... environmental impacts arising from the acquisition of raw materials, processing, transport and recycling at the end of its life' ... they are '... significantly outweighed by the environmental, social and economic benefits that concrete delivers' (Cement Concrete & Aggregates Australia 2013). Ultimately, society must consider whether emitting a large proportion of the world's carbon producing gases is something that outweighs the 'environmental, social and economic benefits' of products such as concrete or for that matter, steel or aluminium.

If the carbon footprint associated with concrete manufacturing can be used as a guide, then few can match the tangible environmental benefits of sustainably managed timber or plantation timber. Timber's attributes such as its storage of carbon dioxide, its comparatively low embodied energy footprint, the re-use of manufacturing residues, and if sourced from plantation and sustainably managed forests, it is conditionally renewable (Wood Solutions 2011).

The extensive use of lower grade timbers in nail laminated panels such as F7 in lieu of MGP10 or MGP12 have the potential to inhibit market acceptance if they were perceived to result in an inferior product, regardless of the potential environmental benefits associated with an increased use of plantation timber. The coactive nature resulting from the lamination process provides an opportunity to use lower grade or even the selective use of non structural grade timber in such a way that a new product or system is created with its own property set that takes advantage of the collective strength of the timbers by distributing any weakness. This could provide a viable value-added outlet for non MGP products that would otherwise be sold at a loss. This optimisation of the material may not be enough in itself to be accepted by the market due to perceived negative connotations associated with so called 'low grade' timbers, but when the marketing focus is applied to the environmental advantages in conjunction with the potential economic savings, they have the potential to be accepted by the market.

In support of this proposition, it needs to be stated that the majority of timbers contain potentially usable structural properties and determining ways to optimise them is the challenge. Timbers that conform to the various MGP standards can be safely used for applications, such as wall framing, that require each and every stick to be capable of withstanding the expected design loads imposed on a structure. Timbers that fall outside the MGP spectrum are not devoid of structural properties and therefore

are a resource that has the potential to be used in a structural capacity if treated appropriately.

Correspondence between the author, Richard Schaffner of Wespine and Geoff Stringer of Hyne Timber discussing this issue illustrated that the descriptive terminology used to describe a timber based product could have a significant effect on solid timber's market acceptance in the Australian market and that the use of terms that infer low or poor quality should be avoided. Both Richard Schaffner and Geoff Stringer sit on the Australian Forest Products Association's Technical Committee. This issue is one that has been considered by the committee, which is actively seeking solutions to address it as part of their drive to find new value-added applications for non MGP compliant timbers within the constraints of their technical and saw milling efficiencies and production focus as mandated by the FWPA.

In response to these discussions, the following discussion paper was written by the author to explore these issues and articulate some solutions:

1.18.1 - New Timber Grade Terminology and Solid-Timber Plate Products

30 July 2012

The Context

Trees are some of the most spectacular and awe inspiring natural structures known to man. The giant Karri trees in the south west of Western Australia, the Sequoia of North America and the Kahikatea of New Zealand are a few such examples. Some of these trees are capable of reaching heights of over 100 metres and can be hundreds of years old. This is possible because the timber within a tree trunk that varies in strength along its length works in unison to create an exceptionally strong bond via concentric radial laminations in the form of growth rings. Any inherent weaknesses from knots or resin shakes along the trunk are supported by the load sharing relationship inherent within the naturally occurring laminated cellular format.

In a type of biomimicry, industry has been laminating small solid timber sections to create large structural timber posts and beams in the form of Glulam (Glue Laminated), LVL (Laminated Veneer Lumber) and more recently CLT

(Cross Laminated Timber) plate structures to construct a variety of buildings. The key to the structural robustness of these products is the strength of the bonding techniques between the lamellas and the subsequent load sharing relationship that is established. The effect of this arrangement is that any weakness within an individual member is supported unilaterally by its surrounding timbers. This allows the creation of strong, relatively lightweight structural elements that result in a greater effect than the sum of any individual parts.

The Problem With Existing Timber Grade Terminology

Traditionally, the sawmill industry has referred to timbers that fall outside the standard established structural grades as 'low grade' or 'non structural' timber. This grading system is based on a long established model that assumes each individual member will be used in isolation as one component within a light timber frame structure. Timbers that do not conform to the required strengths for this grading system are often sold at a loss or are used to create low return items such as timber pallets. With the relatively recent advent of solid-timber plate construction techniques, timbers that are traditionally excluded from structural timber applications in the light weight timber stud frame sector become a key component of solid timber products via the load sharing capacity of plate lamination. To continue referring to each individual member as 'low grade' or 'non structural' when it clearly has structural properties that can be formulated to provide a consistent structural product, such as laminated panel products, is no longer appropriate.

Industry needs to move away from defining solid timber plate products as comprising low grade or non structural timbers. The continued use of this terminology has the potential to infer an inherent weakness in the product as a whole and has the potential to unfairly bias consumers' confidence in new solid timber plate systems and their acceptance as a viable building solution. It could be said that continuing to use these inherited terms when referring to solid timber plate structures is akin to inferring that concrete is weak and unreliable because it is made of fine grey powder, crushed stones and water, or that steel is unsafe because it buckles when hot. Clearly separating the end product from the nature of its source material or ingredients is critical when considering its suitability to perform a particular structural function.

A Solution

The author proposes that it is more appropriate to identify the sawn feed timber for solid timber plate products as Multi-Grade Timbers or simply MGT. If required, sub categories within this new class of timber could then be suffixed MGT₁ or MGT₂ etc based on visual grading specifications depending on the intended structural requirements of the finished plate product. Some alternatives to the Multi-Grade Timber or MGT term could be Free Grade, Cross Grade (or XGrade) or LamGrade (Laminate Grade).

The two most important factors in determining a suitable name for these sawn feed timbers are to ensure that it does not unfairly bias the end product by inferring structural weakness on the whole and that the term achieves industry wide acceptance to minimise confusion and ensure clarity when designing a plate's structural requirements.

An Example of New Terminology

As an example, a solid timber floor plate required to span 5 metres with a combined dead and live load of 20kN might be required to utilise 50% MGT₁ and 50% MGT₁₀. A solid timber wall plate might be required to comprise 80% MGT₁ and 20% MGT₂, and a roof plate might be comprised wholly of MGT₁.

In promoting new solid timber plate products, a sawmill could release a statement along the following lines:

Using previously under utilised '*Multi-Grade*' Timbers, we have increased the sawmill's ability to improve our fibre return through the creation of a new high-quality solid-timber engineered product. The structural load sharing capacity of this new building system allows us to utilise the strengths of each individual element through plate lamination. This system creates new, economical and environmentally friendly solid timber walls, floors and roof panels from timber that traditionally falls outside the requirements of light timber frame construction.

Richard Schaffner and Geoff Stringer each provided considered responses to the above which are provided in the appendix.

In the following three chapters, a design for an engineered timber building solution is developed through its application to a theoretical three storey residential building.

The design is based on the recently completed masonry building on the campus of the *University of Western Australia* called *Currie Hall*. The projected build costs for the theoretical engineered timber variant of the *Currie Hall* proposal (hereafter referred to as Currie Hall 2 or CH²) would indicate that the combination of low cost source material and a reduced site build time, provides large scale prefabricated timber structural building elements with significant cost and construction process advantages when compared to traditional methods.

2.0 - AN AUSTRALIAN ENGINEERED TIMBER WALL

This chapter investigates the development a simple engineered timber panelised wall system that uses low grade Australian plantation timber, readily available fabrication skills and low tech manufacturing techniques. The intent is to identify readily available Australian materials, products and skills that would be required to develop a prefabricated engineered timber structural solution that is specifically suited to the Australian context.

2.1 - An Alternative Method of Construction

The structural wall system introduced in this chapter is a solid, panelised engineered timber wall solution that uses low grade plantation timber arranged as a double leaf with a central cavity in a manner similar to cavity brick or brick veneer construction. It uses readily available Australian materials, products and skills and is intended to be specifically suited to the Australian context. Whilst the Swedish prefabrication building methods explored in Chapter One of this thesis may not have had their genesis in solutions developed specifically to utilise low grade lumber, they can still provide valuable lessons for Australia in terms of systems development, advances in prefabricated manufacturing technologies and in product quality and construction standards.

Australia's timber milling industry produces large amounts of non-structural grade lumber that is not profitable. Both Hyne Timber and Wespine have indicated to the author that up to 50% of their annual production volume is unsuitable for structural frame applications and is sold at a loss. This vast underperforming resource has the potential to be used in an engineered timber building solution. A solid timber based system with its associated mass, appearance of strength and permanence that can effectively utilise this resource is significantly different to both traditional light timber frame and other new panelised wall systems such as SIPS (Structurally Insulated Panels). Light weight panelised system such as SIPS have yet to firmly establish themselves in Australia, despite presenting convincing arguments highlighting their acoustic, thermal and construction time/cost advantages over cavity brick (SIPS Industries 2014). Panelised concrete construction in the commercial sector is well established in Australia, but continues to struggle for market acceptance in suburban residential construction because of cost and perceived detailing difficulties, despite it passing the 'knock test' (refer Section 1.12 in Chapter One and the transcript interview with Mr Bob Pearce in Appendix B for more discussion on the 'knock test'). If marketed appropriately, solid timber's similarity to the 'solid feel' of brick when subject to the

'knock test', combined with the ease of detailing associated with timber, would be important aspects to stress when establishing it as a new structural system. Any new structural wall system that the end consumer does not feel passes this test and is also perceived as difficult to detail will struggle to gain acceptance in Australia. Often, a consumer's sense of a structure's solidity is associated with its perceived permanence and potential longevity. This can simply be a 'feeling' based criterion rather than one influenced by actual building science or performance and thus any new system being established will require more than simply a technical solution. It will need to address society's acceptance and perceptions of various building materials, their cultural expectations and their associated financial implications.

As this thesis progressed, it became apparent that a simple Gun-nailed Parallel Laminated Timber (GPLT) solid wall panel system could be developed within the confines of existing trade skills and equipment that would address the 'solid' nature of a structure increasingly expected by the Australian market. In establishing such a system it would be beneficial if it was relatively easily manufactured by either an existing frame and truss manufacturer or by a sawmill as a value-added engineered product to take advantage of existing skills, systems and technology.

The lamination of small sections of timber to form larger sections is a well established system of engineering timber used to achieve a variety of outcomes. Laminating timber in a parallel format, while not as structurally efficient as CLT due to the parallel lamella arrangement versus the cross lamella arrangement, does still contain a usable structural capacity that could be a viable entry point for Australia into solid timber panelised construction. The arrangement of solid panelised timber walls, whether they be cross or parallel laminated, operates in a similar manner to the structure within honeycomb as a form of biomimicry where all the wall elements simultaneously provide vertical load carrying capacity and perform both the shear and cross bracing roles. Chapter Three presents a theoretical design solution that attempts to address these criteria for a three storey multi-residential building.

A system of interdependent structural parallel walls would suit residential applications where flexible room layouts were less critical than those required for commercial buildings. Commercial buildings that do require large open plan spaces with non-structural room dividers could still utilise these types of parallel laminated elements as a hybridized form of construction where fixed spatial functions such as utility rooms, lift and stairwell walls were required in conjunction with traditional timber, steel or concrete beams to allow for larger span open plan areas.

By restricting the building system design parameters to existing standard timber working skills and equipment and with the aim of an individual panel being capable of being erected without the need for heavy lifting equipment, a simple, parallel laminated panel was developed that has the potential for use in Building Code of Australia's (BCA) Residential Class buildings 1, 2, 3 and 9c and Commercial Class buildings 5, 6, 9a and 9b. Potentially taller buildings using the BCA's Alternative Solutions assessment method of demonstrating compliance to achieve Performance Requirements could also be achieved. This is discussed further in Subsection 2.2.7, Building Classification and Compliance, of this chapter.

The mechanical, thermal and acoustic characteristics of solid timber walls operate differently to masonry walls, potentially making the double leaf and cavity arrangement redundant if condensation issues can be managed. This approach may be correct for low rise construction as a purely technically sufficient solution, but, as previously established, could fail in gaining market acceptance in Australia. The established acceptance of masonry's bulk, feel and acoustic performance dictates that any competing system will struggle to achieve its potential uptake, regardless of any superior attributes it might possess. Even significant cost and construction time savings will be viewed with suspicion if the perceived need for a 'solid' feel to the construction is not taken into account.

2.2 - Gun-Nailed Parallel Laminated Timber (GPLT) Wall Panels

In conjunction with Australia's vast low grade timber resource and principles drawn from Sweden's off-site construction methodologies, two prefabricated timber wall panels were developed for this thesis to demonstrate a potential application; one using 70mm x 35mm MGP grade timber and the other using 80mm x 40mm 'Multigrade' timber. The use of MGP timber in one of the panels provides a known structural base point from which to engineer the structure as a solid timber panelised building. The use of ungraded timber in the second wall panel explores the potential to exploit this large underutilised Australian resource.

Gun-nailed Parallel Laminated Timber (GPLT) wall panels, developed as part of this thesis, are structural wall panels using multigrade timbers intended to be manufactured off site utilising materials, skills and technologies that currently exist in Australia. The logic of this system involves the off-site manufacturing of small, individual parallel laminated timber panels that are connected on site to make larger wall elements.

The three key design constraints were:

- Individual panel weight to be kept to a minimum so as to allow two men to position without the need to use a crane.
- To ensure rigidity.
- Panel to panel junctions to be coherent and assist in facilitating efficient on-site building assembly.

The GPLT wall panel structural system can be described as a rigid panelised planar concept that, through the simultaneous co-action between conjoined members, provides both vertical and lateral load resistance to a building. The floor diaphragm of the building resists lateral loads via fastenings fixed to the continuous top plate that is attached to the panels using light gauge steel brackets. The lateral loads are then

While the intent of this approach to engineered timber and prefabrication is to form a planar, solid timber panel from smaller individual elements, the method of laminating these elements together must first be established. The factors that have influenced nailing as the method of choice have been the availability of material, equipment, existing local skills and the architectural requirements of the case study design. There are several methods currently being used in Europe to laminate timber into solid structural panels. These typically include high pressure gluing methods, but also can be timber dowels, steel or aluminium nails or machined tongue and groove fixings. Many factors can influence the most suitable fixing method, from the intended task and loads to be carried by the panel to the available manufacturing skills and equipment.



Figure 2.2 1:10 scale GPLT Panels and wall element cutaway models. Images: D.Bylund

The initial fixing method considered to secure each of the individual members together in a parallel laminated format was friction fitted Tasmanian oak hardwood timber dowels. Timber dowels allowed the unrestricted use of CNC cutting for openings and simplified future panel modifications. This lamination method was also considered because access to equipment such as a large scale flat bed press used to produce glue laminated panels is not generally readily available in Australia and as such, would require large scale infrastructure investments in both presses and heavy lifting gantries. In discussions with Wespine and Hyne Timber, it was deemed that the level of investment required for large scale glue lamination was unlikely to be considered until a market for the product was established. Following consultation with MLB Consulting

Engineers, based in Auckland, New Zealand, it also became apparent that dowel fixing would not be feasible because the likely structural performance required by a solid timber panel wall element in a three storey application such as CH² would be difficult to achieve.

With both glue laminating and dowel fixing rejected, the only remaining viable fixing method was nail lamination. Existing technologies designed to fire nails into wood from a gas cartridge or electric powered nail gun allowed for an off-the-shelf automated or semi-automated fixing solution which is readily available and well understood in the Australian building industry and this was the primary factor behind nail lamination being adopted as the fixing method for this research.

The use of nails as the lamella fixing method introduces some panel cutting and shaping restrictions that can result in a reduction in the panel's flexibility and ease of working. These limitations were considered to be offset by the relative ease of nail fixing which, as already established, is readily achievable given it is a common and well understood system of fixing timber in Australia. This attribute makes it suitable as a first stage or introductory method of introducing planar, solid timber construction to the Australian market.

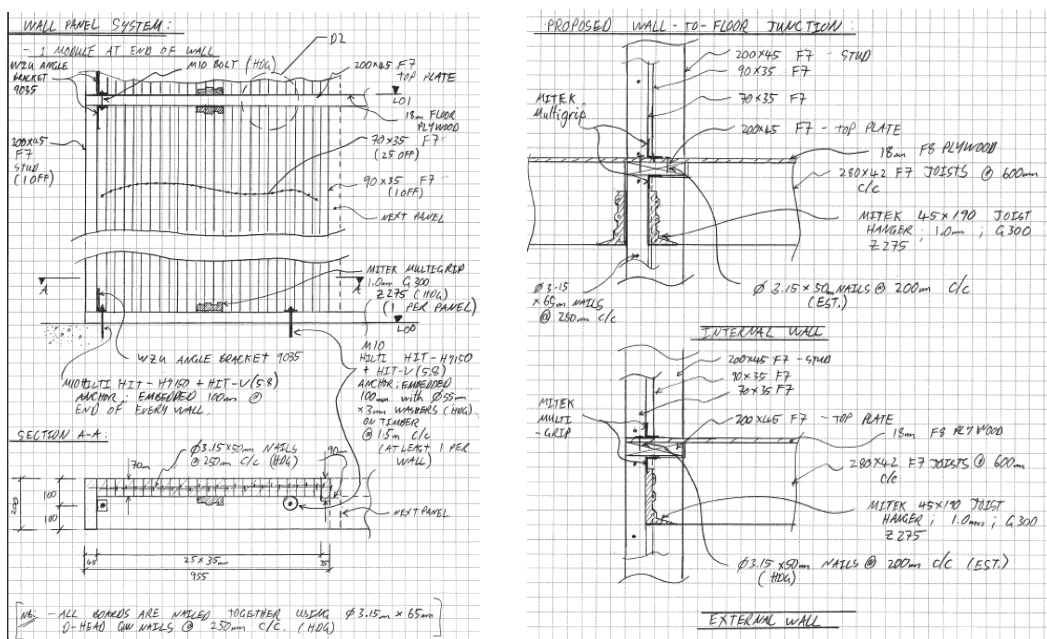


Figure 2.3 Sketched exploration of the GPLT panels for the CH² building by MLB Consulting Engineers

Some contra-indications exist with the use of mild steel nails due to difficulties associated with cutting or trimming of the panels with standard saw blades and CNC cutters. This factor can, if post production cutting is required, be overcome with the use of specialised saw blades with high strength cutting tips capable of withstanding nail strikes. This restriction ensures a minimum of timber wastage because each individual panel is optimised for its location within the wall rather than the whole wall being produced as a large blank which is then cut out and trimmed to size as is common with CLT.

The engineering of the gun-nail lamination concept was optimised to suit the design alternative for Currie Hall (CH²) (refer to Chapters Three and Four) with the assistance of MLB Consultation Engineers who were engaged by the author to undertake the engineering design requirements.

The panel's wind and earthquake structural performance requirements for the Perth location were calculated according to ARUP Engineers' assessment of the *Currie Hall* residential project at the Crawley site for the *Pallasis Architects'* masonry design.

These were:

G9. Design wind loads:

- Importance level (BCA table b1.2a) - 2
 - Annual probability of exceedance (BCA table b1.2b) - 500
 - Wind region - A1
 - Ultimate limit state wind speed (Vuls) 45 metres/sec.
 - Serviceability limit state wind speed (Vsls) 37 metres/sec.
- (Note wind speed variation with direction is as AS1170.2)

Terrain category - 3

- G10. Design earthquake loads:
 - Importance level as per note G9.
 - Annual probability of exceedance (BCA table B1.2b) - 500
 - Site sub soil class - Ce
 - Site hazard factor - 0.09
 - Earthquake design category - 2
 - Probability factor, Kp = 1.0
- (ARUP 2010)

Radiata pine was chosen as the panel timber material because it is readily available in a range of standard sizes and is a relatively low cost locally grown

plantation timber. Commercially significant quantities of multigrade timber are produced by most Australian softwood mills.

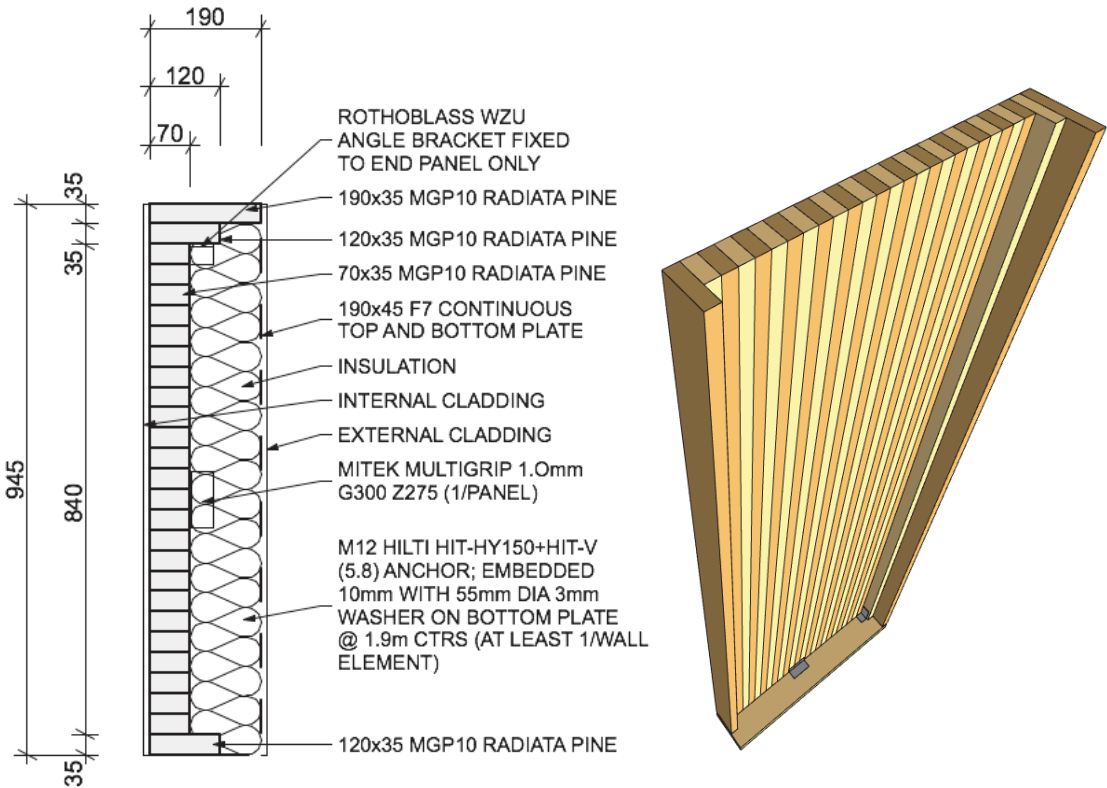


Figure 2.4 Preliminary single skin GPLT panel plan details and perspective view

Using standard 70mm x 35mm MGP10 graded Radiata pine Dry Dressed sawn timber, milled at Wespine’s West Dardanup sawmill, the panel’s maximum width of 945mm was calculated on the assumption that it could potentially be tilted up into place by two workmen, each lifting a maximum of approximately 45kg. It was therefore determined that the panel’s total weight could be within the range of 90kg to 110kg assuming that the only manual lifting would be a ‘tilting up’ action rather than a dead lift.

This weight limitation was imposed with the intent of minimising the need for heavy mechanical lifting equipment, either in the production facility or on site. When the panel reached the building site, it would be lifted from a truck mounted lifter crane and either stacked on site near its final location or moved directly into place using lifting trolleys.

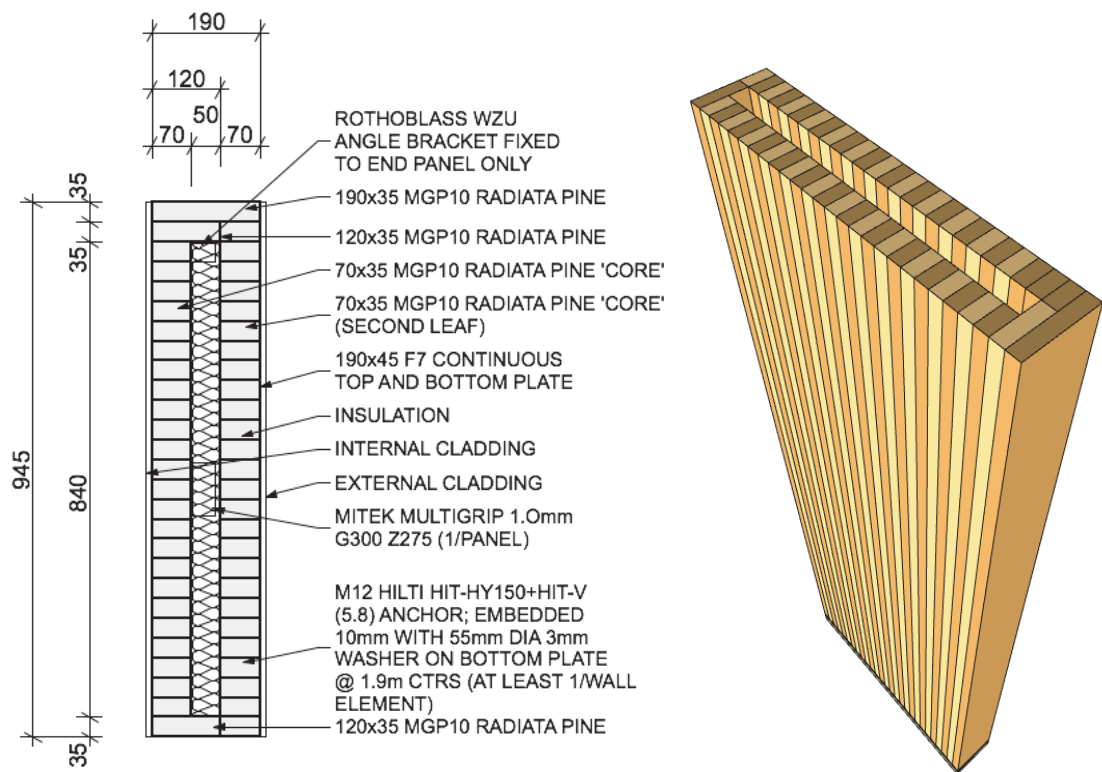


Figure 2.5 Preliminary double skin GPLT panel plan detail and perspective view

The system of joining each panel to the next benefited from the existing modularity within standard timber sizes in Western Australia. Initially, the panel was comprised of a single 190mm x 35mm end piece fixed to a 120mm x 35mm trimmer which in turn was fixed to a series of 70mm x 35mm 'core' timbers. At the opposite end, a second 120mm x 35mm 'end trimmer' was added to provide a fixing point for the next panel in a wall sequence. By arranging the members in this way, a second 70mm x 35mm skin can be fixed to the two 120mm x 35mm trimmers to allow a double skin variant with a total thickness, excluding external and internal linings, of 190mm. This 'double leaf' arrangement also allowed for a wall system that resembled the scale, mass and solid nature of double brick, and with linings comes close to a double brick wall width of 230mm, thus addressing the issue of masonry market dominance resulting in perceived value from 'solid' construction as identified in Chapter One, Section 1.12 - Current Methods of Australian Residential Construction.

As the proposed CH² design would be developed with GPLT panels, it became evident that acoustic attenuation measures would be required to meet the BCA's

acoustic requirements for both Class 2 and 3 residential buildings. The timber's mass in the panels would be insufficient to adequately provide acoustic insulation. The end trimmer elements connecting each leaf, while providing a structural connector would also create an acoustic bridge across the cavity with the potential to allow inter-apartment noise transfer. To address this, a discontinuous acoustic wall tie/connector was developed to ensure complete structural separation between apartments.

The discontinuous construction resulted in a revised inter-panel/interleaf fixing method that replaced the 120mm x 35mm fixing plate and the 190x35 end trimmer with a specially developed adaptation of a standard timber frame acoustic wall tie. The new wall tie has face external fixing elements that form an 'H' pattern when viewed in plan. This distinctive shape has been used to derive its name - The 'H' Acoustic Wall Tie.

The design and development of this element is discussed in greater detail in the Acoustic Performance Subsection 2.2.9.

2.2.1 - Load Testing Summaries

Following the structural calculations and design undertaken on the panel concept by MLB Consulting Engineers, Professor Ken Kavanagh from the School of Civil and Resource Engineering at the University of Western Australia also undertook a review of the structural aspects of the panel prior to its physical testing in the Civil Engineering testing facility. According to Professor Kavanagh, based on the expected loads in the CH² design, each panel would be required to withstand a load of approximately 70kN (refer Table 2.3 for structural test results). He also concluded that each panel should be capable of withstanding a maximum load of 250kN before buckling failure occurred. Seismic loads at the UWA site were also considered by MLB but were found to be non-critical.

The following gravity loads and wind loads were assumed for CH²:

Load	kPa
Floor dead load (G)	0.97kPa
Floor live load (Q)	2.00kPa
Roof dead load (G)	0.36kPa
Roof live load (Q)	0.25kPa
Design wind velocity	45 m/s
Wind pressure in accordance with AS1170.2:2002	0.84kpa

Table 2.1 CH², Design Gravity and Wind Loads

2.2.2 - Australian and New Zealand Standards Compliance

MLB Consulting Engineers have confirmed through their structural analysis that the GPLT panel system (refer to Appendix D) conforms to the following relevant Australian and New Zealand standards:

Standard	Title
AS1720. 1:2010	Australian Standard: Timber Structures. Part 1: Design Methods
AS/NZS 1170	Australian and New Zealand Standard: Structural Design Actions
AS3660:2001	Australian Standard: Termite Management Set
AS1604. 1:2010	Australian Standard: Specification for Preservative Treatment - Sawn and Round Timber
AS4100:1998	Australian Standard: Steel Structures

Table 2.2 CH² Australian Standards compliance

2.2.3 - Prototype Wall Panel Structural Testing

Several full scale prototype panels were made to test the nailing procedure, actual weight and balance during manufacture, handling and erection characteristics, and to carry out simulated gravity load testing. Compression testing was carried out on the Amsler Compression Testing Machine in the University of Western Australia's Civil Engineering Department and was recorded using a proprietary program, written by the Civil Engineering Department in 2007 using LabVIEW (National Instruments 2012).



Figure 2.6 Prototype panel being prepared for load testing at UWA's Civil Engineering physical testing facilities.. Full scale prototype under construction (left) and completed (right).

2.2.4 - DDS MGP10 GPLT Wall Panel Prototype

A 400mm x 2400mm high DDS MGP10 wall panel segment was tested to confirm load buckling characteristics up until failure.

A laser was independently positioned to measure deflection in the centre of the panel when placed under graduated load. Under load, the panel exhibited buckling characteristics consistent with the modeling.

As can be seen in Table 2.4, the panel gradually exhibited a buckling displacement of approximately 0.5mm to the left up until approximately 40kN. From 40kN to 80kN, it gradually returned to centre and then proceeded to progressively buckle to the right to a point that it was deemed as failure (13mm deflection under 242kN of load). No explanation was given by the supervising technician for the left to right deflection beyond simple settling as the panel adjusted to withstand the applied pressure.

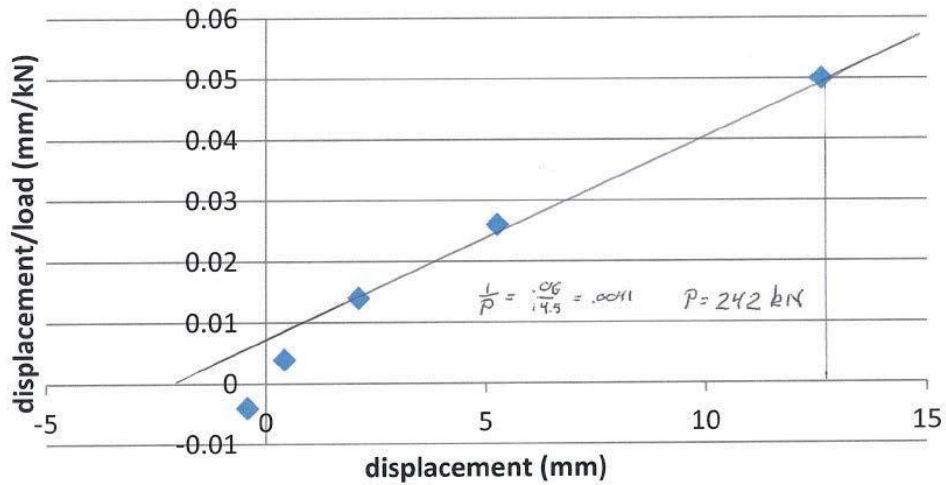


Table 2.3 MGP10 Southwell plot for buckling. Calculations by Professor Ken Kavanagh

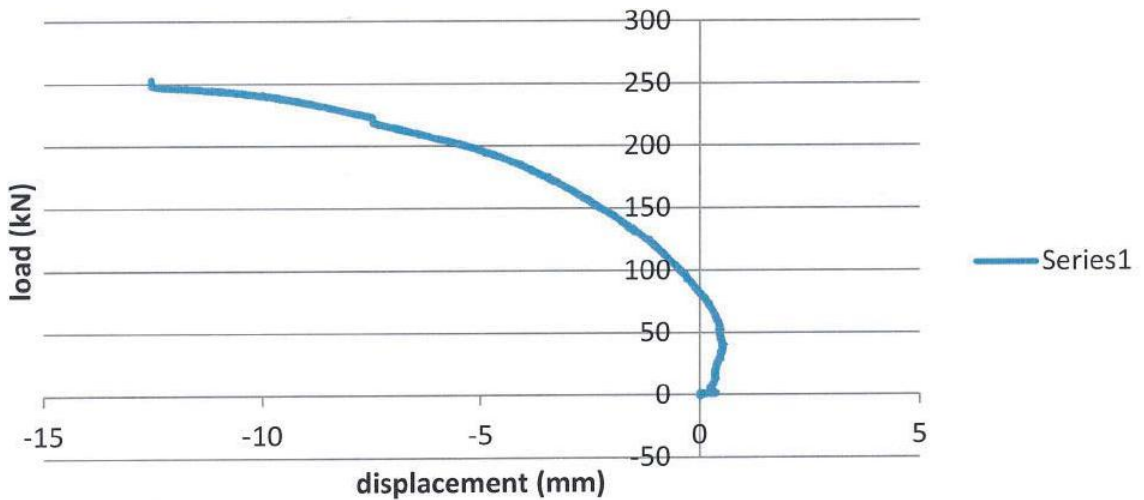


Table 2.4 MGP10 Load vs. Displacement test results. Calculations by Professor Ken Kavanagh

2.2.5 - Multigrade DRS GPLT Wall Panel Prototype

The Multigrade Dry Rough Sawn (DRS) GPLT panel ungraded timber prototype was tested under the same conditions as the Dry Dressed Sawn (DDS) MGP10 GPLT panel. Being rough sawn, each individual 80mm x 40mm piece is approximately 23.5% larger by volume. The load test resulted in a buckling failure of 360kN (18mm deflection). This failure point load is 32% higher than the DDS MGP10 test results. The Multigrade timbers have the potential to contain wood that ranges from non structural grade through to MPG15. For the purposes of these tests, failure was determined to be the point at which the buckling continued at the same rate or greater without any further increase in load.

According to Wespine, it is probable that the random choice of the Multigrade timber is likely to have resulted in a high representation of MGP10 and MGP12 timber. Conversely, the DDS MGP10 timber is unlikely to have a significant number of higher grade timber as this would be selected out as part of the grading process. This factor would explain the disproportionately higher performance of the rough sawn panel.

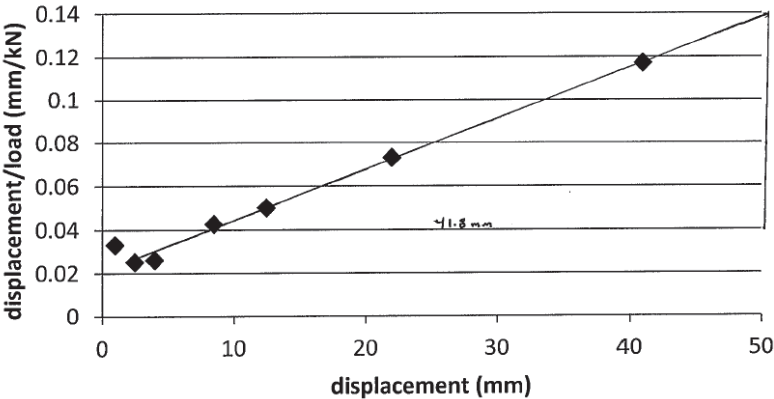


Table 2.5 Ungraded GPLT timber Load vs. Displacement test results. Calculations by Professor Ken Kavanagh

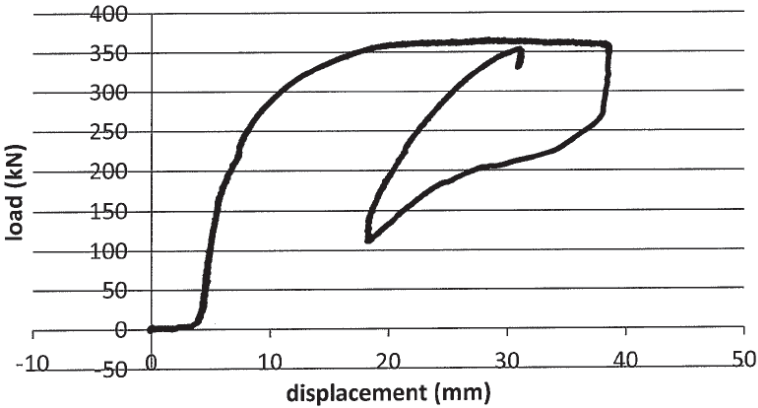


Table 2.6 Ungraded timber GPLT Southwell plot for buckling. Calculations by Professor Ken Kavanagh

According to the results indicated in Table 2.6, combined gravity and live loads greater than 70kN could be expected to cause some panel deflection. The MGP10 panel was deemed to have failed under a 250kN load. At this point the panel's buckling deformation had reached 13mm and the ungraded panel failed at 360kN where its buckling deformation was 18mm.

2.2.6 - Prototype GPLT Structure

Over a period of three days in late June 2012, a 3.4m x 3.4m cube shaped structure (Figure 2.8) was prefabricated and erected at Wespine's Dardanup sawmill. The process of panel manufacture and construction allowed a demonstration of solid timber panelised construction where various aspects of panel fabrication and erection could be tested. Being undertaken at a sawmill allowed for direct interaction with key mill employees providing for some valuable insights into the potential for Australian sawmill based prefabrication. Having the mill employees participate in the process provided feedback into how the process of automated panel fabrication might occur, highlighting the benefits of direct industry involvement in the development of new engineered timber products and systems.

For the construction of the cube structure, Wespine supplied three packs of 75mm x 38mm Dry Rough Sawn (DRS) Radiata pine. Each pack contained 117, three metre lengths of ungraded, kiln dried pine. Eight lengths of 240mm x 35mm pine to be used as top and bottom plates for the walls were also supplied. The panels were built using a simple layout jig. The jig allowed the first lamella to be pushed up against a fixed backstop gate element (Figure 2.7).

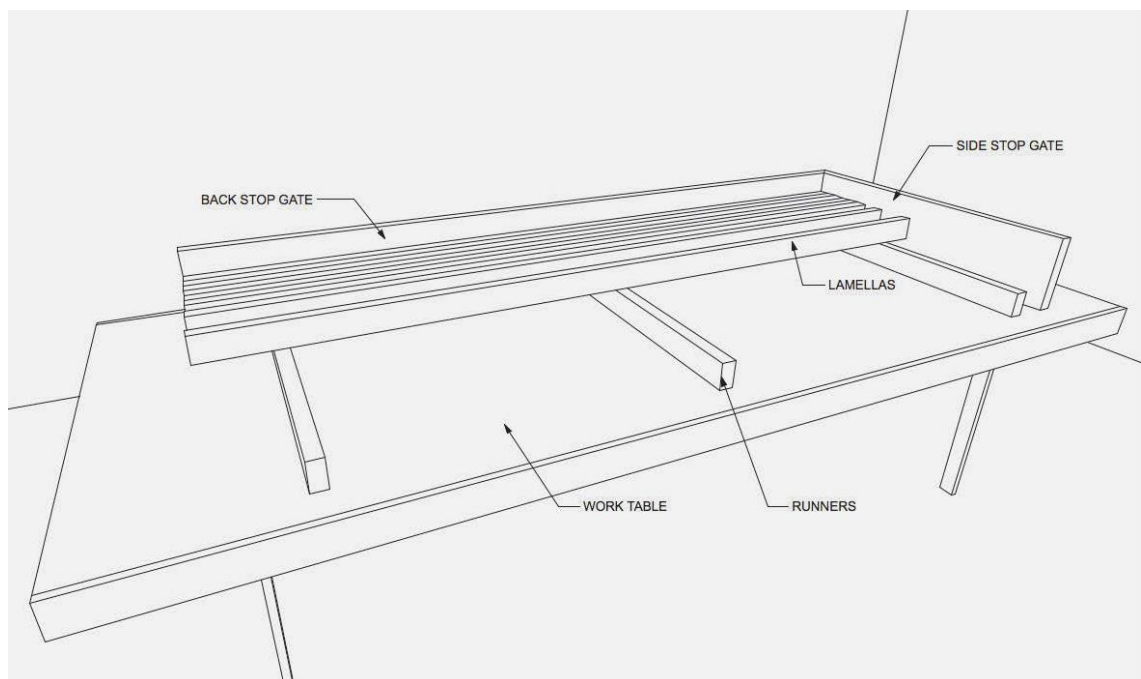


Figure 2.7 GPLT panel manufacturing table and jig.

Once the first lamella was positioned, each subsequent lamella was then placed against the previous member and gun-nailed by hand into place at 250mm centres in compliance with the engineer’s nailing specification. The nail gun used, a *Paslode* Impulse Framing Nailer, was sourced from a local machinery hire business and was typical of the hand held timber framing nail gun units available in Australia and therefore, representative of the type of nail gun likely to be readily accessible. Due to the repetitive nature of the nailing sequence for GPLT panel manufacture, continuous use of a hand held framing nail gun has the potential to cause worker fatigue resulting in time consuming nailing misfires, incorrect nail positioning, unintentional skew nailing and time inefficiencies resulting from the need to manually reload the nail belts into the gun. Regular rest breaks would be beneficial if hand nailing was the primary fixing method. The manufacture of large numbers of panels could easily be optimised through the development of an automated timber feeding system to position and nail each lamella.

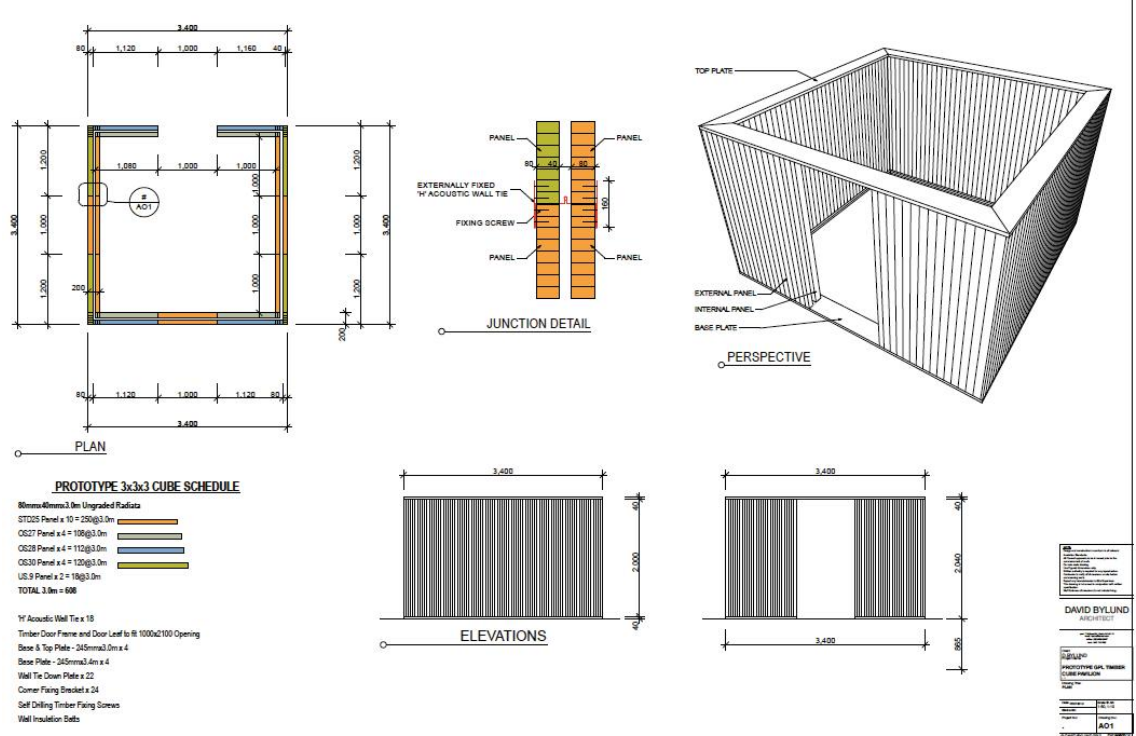


Figure 2.8 Cube structure concept plans, elevations and perspective drawings

The nails used were 75mm x 3.06mm Bright Steel ‘D Head’ nails. A total of 4,400 nails, positioned at 250mm centres along the length of each lamella, were

required to manufacture the 22 panels needed for the cube structure based on the CH² specification. Twelve 'H' Acoustic Wall Ties were also required to tie the inner and outer leaves. Being a temporary structure, eight light weight flat galvanised steel plates were used to secure the corners and hold the wall segments to the 240mm x 35mm base plate. Permanent structures, such as CH², would require the use of the fixing plates and brackets specified by the engineer.

Undertaking the manufacture of a number of GPLT panels demonstrated that individual GPLT leaves must be handled with care during transport and positioning due to the panel's propensity to flex between the lamellas when in an unsupported horizontal position. The nail lamination concept appears to work well as a basic method of laminating when glue and presses are not available. It also appears to be a method capable of maintaining the panels' structural integrity under load, as demonstrated by the load testing undertaken at UWA's School of Civil and Resource Engineering. While the laminated plate retains its structural integrity when supported on the jig and when in its final upright position, it does have the potential to partially delaminate due to a slight serpentine flex when lifted if this support is not maintained.

This serpentine flexing could be reduced by optimising the nail fixing method to assist the plate's ability to withstand transport and positioning stresses or by fixing a diagonal steel strap. The panels manufactured for this structure were nailed along each lamella's long axis centre line at 250mm centres as per Figure 2.9.

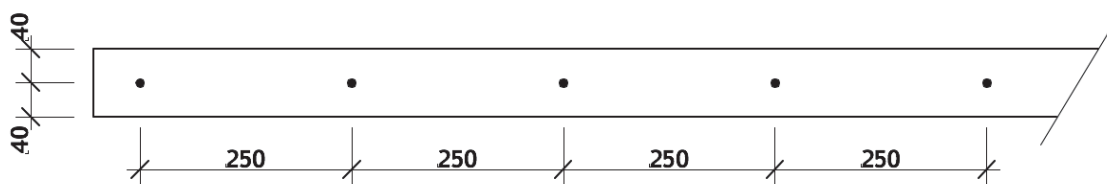


Figure 2.9 In line nailing pattern

If the nailing pattern were to feature a slightly skewed firing angle combined with an offset nail pattern that alternately positioned them closer to the two outer faces of each piece of timber, the potential for unintended delamination of the panel during transport and positioning could be minimised (refer Figure 2.10).

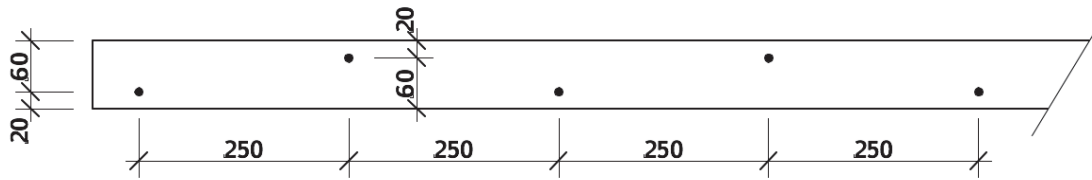


Figure 2.10 Offset nailing pattern

A double skin solid timber panel system requires a unique erection process that determines the order of installation. Figure 2.11 shows the pre-planned panel installation sequence required for the construction of the cube structure.

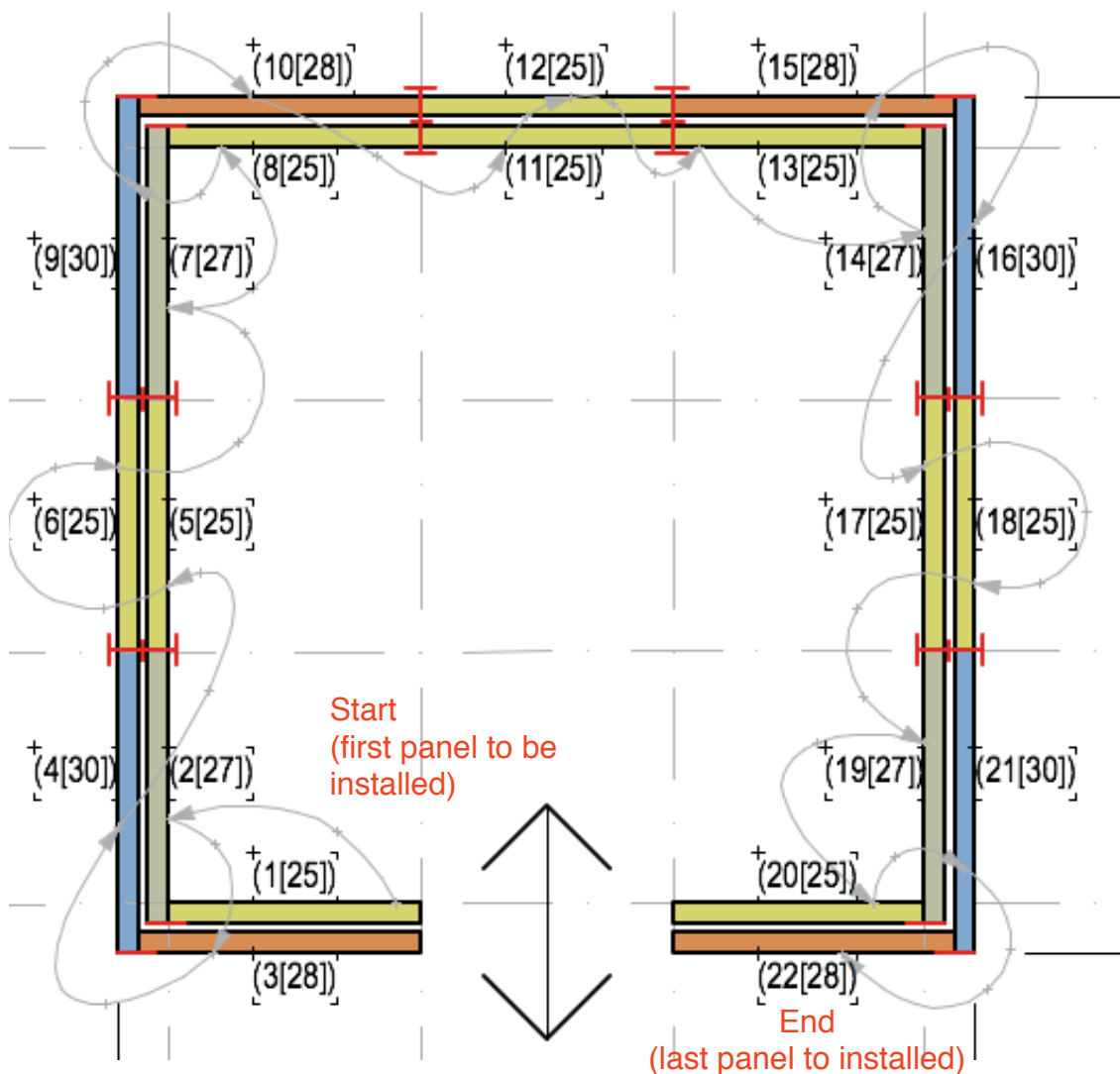


Figure 2.11 Panel erection order diagram.

The construction of the small cube structure demonstrated that it is critical that each panel must be placed into position in the correct order to ensure the alignment of

wall junctions. End panels that form junctions to create corners are slightly longer than standard wall panels to ensure that the outer leaves meet correctly and the inner leaves are the correct size to maintain the cavity's integrity. The preplanning of the on-site panel erection sequence is critical to the process and must be undertaken before the panel manufacture and construction is commenced. Each 'H' Acoustic Wall Tie must be fixed to both the internal and external leaves before the next panel can be fitted into place. Unlike cavity brick walls where the internal and external leaves are built up slowly allowing for wall ties etc to be installed progressively, double leaf, solid panelised methods require a staged installation to avoid blocking the internal access required to fix the anchor brackets.

The arrows and numbers adjacent to each leaf indicates installation order (1 to 22) and panel width:

- [25] Lamella Panel [green],
- [27] Lamella Panel [grey],
- [28] Lamella Panel [orange]
- [30] Lamella Panel [blue]

The process of designing and construction (refer Figure 2.12) of the cube structure has demonstrated the viability of prefabricating GPLT wall panels on a small scale and the value in constructing a simple structure to test the panel montage process.

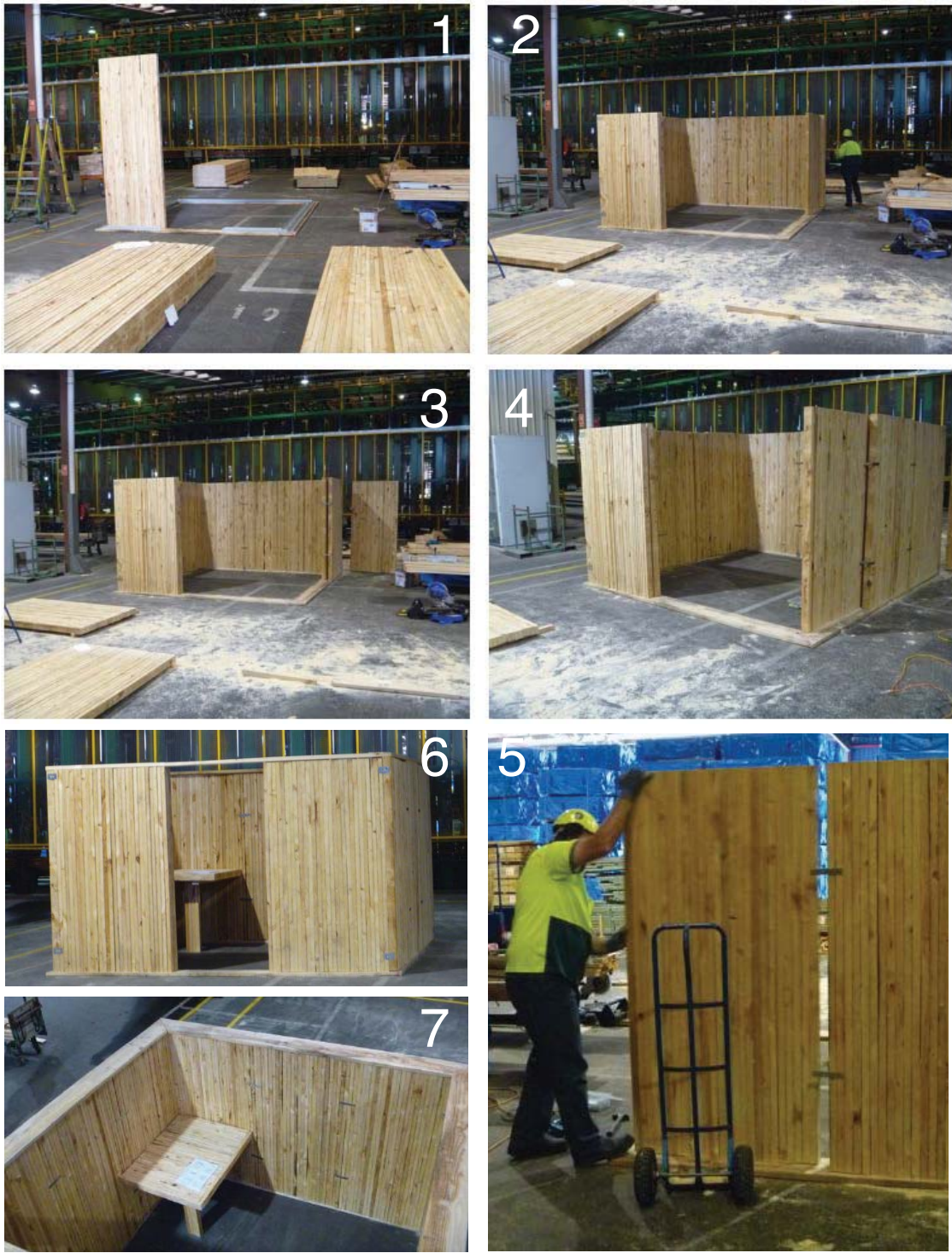


Figure 2.12 Cube construction images 1 to 7. The prefabricated panels can be seen in stacks in the foreground and background of the upper left images. Finalised cube structure in lower left images. Lower right shows a mill employee locating a panel using a standard bag trolley. Photo by D.Bylund

2.2.7 - GPLT and BCA Building Classification

The Building Code of Australia (BCA) states that residential buildings other than one and two storey Class 1 dwellings must be constructed according to stringent acoustic and fire standards. Depending on the type of construction and specifics of the building's design, these can be met by conforming to Deemed-to-Satisfy (DTS) provisions. If a building's structural typology is not covered by those applicable to the DTS provisions, demonstration of a particular performance requirement can be met by providing an 'Alternative Solution'.

Currie Hall would be classified as a Class 3 building. The Building Code of Australia (BCA) 2011 states in Table C1.1 that Type A construction (the most fire resistant type of construction) is required for Fire Resistance and Stability for this class of structure.

Unless a conditional concession is applicable such as those granted to Class 2 timber framed buildings that are three storeys or less, all internal load bearing walls in three storey, Type A construction buildings must be either concrete or masonry to be approved under the DTS provisions. This provision reflects the conservative approach to fire safety that the BCA adopts. One of the implications of this is that new technologies such as solid timber construction are excluded from being approved under the DTS provisions if intended for a project that is four or more storeys. The fire and acoustic performance of solid timber construction is yet to be accounted for in the BCA's DTS provisions and thus projects that fall outside the DTS requirements must be assessed under the 'Alternate Solution' method. This puts solid timber construction at a fundamental disadvantage over concrete and masonry, despite being more similar in character and performance than to timber frame, because the additional costs associated with demonstrating an alternate solution can be prohibitive. This disadvantage has the potential to disproportionately bias against the advantages of solid timber construction such as significantly faster construction times and the

significantly lower environmental impact of the use of renewable plantation timbers when compared to deemed-to-satisfy solutions using steel, masonry or concrete.

As mentioned above, in contrast to three storey Class 3 buildings, a similar Class 2 building can be built using timber framing and approved under the DTS provisions under Clause 3.10 of the BCA, provided that the insulation used in the walls is non-combustible and automatic smoke alarms are fitted. It is reasonable to assume that an architect or developer is more likely to consider a solid timber structural system for a project similar to the GPLT based CH² proposal if it could be approved under the DTS provisions; alternatively, given the similarity between Class 2 and Class 3 buildings, it could be argued that approval could be sought as a Class 2 building.

Until solid timber panelised systems are identified in the BCA/NCC with DTS provisions, the Australian Building Codes Board (ABCB) building product certification scheme entitled 'CodeMark' would be the most direct method of determining BCA/NCC compliance via a performance based methodology.

According to the ABCB, the CodeMark scheme is intended to '... encourage innovation ...' via a '... performance-based approach to building construction and design' (ABCB CodeMark 2013). This would provide GPLT panels with a nationally accepted compliance certification via the performance based method for a given period. To achieve CodeMark certification, a CodeMark application can be assessed by registered certification bodies such as SAI Global, Global-Mark or CertMark Australasia.

It should be noted that currently only the above mentioned certification companies can assess new building systems and products and as such, the demonstration of BCA/NCC compliance via the alternative solution method for CH² as proposed is not the intention of this thesis.

2.2.8 - Expected Fire Resistance

As a composite wall panel system, GPLT, as defined in this study, incorporates both an external cladding and internal lining. Currie Hall's location relative to the surrounding buildings determines the necessary Fire Resistance Level (FRL) for the load bearing walls according to Section C1.1, Table 3 of the BCA. Assuming that the design is assessed as a Class 2 building, relative to the nearest building (on the southern side), the required external wall FRL is 90/60/60. The internal walls' FRL is 90/90/90 for both load bearing stair shaft walls and load bearing walls between the sole occupancy units.

Data specifically designed to demonstrate methods of achieving the required FRL in Australian timber construction is limited to timber framed construction in documents such as CSR's *'The Red Book'* and Wood Solutions' *'Timber-framed Construction for Multi-residential Buildings Class 2, 3 & 9c'*. Both publications utilise the encapsulation method of meeting compliance by using Gyprock lining and/or Fibre Cement Wall board to achieve compliance. While these methods of compliance are applicable because of the composite nature of GPLT, test results on European CLT would indicate that the solid nature of a panelised timber wall significantly improves a building's ability to maintain structural integrity in a fire because the charring effect is limited to only one continuous panel face when encapsulation is not used. It is well established that the burnt layer or 'char' that accumulates on the face of timber when exposed to flames acts as a protective element on the inner timber allowing the element to retain its structural integrity. Charring rates do vary between timber species and this needs to be taken into account when specifying the timber to be used. Radiata pine's charring rate is 0.8mm/ minute (EWPAA 2012).

The solid laminated arrangement of members within both CLT and GPLT mean that there is no cavity or hollow core to the panel itself as is typical with standard timber frame construction. This solid nature has the effect of restricting a fire's ability to burn through a wall as it only has access to one face of each of the lamellas within the wall

as each edge face is protected by their immediate neighbours. This charring effect on timber can be measured and the subsequent rate of burn can be used to ensure that a solid timber wall, floor or roof is designed with adequate thickness to maintain the necessary structural integrity for the duration required to retain its load carrying capacity.

Recent fire testing of a three storey CLT structure by the SOFIE-Fief Valley Building Systems Research Project, coordinated by WALSA, an institute of the National Research Council of Italy, has demonstrated CLT's capacity to retain its structural integrity in fire conditions exceeding 1000 degrees Celsius (CNR-IVALSA 2007). The CLT maintained its natural insulating properties by providing sufficient protection from extremes of heat in adjoining rooms to allow the occupants to survive for the period of the test.

In contrast to steel structures, it is well recognised that solid timber buildings will generally outperform their steel counterparts in a fire, especially if the fire retardant measures applied to the steel have been compromised.

The 50mm cavity between the two leaves in the double leaf GPLT wall configuration would be filled with a wool based insulation material to provide additional acoustic and thermal performance. The insulation material also has the capacity to act as a fire inhibitor in the situation where a fire breaches one of the GPLT panels. Data supplied by Albany Wool Insulation state that the wool is naturally flame resistant and when tested to AS/NZ 4859.1 the following results were achieved:

- Ignitability - 0
- Spread of flame - 0
- Heat evolved - 0
- Smoke development - 0 to 1

(Albany Woolstore Insulation 2005)

The minimisation of the risk of fire spreading through the core of the double leaf GPLT panel would require a design solution that factored the fire resistant qualities of

the wool insulation and adequate flame resistant linings between floors and other attached structural elements. The steel plates and connectors that connect and fix down GPLT panels would require intumescent paints on all exposed surfaces or be encapsulated behind gyprock or a similar material. The inclusion of fire sprinkler systems would also assist in achieving fire compliance.

2.2.9 - Acoustic Performance

Solid timber panels have inherent airborne noise absorption properties as evidenced by the widespread use of perforated timber panels in performance spaces.

As the number of solid timber buildings have increased in Sweden, the acoustic testing methods themselves are being questioned and disparities between theoretical outcomes and actual outcomes are emerging. Anecdotal evidence from Sweden indicates that solid timber multi-residential buildings out perform their calculated impact noise levels. One explanation for this is that the calculation methodologies themselves favour traditional forms of construction resulting in an inherent bias towards steel and concrete. Societal expectations of acceptable noise levels will vary from place to place and this must also be taken into consideration.

Until a significant number of solid timber buildings are completed in Australia, it is yet to be determined if a similar trend will be exhibited here.

It is well established that detailing is critical to meeting acoustic expectations when designing with timber. Unlike detailing with concrete that typically assumes that its mass will provide sufficient acoustic attenuation, timber multi-residential structures must incorporate detailed acoustic decoupling through sound attenuating measures such as acoustic wall ties, acoustic insulation layers and hybrid timber concrete inter-storey floors. This method of taking acoustic considerations into the architectural and structural design is known as discontinuous construction.

The BCA's list of acceptable forms of construction does not contain any directly comparable descriptions of wall types from which to apply a DTS solution to a GPLT

wall element, but does endorse the principles of discontinuous construction for timber based structures. The double skin variant of GPLT as proposed in this thesis utilises a discontinuous construction approach to noise transfer minimisation that is intended to conform to the BCA's requirements.

Based on advice received from Mr Norbert Gabriels of *Gabriels Environmental Design Pty Ltd*, discontinuous construction in conjunction with double layers of sound rated linings will achieve the DTS requirement of $Rw+Ctr$ 50. Mr Gabriels estimated that the initial double skin variant of the GPLT wall was estimated to achieve $Rw+Ctr$ 40 when incorporated with double layers of fire and sound rated linings. This 10db difference is significant and was the result of the inclusion of the 190mm x 35mm end piece and the two 120mm x 35mm trimmers in each panel. These elements bridge the gap between the two leaves and in effect, create a bridge that has the potential to carry sound waves. Based on Mr Gabriel's advice, it would seem reasonable to expect that the final variant of the double leaf GPLT wall will remove the 190mm x 35mm end piece and replace it with an acoustic wall tie of some kind. As previously noted, in conjunction with Matrix Industries Pty Ltd, a variant of an off-the-shelf wall tie was developed that allowed the tie to be fixed to the external faces of each leaf. This new wall tie removed the need for a 120mm x 35mm end trimmer as a fixing point for each leaf. The author has named this variant of the Matrix Industries' acoustic wall tie the '*H' Acoustic Wall Tie* as it resembles the letter H when viewed in plan. Two '*H' Resilient Wall Ties* fixed to the ends of each panel should easily meet the acoustic performance requirement of $Rw+Ctr$ 50 and possibly even approach $Rw+Ctr$ 60 (refer Figures 2.13, 2.14 and 2.15)



Figure 2.13 Off-the-shelf Resilient Wall Tie (MB01GA), (left) and wall tie in position (right) by Matrix Industries Pty Ltd. This system proved to be unfeasible because the fixings required access to an internal face of the 120mm x 35mm end trimmer.

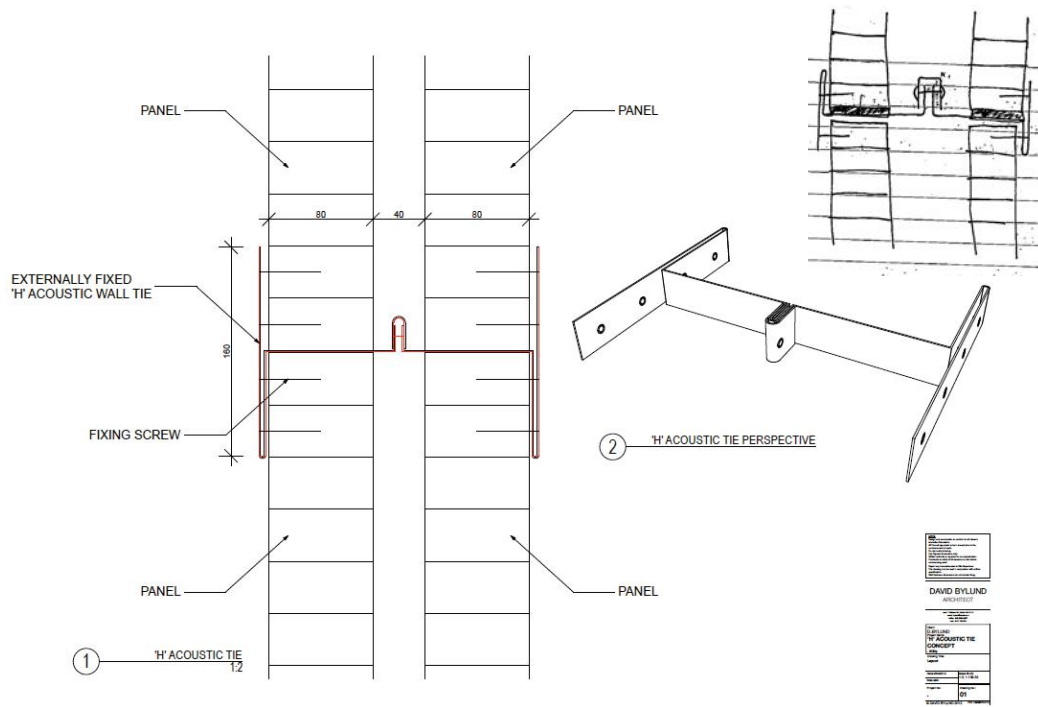


Figure 2.14 Concept drawings for the 'H' Acoustic Wall Tie following acoustic modifications to the original system developed with MLB Consulting Engineers.

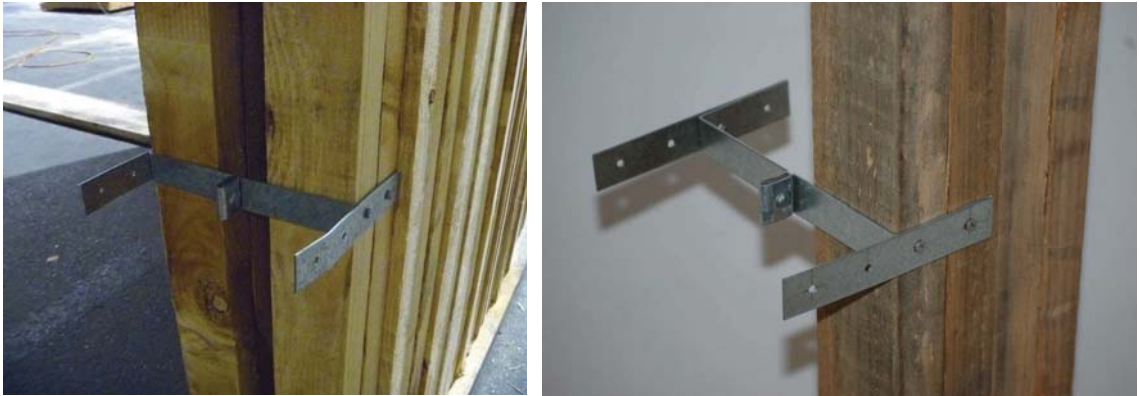


Figure 2.15 Prototype 'H' Acoustic Wall tie fixed to double leaf GPLT wall element. Photo D.Bylund

2.2.10 - Thermal Performance

The thermal performance of a wall system needs to be assessed in the context of the climatic conditions of the area in which the building is to be located. Australia has eight climatic zones ranging from Zone One's hot humid summers in the far north, Zone Three's hot dry summers with mild winters in central Australia to wet summers with cool winters in Zones Five and Six and Zone Seven's mild summers with cold winters. The vast majority of Australia's population lives either in Zone Five, Six or Seven with a

smaller, but significant portion of the population living in Zone Two in Queensland's southern region.

Currie Hall is situated in the Perth suburb of Crawley. Perth and its urban surrounds are classified as Climate Zone 5 which refers to a warm temperate climate.

Table J1.5a Options for Each part of an External Wall that is Part of an Envelope of the BCA states that for Climate Zones Four, Five, Six and Seven, external walls require a minimum total R-Value of 2.8. This can be reduced to R2.3 if the density of the wall is 220 kg/m² or greater (clause - (a), (ii), (A)). According to the BCA Table 2a Thermal Conductivity of Typical Wall, Roof/Ceiling and Floor Materials, a typical composite GPLT wall incorporates external aluminium cladding (2,680 kg/m³ Surface Density of 10.72 kg/m²), two leaves of GPLT (1,012 kg/m³ = 70.84 kg/m²) and two internal layers of Gypsum (1,160 kg/m³ = 22.8 kg/m²). This equates to a cumulative Surface Density of 104.44 kg/m². Being less than the 220 kg/m² required, the R0.5 reduction would not apply. Notwithstanding this, the total R-Value of a double leaf GPLT wall is estimated to be R3.81 which surpasses the required R2.6 minimum. The following table shows the accumulated materials used in an external aluminium clad GPLT wall composite with their respective R-Values, demonstrating its capacity to surpass the requirements for Australia's climatic zones Four, Five and Six.

Item	Description	R-Value
1	Outdoor air film (t m/s)	0.04
2	4mm Alucabond Cladding	0.01
3	20mm airspace	0.17
4	70mm Radiata pine (GPLT panel)	0.51
5	40mm Felted Foil Backed Wool Insulation	2.5
6	70mm Radiata pine (GPLT panel)	0.51
7	Plaster Board (13mm Gypsum)	0.07
TOTAL		3.81

Table 2.7 Estimated double leaf GPLT Total R-Values

2.2.11 - Insect Resistance

Untreated softwood timber in Australia is vulnerable to attack from termites or 'white ants' and the European House Borer. Effective management strategies used to provide protection against insect attack include the use of treated timber in conjunction with the judicious application of other preventative measures such as the inclusion of physical barriers and ensuring moisture cannot penetrate the structure.

To protect against potential insect attack, the GPLT panels intended for use in buildings located south of the Tropic of Capricorn use 'Blue Pine' (refer Figure 2.16), a treated timber using an organic compound based on pyrethroids (found naturally in chrysanthemum daisies). This treatment accords with AS/NZS 1604.1: 2002 using Tanalith T (H2 Blue) for hazard category H2. This 'off-the-shelf' approach is cost effective and in keeping with the aim of utilising as many locally available materials and skills as possible.

Buildings located north of the Tropic of Capricorn using GPLT would require timber treated with products such as Hynne Timber's T2 - Red.



Figure 2.16 Image of Wespine's Blue Pine in a typical stick wall frame application. Image sourced from wespine.com.au

2.2.12 - Junctions and Fixings

As with all timber methods of construction, GPLT walls require a variety of fixing solutions to connect the floor, roof and floor elements.

All GPLT junctions utilise a combination of commercially available off-the-shelf steel brackets, hot dipped galvanised gun driven nails and rib head, hot dipped galvanised or Climaseal® 3 coated screws. All bolts, anchors, nuts and washers are hot dipped galvanised Isometric Hexagonal mild steel Grade 4.6 complying to AS/NZS 1111 and AS/NZS 1112. All nuts and bolts that bear directly against timber have a washer to spread the contact load. MiTek Multigrip timber framing anchors and Rothoblass WZU Angle Bracket 15550 are used as fixing brackets. The Multigrip brackets fix each individual panel to the continuous base and top plates. The WZU brackets fix at each end of the completed wall through the base plate into the structural substrate acting as hold-down brackets. The final version made the MiTek Multigrip brackets redundant through the inclusion of the 90mm x 90mm 'U' shaped galvanised channel that sits the full length of each wall element. This element secures the wall to the floor structure below and allows for the entire length of the wall to be constrained within the 'U' channel as can be seen from the figures below.

The test structure, built at Wespine's Dardanup factory, exhibited a propensity for the individual wall to develop a slight serpentine form in plan if there were any individual lamellas protruding beyond the majority. This could result from slightly inaccurate trimming of the wall along its base or a slightly uneven floor structure. The inclusion of the 'U' channel ensures a secure fixing along the entire wall's length.

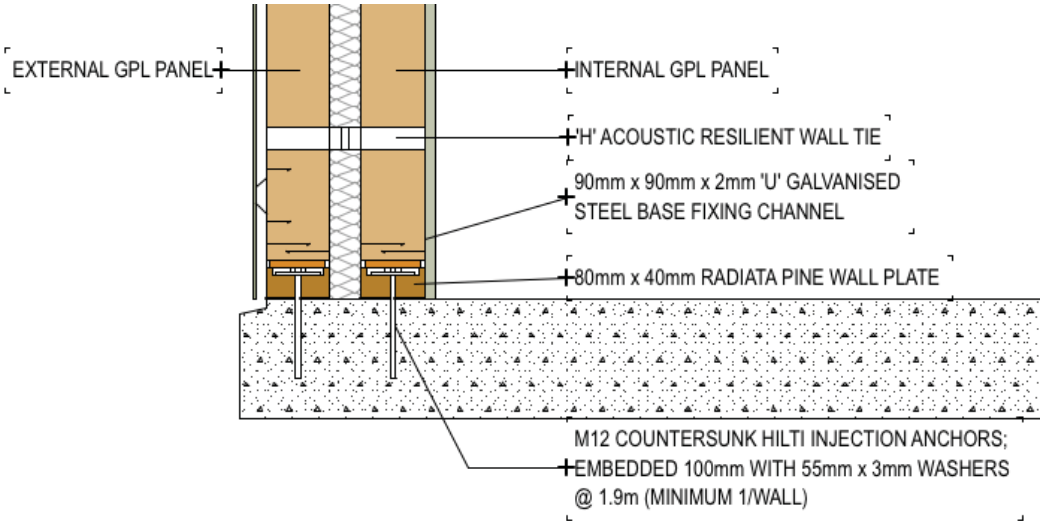


Figure 2.17 Section of a GPLT wall showing fixing to slab

Inclusion of the 'U' channel element could potentially increase the cost. It also requires more care when lowering each element into position to ensure that the channel's side walls are not damaged by the weight of the wall as it is being positioned.

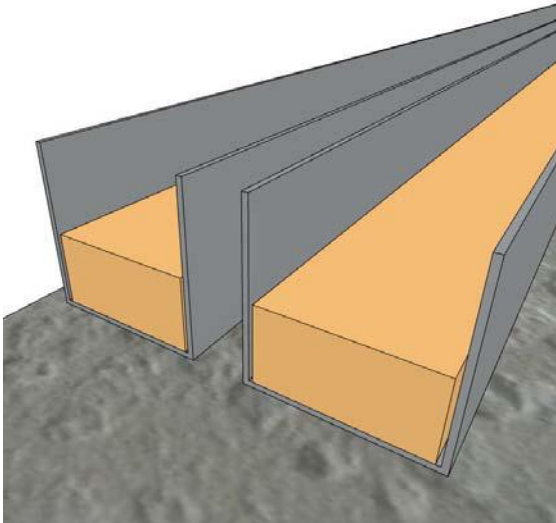


Figure 2.18 3D view of U-channel with pine floor plate and cavity between inner and outer wall leaves.

2.2.13 - Timber and Dimensional Expansion and Contraction

Timbers sawn and dried in one climate and transported to another for on-site construction may react to a change in climate that could adversely affect a building. Understanding how GPLT panels respond to climatic variation would assist in minimising any negative outcomes that could result from production in one climate, such as the mild winter and dry summer of Western Australia's southwest, and transported to another climate, such as northern Australia's tropical zone.

Being a natural material, timber reacts hygroscopically to changes in humidity. Normal seasonal variations in the relationship between the ambient temperature and the relative humidity could have an unintended effect on GPLT wall panels, especially those located on exterior walls or near wet areas. The timber specified for all GPLT panels, both for DDS and DRS timber, will be kiln dried to approximately 12% moisture content. This artificial drying of timber is carried out to '... pre-condition the timber to its expected environment ...' thus '... minimising many problems that might otherwise occur ...' and '... the strength properties of most species increase with its degree of

dryness, while wood with a moisture content maintained below 20% will be immune to decay' (State Forests of New South Wales 1996).

Panelised timber products such as KLH's CLT claim near 100% dimensional stability with '... negligible movement Parallel to Board ...' and '... 0.2 mm/m per % moisture outside Normal to Board' (KLH UK 2013). This level of stability from unmodified timber is a result of the kiln drying to a moisture level of approximately 12% +/- 2% and the cross layering of lamellas acting to constrain timber's normal expansion and contraction. Restraining timber in this way can result in significant tensions developing within the panel that have been known to result in splitting depending on the inter panel gluing method. GPLT does not have CLT's cross layering of timbers acting to minimise any dimensional change in the panel size as it reacts naturally to fluctuations in humidity. Over a full wall length, the expansion or contraction of GPLT's parallel laminated timbers is managed by the inclusion of 3mm foam strips located between each panel acting as a type of expansion joint. The short length of the GPLT wall elements relative to the whole wall length allow for the inclusion of multiple control joints, thus, a 20 metre wall which is comprised of approximately 20 individual GPLT panels can also have up to 20 control joints sandwiched between each panel. If the GPLT panels were to expand in length as they reacted to changes in the surrounding humidity, any potential compounding effect on the wall's overall length is absorbed by the control joints. This feature provides an effective and simple counter measure to overall dimensional wall length change without inducing significant stresses within each panel from cross lamination.

2.2.14 - Expected Maintenance Regimes and End of Life Deconstruction

GPLT buildings should withstand typical wear and tear issues comparable to any other modern structure over the building's expected life span. As with most timber structures, moisture exclusion is paramount. Detailing and regular inspections of external water proofing elements and internal plumbing fixtures and fittings will be a

significant factor in retaining structural integrity. Periodic termite inspections and the provision of an effective chemical barrier in line with standard practice for timber buildings will also be key elements of any preventive maintenance regime.

As with nail plate roof trusses, the use of gun nailing as a method of fixing GPLT panels together could cause complications at the end of the building's life. Building material re-use regimes that take advantage of the panelised nature of GPLT would be more appropriate than attempting to disassemble the panels into their most basic components, that is, down to their individual lamellas. If the intended re-use did not require panel deconstruction down to a stick-by-stick basis, then the panels, subject to structural inspection, could be re-used in the construction of a new building.



Figure 2.19 Fixing the 'H' acoustic wall tie to the external face of the outer GPLT leaf using an electric drill and a #2 Phillips head driver. Photo D.Bylund

If design for disassembly were to be a feature of a building, then the original panel fixing method, through the use of 120mm x 35mm end trimmers, would be difficult if not impossible to do without the use of significant destructive force. The revised inter-panel fixing method using the 'H' acoustic wall ties has an inherent ease of deconstruction advantage resulting from the external face fixing using self drilling #2 Phillips head screws that are both simple to install and simple to remove.

2.3 - Prospective Prefabrication Delivery Routes for GPLT Wall Panels

The CH² cost analysis, presented in Chapter Three, is based on the GPLT panels being fabricated off site in an existing timber truss and frame manufacturer's facility.

This method of manufacture, while relatively straightforward, could be greatly improved by the incorporation of panel prefabrication into a sawmilling facility via

automated processes, as has become common in Scandinavia and central Europe. Greater automation processes infer higher plant, factory and setup costs. For a sawmill or timber building company to consider this approach it would require extensive cost analysis in conjunction with a thorough assessment of the market's willingness to adopt products such as these. Chapter One explored a number of Swedish companies (Martinsons, SolidWood Scandinavia KLH AB and Lindbäck Bygg) who have embraced highly automated production methods to both sawmilling and engineered timber construction methodologies.

Four prospective prefabrication delivery routes for GPLT wall panels have been identified. The manufacturing of solid timber GPLT panels can be carried out with commonly available timber working equipment. The various methods of delivery range from independent production to vertically integrated timber supply, panel production, transport to site and building construction.

The four prefabrication methods are:

- Truss and frame manufacturers diversifying to produce panels to order
- Specialist panel manufacturers producing GPLT panels to order
- Sawmills manufacturing GPLT panels as blanks
- Sawmills manufacturing GPLT panels to order and diversifying into construction as a 'vertically integrated building solution' team member

Key elements of each method are outlined below.

2.3.1 - Truss and Frame Manufacturers

Truss and frame manufacturers diversifying and producing GPLT panels to order:

- Sawmills provide lower grade lumber as required to truss and frame manufacturers in the same method currently used to provide structural timber for the truss and frame industry.
- Truss and frame companies manufacture panels as an additional product to their existing wall frames and floor and roof trusses.
- As with their existing framed products, they manufacture panels to order and accept the risks associated with manufacturing and providing a building product/solution.
- Builders build using the GPLT panels sourced from truss and frame manufacturers or timber merchants and source the associated hardware independently.



Figure 2.20 Prototype GPLT panel in truss and frame manufacturer's factory. Photograph by D.Bylund

2.3.2 - Specialist Panel Manufacturers

Specialist panel manufacturers producing GPLT panels to order:

- Sawmills provide multigrade lumber as required to specialist panel manufacturers in the same method currently used to provide structural timber to the timber truss and frame industry.
- Specialist panel manufacturers produce panels to order and accept the risks associated with manufacturing and providing a building product/solution.
- Builders build using the GPLT panels sourced from truss and frame manufacturers or timber merchants and source the associated hardware independently.



Figure 2.21 Prototype GPLT panels in truss and frame manufacturer's factory. Photograph by D.Bylund

2.3.3 - Sawmills Manufacturing GPLT Panels as Blanks

Sawmills manufacturing GPLT panels as blanks:

- Sawmills diversify into producing blank panels in a standard range of sizes to fit common building applications e.g. 600mm x 1000mm, 1200mm x 1000mm, 2400mm x 1000mm, 2800mm x 1000mm.
- Blanks are sold to timber merchants or builders.
- Builders modify panels as required and source the associated hardware independently.
- Sawmills accept the risks associated with manufacturing and providing a building product/solution but are not directly associated with the architect, structural engineer or building contractor beyond sales and marketing or general technical queries (non project specific).



Figure 2.22 Prototype GPLT panels being manufactured in a sawmill. Photograph by D.Bylund

2.3.4 - Vertically Integrated Sawmills

Sawmills manufacturing panels to order and diversifying into construction as a 'vertically integrated building solution' team member:

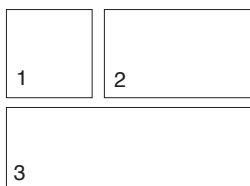
- Sawmills diversify into producing panels to order.
- Strategic relationships are developed by the sawmill with architects and structural engineers as specialist professional service providers who are trained in the specifics of building design using GPLT panels.
- Sawmills develop strategic relationships with builders and hardware suppliers to integrate manufacture, supply and construction solutions to the private and public sector.
- Projects that best suit GPLT solutions are actively tendered for in collaboration with builders and developers.
- In conjunction with the other partners, sawmills accept the risks associated with manufacturing and providing a vertically integrated building product or solution.
- GPLT building solutions are promoted as a total solution approach that highlights the advantages of vertically integrated prefabricated timber construction.



Figure 2.23 Modern sawmilling operation in Sweden preparing timber for finger jointing and lamination.
Photograph by D.Bylund

2.4 - Wall Panel Transport - From Factory to Building Site

The two significant factors affecting the transport of prefabricated building components, whether they be floor, wall or roof elements, is their weight and size. These two factors are dictated by established load restrictions enforced by state and federal authorities in Australia. These load restrictions in turn inform the maximum size of prefabricated elements. Loads that exceed a standard load's width, length, height and weight can be transported, but special permits, pilot vehicles, police and power utilities are required to escort the load and these can add significant costs to a project, potentially reducing the costs benefits of prefabrication.



1. Precast concrete panels on a semi-trailer in Perth, Western Australia on their way to a building site. Photograph. S. Bylund
2. CLT panels on a semi-trailer being off-loaded at a building site near Graz, Austria Photograph D.Bylund
3. CLT panels on a semi-trailer being off-loaded at a building site near Graz, Austria Photograph. D.Bylund

Figure 2.24 Precast concrete panels compared to CLT panels loaded on trucks. Note the number of concrete panels and the number of CLT panels

The use of GPLT wall panels has the potential to reduce the number of trucks on Australian roads traveling to building sites. In contrast to precast concrete, GPLT panels are considerably smaller and substantially lighter. Load arrangements on a semi-trailer or rail car could easily accommodate the 2400mm/2800mm x 1m

dimensions of a standard GPLT panel. A typical flat bed semi-trailer is restricted to two or three precast concrete panels because of their weight (refer Figure 2.24). As already demonstrated, GPLT panels weigh significantly less than concrete. For example, a 100mm thick, 2.4m x 12m precast concrete panel might weigh as much as 6.3 tonnes (assuming 2,200 kg/m³); the comparable GPLT wall, made up of 12 panels, only weighs approximately 1.1 tonnes (assuming 506 kg/m³).

As can be seen in Figure 2.24, only two precast concrete panels can be accommodated on the semi-trailer in the image on the upper left whereas the lower and upper right images show a semi-trailer full of timber panels. The transport efficiencies associated with solid timber panels over precast concrete are self evident.

The cubic weight of masonry bricks can vary from 1430 kg/m³ to 1950 kg/m³. The cubic weight of concrete can range from 1100 kg/m³ to 2200 kg/m³ and the cubic weight of Radiata pine is 506 kg/m³ (BCA 2011). The weight comparison between these three materials, 0.43t/1.85t/m³ (bricks), 1.1t/2.2t/m³ (concrete) and 0.5t/m³ (timber), will significantly affect their transport to site as well as traffic management throughout the building process. Standard brick cartage trucks can carry 28 brick packs. Currie Hall required 168m³ of bricks which equates to 270 packs. Ten truckloads would be required to deliver the necessary number of bricks. Limited site access would restrict on-site storage resulting in a staggered delivery program over the period.

In contrast, the CH² design has 150m³ of GPLT panels. A standard three axle semi-trailer can carry up to 24 tonne and has 77m³ to 80m³ volume load capacity. The 24 tonne capacity limits the number of panels that can be transported, restricting the volume that could be carried in one load and requiring three truckloads.

While the Currie Hall project was not built with precast concrete panels, it did require a significant number of heavy weight, articulated vehicles to deliver the brick packs to the site over the period of masonry construction. According to the project building schedule provided by Palassis Architects, this equated to a period of 75 working days over a three month period. Large numbers of heavily loaded trucks

delivering materials to site could adversely affect other road users at the time as well as influence the amenity of the area during the construction period.



Figure 2.25 Brick packs delivered to the Currie Hall building site waiting to be laid. Image supplied by Palassis Architects

2.5 - GPLT Wall Panel and Three Dimensional Volumetric Construction

Framed Three Dimensional (3D) volumetric module construction is a popular method of timber building prefabrication in Scandinavia. It requires large covered factory floor areas specially equipped and automated to produce lined, serviced wall frames and truss floors in a production line approach.



Figure 2.26 Lindbäcks' automated timber floor panels under construction and volume module production line in Sweden. Photo. D.Bylund

Ninety percent of Sweden's free standing cottage construction and an increasingly large number of multi-storey residential apartments are now built this way. Building in a controlled factory environment allows for a very high level of quality control.

Sophisticated structural, thermal and acoustic solutions that would be difficult to achieve in a traditional on-site building environment can be achieved relatively efficiently with off-site construction methodologies. Building time frames can be significantly reduced when this process is automated. Efficiencies from adopting a 'Lean' approach to construction can provide further benefits. According to Lean Enterprise Australia, the intent of adopting a 'Lean' approach '... is to provide higher quality products with fewer defects'. The Lean production processes attempt '... to minimise human effort, use less space, less capital and less time when compared to traditional systems of mass production (Lean Enterprise Australia 2010).

Sawmills often have strategic relationships directly with the main contracting builder, or operate their own prefabrication companies providing them with secure timber supply contracts.

The process involves a high level of integration between the architect, specialist structural engineer (often supplied in-house) and the main building contractor. Projects are frequently conceived as volume module projects to ensure the design is optimised to suit the volume module constraints. The volume modules themselves are designed to be transported on trucks and lifted by large cranes on site. Modules are often stacked eight to nine storeys high and in combination are designed to create two, three and four bedroom apartments.

This approach to construction requires large scale infrastructure investment and significant key personnel training. A significant proportion of the labour on the construction line is carried out by semi-skilled workers under the supervision of a specially trained tradesman. The on-floor teams are also often trained in the on-site construction requirements and will work on a project from its inception to completion.

GPLT wall panels could be used for volume module construction. However, their weight may negatively affect the significant strength-to-weight advantage commonly associated with standard timber frame construction used in Swedish volume module construction. In Sweden, hybrid structures are beginning to appear that use CLT for

load bearing flooring and roof elements and prefabricated timber frame volume modules for the room layouts.

GPLT panel construction does not require the large scale off-site infrastructure that is associated with highly automated volume module construction. The incorporation of sophisticated thermal and acoustic built solutions as part of the architectural design and specification are completed on site. Once a market was established, the potential to automate the lamination process and incorporate insulation prior to installing the panels on site could be further investigated.

Framed 3D volumetric construction requires the exclusive use of structural grade timber for all structural applications. The cost advantages of GPLT over volume modules are lower prefabrication equipment and training costs combined with, depending on its application, a significant increase in non structural or lower structural grade timber usage. For example, 1m² of wall using GPLT panels requires significantly more timber than framed volume module construction. A typical stud framed timber 1m² wall, assuming studs are placed at 450mm centres, requires a top plate, base plate and three studs (plus noggings/dwangs). This equates to approximately five lineal metres of structural timber. The same wall segment using GPLT requires 45 one metre lengths plus a top and bottom plate, equating to approximately 47 lineal metres of timber.

GPLT panels provide the sawmill industry with a significant opportunity to utilise lower grade timber in a value-added, prefabricated product. The product itself is relatively rudimentary compared to volume module construction. The simplicity of GPLT panels can be an advantage where a sawmill has limited capacity to invest heavily in prefabrication equipment or systems, but still wishes to value add using its 'multigrade timber'.

2.6 - Comparison Between GPLT Wall Panels and Cross Laminated Timber (CLT)

The large scale automated manufacture of planar CLT panels, commonly seen in Scandinavia and central Europe, requires substantial investment in glue and hydraulic press equipment. Due to the large format of the panels, heavy lifting gantries are needed to shift them from the press to the cutting floor and into storage pending transport to site. Computer Numerically Controlled (CNC) cutting equipment is also required to optimise the manufacturing process. When on site, the panels are lifted from the truck using large scale cranes and positioned into place. CLT panels can be used for segmented floor and roof elements and full length walls. This simplifies the on-site montage process and results in very fast construction times.



Figure 2.27 Detail of CLT building under construction in Sweden. Photo. D.Bylund

Beyond the panel and associated openings, only limited services chasing can be done off site. Once the panels are positioned, standard construction fit-out and lock-up procedures need to be carried out. Being solid timber, the services and fit-out process in a CLT structure is generally quicker and easier than with masonry and concrete as any cutting, drilling or fixing requires less effort due to the ease of working with timber.

A potential flow on benefit from the simplified working requirements associated with solid timber construction is the potential for a reduction in work related repetitive strain musculoskeletal injuries that have become synonymous with working with steel, concrete and masonry structures.

As with CLT, GPLT panels are also planar in nature and therefore share many of the traits associated with planar construction. The individual lamellas in GPLT are often dimensionally smaller than CLT, but CLT's cross lamination arrangement gives it significant dimensional stability advantages. As they are both solid timber walls, they require a similar volume of timber, depending on wall thickness, to manufacture although the potential for GPLT panels to use rough sawn timber in combination with the relatively simple nailing lamination process requires significantly less machining to prepare the individual lamellas for lamination.

Individual GPLT panels are the same height as CLT, but are only one metre wide. A 20 metre long CLT wall might comprise one long panel, whereas a 20 metre long single leaf GPLT wall will be made up of 20 individual segments. This introduces a number of advantages and disadvantages to both systems. More time is required on site to connect the GPLT segments, but transport to site is significantly easier. GPLT panels do not require heavy lifting equipment and depending on their height, can be positioned by two men with a lifting trolley. GPLT panels are designed for both single skin walls and double skin walls with a cavity. The double skin GPLT walls can accommodate additional acoustic and thermal insulation located in the cavity. CLT requires these layers on the outer face of the wall which can complicate the building and finishing process.

As the GPLT panel concept is still being developed and has not been commercialised, it is difficult to provide a direct cost advantage comparison with CLT. Notwithstanding this, the significantly simpler infrastructure requirements needed for its manufacture and handling indicate that it will be cheaper to produce, transport and erect on site.

2.7 - Theoretical Structural Building Height Limit for GPLT Wall Panels

As part of a research project commissioned in February 2013 by the New Zealand based timber research group Solid Wood Innovation (SWI), the author was commissioned, in conjunction with MLB Consulting Engineers, to explore the theoretical building height limit using the GPLT wall panels. To test a theoretical building height limit, some assumptions pertaining to expected performance criteria are required. These assumptions were defined by choosing a theoretical site in New Zealand from which to base the calculations. The theoretical investigation detailed in this thesis for the alternative engineered timber CH² has demonstrated the panels' suitability for three storeys on a site in Perth, Western Australia. This data was used as a base from which to test their performance in Auckland which has more demanding seismic and wind load requirements. The double leaf GPLT wall panels provide both vertical and lateral load resistance where one leaf is engineered to withstand both forces and the other leaf is only required to carry vertical loading.

MLB's structural report found that above five storeys, the failure mode of the structure would be either buckling of the laminated timber panels, resulting in structural instability, or crushing of the bottom plates, which are loaded perpendicular-to-grain resulting in unacceptable levels of vertical deflection. Given that the seismic performance was a significant factor in determining the theoretical height limit of a GPLT building in Auckland, MLB's engineering report suggests that the simplest approach to achieve six or greater storeys would be to reduce the weight of the typical floor. At present 70mm of sand is used for acoustic performance. Substituting this with a lightweight alternative may reduce the mass of the typical floors by over 50% and thus positively influence the seismic performance of the structure in the event of an earthquake. Above the five storey range, the serviceability limit state (1/25 year) deflection dictates the required lamination nail spacing. Nail spacings would need to reduce significantly to satisfy this performance requirement, which, depending on the level of automation used, may affect the economy of the structural system.

2.8 - Planar Construction - Bespoke and Sculptural Design Opportunities

Timber is unique in its ability to be worked and sculpted. As with CLT, prefabricated GPLT panels have the potential to be used to create unique and interesting architectural forms. With an increasing number of architects discovering CLT as a building material, it is reasonable to assume that solid timber planar elements will become increasingly common in contemporary architecture and will also be used to craft bespoke architectural designs and sculptural creations. An example of this is the London architectural practice, dRMM's *MK40 Tower*, winner of the 2008 Local Authority Building Control (LABC) Built in Quality – National Awards for Best Structural Project in England and Wales.



Figure 2.28 dRMM's DMK40 Tower. Images supplied by dRMM: drmm.co.uk/projects/mk40-tower/

Another example is *The Termite Pavilion* by Softroom Architects. Here, CLT is layered to create a larger than life sculptural form that imitates a termite mound's interplay between solid and void.

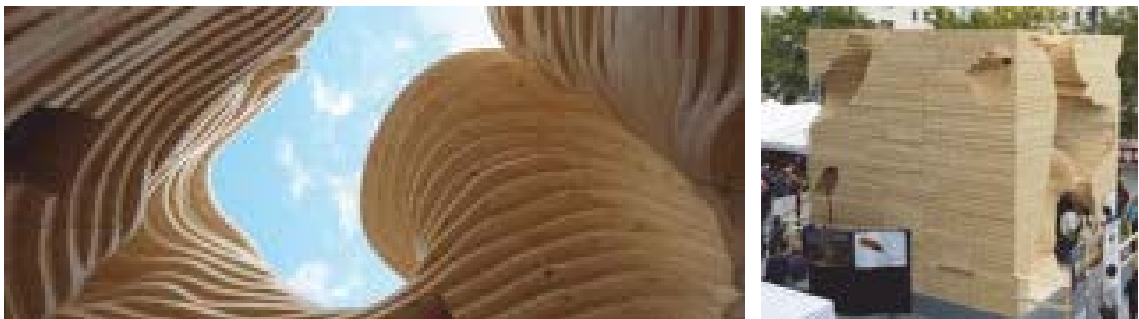


Figure 2.29 The Termite Pavilion. Images supplied by KLH: klhuk.com

As with CLT, GPLT has the potential to suit the emerging field of architectural expression known as folded plate structures.

In Switzerland, architect Dr Hani Buri, in conjunction with architect and engineer Professor Yves Weinand from Laboratory for Timber Constructions – IBOIS, authored a paper entitled, *ORIGAMI – Folded Plate Structures*. Here they explore origami pleating techniques to inform folded plate forms using CLT.

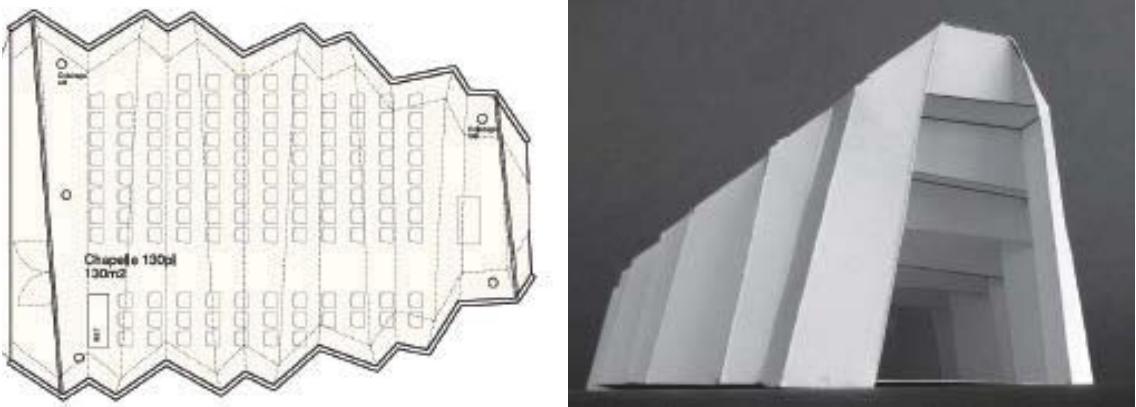


Figure 2.30 Folded plate chapel in Lausanne, Switzerland. Images by Hani Buri

The architectural form of the redesigned Currie Hall project presented in Chapter Three has been developed to demonstrate the application of the GPLT structural concept. The architectonics have been kept simple with the only expressed GPLT timber wall elements in the public entry area and in the central circulation areas on the upper floors. All other internal areas would be clad with Gyprock and Alucobond on the external faces.

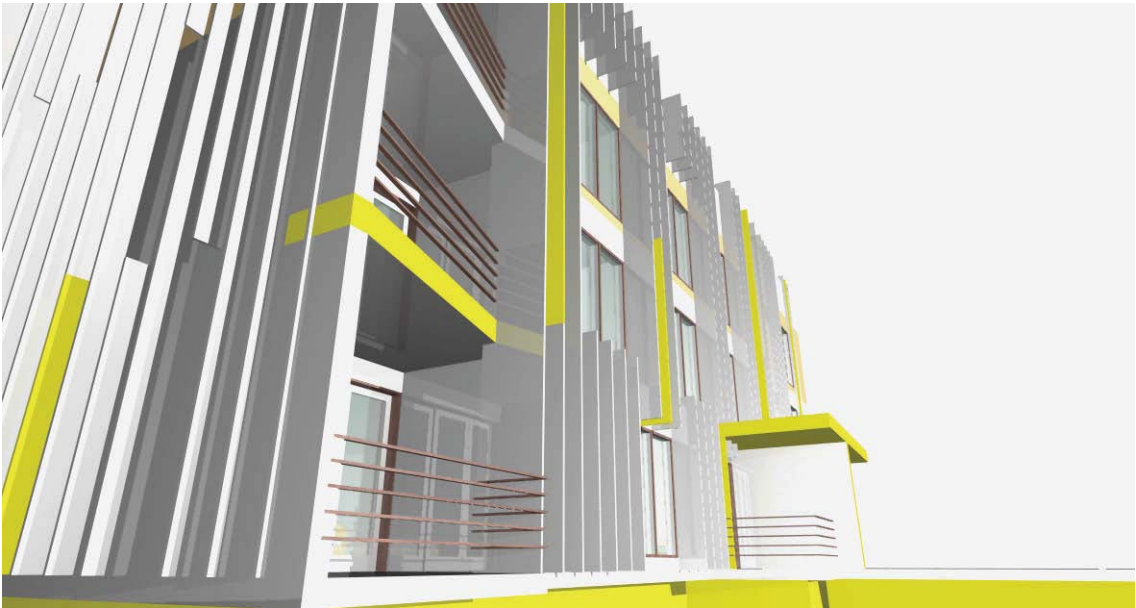


Figure 2.31 Early concept perspective of CH².

3.0 - CURRIE HALL - A DESIGN EXPLORATION

This chapter optimises the GPLT panel design detailed in Chapter 2 through the theoretical application to a three storey residential building located on campus at the University of Western Australia. The building's design was derived from an actual brief used to construct Currie Hall, a masonry student accommodation building. Currie Hall was completed in 2012 and has provided a cost and feasibility reference point from which to compare and contrast an engineered timber solution.

3.1 - Currie Hall - A Benchmark Masonry Building

Located on the *University of Western Australia's* Crawley campus, this building was selected as a case study project for the purpose of comparing it with a typical Western Australian building methodology and to provide a design brief from which an alternate localised engineered timber solution could be developed.

The Currie Hall student accommodation building was designed by local Perth architectural firm *Palassis Architects* and built by *De Francesch Builders* (Builders Registration Number 7563). Structural engineering was provided by the Perth office of *ARUP*. Mechanical engineering was supplied by *DB Mechanical Consulting*, Perth, hydraulic engineering by *SKM Perth* and electrical engineering by *BCA Consults*, Perth.

Currie Hall is a three storey masonry building with a gross internal floor area of 822m². Walls are load bearing double leaf clay bricks and concrete blocks with a 50mm cavity. It is constructed on a floating 100mm thick steel reinforced concrete ground floor slab with reinforced concrete perimeter footings. The upper floors are 172mm thick suspended steel reinforced concrete slabs. The roof structure is a double pitched (5° and 25° respectively) steel frame with Colorbond sheeting and a circular, poly carbonate skylight. There are fifteen single bed-sit rooms with shared facilities, eight partially self contained rooms and one fully self contained apartment (refer to Table 3.1 for more details). Build cost was approximately \$3.3 million (approximately \$4,000/m²) and it took one year to complete. It is typical of materials, costs, construction processes and build times in Western Australia. Originally the brief required the rooms to cost approximately \$100,000 each, but due to variations during construction and unforeseen site issues, the expenditure per room was \$137,500. The project was partially funded by the Australian Federal Government's *National Rental Affordability Scheme*.

The Site Plan and Ground Floor Plan can be seen Figure 3.1. Refer to Appendix E and F for more detailed architectural plans and a photographic montage of the construction sequence.

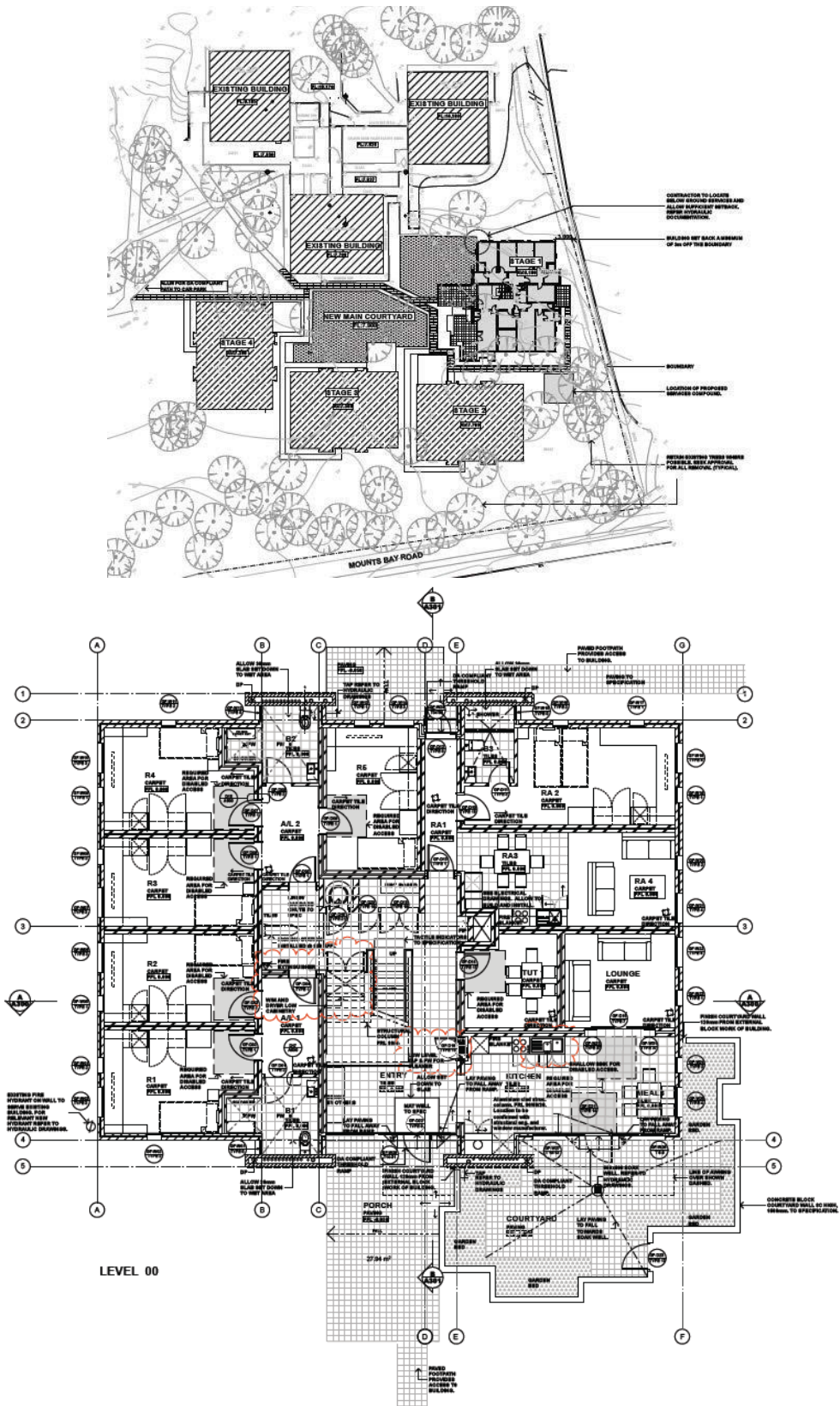


Figure 3.1 Currie Hall (stage 1) – Site Plan and Ground Floor Plan. Images supplied by Pallasis Architects



Figure 3.2 Currie Hall (stage 1) – Elevations. Images supplied by Pallas Architects The as-built scheme includes the following rooms:

First Floor (Ground) Gross Internal Floor Area (GIFA) - 274m ²	Second Floor GIFA - 274m ²	Third Floor GIFA- 274m ²
5 single bed-sit rooms (15m ² each)	5 single bed-sit rooms (15m ² each)	5 single bed-sit rooms (15m ² each)
2 shared bathrooms (6.5m ² each)	2 shared bathrooms (6.5m ² each)	2 shared bathrooms (6.5m ² each)
2 shared kitchenettes (6.5m ² each)	2 shared kitchenettes (6.5m ² each)	2 shared kitchenettes (6.5m ² each)
1 fully self contained unit (55m ²)	4 partially self contained units (22m ² each)	4 partially self contained units (22m ² each)
1 communal kitchen (24m ²)	1 communal tutorial room (9.5m ²)	1 communal tutorial room (9.5m ²)
1 communal lounge room (12m ²)		
1 communal tutorial room (9.5m ²)		

Table 3.1 As built Currie Hall room floor by floor room schedule



Figure 3.3 Currie Hall (stage 1) – Completed building, August 2012. Images - D.Bylund

3.2 - Currie Hall - A Benchmark Construction Cost Analysis

Five building companies submitted tenders which averaged \$2,930,709 for the Palassis Architects' design for Currie Hall.

The winning tender was \$2,940,100 which equates to \$3,576/m² (gross internal floor area). For reference, the Davis Langdon building rates, as published in the Australian Institute of Architects 2010 3rd edition of *The Architect* state that medium rise apartments range from \$2,750/m² to \$3,250/m². Each tenderer supplied an itemised cost schedule and the masonry and block work ranged from \$260,476 to \$280,000 with an average of \$268,899. The winning tenderer's masonry and block work was \$277,740.

Each floor contains approximately 56m³ of masonry and block work, totaling 168m³ across all three levels. Based on the average tender price for the masonry and block work as outlined above, this equates to a supply and lay price of \$1600/m³. The actual tender cost equaled \$1653/m³.

It is assumed that all construction costs other than footings, walls (changed from brick to solid timber GPLT) and the upper floor structures (changed from suspended, reinforced concrete to timber floor joists with 70mm of sand sandwiched to provide additional acoustic absorption) will be the same between both versions of Currie Hall. It is reasonable to assume that the footings for the redesigned GPLT CH² should be less expensive due to the lower load carrying capacity required to be engineered for the approximately two thirds reduction in weight over masonry and suspended concrete floors. This conclusion is supported by the research findings presented at the 2012 World Conference on Timber Engineering (WCTE2012) entitled CLT Apartment Blocks for the Sydney Affordable Housing Market. The authors found that 'Multi-storey timber construction is considerably lighter than RC construction, and on poor foundation material can represent a worthwhile cost saving in terms of foundations' (Hough, Kell & Koopman 2012).

3.3 - Currie Hall 2 - An Indication of Probable Cost

Costs for any new concept can be difficult to assess. Without access to previous comparable project cost data, a cumulative assessment of probable cost has been used to assess the likely cost for the alternative Currie Hall project. Using estimates provided by Wespine, Timbercheck Truss and Frame Manufacturer and Matrix Industries, the following is intended to provide an indication of probable cost for the timber supply, panel fabrication and transportation from Wespine's Dardanup sawmill to a local truss and frame manufacturer and then to the building site in Crawley, Perth. The supply of the acoustic wall ties, on-site panel installation, the builder's margin and a factor for contingencies have also been included.

Unless otherwise noted, all costs exclude the Australian Federal Government's Goods and Services Tax (GST).

3.4 - Currie Hall 2. An Alternative GPLT Proposal

An alternative Currie Hall proposal was developed, based on the original Currie Hall design brief, as a theoretical alternative to test an engineered timber structural system. The alternative CH² brief was derived via a process of reverse engineering the Pallas Architects' design and assessing tender documentation provided by them for its construction. From this information, an all new design solution was developed that conformed to the requirements of the original architectural brief, while also providing a vehicle for the exploration of a new engineered timber building solution. In keeping with the stated project objective, the aim was to develop a structural engineered timber system that could be prefabricated and constructed in Australia using currently available local materials, skills and equipment.

The finalised panel concept and its application to the CH² brief are contained in the architectural drawings presented in Chapter Four and should be read in conjunction with this chapter. A typical floor plan, the front, side elevation and axonometric view of the Ground (1st) Floor are shown below.



Figure 3.4 Alternative CH² front and side elevations

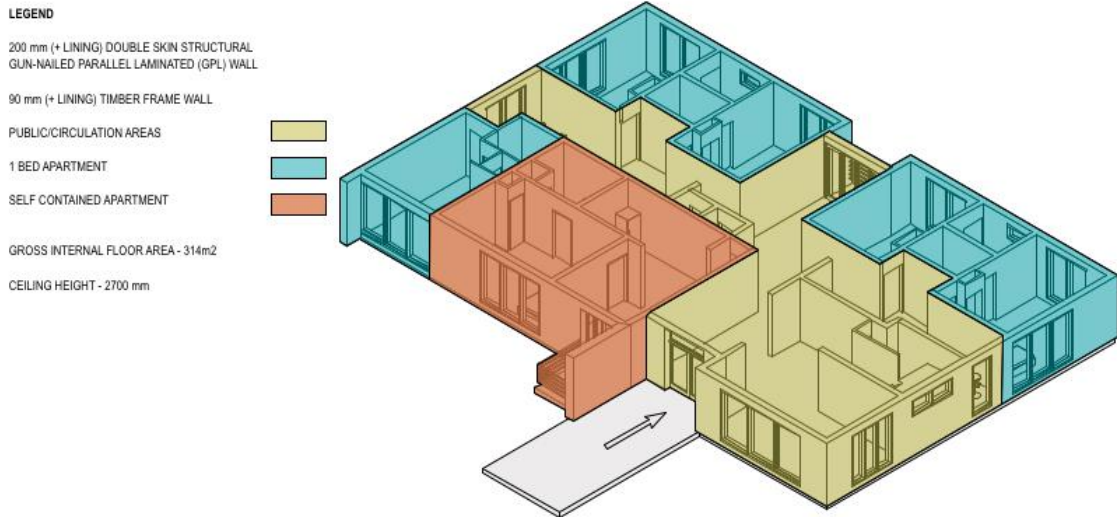


Figure 3.5 CH² axonometric view showing design configuration

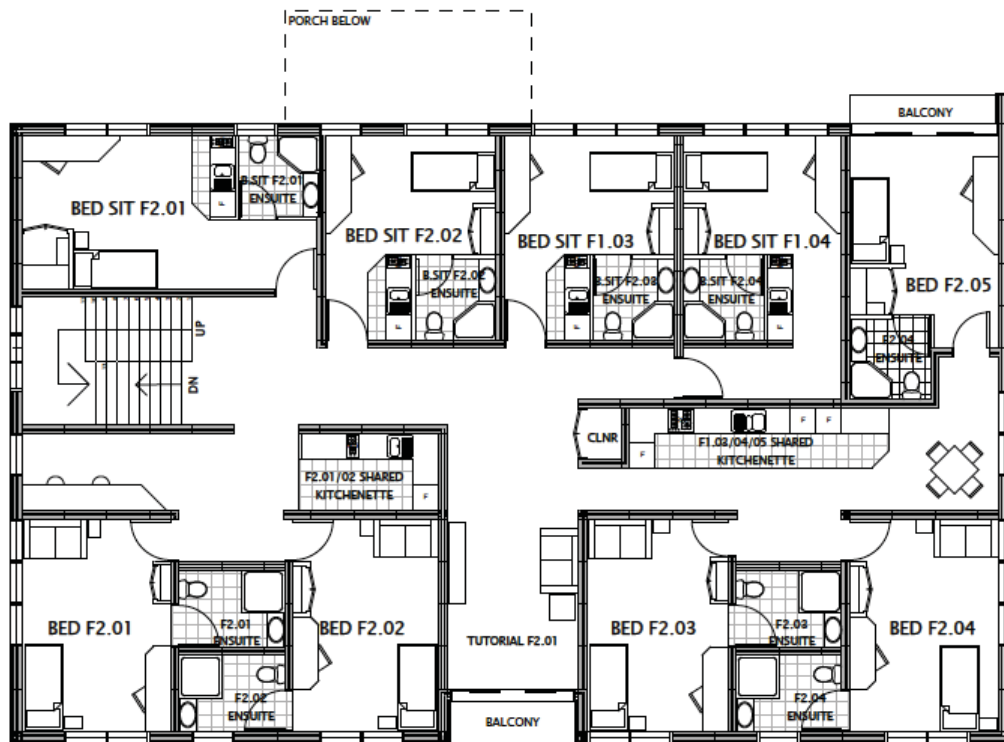


Figure 3.6 Currie Hall 2. A typical upper floor plan

3.4.1 - Acoustic Wall Ties

The CH² design would require 352 'H' Acoustic Wall Ties. Matrix Industries has calculated that they would retail for \$6.89 + GST each. Based on these costs, 352 'H' Acoustic Wall Ties would equate to approximately \$2,425+GST. Refer to Chapter Two, Subsection 2.2.9 for more detail on building acoustics and the 'H' Acoustic Wall Ties.

3.4.2 - GPLT Wall Panel - Transport To Site

Transport costs supplied by Wespine from their Dardanup Sawmill are based on \$15/m³ for sawn timber. Based on the 150m³ required, this would equate to \$2,250 from Bunbury to the building site in Crawley, Perth.

3.4.3 - GPLT Wall Panels and Proposed On-Site Construction Sequence

As with all construction methodologies, prefabricated GPLT wall panels require a structured approach to the assembly and on-site building or 'montage' process. While the single skin variant of GPLT is relatively simple to erect on site, the double leaf variant requires additional planning to ensure its correct installation due to the more complex nature of corner junctions resulting from the inclusion of a cavity.

The following construction sequence outlines the typical panel erection process for CH², utilising the double leaf variant of GPLT walls. It assumes a standard engineered ground floor concrete slab has been poured and that all upper floors are standard timber joists with structural timber flooring and acoustic insulation.

The individual panels are first manufactured off site according to the panel schedule (refer Chapter Four for the complete, floor by floor panel schedules) and transported to site. The panels must be delivered and stacked in the correct order to allow for their installation according to their floor position.

As discussed previously, a double skin solid timber panel system requires a regimented erection process that determines the order of installation. Panels that form junctions or intersections require slightly longer panels with several additional lamellas to ensure that the outer leaves meet and the inner leaves are the correct size to maintain the cavity's integrity. The additional lamellas required to connect the two inner or outer leaves at a corner junction can be seen in red. Each panel is numbered individually for manufacturing, scheduling, and on-site positioning purposes. Below is an example of the panel numbering and continuous wall cavity flow arrangement typically required.

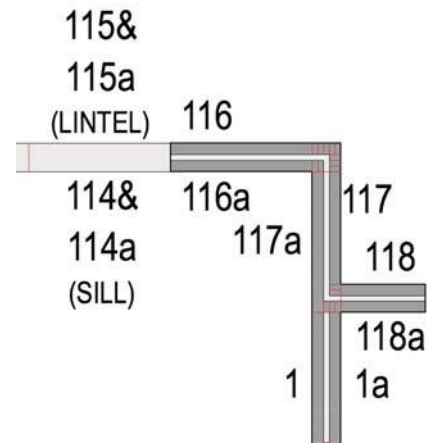


Figure 3.7 Currie Hall 2's typical panel numbering and continuous wall cavity flow arrangement

The scheduling of the on-site panel erection sequence is critical to the process and must be undertaken by the architect in conjunction with the contractor before the site work is commenced. Planning of the available space around the site is also critical to allow for panel deliveries to be placed in the correct order for installation.

Each 'H' Acoustic Wall Tie must be fixed to both the internal and external leaves before the next panel can be fitted into place. Unlike cavity brick walls where the internal and external leaves are built up slowly allowing for wall ties etc to be installed progressively, double leaf, solid panelised methods require a staged installation to avoid restricting the internal fixing access.

The following construction sequence was developed in conjunction with MLB Consulting Engineers:

1. Pour ground level concrete slab and allow to set.
2. Mark out all ground floor wall positions on the slab and lay out with 90mm x 90mm galvanized steel 'U' channels for the inner and outer leaves of each wall. Ensure the 'U' channels are positioned 50mm apart to allow for the wall cavity.

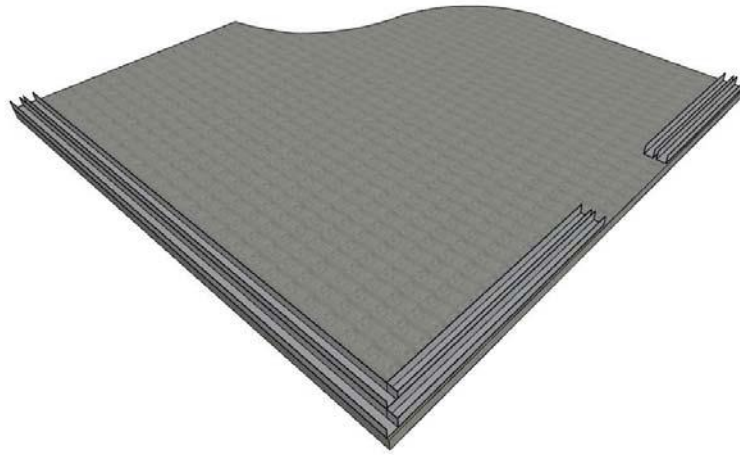


Figure 3.8 Slab with steel channels

3. Place 80mm x 40mm Radiata pine wall bottom plate into the 'U' channel lengths and mark out fixing positions at 2m centres. Countersink and drill the base plates to allow the wall panels to sit directly on the base plate. Anchor the plate through the 'U' channel to the slab using HILTI injection anchors. Note that the anchors at the end of each wall will also secure Rothoblass WZU hold down brackets.

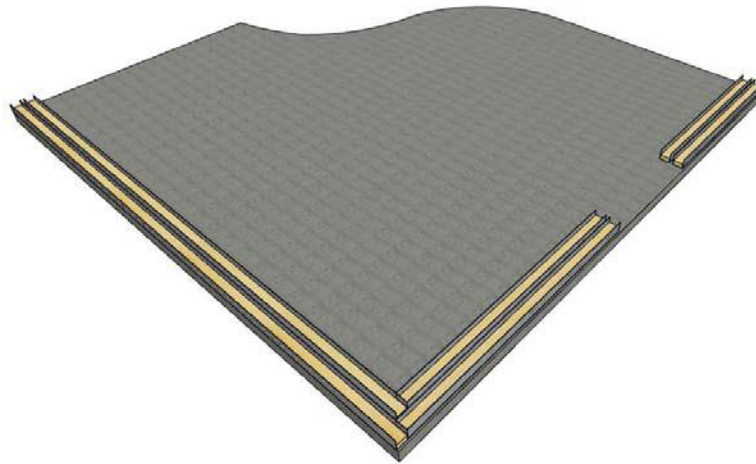


Figure 3.9 Slab with steel channels and timber plate

4. Where possible, fit the first two external wall leaves at a corner to allow them to self support each other when fixed in place.

5. Lift the first corner panel into position, locating it on top of the floor plate and fix it in place using a Rothoblass WZU (15555) angle bracket through the base plate to the HILTI tie-down anchor.

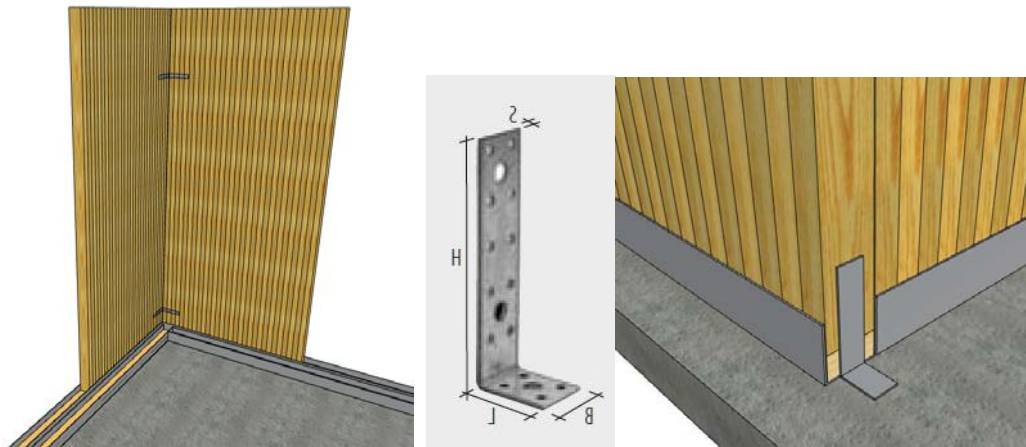


Figure 3.10 Corner panels with angle bracket

6. Using self drilling 10 gauge wood screws at 300mm centres, fix the base of the first outer leaf panel into the outer face of the 'U' channel.
7. Using 10 gauge wood screws, fix two 'H' Acoustic wall ties to the external face of the first panel at 400mm above the floor and 400mm below the ceiling and place the cavity insulation against the inner face of the panel according to the manufacturer's instructions.

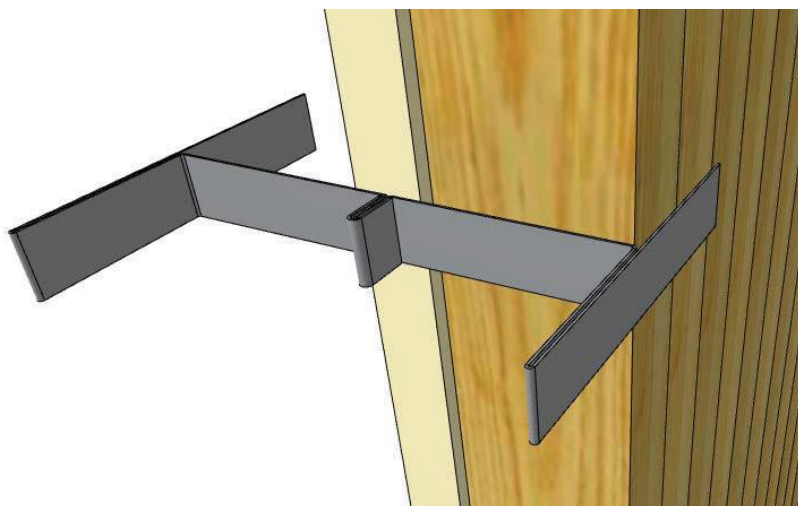


Figure 3.11 "H" acoustic tie and insulation

8. Position the inner panel leaf on top of the inner base plate adjacent to the first panel and screw fix to the 'H' acoustic wall ties. Ensure the two ends of the

panels align to the next two panels. Screw fix into the inner leaf's sides of the 'U' channel as per the previous steps. If it is determined that expansion or contraction of the timbers could adversely affect the structure, 3mm foam packing strips could be placed between the panels to act as a control joint.

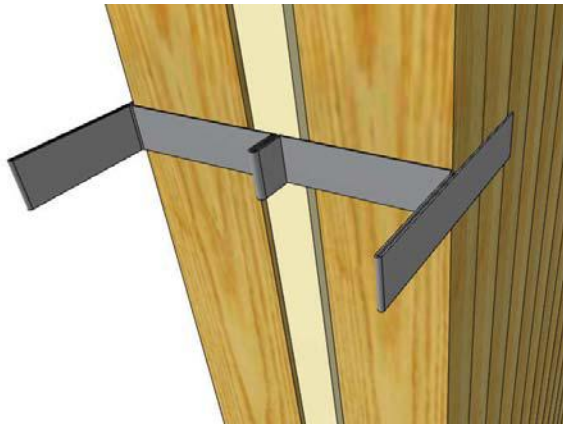


Figure 3.12 "H" acoustic tie, insulation and both inner and outer panels

9. Repeat the above process until the final panel is in place to make up the entire wall length. Repeat the previous six steps for all ground floor walls then fix the 80mm x 40mm top plates to all walls with Multigrip anchors.



Figure 3.13 Corner panel assembly including openings

10. At the end of each wall, provide through bolts to act as tie downs for the wall panels on the floor above. Position WZU angle brackets on the top plate and tighten through bolts.
11. Position floor joists on top of the wall plate using MiTek joist hangers.

12. Install floor panelling onto joists and commence positioning the first wall panel segment for the second storey over the adjacent first storey wall plate below. Fasten with a WZU bracket on the 80mm x 40mm member.



Figure 3.4 Cutaway of completed ground floor walls showing slab, walls with internal lining and timber floor structure above.

3.4.4 - GPLT Timber Supply Costs

CH²'s ground floor contains 48.6m³ of double leaf GPLT internal and external wall, the first floor has 50.5m³ of double leaf GPLT internal and external wall and the top floor has 50.7m³ of double leaf GPLT internal and external wall. This equates to a total of 149.8m³ of timber.

The supply cost estimates for the provision of Radiata pine as Dry Dressed Sawn (DDS) and Dry Rough Sawn (DRS) ex Wespine's Dardanup mill, including Blue Pine treatment as supplied by Wespine, are as follows:

DDS MGP10 timber - $\$500/\text{m}^3 \times 149.8\text{m}^3 = \$74,900$.

DRS ungraded timber - $\$350/\text{m}^3 \times 149.8\text{m}^3 = \$52,430$.

*Refer to the panel spreadsheets in the architectural drawings for a detailed analysis of the number and type of panels required.

3.4.5 - GPLT Wall Panel Fabrication

This modeling assumes that the panels will be made at an existing truss and frame manufacturer to take advantage of the readily available equipment and skills

required for GPLT panels. An alternative model that streamlines the process and begins to incorporate some vertical integration is for the sawmill to manufacture the panels themselves. Likely costings for this were not available at the time of research so have not been included in this thesis. This issue is discussed further in Section 2.3 entitled *Prospective Prefabrication Delivery Routes for GPLT Wall Panels*.

The truss and frame based panel fabrication costs have been calculated, excluding the initial set up of a jig on a flat bed table and the creation of the necessary shop drawings, to equate \$105 per hour for three semi skilled workmen and the gun-nail hardware. The costings are based on figures supplied by Greg Meacham, former Managing Director of *Timbercheck Truss and Frame*.

Based on the prototype build time, a fabrication time of 20 minutes per panel is assumed. Over a 7 hour day this equals 21 panels per day,

CH² has 704 panels. At 21 panels per day, this equates to 33.5 days fabrication or about seven weeks at a total cost of approximately \$24,620.

3.4.6 - On-Site Wall Panel Installation

Without a precedent GPLT design, it is difficult to calculate the on-site assembly time for GPLT panels for a project such as the proposed CH². Based on the extremely fast CLT on-site build time of the eight storey Murray Grove project in the UK (27 days with four men) (TRADA 2009), it could be assumed that the on-site installation of the GPLT panels would also be relatively fast compared to the laying of brickwork. The Murray Grove project averaged one week per storey, including panel transport from Austria. Given that GPLT and panelised timber construction is a new concept in Western Australia, it could be assumed that the on-site construction would be slower than CLT. Furthermore, CLT walls usually consist of one solid panel per wall length whereas GPLT walls are made up of a series of two, side by side one metre long panels.

It would be reasonable to expect that GPLT panels would take longer to erect than a CLT building. However, for the purposes of this exercise it will be assumed that the CH² structure would require one week per floor. This allows a total of three weeks to erect the entire structure on site, ready for lock up, including the installation of prefabricated floor trusses.

As a point of reference, according to Palassis Architect's actual Currie Hall building program, 15 weeks had been allowed for laying and cleaning of the bricks. Assuming the on-site work would require three semi skilled workers, (two fixing, one operating a light crane), the on-site labour cost, based on a three week period assuming \$300/day per worker equates to approximately \$13,500.

3.4.7 - Building Cost Contingencies

Construction projects often allow for a contingency sum. The amount can vary depending on the level of architectural and engineering detail and specification or for unknown site conditions. A common contingency amount in this construction sector is 10%. Based on a subtotal of the above costs, this would equate to approximately \$10,760 for the DDS MGP10 timber and \$8,510 for the DRS ungraded timber.

3.4.8 - Builder's Margin

Projects typically attract a 20% builder's margin or mark up to cover their overheads and profit. Based on the subtotal of the above figures, this would equate to \$25,691 for the DDS MGP10 and \$20,747 for the DRS ungraded timber.

3.4.9 - The Australian Goods and Services Tax

The Australian Government has implemented a 10% Goods and Services Tax (GST) to the majority of goods sold and services provided in Australia. Construction is not excluded from this and subsequently, the GST adds a significant cost burden to all building projects.

Based on the total of the above amounts (\$169,146 for DDS MGP10 and \$139,482 for the DRS ungraded timber), the GST would be \$15,416 and \$12,448 respectively. The total sum, including GST, equates to \$184,562 for the DDS MGP10 timber and \$151,930 for the DRS ungraded.

The following table shows the comparative GPLT costs relative to Light Timber Frame and Masonry. It should be noted that all costs shown are based on indicative amounts only and have been compiled as an academic exercise for the purposes of providing some commentary on the theoretical costs of a GPLT building based in Perth, Western Australia.

ITEM	Light Timber Frame (1,279.5 m² - MGP10)	DRS Ungraded (149.8m³)	DDS MGP10 (149.8m³)	Masonry (168m³)
Timber Supply	\$31,975.00	\$52,430.00	\$74,900.00	NA
Panel Manufacture	NA	\$24,620.00	\$24,620.00	NA
Transport	\$1,000.00	\$2,250.00	\$2,250.00	included
Acoustic Wall Ties	NA	\$2,425.00	\$2,425.00	included
On-Site installation labour	\$44,782.00	\$13,500.00	\$13,500.00	included
Scaffold (estimated)	\$25,000.00	\$15,000.00	\$15,000.00	\$35,000.00
SUBTOTAL	\$102,757.00	\$110,225.00	\$132,695.00	\$277,740.00
10% Contingency (assumed)	\$6,622.00	\$8,510.00	\$10,760.00	\$27,774.00
SUBTOTAL	\$109,379.00	\$118,735.00	\$143,455.00	\$305,514.00
20% Builders' Margin (assumed)	\$14,569.00	\$20,747.00	\$25,691.00	included
SUBTOTAL	\$123,948.00	\$139,482.00	\$169,146.00	\$305,514.00
10% GST (Australia)	\$12,519.00	\$12,448.00	\$15,416.00	\$34,051.00
TOTAL	\$136,467.00	\$151,930.00	\$184,562.00	\$339,565.00

Table 3.2 Cost Comparison between Light Timber Frame (estimate based on combined labour and materials costs/m² supplied by Perth based *Jesset Estimating Services*), DRS ungraded timber, DDS MGP 10 and Masonry for Currie Hall Cost table.

Further to the above indication of probable costs for GPLT, a reduction in other construction related expenditure items could be expected as follows:

- Smaller footing requirements. Radiata pine (506kg/m³) weighs approximately two thirds less than masonry (1430 kg/m³).
- Hardwall internal linings are generally less expensive than render for multi-storey construction.
- Reduction in scaffolding costs due to internal build process.
- Reduced holding costs from faster build time
- Additional cost considerations over masonry.
- External cladding layer, sarking and associated flashing. Had the original Currie Hall been rendered, as is often the case in buildings of this nature, then these costs would be partially negated.
- Insulation in the majority of walls fulfilling the role of acoustic and thermal insulation.

From the above calculations, it can be seen that the supply and installation of the GPLT solid timber panel walls (excluding crane hire) for the alternative CH² proposal could potentially range from \$151,930 for DRS ungraded panels to \$184,562 for MGP10 DDS panels. These figures appear to reflect a significant reduction in cost over brickwork of \$108,180.40 and \$140,809.50 respectively. The apparent difference between solid timber, double leaf GPLT panel walls and standard double leaf masonry points to a significant reduction in cost over standard construction methods.

On a supply and install cost per panel basis for the GPLT CH² design, the DRS panels equate to \$215/panel and the DDS equate to \$262/panel.

Caution should be exercised in drawing any finite conclusions from this data without further research into assessing the likely actual costs of supply, manufacture, transport, site installation and fit out in conjunction with a reputable quantity surveyor,

timber supply company and builder who has previous experience in multi-storey solid timber construction.

3.4.10 - Exclusions

Additional costs that would be directly associated with the use of GPLT panels in construction that have been excluded from the above indication of probable cost are insulation, fixings such as self drilling timber screws, off-the-shelf brackets, the 80mm x 40mm wall plates, the galvanized 'U' channel and the cost of crane hire. These items would require additional research outside the scope of this thesis.

4.0 - CURRIE HALL 2 - PLANS

This chapter applies the engineered timber panelised wall system developed in Chapter Three to a theoretical three storey residential building located in Perth, Western Australia.

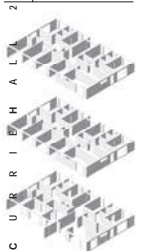
INDEX	
DRAWING #	TITLE
A1.1	COVER
A1.2	SITE PLAN
A1.3	FIRST FLOOR (GROUND) PLAN
A1.4	FIRST FLOOR GPL WALL PANEL ARRANGEMENT PLAN
A1.5	FIRST FLOOR EXTERNAL WALL PANEL ARRANGEMENT
A1.6	FIRST FLOOR INTERNAL WALL PANEL ARRANGEMENT
A1.7	SECOND FLOOR PLAN
A1.8	SECOND FLOOR GPL WALL PANEL ARRANGEMENT PLAN
A1.9	SECOND FLOOR EXTERNAL WALL PANEL ARRANGEMENT
A1.10	SECOND FLOOR INTERNAL WALL PANEL ARRANGEMENT
A1.11	THIRD FLOOR PLAN
A1.12	THIRD FLOOR GPL WALL PANEL PLAN ARRANGEMENT
A1.13	THIRD FLOOR EXTERNAL WALL PANEL ARRANGEMENT
A1.14	THIRD FLOOR INTERNAL WALL PANEL ARRANGEMENT
A1.15	ROOF PLAN
A1.16	ELEVATIONS
A1.17	SECTION S1 & S2
A1.18	DETAILS 1 - 4

(Note: Plans scaled to fit A4)



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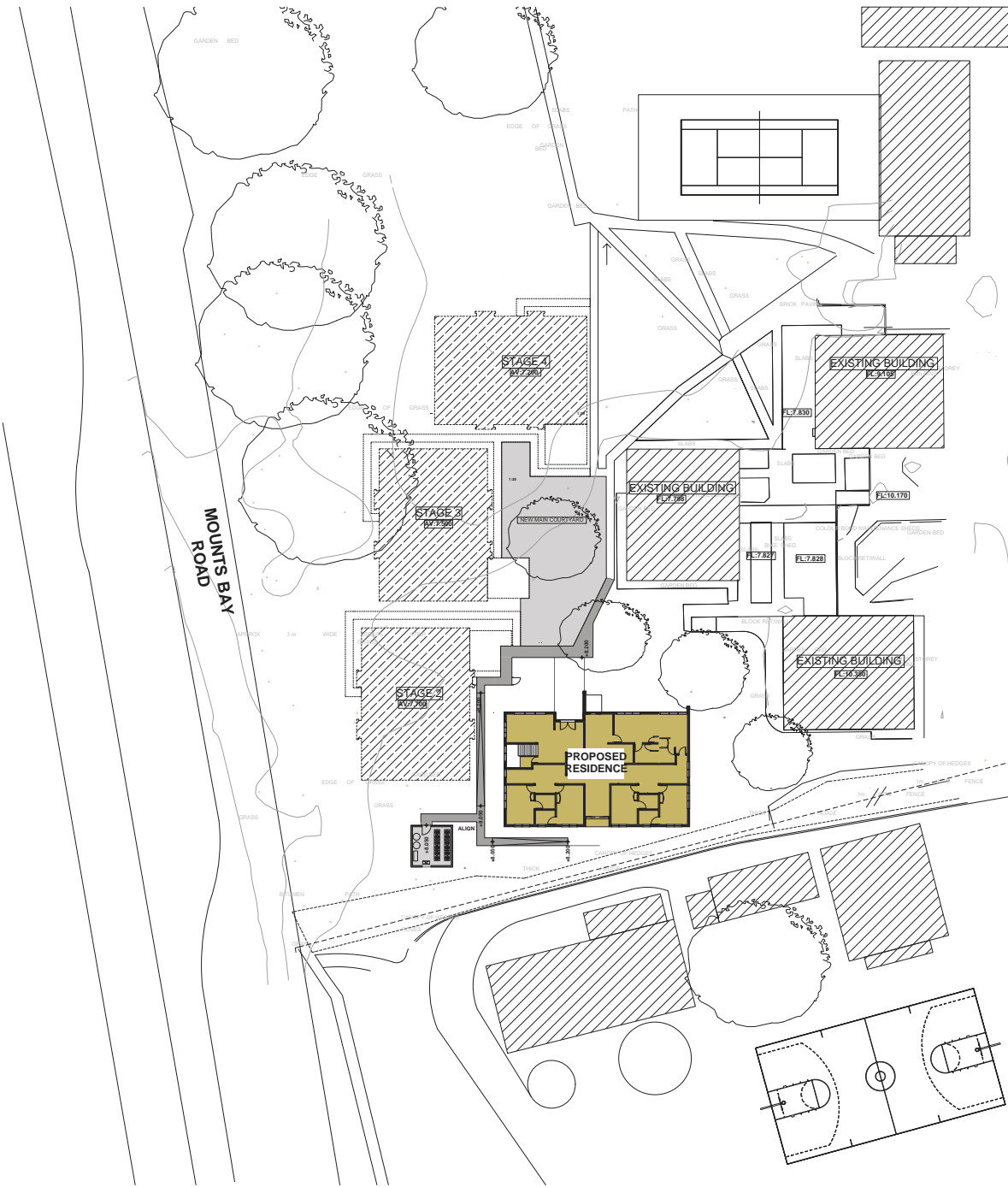
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<small>Date: 19 March 2013</small> <small>Scale: 1:100</small>		<small>Sheet: 01</small>
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CURRIE HALL 2 (CH²)

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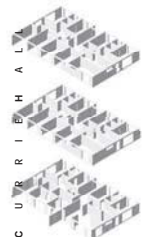
GUN-NAILED PARALLEL LAMINATED TIMBER (GPLT) WALL CONSTRUCTION

4.1 - Site Plan



SITE PLAN
1:400

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Date: 16 March 2011 Drawn: DA Status: OK 2011a		Date: 16 March 2011 Drawn: DA Status: OK 2011a	
Project: CURRIE HALL REDESIGN 300A, STIRLING HIGHWAY, CORREBY PERTH, WESTERN AUSTRALIA		Sheet No: A1.2	



4.2 - First Floor Plan



FIRST FLOOR PLAN
1:100

LEGEND

200 mm (+ LINING) DOUBLE SKIN STRUCTURAL GUN-NAILED PARALLEL LAMINATED (GPL) WALL

90 mm (+ LINING) TIMBER FRAME WALL

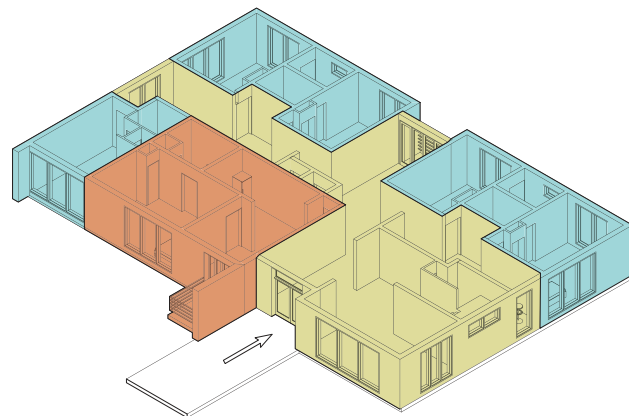
PUBLIC/CIRCULATION AREAS

1 BED APARTMENT

SELF CONTAINED APARTMENT

GROSS INTERNAL FLOOR AREA - 314m²

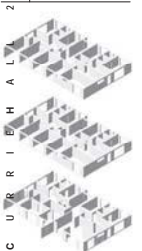
CEILING HEIGHT - 2700 mm



FIRST FLOOR SPATIAL UNIT AXONOMETRY
1:200

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FIRST FLOOR (GROUND) PLAN

Date: 19 March 2013
Scale: 1:100
Drawing: 2011a
Sheet: A1.3

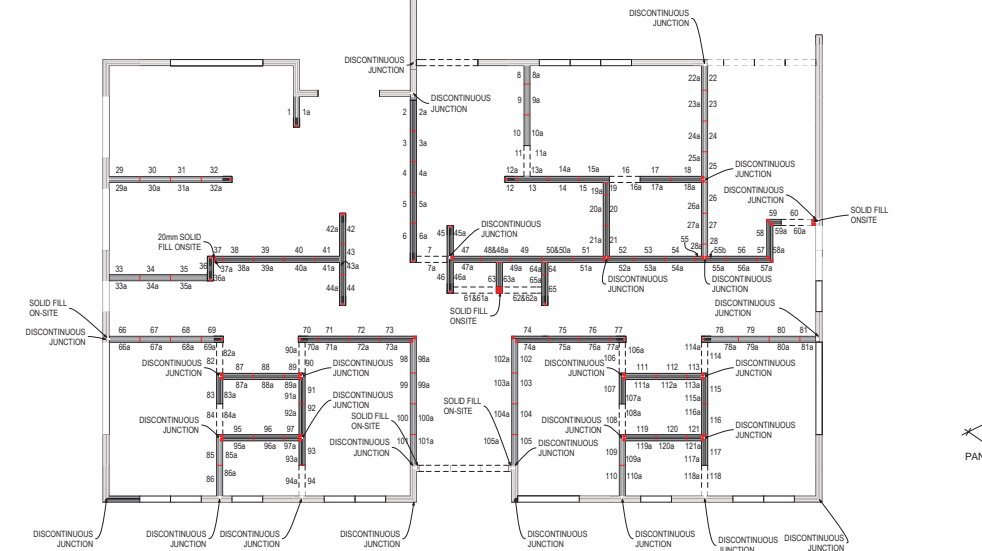
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LOCATION DIAGRAM

PANEL SCHEDULE SPREADSHEET

PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (meters)	POSITION	END CLOSURE	PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (meters)	POSITION	END CLOSURE	PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (meters)	POSITION	END CLOSURE
1a	1	25	2.7	FLOOR	YES	37a	0.28	1	2.7	FLOOR	NO	73a	0.8	1	2.7	FLOOR	NO
2	1	25	2.7	FLOOR	NO	38	1	25	2.7	FLOOR	NO	74	1	25	2.7	FLOOR	NO
2a	1	25	2.7	FLOOR	NO	38a	1	25	2.7	FLOOR	NO	74a	1.12	28	2.7	FLOOR	NO
3	1	25	2.7	FLOOR	NO	39	1	25	2.7	FLOOR	NO	75	1.2	30	2.7	FLOOR	NO
3a	1	25	2.7	FLOOR	NO	39a	1	25	2.7	FLOOR	NO	75a	1	25	2.7	FLOOR	NO
4	1	25	2.7	FLOOR	NO	40	1	25	2.7	FLOOR	NO	76	1	25	2.7	FLOOR	NO
4a	1	25	2.7	FLOOR	NO	40a	1	25	2.7	FLOOR	NO	76a	1	25	2.7	FLOOR	NO
5	1	25	2.7	FLOOR	NO	41	1	25	2.7	FLOOR	NO	77	0.52	13	2.7	FLOOR	YES
5a	1	25	2.7	FLOOR	NO	41a	1	25	2.7	FLOOR	NO	77a	0.52	13	2.7	FLOOR	YES
6	1	25	2.7	FLOOR	NO	42	1	25	2.7	FLOOR	YES	78	1.2	30	2.7	FLOOR	YES
6a	1	25	2.7	FLOOR	NO	42a	1	25	2.7	FLOOR	YES	78a	1.2	30	2.7	FLOOR	YES
7	1	25	0.6	LINTEL	YES	43	1	25	2.7	FLOOR	NO	79	1	25	2.7	FLOOR	NO
7a	1	25	0.6	LINTEL	NO	44	1	25	2.7	FLOOR	NO	79a	1	25	2.7	FLOOR	NO
8	0.6	15	2.7	FLOOR	NO	44a	1	25	2.7	FLOOR	YES	79b	DELETED				
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9	1	25	2.7	FLOOR	NO	45a	1	25	2.7	FLOOR	YES	81	0.52	13	2.7	FLOOR	NO
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10a	1	25	2.7	FLOOR	NO	47	0.96	24	2.7	FLOOR	NO	82a	1	25	0.6	LINTEL	NO
11	0.6	15	2.7	FLOOR	NO	47a	0.96	24	2.7	FLOOR	NO	83	1	25	0.6	LINTEL	NO
11a	0.6	15	2.7	FLOOR	NO	48	1	25	2.7	FLOOR	NO	83a	0.8	20	2.7	FLOOR	NO
12	0.4	10	2.7	LINTEL	YES	48a	1	25	2.7	FLOOR	NO	84	1	25	0.6	LINTEL	NO
12a	0.4	10	2.7	LINTEL	YES	49	1	25	2.7	FLOOR	NO	84a	1	25	0.6	LINTEL	NO
13	1	25	2.7	FLOOR	NO	49a	1	25	2.7	FLOOR	NO	85	1	25	2.7	FLOOR	NO
13a	1	25	2.7	FLOOR	NO	50	1	25	2.7	FLOOR	NO	85a	0.8	20	2.7	FLOOR	NO
14	1	25	2.7	FLOOR	NO	50a	1	25	2.7	FLOOR	NO	86	1	25	2.7	FLOOR	NO
14a	1	25	2.7	FLOOR	NO	51	1	25	2.7	FLOOR	NO	86a	1	25	2.7	FLOOR	NO
15	1	25	2.7	FLOOR	NO	51a	1	25	2.7	FLOOR	NO	87	1.08	27	2.7	FLOOR	NO
15a	1	25	2.7	FLOOR	NO	52	0.8	20	2.7	FLOOR	NO	87a	1.08	27	2.7	FLOOR	NO
16	1	25	0.6	LINTEL	NO	52a	1	25	2.7	FLOOR	NO	88	1	25	2.7	FLOOR	NO
16a	1	25	0.6	LINTEL	NO	53	1	25	2.7	FLOOR	NO	88a	1	25	2.7	FLOOR	NO
17	1	25	2.7	FLOOR	NO	53a	1	25	2.7	FLOOR	NO	89	0.56	14	2.7	FLOOR	NO
17a	1	25	2.7	FLOOR	NO	54	1	25	2.7	FLOOR	NO	89a	0.56	14	2.7	FLOOR	NO
18	1	25	2.7	FLOOR	NO	54a	1	25	2.7	FLOOR	NO	90	1	25	0.6	LINTEL	NO
19	0.4	10	2.7	FLOOR	NO	55	0.28	7	2.7	FLOOR	NO	90a	1	25	0.6	LINTEL	NO
19a	0.4	10	2.7	FLOOR	NO	55a	0.28	7	2.7	FLOOR	NO	91	1	25	2.7	FLOOR	NO
20	1	25	2.7	FLOOR	NO	56	1	25	2.7	FLOOR	NO	91a	1	25	2.7	FLOOR	NO
20a	1	25	2.7	FLOOR	NO	56a	1	25	2.7	FLOOR	NO	92	1	25	2.7	FLOOR	NO
21	1	25	2.7	FLOOR	NO	57	0.4	10	2.7	FLOOR	NO	92a	1	25	2.7	FLOOR	NO
22	1	25	2.7	FLOOR	NO	57a	0.52	13	2.7	FLOOR	NO	93	1	25	2.7	FLOOR	NO
22a	1	25	2.7	FLOOR	NO	58	1.12	28	2.7	FLOOR	NO	93a	0.8	20	2.7	FLOOR	NO
23	1	25	2.7	FLOOR	NO	58a	1.12	28	2.7	FLOOR	NO	94	1	25	0.6	LINTEL	NO
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25	1	25	2.7	FLOOR	NO	60	1	25	0.6	LINTEL	NO	95a	1	25	2.7	FLOOR	NO
25a	0.88	22	2.7	FLOOR	NO	60a	1	25	0.6	LINTEL	NO	96	1	25	2.7	FLOOR	NO
26	1	25	2.7	FLOOR	NO	61	1.4	35	0.6	LINTEL	NO	96a	1	25	2.7	FLOOR	NO
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27	1	25	2.7	FLOOR	NO	62	1.28	32	0.6	LINTEL	NO	97a	0.56	14	2.7	FLOOR	NO
27a	1	25	2.7	FLOOR	NO	62a	1.28	32	0.6	LINTEL	NO	98	1.2	30	2.7	FLOOR	NO
28	0.4	10	2.7	FLOOR	NO	63	0.8	20	2.7	FLOOR	NO	98a	1.2	30	2.7	FLOOR	NO
28a	0.4	10	2.7	FLOOR	NO	63a	0.8	20	2.7	FLOOR	NO	99	1	25	2.7	FLOOR	NO
29	1	25	2.7	FLOOR	NO	64	0.4	10	2.7	FLOOR	NO	99a	1	25	2.7	FLOOR	NO
29a	1	25	2.7	FLOOR	NO	64a	0.4	10	2.7	FLOOR	NO	100	1	25	2.7	FLOOR	NO
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30a	1	25	2.7	FLOOR	NO	65a	1	25	2.7	FLOOR	YES	101	1	25	2.7	FLOOR	NO
31	1	25	2.7	FLOOR	NO	66	1	25	2.7	FLOOR	NO	101a	1	25	2.7	FLOOR	NO
31a	1	25	2.7	FLOOR	NO	66a	1	25	2.7	FLOOR	NO	102	1.08	27	2.7	FLOOR	NO
32	1	25	2.7	FLOOR	YES	67	1	25	2.7	FLOOR	NO	102a	1.2	30	2.7	FLOOR	NO
32a	1	25	2.7	FLOOR	YES	67a	1	25	2.7	FLOOR	NO	103	1	25	2.7	FLOOR	NO
33	1	25	2.7	FLOOR	NO	68	1	25	2.7	FLOOR	NO	103a	1	25	2.7	FLOOR	NO
33a	1	25	2.7	FLOOR	NO	68a	1	25	2.7	FLOOR	NO	104	1	25	2.7	FLOOR	NO
34	1	25	2.7	FLOOR	NO	69	0.72	18	2.7	FLOOR	YES	104a	1	25	2.7	FLOOR	NO
34a	1	25	2.7	FLOOR	NO	69a	0.72	18	2.7	FLOOR	YES	105	1	25	2.7	FLOOR	NO
35	1	25	2.7	FLOOR	NO	70	0.64	16	2.7	FLOOR	YES	105a	1	25	2.7	FLOOR	NO
35a	1	25	2.7	FLOOR	NO	70a	0.64	16	2.7	FLOOR	YES	106	1	25	0.6	LINTEL	NO
36	0.8	20	2.7	FLOOR	YES	71	1	25	2.7	FLOOR	NO	106a	1	25	0.6	LINTEL	NO
36a	0.8	20	2.7	FLOOR	YES	71a	1	25	2.7	FLOOR	NO	107	1	25	0.6	LINTEL	NO
37	0.28	7	2.7	FLOOR	NO	72	1	25	2.7	FLOOR	NO	107a	0.8	20	2.7	FLOOR	NO
						72a	1	25	2.7	FLOOR	NO	108	1	25	0.6	LINTEL	NO
						73	1.12	28	2.7	FLOOR	NO	108a	1	25	0.6	LINTEL	NO
											109	1	25	2.7	FLOOR	NO	
											109a	0.8	20	2.7	FLOOR	NO	
											110	1	25	2.7	FLOOR	NO	
											110a	1	25	2.7	FLOOR	NO	
											111	1.08	27	2.7	FLOOR	NO	
											111a	1.08	27	2.7	FLOOR	NO	
											112	1	25	2.7	FLOOR	NO	
											112a	1	25	2.7	FLOOR	NO	
											113	0.56	14	2.7	FLOOR	NO	
											113a	0.56	14	2.7	FLOOR	NO	
											114	1	25	0.6	LINTEL	NO	
											114a	1	25	0.6	LINTEL	NO	
											115	1	25	2.7	FLOOR	NO	
											115a	1	25	2.7	FLOOR	NO	
											116	1	25	2.7	FLOOR	NO	
											116a	1	25	2.7	FLOOR	NO	
											117	1	25	2.7	FLOOR	NO	
											117a	0.8	20	2.7	FLOOR	NO	
											118	1	25	0.6	LINTEL	NO	
											118a	1	25	0.6	LINTEL	NO	
											119	1	25	2.7	FLOOR	NO	
											119a	1	25	2.7	FLOOR	NO	
											120	1	25	2.7	FLOOR	NO	
											120a	1	25	2.7	FLOOR	NO	
											121	0.56	14	2.7	FLOOR	NO	
											121a	0.56	14	2.7	FLOOR	NO	
											121a	0.56	14	2.7	FLOOR	NO	
											TOTAL	225.12	5628				



4.3 - Second Floor Plan



LEGEND

200 mm (+ LINING) DOUBLE SKIN STRUCTURAL GUN-NAILED PARALLEL LAMINATED (GPL) WALL

90 mm (+ LINING) TIMBER FRAME WALL

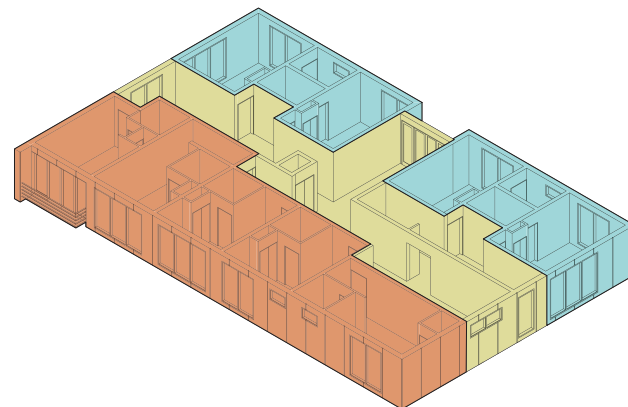
PUBLIC/CIRCULATION AREAS

1 BED APARTMENT

SELF CONTAINED APARTMENT

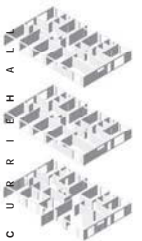
GROSS INTERNAL FLOOR AREA - 318m²

CEILING HEIGHT - 2700 mm



SECOND FLOOR SPATIAL UNIT AXONOMETRY
1:200

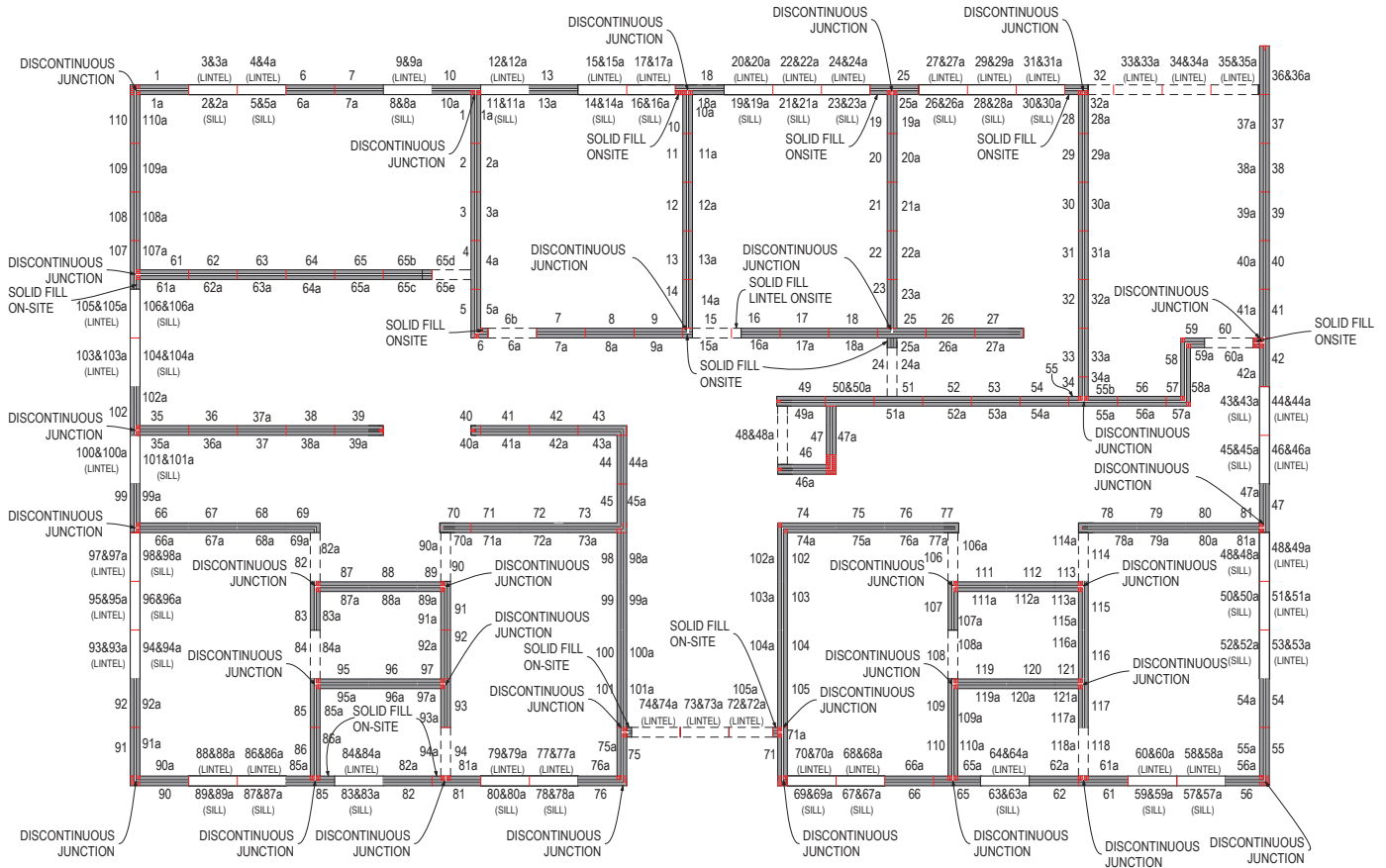
THE UNIVERSITY OF WESTERN AUSTRALIA
ALVA
221013 ISSUE FOR ASSESSMENT



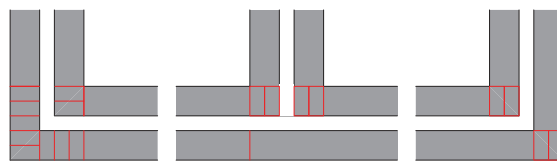
DAVID BYLUND ARCHITECT

Client: UWA	Project: CURRIE HALL REDESIGN
Date: 19 March 2013	Scale: 1:200
Drawn by: DAVID BYLUND	Checked by: DAVID BYLUND
2011a	A1.7





SECOND FLOOR GPL WALL PANEL ARRANGEMENT PLAN
1:75

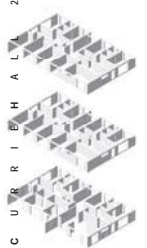


TYPICAL PANEL JUNCTIONS
1:10

EXTRA LAMELLA ELEMENTS.
REFER TO PANEL ARRANGEMENT
SCHEDULES FOR DETAILS



ALVA
221013 ISSUE FOR ASSESSMENT



DAVID BYLUND
ARCHITECT

Client UWA	Project Currie Hall Redesign
Location 1000 Stirling Highway, Fremantle Perth, Western Australia	Scale 1:75, 1:10
Date 14 March 2013	Page 2 of 2
Project 2011a	Sheet No. A1.8



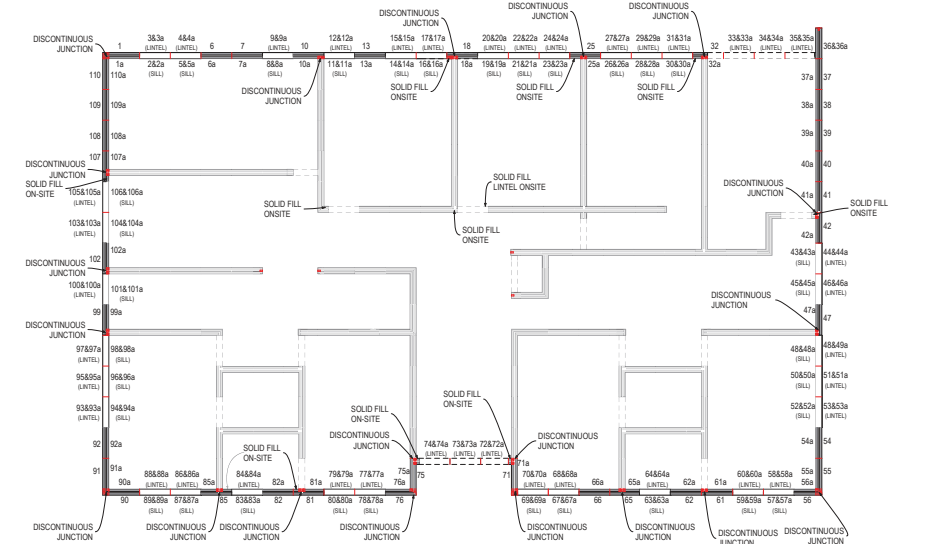
LOCATION DIAGRAM

PANEL SCHEDULE SPREADSHEET

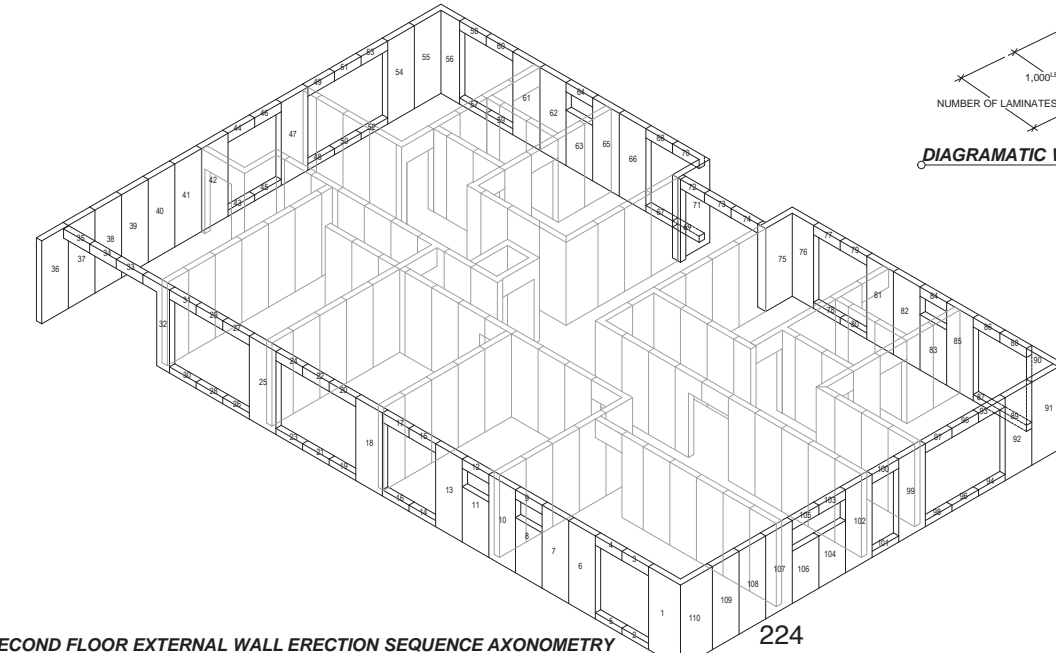
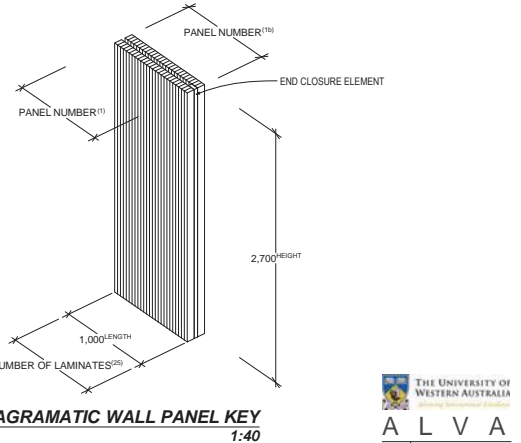
PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE
1a	1	25	2.7	FLOOR	NO
2	1	25	0.2	FLOOR/SILL	NO
2a	1	25	0.2	FLOOR/SILL	NO
3	1	25	0.5	LINTEL	NO
3a	1	25	0.5	LINTEL	NO
4	1	25	0.2	FLOOR/SILL	NO
4a	1	25	0.2	FLOOR/SILL	NO
5	1	25	0.5	LINTEL	NO
5a	1	25	0.5	LINTEL	NO
6	1	25	2.7	FLOOR	NO
6a	1	25	2.7	FLOOR	NO
7	1	25	2.7	FLOOR	NO
7a	1	25	2.7	FLOOR	NO
8	1	25	1.8	FLOOR/SILL	NO
8a	1	25	1.8	FLOOR/SILL	NO
9	1	25	0.3	LINTEL	NO
9a	1	25	0.3	LINTEL	NO
10	1	25	2.7	FLOOR	NO
10a	0.880	22	2.7	FLOOR	NO
11	1	25	1.8	FLOOR/SILL	NO
11a	1	25	1.8	FLOOR/SILL	NO
12	1	25	0.3	LINTEL	NO
12a	1	25	0.3	LINTEL	NO
13	1	25	2.7	FLOOR	NO
13a	1	25	2.7	FLOOR	NO
14	1	25	0.2	FLOOR/SILL	NO
14a	1	25	0.2	FLOOR/SILL	NO
15	1	25	0.5	LINTEL	NO
15a	1	25	0.5	LINTEL	NO
16	1	25	0.2	FLOOR/SILL	NO
16a	1	25	0.2	FLOOR/SILL	NO
17	1	25	0.5	LINTEL	NO
17a	1	25	0.5	LINTEL	NO
18	1	25	0.2	FLOOR/SILL	NO
18a	0.730	19	2.7	FLOOR	NO
19	1	25	0.2	FLOOR/SILL	NO
19a	1	25	0.2	FLOOR/SILL	NO
20	1	25	0.5	LINTEL	NO
20a	1	25	0.5	LINTEL	NO
21	1	25	0.2	FLOOR/SILL	NO
21a	1	25	0.2	FLOOR/SILL	NO
22	1	25	0.5	LINTEL	NO
22a	1	25	0.5	LINTEL	NO
23	1	25	0.2	FLOOR/SILL	NO
23a	1	25	0.2	FLOOR/SILL	NO
24	1	25	0.5	LINTEL	NO
24a	1	25	0.5	LINTEL	NO
25	1	25	2.7	FLOOR	NO
25a	0.820	19	2.7	FLOOR	NO
26	1	25	0.2	FLOOR/SILL	NO
26a	1	25	0.2	FLOOR/SILL	NO
27	1	25	0.5	LINTEL	NO
27a	1	25	0.5	LINTEL	NO
28	1	25	0.2	FLOOR/SILL	NO
28a	1	25	0.2	FLOOR/SILL	NO
29	1	25	0.5	LINTEL	NO
29a	1	25	0.5	LINTEL	NO
30	1	25	0.2	FLOOR/SILL	NO
30a	1	25	0.2	FLOOR/SILL	NO
31	1	25	0.5	LINTEL	NO
31a	1	25	0.5	LINTEL	NO
32	1	25	2.7	FLOOR/SILL	NO
32a	1	27	2.7	FLOOR/SILL	NO
33	1	25	0.3	LINTEL	NO
33a	1	22	0.3	LINTEL	NO
34	1	25	0.3	LINTEL	NO
34a	1	25	0.3	LINTEL	NO
35	1	25	0.3	LINTEL	NO
35a	1	25	0.3	LINTEL	NO
36	1	25	2.7	FLOOR	YES
36a	1	25	2.7	FLOOR	YES
37	1	25	2.7	FLOOR	NO

PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE
38	1	25	2.7	FLOOR	NO
38a	1	25	2.7	FLOOR	NO
39	1	25	2.7	FLOOR	NO
39a	1	25	2.7	FLOOR	NO
40	1	25	2.7	FLOOR	NO
40a	1	25	2.7	FLOOR	NO
41	1	25	2.7	FLOOR	NO
41a	1.08	27	2.7	FLOOR	NO
42	1	25	2.7	FLOOR	NO
42a	0.88	22	2.7	FLOOR	NO
43	1	25	0.2	FLOOR/SILL	NO
43a	1	25	0.2	FLOOR/SILL	NO
44	1	25	0.5	LINTEL	NO
44a	1	25	0.5	LINTEL	NO
45	1	25	0.2	FLOOR/SILL	NO
45a	1	25	0.2	FLOOR/SILL	NO
46	1	25	0.5	LINTEL	NO
46a	1	25	0.5	LINTEL	NO
47	1	25	2.7	FLOOR	NO
47a	0.88	22	2.7	FLOOR	NO
48	1	25	0.2	FLOOR/SILL	NO
48a	1	25	0.2	FLOOR/SILL	NO
49	1	25	0.5	LINTEL	NO
49a	1	25	0.5	LINTEL	NO
50	1	25	0.2	FLOOR/SILL	NO
50a	1	25	0.2	FLOOR/SILL	NO
51	1	25	0.5	LINTEL	NO
51a	1	25	0.5	LINTEL	NO
52	1	25	0.2	FLOOR/SILL	NO
52a	1	25	0.2	FLOOR/SILL	NO
53	1	25	0.5	LINTEL	NO
53a	1	25	0.5	LINTEL	NO
54	1	25	2.7	FLOOR	NO
54a	1	25	2.7	FLOOR	NO
55	1	25	2.7	FLOOR	NO
55a	1	25	2.7	FLOOR	NO
55b	NA	NA	NA	NA	NA
56	0.88	22	2.7	FLOOR	NO
56a	0.76	19	2.7	FLOOR	NO
57	1	25	0.2	FLOOR/SILL	NO
57a	1	25	0.2	FLOOR/SILL	NO
58	1	25	0.5	LINTEL	NO
58a	1	25	0.5	LINTEL	NO
59	1	25	0.2	FLOOR/SILL	NO
59a	1	25	0.2	FLOOR/SILL	NO
60	1	25	0.5	LINTEL	NO
60a	1	25	0.5	LINTEL	NO
61	1	25	2.7	FLOOR	NO
61a	0.88	22	2.7	FLOOR	NO
62	1	25	0.2	FLOOR/SILL	NO
62a	1.04	26	0.2	FLOOR/SILL	NO
63	1	25	1.8	FLOOR/SILL	NO
63a	1	25	1.8	FLOOR/SILL	NO
64	1	25	0.3	LINTEL	NO
64a	1	25	0.3	LINTEL	NO
65	1	25	2.7	LINTEL	NO
65a	0.56	14	2.7	FLOOR	NO
66	1	25	2.7	FLOOR	NO
66a	1	25	2.7	FLOOR	NO
67	1	25	0.2	FLOOR/SILL	NO
67a	1	25	0.2	FLOOR/SILL	NO
68	1	25	0.5	LINTEL	NO
68a	1	25	0.5	LINTEL	NO
69	1	25	0.2	FLOOR/SILL	NO
69a	0.88	22	0.2	FLOOR/SILL	NO
70	1	25	0.5	LINTEL	NO
70a	1	25	0.5	LINTEL	NO

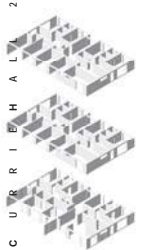
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71	1.08	27	2.7	FLOOR	NO
71a	1	25	2.7	FLOOR	NO
72	1	25	0.3	LINTEL	NO
72a	1	25	0.3	LINTEL	NO
73	1	25	0.3	LINTEL	NO
73a	1	25	0.3	LINTEL	NO
74	1	25	0.3	LINTEL	NO
74a	1	25	0.3	LINTEL	NO
75	1	25	2.7	FLOOR	NO
75a	1	25	2.7	FLOOR	NO
76	1	25	2.7	FLOOR	NO
76a	0.88	22	2.7	FLOOR	NO
77	1	25	0.2	FLOOR/SILL	NO
77a	1	25	0.2	FLOOR/SILL	NO
78	1	25	0.5	LINTEL	NO
78a	1	25	0.5	LINTEL	NO
79	1	25	2.7	FLOOR	NO
79a	0.56	14	2.7	FLOOR	NO
80	1	25	0.2	FLOOR/SILL	NO
80a	1	25	0.2	FLOOR/SILL	NO
81	1	25	0.5	LINTEL	NO
81a	0.88	17	2.7	LINTEL	NO
82	1	25	2.7	FLOOR	NO
82a	1	25	2.7	FLOOR	NO
83	1	25	1.8	FLOOR/SILL	NO
83a	1	25	1.8	FLOOR/SILL	NO
84	1	25	0.3	LINTEL	NO
84a	1	25	0.3	LINTEL	NO
85	1	25	2.7	FLOOR	NO
85a	0.56	14	2.7	FLOOR	NO
86	1	25	0.2	FLOOR/SILL	NO
86a	1	25	0.2	FLOOR/SILL	NO
87	1	25	0.5	LINTEL	NO
87a	1	25	0.5	LINTEL	NO
88	1	25	2.7	FLOOR	NO
88a	1	25	2.7	FLOOR	NO
89	1	25	0.5	LINTEL	NO
89a	1	25	0.5	LINTEL	NO
90	1.12	28	2.7	FLOOR	NO
90a	1	25	2.7	FLOOR	NO
91	1	25	0.5	LINTEL	NO
91a	1	25	0.5	LINTEL	NO
92	1	25	2.7	FLOOR	NO
92a	1	25	2.7	FLOOR	NO
93	1	25	0.2	FLOOR/SILL	NO
93a	1	25	0.2	FLOOR/SILL	NO
94	1	25	0.5	LINTEL	NO
94a	1	25	0.5	LINTEL	NO
95	1	25	0.2	FLOOR/SILL	NO
95a	1	25	0.2	FLOOR/SILL	NO
96	1	25	0.5	LINTEL	NO
96a	1	25	0.5	LINTEL	NO
97	1	25	0.2	FLOOR/SILL	NO
97a	1	25	0.2	FLOOR/SILL	NO
98	1	25	0.5	LINTEL	NO
98a	1	25	0.5	LINTEL	NO
99	1	25	2.7	FLOOR	NO
99a	0.88	22	2.7	FLOOR	NO
100	1	25	0.2	FLOOR/SILL	NO
100a	1	25	0.2	FLOOR/SILL	NO
101	1	25	0.5	LINTEL	NO
101a	1	25	0.5	LINTEL	NO
102	1	25	2.7	FLOOR	NO
102a	0.88	22	2.7	FLOOR	NO
103	1	25	0.2	FLOOR/SILL	NO
103a	1	25	0.2	FLOOR/SILL	NO
104	1	25	0.5	LINTEL	NO
104a	1	25	0.5	LINTEL	NO
105	1	25	0.2	FLOOR/SILL	NO
105a	1	25	0.2	FLOOR/SILL	NO
106	1	25	0.5	LINTEL	NO
106a	1	25	0.5	LINTEL	NO
107	1	25	2.7	FLOOR	NO
107a	0.88	17	2.7	FLOOR	NO
108	1	25	2.7	FLOOR	NO
108a	1	25	2.7	FLOOR	NO
109	1	25	2.7	FLOOR	NO
109a	1	25	2.7	FLOOR	NO
110	1.08	30	2.7	FLOOR	NO
110a	1.2	30	2.7	FLOOR	NO
111	NA	NA	NA	NA	NA
111a	NA	NA	NA	NA	NA
112	NA	NA	NA	NA	NA
112a	NA	NA	NA	NA	NA
113	NA	NA	NA	NA	NA
113a	NA	NA	NA	NA	NA
114	NA	NA	NA	NA	NA
114a	NA	NA	NA	NA	NA
115	NA	NA	NA	NA	NA
115a	NA	NA	NA	NA	NA
116	NA	NA	NA	NA	NA
116a	NA	NA	NA	NA	NA
117	NA	NA	NA	NA	NA
117a	NA	NA	NA	NA	NA
118	NA	NA	NA	NA	NA
118a	NA	NA	NA	NA	NA
119	NA	NA	NA	NA	NA
119a	NA	NA	NA	NA	NA
120	NA	NA	NA	NA	NA
120a	NA	NA	NA	NA	NA
121	NA	NA	NA	NA	NA
121a	NA	NA	NA	NA	NA
TOTAL	216.92	5414			



FIRST FLOOR EXTERNAL WALLS ERECTION SEQUENCE PLAN
1:120
NOTE: INTERIOR LEAF 'A' PANEL NOT SHOWN IN AXONOMETRIC VIEW. REFER TO PLAN VIEW AND SPREADSHEET FOR 'A' PANEL LOCATION & SPECIFICATION

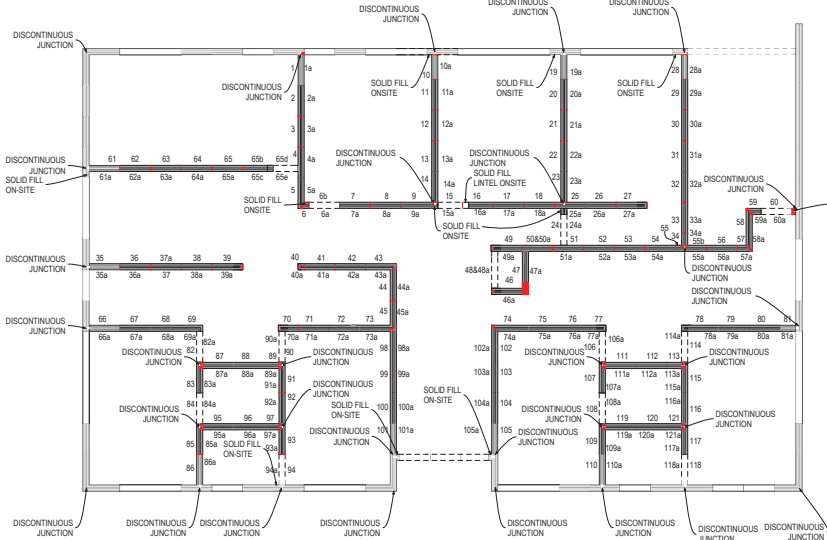


SECOND FLOOR EXTERNAL WALL ERECTION SEQUENCE AXONOMETRY
1:120



PANEL SCHEDULE SPREADSHEET

PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE	PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE	PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE
1a	1.08	27	2.7	FLOOR	NO	38	1	25	2.7	FLOOR	NO	71a	1	25	2.7	FLOOR	NO
2	1	25	2.7	FLOOR	NO	38a	1	25	2.7	FLOOR	NO	72	1	25	2.7	FLOOR	NO
2a	1	25	2.7	FLOOR	NO	39	1	25	2.7	FLOOR	YES	72a	1	25	2.7	FLOOR	NO
3	1	25	2.7	FLOOR	NO	39a	1	25	2.7	FLOOR	YES	73	1.12	28	2.7	FLOOR	NO
3a	1	25	2.7	FLOOR	NO	40	0.2	5	2.7	FLOOR	YES	73a	1	25	2.7	FLOOR	NO
4	1	25	2.7	FLOOR	NO	40a	0.2	5	2.7	FLOOR	YES	74	1	25	2.7	FLOOR	NO
4a	1	25	2.7	FLOOR	NO	41	1	25	2.7	FLOOR	NO	74a	1.12	28	2.7	FLOOR	NO
5	1	25	2.7	FLOOR	NO	41a	1	25	2.7	FLOOR	NO	75	1.2	28	2.7	FLOOR	NO
5a	0.880	22	2.7	FLOOR	NO	42	1	25	2.7	FLOOR	NO	75a	1	25	2.7	FLOOR	NO
6	0.282	7	2.7	FLOOR	NO	42a	1	25	2.7	FLOOR	NO	76	1	25	2.7	FLOOR	NO
6a	1	25	0.6	LINTEL	NO	43	1	25	2.7	FLOOR	NO	76a	1	25	2.7	FLOOR	NO
7	1	25	2.7	FLOOR	NO	43a	1	25	2.7	FLOOR	NO	77	0.52	13	2.7	FLOOR	YES
7a	1	25	2.7	FLOOR	NO	44	1	25	2.7	FLOOR	NO	77a	0.52	13	2.7	FLOOR	YES
7b	1	25	2.7	FLOOR	NO	44a	1	25	2.7	FLOOR	NO	78	1.2	28	2.7	FLOOR	YES
8	1	25	2.7	FLOOR	NO	45	1	25	2.7	FLOOR	NO	78a	1.2	28	2.7	FLOOR	YES
9	1	25	2.7	FLOOR	NO	45a	1	25	2.7	FLOOR	NO	79	1	25	2.7	FLOOR	NO
9a	1	25	2.7	FLOOR	NO	46	1.08	27	2.7	FLOOR	NO	79a	1	25	2.7	FLOOR	NO
10	1	25	2.7	FLOOR	NO	46a	1.2	30	2.7	FLOOR	YES	79b	1	25	2.7	FLOOR	NO
10a	1	25	2.7	FLOOR	NO	47	1.2	30	2.7	FLOOR	NO	80	1	25	2.7	FLOOR	NO
11	1	25	2.7	FLOOR	NO	47a	1.32	33	2.7	FLOOR	NO	80a	1	25	2.7	FLOOR	NO
11a	1	25	2.7	FLOOR	NO	48	1	25	0.7	LINTEL	NO	81	0.52	13	2.7	FLOOR	NO
11b	1	25	2.7	FLOOR	NO	48a	1	25	0.7	LINTEL	NO	81a	0.52	13	2.7	FLOOR	NO
12	1	25	2.7	FLOOR	NO	49	1	25	2.7	FLOOR	NO	82	1	25	0.6	LINTEL	NO
12a	1	25	2.7	FLOOR	NO	49a	1	25	2.7	FLOOR	YES	82a	1	25	0.6	LINTEL	NO
13	1	25	2.7	FLOOR	NO	50	1	25	2.7	FLOOR	NO	83	1	25	0.6	LINTEL	NO
13a	1	25	2.7	FLOOR	NO	50a	1	25	2.7	FLOOR	NO	83a	0.8	20	2.7	FLOOR	NO
14	1	25	2.7	FLOOR	NO	51	1	25	2.7	FLOOR	NO	84	1	25	0.6	LINTEL	NO
14a	1	25	0.6	LINTEL	NO	51a	1	25	2.7	FLOOR	NO	84a	1	25	0.6	LINTEL	NO
15	0.8	20	0.6	LINTEL	NO	52	1	25	2.7	FLOOR	NO	85	1	25	2.7	FLOOR	NO
15a	0.8	20	0.6	LINTEL	NO	52a	1	25	2.7	FLOOR	NO	85a	0.8	20	2.7	FLOOR	NO
16	0.8	20	2.7	FLOOR	NO	53	1	25	2.7	FLOOR	NO	86	1	25	2.7	FLOOR	NO
16a	0.8	20	2.7	FLOOR	NO	53a	1	25	2.7	FLOOR	NO	86a	1	25	2.7	FLOOR	NO
17	1	25	2.7	FLOOR	NO	54	1	25	2.7	FLOOR	NO	87	1.08	27	2.7	FLOOR	NO
17a	1	25	2.7	FLOOR	NO	54a	1	25	2.7	FLOOR	NO	87a	1.08	27	2.7	FLOOR	NO
18	1	25	2.7	FLOOR	NO	55	0.282	7	2.7	FLOOR	NO	88	0.56	14	2.7	FLOOR	NO
18a	1	25	2.7	FLOOR	NO	55a	0.282	7	2.7	FLOOR	NO	88a	0.56	14	2.7	FLOOR	NO
19	1	25	2.7	FLOOR	NO	56	1	25	2.7	FLOOR	NO	89	1	25	0.6	LINTEL	NO
19a	1	25	2.7	FLOOR	NO	56a	1	25	2.7	FLOOR	NO	90	1	25	0.6	LINTEL	NO
20	1	25	2.7	FLOOR	NO	57	0.4	10	2.7	FLOOR	NO	90a	1	25	0.6	LINTEL	NO
21	1	25	2.7	FLOOR	NO	57a	0.4	10	2.7	FLOOR	NO	91	1	25	2.7	FLOOR	NO
22	1	25	2.7	FLOOR	NO	58	1.12	28	2.7	FLOOR	NO	91a	1	25	2.7	FLOOR	NO
22a	1	25	2.7	FLOOR	NO	58a	1.12	28	2.7	FLOOR	NO	92	1	25	2.7	FLOOR	NO
23	1	25	2.7	FLOOR	NO	59	NA	NA	NA	NA	NA	92a	1	25	2.7	FLOOR	NO
23a	1	25	2.7	FLOOR	NO	59a	0.48	12	2.7	FLOOR	NO	93	1	25	2.7	FLOOR	NO
24	1	25	0.6	LINTEL	NO	59a	0.36	9	2.7	FLOOR	NO	93a	0.8	20	2.7	FLOOR	NO
25	1	25	2.7	FLOOR	NO	60	1	25	0.6	LINTEL	NO	94	1	25	0.6	LINTEL	NO
25a	1	25	2.7	FLOOR	NO	60a	1	25	0.6	LINTEL	NO	94a	1	25	0.6	LINTEL	NO
26	1	25	2.7	FLOOR	NO	61	1	25	2.7	FLOOR	NO	95	1	25	2.7	FLOOR	NO
26a	1	25	2.7	FLOOR	NO	61a	1	25	2.7	FLOOR	NO	95a	1	25	2.7	FLOOR	NO
27	1	25	2.7	FLOOR	NO	62	1	25	2.7	FLOOR	NO	96	1	25	2.7	FLOOR	NO
27a	1	25	2.7	FLOOR	YES	62a	1	25	2.7	FLOOR	NO	96a	1	25	2.7	FLOOR	NO
28	1	25	2.7	FLOOR	NO	63	1	25	2.7	FLOOR	NO	97	0.56	14	2.7	FLOOR	NO
28a	1	25	2.7	FLOOR	NO	63a	1	25	2.7	FLOOR	NO	97a	0.56	14	2.7	FLOOR	NO
29	1	25	2.7	FLOOR	NO	64	1	25	2.7	FLOOR	NO	98	1.08	27	2.7	FLOOR	NO
29a	1	25	2.7	FLOOR	NO	64a	1	25	2.7	FLOOR	NO	98a	1.08	27	2.7	FLOOR	NO
30	1	25	2.7	FLOOR	NO	65	1	25	2.7	FLOOR	NO	99	1	25	2.7	FLOOR	NO
30a	1	25	2.7	FLOOR	NO	65a	1	25	2.7	FLOOR	NO	100	1	25	2.7	FLOOR	NO
31	1	25	2.7	FLOOR	NO	65b	1	25	2.7	FLOOR	NO	100a	1	25	2.7	FLOOR	NO
32	1	25	2.7	FLOOR	NO	65c	1	25	2.7	FLOOR	NO	101	1	25	2.7	FLOOR	NO
32a	1	25	2.7	FLOOR	NO	65d	1	25	2.7	FLOOR	NO	101a	1	25	2.7	FLOOR	NO
33	1	25	2.7	FLOOR	NO	66	1	25	2.7	FLOOR	NO	102	1.08	27	2.7	FLOOR	NO
33a	1	25	2.7	FLOOR	NO	66a	1	25	2.7	FLOOR	NO	102a	1.2	28	2.7	FLOOR	NO
34	0.4	10	2.7	FLOOR	NO	67	1	25	2.7	FLOOR	NO	103	1	25	2.7	FLOOR	NO
34a	0.4	10	2.7	FLOOR	NO	67a	1	25	2.7	FLOOR	NO	103a	1	25	2.7	FLOOR	NO
35	1	25	2.7	FLOOR	NO	68	1	25	2.7	FLOOR	NO	104	1	25	2.7	FLOOR	NO
35a	1	25	2.7	FLOOR	NO	68a	1	25	2.7	FLOOR	NO	104a	1	25	2.7	FLOOR	NO
36	1	25	2.7	FLOOR	NO	69	0.72	18	2.7	FLOOR	YES	105	1	25	2.7	FLOOR	NO
36a	1	25	2.7	FLOOR	NO	69a	0.72	18	2.7	FLOOR	YES	105a	1	25	2.7	FLOOR	NO
37	1	25	2.7	FLOOR	NO	70	0.84	16	2.7	FLOOR	YES	106	1	25	0.6	LINTEL	NO
						70a	0.64	16	2.7	FLOOR	YES	106a	1	25	0.6	LINTEL	NO
												107	1	25	0.6	LINTEL	NO
												107a	0.8	20	2.7	FLOOR	NO
												108	1	25	0.6	LINTEL	NO
												108a	1	25	0.6	LINTEL	NO
												109	1	25	2.7	FLOOR	NO
												109a	0.8	20	2.7	FLOOR	NO
												110	1	25	2.7	FLOOR	NO
												110a	1	25	2.7	FLOOR	NO
												111	1.08	27	2.7	FLOOR	NO
												111a	1.08	27	2.7	FLOOR	NO
												112	1	25	2.7	FLOOR	NO
												112a	1	25	2.7	FLOOR	NO
												113	0.56	14	2.7	FLOOR	NO
												113a	0.56	14	2.7	FLOOR	NO
												114	1	25	0.6	LINTEL	NO
												114a	1	25	0.6	LINTEL	NO
												115	1	25	2.7	FLOOR	NO
												115a	1	25	2.7	FLOOR	NO
												116	1	25	2.7	FLOOR	NO
												116a	1	25	2.7	FLOOR	NO
												117	1	25	2.7	FLOOR	NO
												117a	0.8	20	2.7	FLOOR	NO
												118	1	25	0.6	LINTEL	NO
												118a	1	25	0.6	LINTEL	NO
												119	1	25	2.7	FLOOR	NO
												119a	1	25	2.7	FLOOR	NO
												120	1	25	2.7	FLOOR	NO
												120a	1	25	2.7	FLOOR	NO
												121	0.56	14	2.7	FLOOR	NO
												121a	0.56	14	2.7	FLOOR	NO
												TOTAL	234	5847			



4.3 - Third Floor Plan



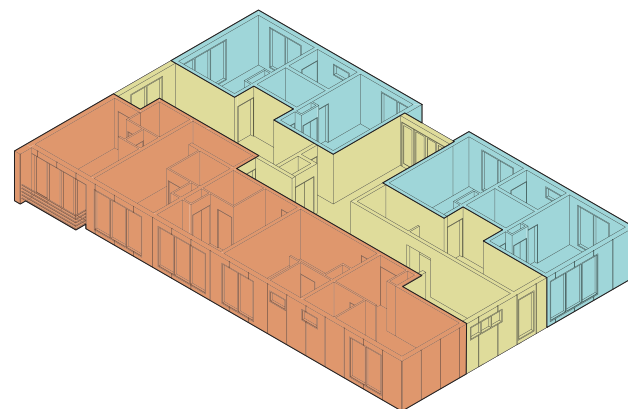
THIRD FLOOR PLAN
1:100

LEGEND

- 200 mm (+ LINING) DOUBLE SKIN STRUCTURAL GUN-NAILED PARALLEL LAMINATED (GPL) WALL
- 90 mm (+ LINING) TIMBER FRAME WALL
- PUBLIC/CIRCULATION AREAS
- 1 BED APARTMENT
- SELF CONTAINED APARTMENT

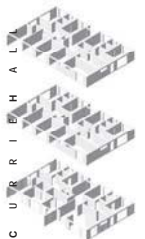
GROSS INTERNAL FLOOR AREA - 318m²

CEILING HEIGHT - 2700 mm



THIRD FLOOR SPATIAL UNIT AXONOMETRY
1:200

THE UNIVERSITY OF WESTERN AUSTRALIA
ALVA
211013 ISSUE FOR ASSESSMENT



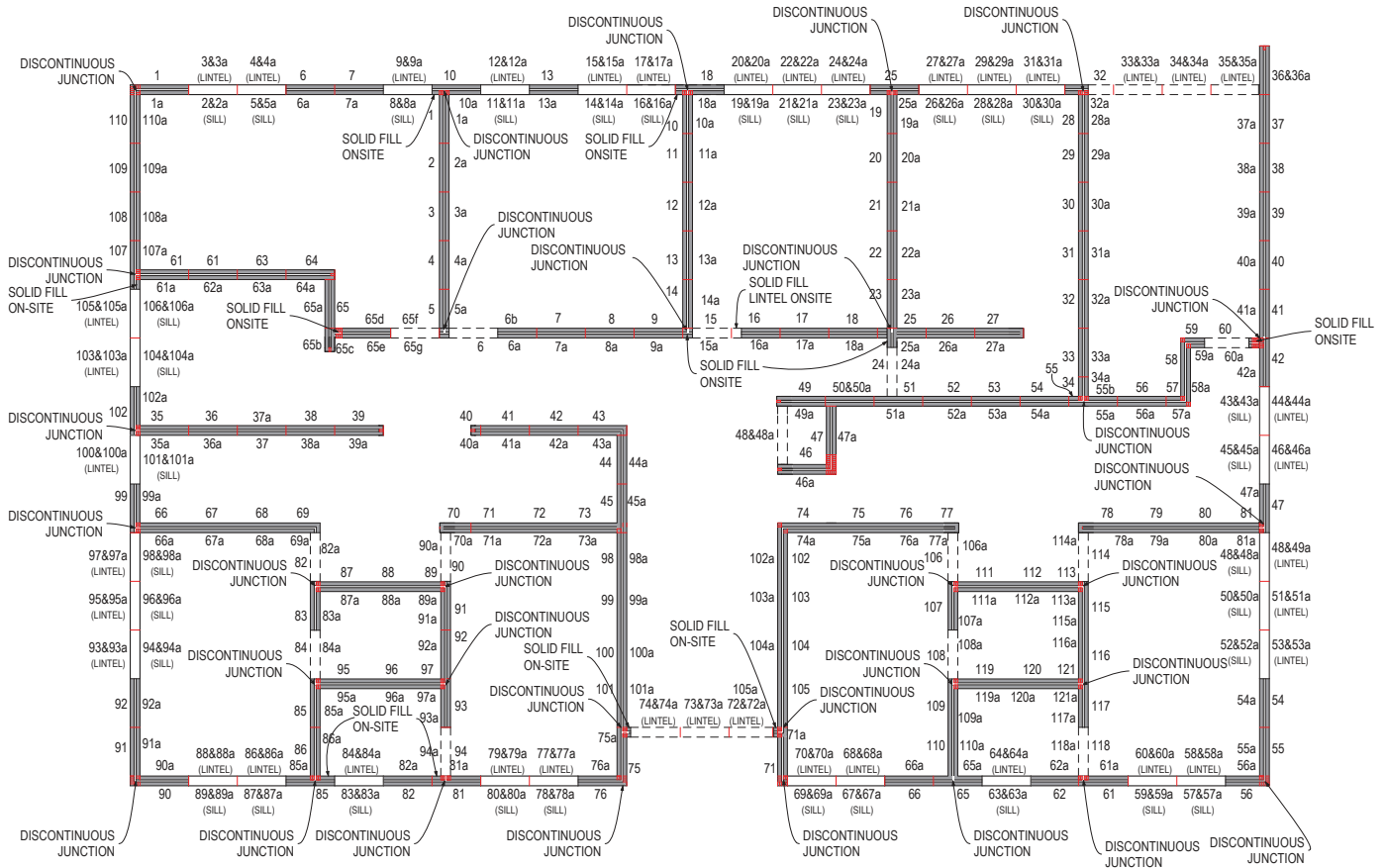
DAVID BYLUND
ARCHITECT

UWA
PROJECT
CURRIE HALL REDESIGN
PERKIN WESTERN AUSTRALIA

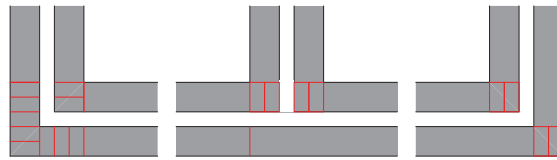
Date: 19 March 2013	Drawn By: C217947
Scale: 1:200	Sheet: 2011a
Project: 2011a	Revision: A1.11



LOCATION DIAGRAM

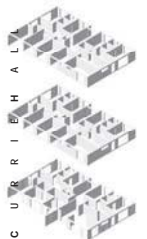


THIRD FLOOR GPL WALL PANEL ARRANGEMENT PLAN
1:75



TYPICAL PANEL JUNCTIONS
1:10

EXTRA LAMELLA ELEMENTS.
REFER TO PANEL ARRANGEMENT
SCHEDULES FOR DETAILS



DAVID BYLUND
ARCHITECT



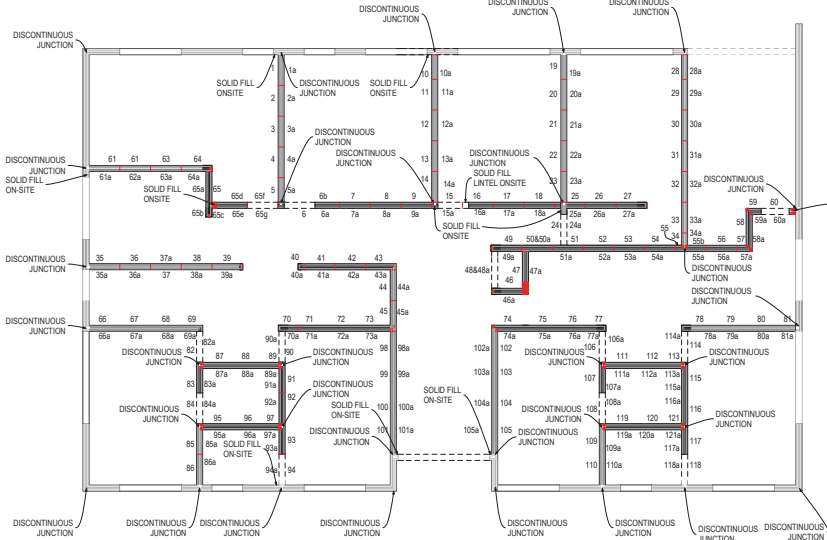
Client UWA	Project Name CURRIE HALL REDESIGN
Location 100A STIRLING HIGHWAY, GOSWELLY PERTH, WESTERN AUSTRALIA	Scale 1:10
Date 14 March 2013	Issue No. 175 / 2111a.47, 1-10
Page No. 2011a	Sheet No. A1.12

PANEL SCHEDULE SPREADSHEET

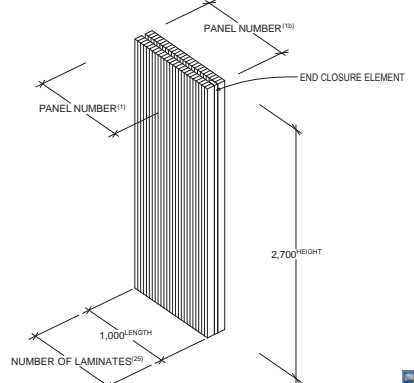
PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE	PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE	PANEL NUMBER	LENGTH (metres)	NUMBER OF LAMINATES	HEIGHT (metres)	POSITION	END CLOSURE
1a	1	25	2.7	FLOOR	NO	38	1	25	2.7	FLOOR	NO	71a	1	25	2.7	FLOOR	NO
2	1	25	0.2	FLOOR/SILL	NO	38a	1	25	2.7	FLOOR	NO	72	1	25	0.3	LINTEL	NO
2a	1	25	0.2	FLOOR/SILL	NO	39	1	25	2.7	FLOOR	NO	72a	1	25	0.3	LINTEL	NO
3	1	25	0.5	LINTEL	NO	39a	1	25	2.7	FLOOR	NO	73	1	25	0.3	LINTEL	NO
3a	1	25	0.5	LINTEL	NO	40	1	25	2.7	FLOOR	NO	73a	1	25	0.3	LINTEL	NO
4	1	25	0.2	FLOOR/SILL	NO	40a	1	25	2.7	FLOOR	NO	74	1	25	0.3	LINTEL	NO
4a	1	25	0.2	FLOOR/SILL	NO	41	1	25	2.7	FLOOR	NO	74a	1	25	0.3	LINTEL	NO
5	1	25	0.5	LINTEL	NO	41a	1.08	27	2.7	FLOOR	NO	75	1	25	2.7	FLOOR	NO
5a	1	25	0.2	FLOOR/SILL	NO	42	1	25	2.7	FLOOR	NO	75a	1	25	2.7	FLOOR	NO
6	1	25	2.7	FLOOR	NO	42a	0.88	22	2.7	FLOOR	NO	76	1	25	2.7	FLOOR	NO
6a	1	25	2.7	FLOOR	NO	43	1	25	0.2	FLOOR/SILL	NO	76a	0.88	22	2.7	FLOOR	NO
7	1	25	2.7	FLOOR	NO	43a	1	25	0.2	FLOOR/SILL	NO	77	1	25	0.2	FLOOR/SILL	NO
7a	1	25	2.7	FLOOR	NO	44	1	25	0.5	LINTEL	NO	77a	1	25	0.2	FLOOR/SILL	NO
8	1	25	1.8	FLOOR/SILL	NO	44a	1	25	0.5	LINTEL	NO	78	1	25	0.5	LINTEL	NO
8a	1	25	1.8	FLOOR/SILL	NO	45	1	25	0.2	FLOOR/SILL	NO	78a	1	25	0.5	LINTEL	NO
9	1	25	0.3	LINTEL	NO	45a	1	25	0.2	FLOOR/SILL	NO	79	1	25	2.7	FLOOR	NO
9a	1	25	0.3	LINTEL	NO	46	1	25	0.5	LINTEL	NO	79a	0.38	9	2.7	FLOOR	NO
10	1	25	2.7	FLOOR	NO	46a	1	25	0.5	LINTEL	NO	80	0.56	14	2.7	FLOOR	NO
10a	0.880	22	2.7	FLOOR	NO	47	0.88	22	2.7	FLOOR	NO	80a	1	25	0.2	FLOOR/SILL	NO
11	1	25	1.8	FLOOR/SILL	NO	47a	0.88	22	2.7	FLOOR	NO	80b	1	25	0.2	FLOOR/SILL	NO
11a	1	25	1.8	FLOOR/SILL	NO	48	1	25	0.2	FLOOR/SILL	NO	81	1	25	0.5	LINTEL	NO
12	1	25	0.3	LINTEL	NO	48a	1	25	0.2	FLOOR/SILL	NO	81a	0.88	17	2.7	FLOOR	NO
12a	1	25	0.3	LINTEL	NO	49	1	25	0.5	LINTEL	NO	82	1	25	2.7	FLOOR	NO
13	1	25	2.7	FLOOR	NO	49a	1	25	0.5	LINTEL	NO	82a	1	25	2.7	FLOOR	NO
13a	1	25	2.7	FLOOR	NO	50	1	25	0.2	FLOOR/SILL	NO	83	1	25	1.8	FLOOR/SILL	NO
14	1	25	0.2	FLOOR/SILL	NO	50a	1	25	0.2	FLOOR/SILL	NO	83a	1	25	1.8	FLOOR/SILL	NO
14a	1	25	0.2	FLOOR/SILL	NO	51	1	25	0.5	LINTEL	NO	84	1	25	0.3	LINTEL	NO
15	1	25	0.5	LINTEL	NO	51a	1	25	0.5	LINTEL	NO	84a	1	25	0.3	LINTEL	NO
15a	1	25	0.5	LINTEL	NO	52	1	25	0.2	FLOOR/SILL	NO	85	1	25	2.7	FLOOR	NO
16	1	25	0.2	FLOOR/SILL	NO	52a	1	25	0.2	FLOOR/SILL	NO	85a	0.56	14	2.7	FLOOR	NO
16a	1	25	0.2	FLOOR/SILL	NO	53	1	25	0.5	LINTEL	NO	86	1	25	0.2	FLOOR/SILL	NO
17	1	25	0.5	LINTEL	NO	53a	1	25	0.5	LINTEL	NO	86a	1	25	0.2	FLOOR/SILL	NO
17a	1	25	0.5	LINTEL	NO	54	1	25	2.7	FLOOR	NO	87	1	25	0.5	LINTEL	NO
18	1	25	0.2	FLOOR/SILL	NO	54a	1	25	2.7	FLOOR	NO	87a	1	25	0.5	LINTEL	NO
18a	0.730	18	2.7	FLOOR	NO	55	1	25	2.7	FLOOR	NO	88	1	25	2.7	FLOOR	NO
19	1	25	0.2	FLOOR/SILL	NO	55a	1	25	2.7	FLOOR	NO	88a	1	25	2.7	FLOOR	NO
19a	1	25	0.2	FLOOR/SILL	NO	55b	NA					89	1	25	0.5	LINTEL	NO
20	1	25	0.5	LINTEL	NO	56	0.98	22	2.7	FLOOR	NO	89a	1	25	0.5	LINTEL	NO
20a	1	25	0.5	LINTEL	NO	57	0.76	19	2.7	FLOOR	NO	90	1.12	28	2.7	FLOOR	NO
21	1	25	0.2	FLOOR/SILL	NO	57a	1	25	0.2	FLOOR/SILL	NO	90a	1	25	2.7	FLOOR	NO
21a	1	25	0.2	FLOOR/SILL	NO	57b	1	25	0.2	FLOOR/SILL	NO	91	1	25	0.5	LINTEL	NO
22	1	25	0.5	LINTEL	NO	58	1	25	0.5	LINTEL	NO	91a	1	25	0.5	LINTEL	NO
22a	1	25	0.5	LINTEL	NO	58a	1	25	0.5	LINTEL	NO	92	1	25	2.7	FLOOR	NO
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PANEL SCHEDULE SPREADSHEET

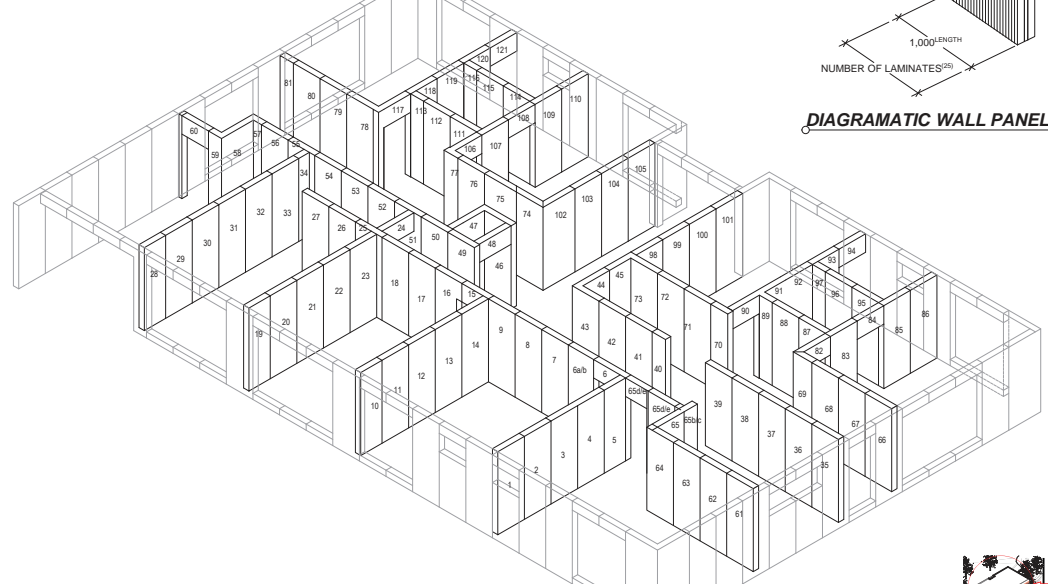
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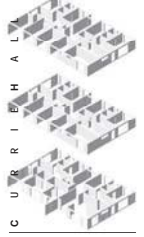
THIRD FLOOR INTERNAL WALL ERECTION SEQUENCE PLAN
1:120
NOTE: INTERIOR LEAF 'A' PANEL NOT SHOWN IN AXONOMETRIC VIEW. REFER TO PLAN VIEW AND SPREADSHEET FOR 'A' PANEL LOCATION & SPECIFICATION



DIAGRAMATIC WALL PANEL KEY
1:40



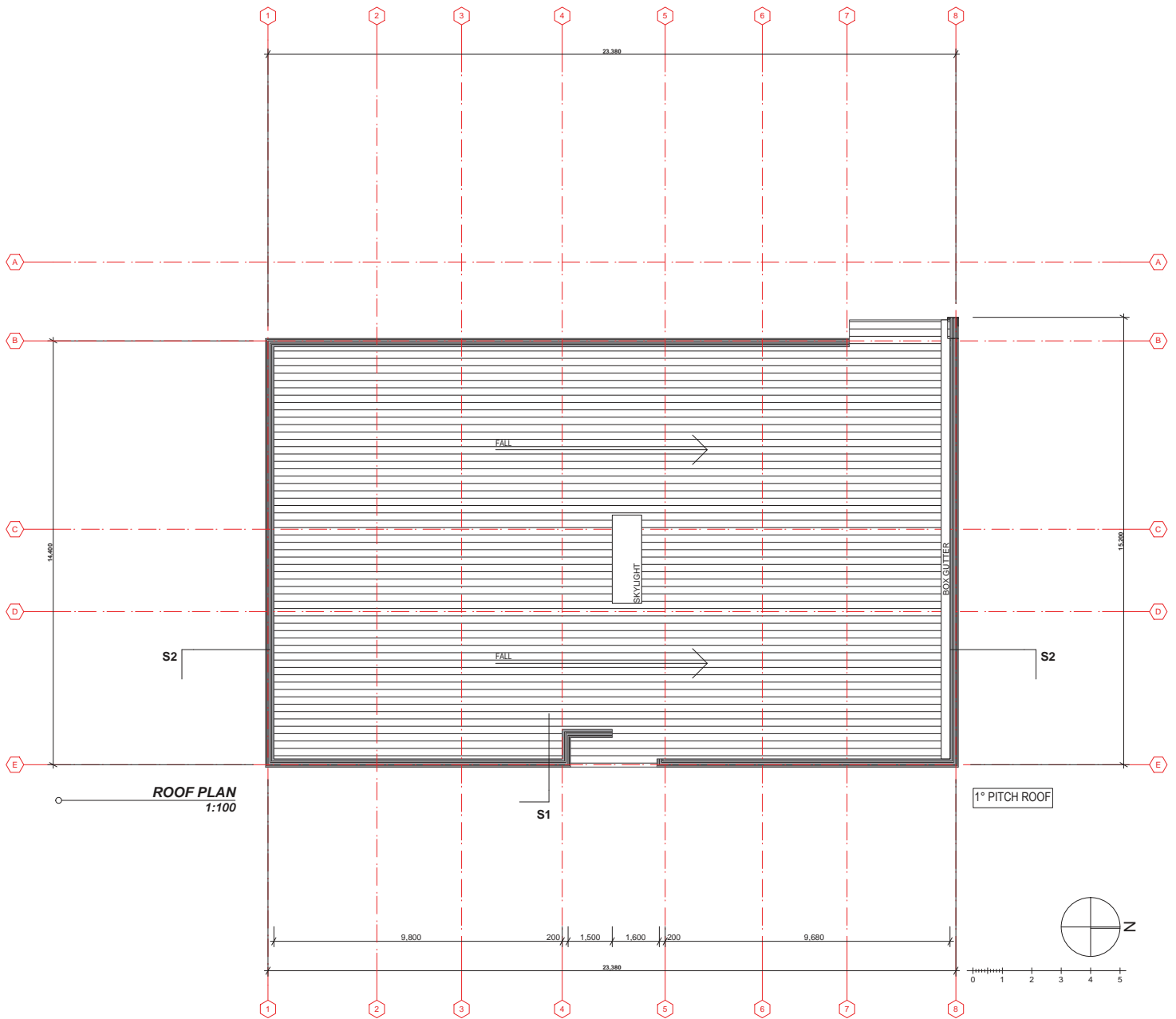
THIRD FLOOR INTERNAL WALL GPL WALL ERECTION SEQUENCE AXONOMETRY
1:120



DAVID BYLUND ARCHITECT

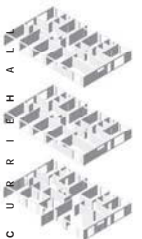
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Project: CURRIE HALL REDESIGN
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4.4 - Roof Plan



ROOF PLAN
1:100

1° PITCH ROOF



DAVID BYLUND
ARCHITECT

Date: 19 March 2013 Drawn by: DAVID BYLUND Title: CURRIE HALL REDESIGN Project: CURRIE HALL REDESIGN, CURRIE HALL, PERTH, WESTERN AUSTRALIA	
Date: 19 March 2013 Drawn by: DAVID BYLUND	Title: CURRIE HALL REDESIGN Project: CURRIE HALL REDESIGN, CURRIE HALL, PERTH, WESTERN AUSTRALIA
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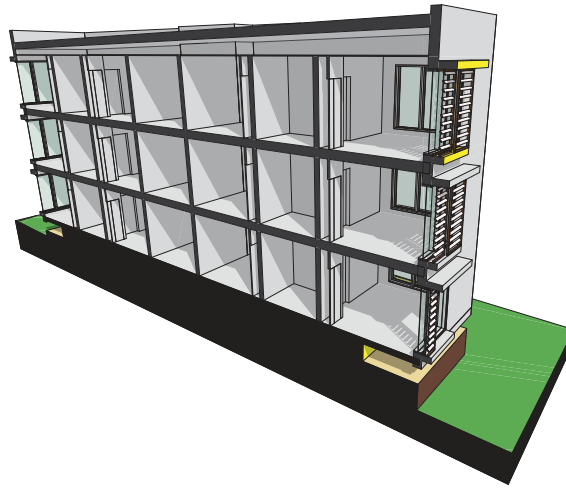


LOCATION DIAGRAM

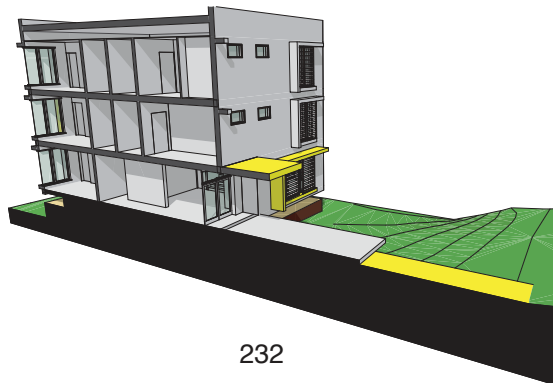
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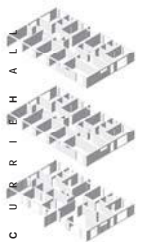
SECTION 2
1:100



SECTION 1
1:100



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MURDOCH, WESTERN AUSTRALIA
6150

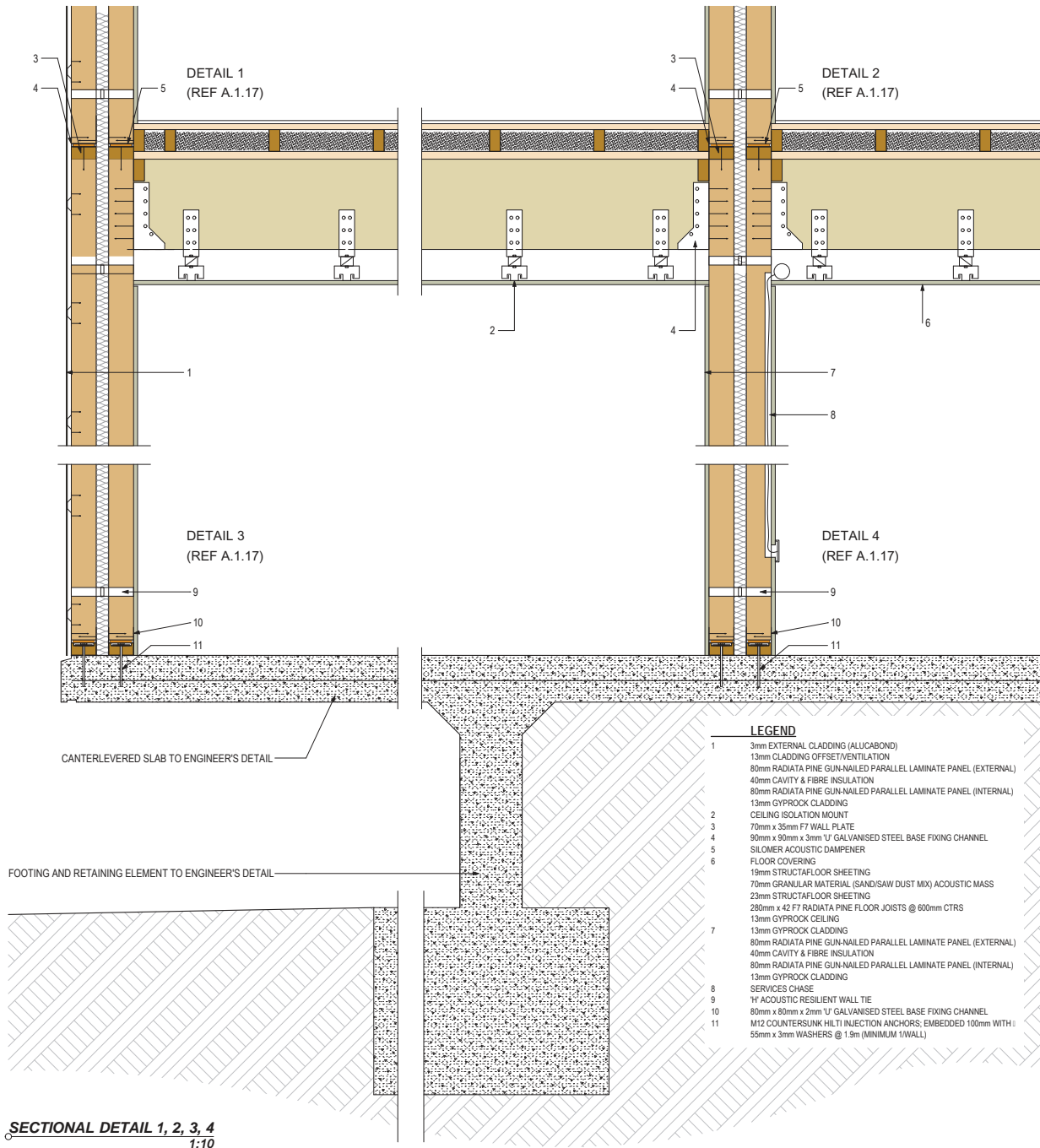
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Date: 01/02/2013
Perth, WESTERN AUSTRALIA

SECTION S1 & S2

Date: 19 March 2013
Scale: 1:100
Drawing No: 1-218.81
2011a | A1.17

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4.7 - Details 1- 4



5.0 - CONCLUSIONS

This thesis has investigated Swedish off-site building and prefabricated engineered construction industry and methodologies for the purpose of considering Australia's capacity to develop its own prefabrication and engineered timber construction solutions to a similar level of those exhibited in Sweden. The intent has not been to create a new architectural style mirroring those associated with Swedish prefabrication or through the use of engineered timber, but rather to explore the Swedish advances in these areas, the background behind those advances and speculate on their potential application, suitability and modification for use in Australia if it were to advance in a similar direction.

It has been demonstrated in Sweden, central Europe and, incidentally, by the work of architects such as Canadian Michael Green, that new developments in engineered timber construction have the potential to suit small, medium and large scale, off-site and prefabricated buildings in both the residential and commercial sector.

If the benefits of alternative construction methods such as those explored in this thesis can be kept at the forefront of the timber design and construction debate, then timber's perceived structural limitations will continue to be resolved through new technical solutions as Australian architects, builders and developers engage with solid wood processors to find new avenues to solve future design applications.

New timber based construction methodologies have the prospect of becoming a significant alternative to existing building approaches in Australia. An example of an Australian based developer exploring new techniques in timber construction is the recently completed Forté ten storey residential building in Melbourne by Lend Lease.

This research has presented the development and preliminary testing of one method of utilising low grade or 'multigrade' Radiata pine that falls outside the Machine Grade Pine spectrum to create a laminated solid timber wall panel. By using existing, readily available and affordable fixing technologies and simple timber working skills, the theoretical prefabrication of major structural elements for a three storey residential

building has been explored to demonstrate one approach to an Australian prefabrication and engineered design solution.

The author has used an existing three storey residential masonry based project as a benchmark building, to develop the case for the construction industry to consider using more prefabricated engineered timber in Australia. The solid timber panelised method developed throughout the course of this research has demonstrated that timber supply, prefabrication manufacturing, and the on-site construction or 'montage' process using solid timber structural wall elements have the potential to be the catalyst to the introduction of a new method of residential and commercial construction in Australia.

Barriers include the need to streamline regulatory and compliance requirements by incorporating solid timber construction in the BCA/NCC with Deemed-to-Satisfy provisions by identifying solid timber construction separately from timber frame for timber structures over three storeys.

The willingness or otherwise of sawmill companies to expand into value-adding their low grade product and even providing vertically integrated supply and install services will be a significant factor influencing the expansion of engineered timber and off-site construction.

In the case of planar structural elements, the technical skills required for manufacturing, access to affordable source material, transport and erection infrastructure, junctions and fixing methodologies, associated build costs and suitable design opportunities appear to be readily available. Resistance to insects, fire resilience, thermal and acoustic performance can now be demonstrated using reliable and tested measures.

The environmental benefits of sustainably managed timber over steel and concrete are also becoming well recognised as having positive marketing potential.

The marketing of new engineered timber products and systems, for example Sweden's Trä8 by Moeleven and Södra's SödraSmart, will also make a significant

impact on Australia's acceptance and uptake of new timber products and new methods of construction.

Companies intending to develop prefabricated engineered timber building solutions must overcome issues such as pre-existing biases against the structural use of wood in preference for concrete, steel or masonry; lack of vertical integration by timber producers into the building sector and emerging preferences for light weight roll formed steel exhibited by some of Australia's largest mining companies in their north western developments.

This study concludes that significant opportunities do exist in Australia for off-site construction utilising engineered timber in structural applications. An example of the opportunities that exist is the recent acknowledgment of the two ply nailed CLT panels developed for the Kiln Control Room (refer Appendix I) that was designed by the author and submitted to the 2014 Australian Timber Design Awards. This project was nominated as a finalist in the Judge's Innovation Award in conjunction with two other innovative developments in timber construction.

The development of localised products that create new possibilities for value-adding to non MGP grade plantation timber could be used to encourage timber processing companies to expand into value-adding and even provide vertically integrated building solutions. Success in establishing advanced engineered timber building solutions in Australia will be measured by industry and market driven initiatives that point toward increasingly technically challenging building solutions, both as planar and volumetric construction.

6.0 - FURTHER RESEARCH

Based on the outcomes of this research, a number of areas could be investigated further such as:

6.1 - The Public's Perceptions of Timber's Durability

Australian and European methods of testing timber's durability vary significantly. This has the potential to impact on the choice of timber as a viable product for development in Australia and as such, warrants further research into ways of improving testing methods and perceptions of material durability.

6.2 - GPLT and the BCA

Exploring methods of fast tracking acceptable BCA alternative solutions via the *Codemark* system of regulatory approvals and ultimately, the inclusion of solid timber construction in the deemed-to-satisfy provisions will be critical factors in establishing new developments in engineered timber and prefabricated approaches to construction. Further research in these areas will expedite this process and contribute to the acceptance of these issues. Design rules for the use of GPLT would also need to be established to ensure architects and engineers can safely design and specify within its structural parameters.

6.3 - Provisions for the Use of GPLT Panels in Earthquake Prone Areas

Regional seismic design requirements always influence multi-storey construction. In locations where this is an issue, the capacity of the GPLT wall panel to withstand seismic loading should be investigated.

6.4 - Vertical Integration by the Timber Industry into the Construction Sector

Throughout the last 15 years, several of Sweden's major timber producers have made the transition into value-adding to their traditional sawn products by vertically integrating into the construction industry. This has been one of the major factors that

has allowed large scale timber prefabrication of buildings in Sweden to develop so rapidly. Today's Australian timber industry does not provide its clients with vertically integrated prefabrication solutions. Exploring the potential for this level of vertical integration without compromising its existing timber markets will be one of the key areas for future research if the Australian timber industry were to expand beyond its current scope.

6.5 - Marketing and Public Perceptions

Timber suffers from entrenched perceptions that view it as a lower class building material that is unreliable because it rots, twists, is flammable and is eaten by termites. Significant effort by the FWPA and others to address these perceptions and reposition timber within the Australian market has been undertaken to demonstrate the developments that address these concerns, and differentiate it from its poor past performances. Despite this, significant resistance to timber as a reliable construction material continues to exist. Research into appropriate ways of addressing this will improve its uptake through improved consumer confidence in timber's ability to perform as required.

6.6 - Improving Acoustic Performance

In some sectors, light weight residential timber construction in Australia has left timber construction with a poor acoustic performance legacy. Differentiating solid timber construction from light weight timber frame combined with appropriate acoustic design has the potential to compete with other massive approaches to construction and represents a significant area for further research.

6.7 - Fire Testing

As with acoustics, light weight timber frame construction has largely been responsible for the public's perception of timber as an unsafe building material in a fire situation. While timber is a flammable material, its charring rates can be measured and

used to design structures capable of maintaining their structural integrity for extended periods of time. Further research into the performance of GPLT timber panels when subject to fire will be a significant part of developing this technology.

6.8 - Further Full Scale Prototype Construction and Testing

Full scale prototype construction and testing will further validate the outcomes of this research and will be an integral part of establishing the viability of GPLT construction, which will provide confidence to architects, engineers, developers and government agencies.

6.9 - Discontinuous Construction and Structural Stability

Achieving structural stability whilst maintaining discontinuous construction between apartments in residential buildings will be a key area requiring further research as GPLT buildings increase in height.

6.10 - Australia's North West and the Mining Sector

Australia's north western mining sector presents a significant opportunity for GPLT construction and timber prefabrication in general. Investigating ways to compete in this market through improved knowledge of timber's suitability for these regions and type of application will provide sawmills and prefabrication companies the opportunity to provide timber solutions to this expanding market.

7.0 - TERMINOLOGY

AB - Aktiebolag - Swedish Term for 'Proprietary Limited company or 'corporation.

AS - Australian Standards.

Backhauling - The practice of logging trucks carrying a commercial load all or part of the return journey from the sawmill to the forest.

BBA - British Board of Agément.

Bespoke - Custom designed or made to order.

Biodiesel - Diesel fuel made directly from plant oil in lieu of mineral oil.

Bioenergi (sic) - Physical energy derive from biological sources (Wikipedia 2011).

Building Price Index - According to the New South Wales (NSW) Public Works Department, "A building price index is a measure of the change in cost to the owner of building works, from one point in time to another" (NSW Government Public Works 2009).

CAD - Computer Aided Design.

CE - Conformité Européenne, French for "European Conformity".

Complexity Theory - The Study of Complex Systems.

CoPS - Complex Products and Systems.

'CoPS can be defined as high cost, technology intensive, customised, capital goods, systems, networks, control units, software packages, constructs and services' (CoPS Innovation Centre 2004).

CNC - Computer Numerically Controlled machine tools.

CLT - Cross-laminated Timber.

D.A.CH - D(Deutschland), A(Austria), CH(Switzerland). The German speaking countries of Central Europe.

ETA - European Technical Approval.

Free Grade Timber - See Multigrade Timber.

Glulam - Glue Laminated Timber.

Grillage - Framework of timber members in a gridded arrangement.

Half Timber Buildings - A lattice of panels filled with a non-load bearing material or "nogging" of brick, clay or plaster; the frame is often exposed on the outside of the building (Nikolas Davies 2008).

Hardwood - The terms 'softwood' and 'hardwood' do not indicate softness or hardness of particular timbers and some hardwoods are softer and lighter than softwoods. The main differences between hardwoods and softwoods are botanical, relating to the way the tree grows and the way the timber is laid down (FWPA 2010). Hardwood trees are generally Angiosperms (flowering) and are usually broad-leaved; in temperate and boreal latitudes they are mostly deciduous, but in the tropics and subtropics mostly evergreen. Examples of hardwood species available in Australia are: Blackbutt (*Eucalyptus patens*), Spotted Gum (*Corymbia maculata*), Flooded Gum (*Eucalyptus Grandis*), Tallowwood (*Eucalyptus microcorys*), Karri (*Eucalyptus diversicolor*) and Jarrah (*Eucalyptus marginata*).

High Frequency Press - High pressure press that also uses high frequencies to force the water molecules within the glue to agitate. The friction generated between the agitated molecules causes heat, which in turn vaporises the water in the glue, bonding the surfaces together.

Adapted from information provided by Jiyuan Electric.

ISO - International Organization for Standardization.

KERTO - Finnish word meaning parallelism (Wiktionary 2010) and is a product name used by FinnForest (FinnForest 2010) to describe its range of LVL engineered wood products.

KLH - Kreuzlagenholz Massivholz GmbH. An Austrian cross laminated timber manufacturer.

FSC - Forest Stewardship Council Australia.

Lamination - The process of uniting two or more materials together.

Lam Grade - See Multigrade Timber.

Lean - A business system for organizing and managing product development, operations, suppliers, and customer relations. Business and other organizations use Lean principles, practices and tools to create precise customer orientated goods and services (**Lean Enterprise Australia 2010**).

LGL - Laminated Glue Lumber.

LVL - Laminated Veneer Lumber.

LOSPs - Light Organic Solvent Preservatives. A method of preserving timber containing insecticides for internal use and a combination of fungicides and insecticides along with at times, a water repellent. The preservative components are incorporated in a solvent carrier such as white spirit (**TPAA 2012**).

Massive Timber - Solid timber building elements made up of cross-laminated timber panels. Usually used for floors, walls and roofs.

Masonite - Type of manufactured timber hardboard.

MPA - German abbreviation for Materialprüfungsanstalt Universität Stuttgart which can be translated to Stuttgart Materials Testing University

Multigrade Timber or MGT - An alternative name to describe sawn timber that does not conform to the structural grade frame requirements, but is suitable for use in laminate plate products. See also Lam-Grade (Laminate grade), Free Grade and X-Grade. These terms have been coined by the author.

OSB - Oriented Strand Board.

PEFC - Program for the Endorsement of Forest Certification.

Post and Beam - System of construction in timber that uses timber posts as the main vertical structural elements with timber beams spanning the posts.

Prefabrication - The manufacture or fabrication of a structure, or components of a structure, in a location that is remote from the end location of the elements produced.

Plate Action - Horizontal or vertical elements of a building that are designed to act to restrict lateral shear in structures.

Reconstructed - The process of repairing and rebuilding a structure. Usually applies to a building that has been damaged or has been demolished.

Restored - Repair of a building or a section of building. Usually carried out on older buildings that are in disrepair or have been damaged.

Scrimber - The processing (of) small diameter logs developed as a result of research by the Commonwealth Scientific and Industrial Research Organization (CSIRO). The process, and the product, are called Scrimber. The process makes strong structural quality timber out of small logs by separating the wood into interconnected strands, then reforming it into beams using a water-resistant

adhesive. More than 85 percent of the log is utilized compared with the 40 percent utilization obtained by current milling methods. Scrimber (was intended) to open new markets for seven- to ten-year-old plantation trees or thinnings from normal forestry operations (**Food and Agriculture Organizations of the United Nations 2011**).

SFA - English abbreviation for the *Swedish Forest Agency* which is a translation of *Skogsstyrelsen*.

SFIF - English abbreviation of the *Swedish Forest Industries Federation* which is a translation of *Skogsindustrierna*.

Shear Wall Plate Action - A structural element that provides lateral resistance within a structure.

Softwood - The terms 'softwood' and 'hardwood' do not indicate softness or hardness of particular timbers and some hardwoods are softer and lighter than softwoods. The main differences between hardwoods and softwoods are botanical, relating to the way the tree grows and the way the timber is laid down (**FWPA 2010**).

Softwood trees are generally conifers. Examples of softwood species available in Australia are: Radiata Pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*), Hoop Pine *Araucaria Cunninghamii* and Cypress (*Callitris glaucophylla*).

Stave Church - Medieval post and beam wooden church

Standing Volume - The volume of standing trees, living or dead, above the stump and is measured over the bark to the top of the tree. Includes all trees regardless of diameter, tops of stems, large branches and dead trees lying on the ground which can still be used for fibre or fuel. Excludes small branches, twigs and foliage (**OECD 2005**).

Silviculture - The management of forest land for timber production.

TAKT Time - Takt is derived from the German word Taktzeit which translates to cycle time. Takt time sets the pace for industrial manufacturing lines. In automobile manufacturing, for example, cars are assembled on a line, and are moved on to the next station after a certain time - the takt time. Therefore, the time needed to complete work on each station has to be less than the takt time in order for the product to be completed within the allotted time (**Lean Manufacturing Concepts 2010**).

Turn Key - The description given to the process of building by a developer or builder where the completed project is delivered to a client complete and ready to inhabit including white goods, along with floor, window and wall finishes.

UNESCO - The United Nations Educational, Scientific and Cultural Organization.

Wall Stud - A vertical timber member used in framed timber construction. Usually used in light weight, residential construction.

X-Grade Timber - See Multigrade Timber.

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Unless otherwise stated, all photographs are the property of the author

Unless otherwise stated, all \$ amounts are in Australian Dollars

Interview transcripts have been edited for clarity and relevance and where English is not the first language of the interviewee, corrections to the verbal transcripts have been carried out as required.

9.0 - OTHER WORKS OF SIGNIFICANCE

To assist in further contextualising this thesis, the following theses, dissertations, reports, books and patents of direct significant relevance to this work are listed below:

9.1 - Ph.D. Theses

Architectural Aspects of Massive Timber - Structural Form and Systems (2005), Andreas Falk, Luleå University of Technology, Department of Civil and Environmental Engineering, Division of Timber Structures

Prefabrication Strategies in the Timber Housing Industry - A comparison of Sweden and Austrian Markets (2008), Tomas Nord, Luleå University of Technology, Department of Civil and Environmental Engineering, Division of Timber Structures

9.2 - Reports

The Use of Timber in Prefabricated Housing Construction (1980), David Chandler. A report prepared for the Forest Products Association of Western Australia

Timber in multi-residential, commercial and industrial building: Recognising opportunities and constraints (2010), Greg Nolan, Centre for Sustainable Architecture with Wood, University of Tasmania. A report prepared for Forest and Wood Products Australia

9.3 - Undergraduate Dissertations

Structural Performance of Low Grade Timber Slabs (2009), Cameron Summerville, The University of Southern Queensland, Faculty of Engineering and Surveying

An Investigation into the Optimisation of Cross Laminated Timber Panels for use in the Australian Building Industry, Brian Harch, The University of Southern Queensland, Faculty of Engineering and Surveying, 2010

The Utilisation of Low Quality Timber in Australian Structural Systems. An investigation into the feasibility of designs utilising low quality timber for structural purposes (2014)
Tait McCarthy, University of the Sunshine Coast, Faculty of Engineering, 2014

9.4 - Books

Off-site and modern methods of timber construction, a sustainable approach, Robert Hairstans, TRADA Technologies Ltd, 2010

Timber Buildings, Low Energy Constructions (2010), Cristina Benedetti (ed), Free University of Bozen, Bolzano, Faculty of Science and Technology

9.5 - Patents

Cross Laminated Strand Product, Peter Edward Burton, Application number: 13/116,383, Publication number: US 2011/0291441 A1, Filing date: May 26, 2011

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APPENDIX B - THE INTERVIEWS

Field Research Interview Questions/Topics

Engineered and Prefabricated Timber Construction in Sweden:

- How do you see the future of prefabrication with timber in Sweden and are architects, construction companies and developers showing an interest in this type of construction?
- Are you exporting your system and if not, what export opportunities do you envisage and what initiatives would you take to when enter a new market? What difficulties and potential pitfalls would you envisage?
- Describe the structural methodology that your system employs? Is it a 'closed' or 'open' system?
- What type of buildings are built with your system (provide built or under construction examples if possible)?
- What unique architectural and engineering opportunities does your system offer?
- What is a typical cost/m² for the various building typologies built with your system (e.g. family house, apartments etc)?
- Describe the broad infrastructure needs required by your system (e.g. material supply logistics, fabrication beds, special equipment, space requirements, workforce skills/special training, post prefabrication storage, transport and site assembly etc)?
- Are there special considerations that need to be addressed when seeking building approvals with your system?
- What is the typical time frame required to construct a building from commissioning to completion with your system and do you provide delivery guarantees?
- Describe the factory assembly sequences and fabrication techniques involved in manufacturing the various building elements such as the walls, floors and roof with your system?
- How do you allow for the structural stresses inflicted on the elements during transport and lifting?
- What type and grade of timber do you use and what moisture content do you require?
- Are wet areas prefabricated and if so, how do you ensure moisture cannot escape into the surrounding structure?
- What type of connections are used to fix floors, walls and roof elements?
- What measures do you use to address acoustic, thermal and fire performance?
- What measures do you use to protect a finished building from external weathering?
- What bio-security measures do you require when building with your system (e.g. to protect against termites and the European House Borer etc)?
- What measures is your company undertaking to address the environmental impacts of fabrication and construction with your system? Has your company undertaken any research on the cumulative energy demands of building with your system?
- Can buildings built with your system be easily upgrading/retro fitted to allow for change of use opportunities and has your company addressed issues such as end-of-building-life recycling and Design for Disassembly?
- Have you investigated adapting your system to warmer climates (e.g. mediterranean, tropical, desert etc)?

List of interviewees:

Interview	Organisation & Position	Date
DI Johannes Habenbacher - Page 238	KLH Massivholz GmbH, Austria. Chief Civil Engineer	24/03/2010
Mag. Heimo de Monte - Page 246	KLH Massivholz GmbH, Austria. Managing Partner	26/03/ 2010
Dr Amy Rader Olsson - Page 249	KTH Urban Planning Department	26/04/2010
Herr Patrick Jensen - Page 255	Tyréns AB. Building Projects (Byggprojektering) Manager	29/04/ 2010
Professor Lars Stehn - Page 261	Luleå Tekniska Universitet (Luleå Technical University). Head of Avdelningen för byggkonstruktion träbyggnad (Department of Structural Engineering and Timber Structures)	20/05/ 2010
Dr Helena Johnsson - Page 272	Lindbäck Bygg AB. Construction Chief	20/05/2010
Herr Johan Åhlén - Page 277	Moelven. Projekt & Utvecklingschef (Project & Development Manager)	25/05/ 2010
Dr Andreas Falk - Page 285	KTH University, Stockholm. Architect and Academic	01/06/2010
Mr Martin Beel - Page 294	Boral. Western Australian Regional Marketing Manager	08/06/2011
Mr Bob Pearce - Page 310	FIFWA (Forest Industry Federation of Western Australia inc). Executive Director	26/03/ 2011
Mr Lindsay Hesquith - Page 319	Australian Conservation Foundation. Forests Campaign Coordinator	20/06/2011
Mr Ron Adams - Page 328	Wespine. Managing Director. Forest Wood Products Australia. Chairman	10/06/2011
Dr John McGrath - Page 346	The University of Western Australia's Future Farm Industries CRC Research Director	1 July 2011

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(DB)

24 March 2010 - Nordbygg2010 (Nordic Building Expo at Stockholmsmässan) - Stockholm

Interview Synopsis:

Johannes Habenbacher's role as Chief Civil Engineer with KLH is discussed along with the two current research areas of acoustic performance improvement and increasing the panel's ability to span longer distances. Changes in building regulations across Europe and their effect on CLT are discussed. CLT's response to varying climatic conditions along with the methods of managing insect attack. The process, from forest to finished building are reviewed. KLH's ongoing testing of Australian Radiata pinus as a suitable material for CLT are discussed. A comparison between the timber volumes and standard required for CLT compared to standard frame are discussed along with CLT's advantages and disadvantages.

DB - Briefly describe your position and role in the KLH Austria

JH - I am a Civil Engineer. In the company I provide technical advice, I design concepts for the structure, define thickness, solve details and answer queries regarding KLH. We have partners in different companies all over Europe. If they require help, I provide technical support and I also do some research in the company. The main research topic is sound (acoustic performance of the KLH panels). It is the main topic because we already have technical and conditional approvals all over Europe for the structure and for fire resistance as we have the charring rates already defined. Because the sound requirements are different all over Europe, you cannot compare the (acoustic) requirements for Austria with the

German, British or Swedish requirements. Especially here in Sweden the level of sound protection is, in my opinion, the highest level in all Europe. In Sweden it is necessary for us to find new solutions. We cannot use the old solutions in the same way here in Sweden. In Australia, I think you have more or less the British standards. If you compare standards, Austrian standards are somewhere in the middle and the British standard is a slightly lower level. That means (for KLH) it's easier to fulfill the requirements (outside Sweden), you can do it in a cheaper way with fewer different material layers and it's easier to do for airborne and input sound.

DB - Can you give me your opinion of the development of timber construction in Austria and where it is likely to develop in the future?

JH - There have been big changes in the last few years. The last ten years we had big changes in the regulations in how to do the calculations to get approval for structures. We are changing from national Austrian standards to the new European standards. This is not just for the structural issues, but also the fire regulations. At the moment it is the same in Sweden. There are specialists in Sweden and here in Stockholm who are working on the fire resistance of timber buildings. There are also changes in the sound regulations here and at the same time I think they are also changing in Norway. I think in a few years in central Europe we will also have more changes in all these areas. We have these developments because in the last ten years, the universities and industry have worked on glue laminated timber and cross-laminated timber to define its characteristics, to define the solutions. And so, in Austria for example, ten years ago the timber industry, working with construction timber was a very small industry. Now it's a growing industry, but it's still a small part (of the construction sector) if you compare it with concrete, but it's big enough so that universities are working on these topics so that things are developing.

DB - Can you tell me how the KLH panels respond to climatic temperature variations?

JH - When talking about climate and condensation for example, we know that during different months of one year, we have different climates inside and outside and therefore we get different moisture content inside the panels. We know that with timber frame systems it is more critical if you get condensation inside the construction because the amount of timber inside the construction is a very small amount and so you need a lot of foil layers. If there are leakages due to damage to

the foil, you have a very high risk of damage to the wall structure from condensation. In comparison our product uses massive timber elements that are without spaces or voids as we use closed layers. That means that the risk of condensation within the structure of the element and therefore the risk of failure is much lower than with a framing system. Even if there is a small amount of condensation, the massive timber element is able to store this without damage and then to release it later. You can in fact use the storage effect within the KLH to store moisture and temperature without problems. We did some research on the panels in a tropical climate. We took some panels to Malaysia to see what happens inside the element and we found that even if you have a large variation (in temperature) inside with air conditioning systems compared to the hot climate outside the building, the (massive timber) element still works. Of course there is some moisture content increase inside the panel, but that is not enough to cause damage to the structure.

DB - Have you carried out testing on KLH panels with both evaporative and refrigerated air-conditioning in humid climates?

JH - We have only done limited testing on this (air-conditioning), but I am sure that the panels can handle both systems because we have experience with our climate and we have done testing with the opposite climate and we saw that the panels performed well in both.

DB - How does KLH deal with potential insect attack on its panels?

JH - Working with KLH elements, in some countries we have to give protection against termites. In Europe, in Spain or the south of Italy, for example, we usually use local treatments against these insects, When delivering to Spain we used a Spanish product on the surface. We produced the panels and after completing the cutting process, we applied the treatment to all surfaces. We then complete the montage on-site and screw the elements together. We know that termites are always a local problem, you have to look at the local treatments and apply them to the KLH system.

DB - Could you describe KLH's production process from forest to final building?

JH - We buy raw material from the sawmill and we get the planks kiln dried. We also have limited capacity to dry timber ourselves. Usually we get the planks dried to 12% moisture content. We only produce to order, so we don't have continuous

production. Usually we need three to five weeks from when we get the order until the point of delivery of the elements. We use this time to prepare the production process, produce the elements, carry out the cutting and load the panels onto the trucks or into containers and then we have the transport period. We deliver the panels to the building site and then do the montage on-site. When we first get the planks, we check the moisture content and the quality of the wood and do the visual grading. We check if we can use the planks for visible surfaces or for structural non-visible surfaces. Then we have the finger jointing process which is done in a similar way as to the Gluelam industry and then we produce the elements up to a maximum length of 60.5m and almost three metres width. In the technical office, we optimize the panels so that if we only are producing small size elements, we can reduce the amount of wastage by cutting them out from one bigger element. When the panels are produced, we immediately go to the cutting process. It needs about half an hour to cut out all of the openings in one panel. If there are lots of electrical cut-outs in the panel, it can take up to two hours.

DB - Are you able to 'chase in' or recess channels for the services such as electrical cables and hydraulic elements as part of the production process?

JH - Yes it is possible on non-visible surfaces. We can do this if the exact positions are known on the architectural drawings. When on-site it is clad over with another material. Depending on the thickness of the panel, we can fit a specially made plastic conduit into the laminations which can be used to hide the wires when the surface of the timber is visible. We can also fit wires inside door frames for light switches or in skirting for power points. In our office, we use wireless switches to control the lights so there are a number of ways to run the services with our system depending on the situation.

DB - Prefabrication is just beginning in Australia. From your experience what are some of the factors involved in establishing a new timber building system such as KLH timber panels into a new market?

JH - In my opinion, one important thing is to have approval and certification for the product. Without this, it is not possible to sell the elements. If you manufacture an element, you have to give a guarantee of the quality and provide certification for the customer. It is important to get all of the necessary approvals before starting industrial production. Starting off in Australia requires (developing) your own regulations or adopting European regulations. In Europe, cross-laminated timber is still a new product and so we don't have the European standards yet, but we have

national standards so each producer has a special approval for its product. KLH has its own approval and Moelven and Martinsons have their own approvals for their products. At the moment different teams are working on a European code for this cross-laminated timber and how to do structural analysis on it. I think it will be two, three, four or even five years before we have one European code.

DB - You mentioned in an earlier conversation that you have been carrying out testing on Australian grown radiata pine. How is this wood performing?

JH - At the moment we are still looking at the test results, but what we can say is that the gluing system is working well and that I think we will get some really good results with this timber. We are looking at F5 and Merchant grade which I think is a bit lower quality.

DB - How are KLH floor, wall and roof elements connected ?

JH - We do connections in very a easy way with 90° cuttings and screwing the elements together with standard screws and standard angle brackets.

DB - What developments are you working on with your system?

JH - We are working on floor elements for long spans. At the moment an economic span for our standard floor elements is about five or six metres. If the span is longer, you need very thick elements and large cubic amounts of timber so we are developing a 'T' section using KLH flanges and glue laminated webs. The product itself is well developed so we are working on wall build-ups and floor build-ups for different regions to give cheaper solutions for special countries. For example, the floor grid that we show in our brochure for Austria is too expensive for the British, Italian and Spanish markets. They use other products and cheaper materials and they, for example, are wanting to know what is the result if we exchange a layer of timber with a layer of plywood. Another big topic is earthquake loads and stabilisation. CLT is perfect if you want to build a building within an earthquake zone. As the walls are very stiff you can work with smaller wall elements and you can calculate the load on the connections and allow for extra numbers of connectors if required. If the panel receives some damage, you may have to replace some connectors but it has a high level of redundancy so it will remain standing and can be repaired at a later stage, but you don't have collapse of the whole building. Last

year for example, there was a large earthquake in Italy (City of L'Aquila 6 April 2009) and after this the government there decided to build new family row houses with cross-laminated timber because they saw that the safety level was much higher when compared with existing concrete or brick buildings.

Note: KLH's competitor, Binderholz, also from Austria was the successful tenderer to construct many of the new cross-laminated timber buildings using its prefabricated BBS cross-laminated timber panels.

Refer: binderholz-bausysteme.com/ and timber-building.com/news/fullstory.php/aid/629/Shaken,_not_stirred.html

DB - How does KLH explain the large cubic volume of timber required to make massive timber elements when introducing the product to a market that is accustomed to the comparably small volumes of timber used in standard frame systems?

JH - If you compare the systems, you have the structural arguments for multi-storey building. For example, if you have high stabilisation loads, you have structural advantages using cross-laminated timber over framing systems. A second reason is that if you design it correctly, you have climatic advantages with cross-laminated timber. You can use the effect of storage within timber to hold moisture and heat to create a better living quality in the summer and winter months. A further argument is that you have a higher risk of damage to a timber frame structure from moisture. If a single piece of timber gets wet, you have a higher risk of it failing in a relatively short period of time. With a solid timber element, you can store moisture without the risk of damage to the structure. Over all it is a better quality of construction. You can of course combine systems. You can use framed and clad outer walls with cross-laminated timber flooring and structural load bearing inner wall elements so the system is flexible and is not a closed system.

DB - What are the disadvantages of the cross-laminated timber system?

JH - One point is that when comparing cost, you can find cheaper solutions for outer wall and roofing elements. A product with high quality does cost more. Another thing is the large size elements are an advantage when you are doing the montage, but you need to be able to transport these elements and this can be expensive. If you need to load panels into containers for transport, then you need smaller panels and

you can lose some of the advantages of their large size, but compared to concrete panels, cross-laminated timber has a huge advantage because of the weight. Where a truck might be able to transport only one concrete panel element, we can load many panels and and save on transport costs and time.

AF - Another advantage of cross laminate timber over framed systems is that when you have volume construction, with framed systems you have to increase the strength of the modules or elements for them to be able to withstand the transport. You have to increase the strength and rigidity much more than you need in its final built in state. These two projects in Stockholm close to KTH University that used volume elements were very rational from that point of view. There were no problems with the connections, you already have the rigid box without the need for further development of strengthening. Much of the building industry today is moving toward prefabrication to some degree. If you look at the market in Sweden, many of the light timber frame producers work with modularised systems and volume modules to be able to increase the level of prefabrication.

JH - That is a big advantage of the KLH timber panels if you compare it with timber frame, the stiffness of the element is so high, you have no problems with transport. You can use wall elements acting like beams and make box systems, you can fix floor elements hanging from wall elements, you can work without down standing beams so you can use the stiffness of the element in different ways.

AF - One important thing from my perspective is you must work out the advantages of a system so that when you introduce it into a new market you know with what arguments you will promote it. In the US, the argument arises about the volume of timber used where they have had problems with a good supply of timber. Ten years ago, they would never think of using such a system as they didn't have such a good supply of timber as we have in the nordic countries and in middle Europe. But on the other hand, there can be these other qualities of the product that you should stress. One of the driving forces in Austria and Sweden was that they had some much lower quality timber that they were having trouble selling in other ways. Gluing them together into rigid panels is a very efficient way of using the material which we wanted to sell anyway.

JH - In Austria, we have the situation where much more timber is growing per year than we use. As we don't use all this timber that is growing, we have reserves and in Austria, it is a very strong argument to use excess timber in this way. What we also

have in Europe is a very robust discussion about CO₂. With the KLH panels, you can store tons of CO₂. You can build CO₂ neutral buildings and in ten, twenty and thirty years, you can even have negative CO₂. That is a very strong argument to use timber over concrete or bricks. Another thing is that you can use the stiffness of the timber. If you compare a KLH wall element that is usually about ten centimetres thick, to achieve the same level of stiffness in concrete you need twenty or twenty five. If you want to do it in brick you need maybe forty centimetres so we have a very optimised, thin construction. You save space on the site or you can use the saved area to increase the internal floor area.

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David Bylund

(DB)

26 March 2010 - Nordbygg2010 (Nordic Building Expo at Stockholmsmässan) - Stockholm

Interview Synopsis:

Difficulties the company has encountered when trying to establish the KLH Scandinavia company in Sweden are discussed. The success of the Stadthaus Murray Grove project by Waugh Thistleton Architects is also discussed along with the limitations of the Passivhaus technology. Research on Australian Radiata pinus in conjunction with Carter Holt Harvey and Lend Lease is introduced and the importance of gaining regulatory approval in a particular country or region along with an understanding of potential local concerns and expectations associated with the introduction of a new building product are discussed.

DB - Briefly describe your position and role in KLH

HdM - I am the managing director for KLH in Austria and I also own a third of the company. I am responsible for purchasing the raw material and production in Austria and partially in Sweden and I am also responsible for development and company expansion.

DB - How have you found establishing KLH in Sweden?

HdM - In Sweden it is completely different to Europe. The Swedish are a very proud people and if you try and establish as a foreign company it is very difficult to start here. With the entrance laws here, it was better for us to buy a local company so we bought Inland Wood AB who had done some research on the panels for us. One of my colleagues came back to Austria and said that while Sweden is a wood country, they are really only using it for family houses in frame construction so we started a company called KLH-Inland Wood AB. This product (cross-laminated timber) was then completely new so we had to start from nothing. We had a project in Falun

called Kopparstaden (a three storey building and a four storey building totaling 46 apartments in Växjö Skellefteå) but it was very difficult to get acoustic approvals as they (the Swedish concrete lobby organisations) have a very strong lobby group. When the building was finished we spoke with the tenants and they were very satisfied. In the beginning we had our Austrian managing directors there (in Sweden) but that did not work, you have to have the Swedish team there. The Swedish people were taking a very long time to make decisions. They spent four months discussing a balcony detail. We found it really hard to enter. But then we got some really good projects, then there was the financial crisis and everything was put on ice and that was really bad for our company. I think that in middle Europe, we are five years in front of the Swedish in development. We have done multi-storey buildings including the nine storey building in the UK (Stadthaus Residential Development in Murray Grove, London, completed in 2008), but Sweden is on the right path. What is really hot now is the PassivHaus technology, but I am not convinced that the PassivHaus technology will work in the future because of the air-conditioning systems that we don't have experience with. I am concerned about the bacteria in the plastic tubes and the like. We experimented with PassivHaus technology in the alps to maintain a constant temperature of 20° inside, but really that is not enough because everybody wants to have extra heating system and then the passive technology alone doesn't work. I think a low energy standard is perfect. For Australia, for the PassivHaus, sun protection is the most important thing. We did some research in France with a KLH PassivHaus for one year. In summer, we measured up to 40° outside and inside it was not more than 22°. The most important thing is the shadow management.

Note: Refer to the PassivHaus Institut (passiv.de) for further information on the PassivHaus technology discussed here.

DB - Can you tell me about the research you are doing with Australian grown pine in conjunction with Lend Lease and Carter Holt Harvey?

HdM - So, we are doing research on the radiata pine. If it works, we will cooperate with these two companies. It does not make sense to transport panels to Australia, so in the middle to long term we will establish production there. Carter Holt Harvey have the sawmills and the timber, we have the experience with the panel construction and we will establish a franchise system to do the production there. With Lend Lease, they are a developer, so we have the possibility to manage the whole process from forest to finished building. We are working on this (the Forte'

building) now with a time frame of two to five years. The first thing is to define the values by testing the radiata pine panels to determine the spans we can achieve. When that is established we will look at the next step. They are thinking of the first building to be up to eight storeys, but I want to start with a smaller one, maybe two or three storeys so that KLH is introduced in small steps.

DB - Can you describe the key factors that must be taken into account when entering a new market with the KLH product?

HdM - For me, it is the approvals. We need to know the rules in the building industry. We need to know what fire protection and acoustic approvals are needed and what other permissions and technical approvals we require. We also need to understand about finishing, how are things finished inside and outside, what facade is common, is it wood, is it steel, is it bricks? A simple example. For our first office, we did the facade with a rough sawn larch weather board with just a wood finish. Over time the timber face darkened and people in the region started to say, you can't build your house with KLH because it will look like that. So we have to develop the system so that it looks like a normal house. In Austria and middle Europe, we commonly have the putz (rendered) facade, but you can't just combine putz with a wood finish and with something else, you must have a system that looks like a standard house in the area and the context. We also need to understand the context of the building industry because we are only the producer. The concrete industry is changing the system toward tilt-up prefabrication. If we exchange prefabricated concrete elements with prefabricated wood elements, would we be able to use the normal way they do the tilt-up and could we do the finishes after tilting the panels up or would we do the external finishing and install the ceilings during the fabrication stage? You also have turn-key companies. They would need to be taught how to finish off the building with the electrical and plumbing techniques specifically for our product. These are some of the things you need to consider when entering a market. We are currently preparing manuals for production and construction. We have a general world wide manual and are making specific manuals for each country. The most important thing is that you must have somebody in a new market who knows the system for sales and for technical support.

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Dr Andreas Falk

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David Bylund

(DB)

26 April 2010 -Drottning Kristinas Vägen 30, 1044, Stockholm

Interview Synopsis:

Dr Olsson's role in Nordbygg 2010's Timber City 2012 seminar and her reference to the children's story, The Three Little Pigs as a metaphor for the way people perceive different building materials is discussed. The role local governments can play in determining larger scale developments and their material choice is discussed. Several examples from Stockholm are reviewed in the light of this along with the way building material choice can affect the way a project is perceived.

DB - At the Nordic Building Fair 2010 (Nordbygg 2010), held at Stockholm International Fairs facility (Stockholmsmässan), the *Swedish Timber Construction Administration* (Sveriges Trädbyggnadskansli) organised a seminar promoting the Timber City 2012 (Trästad 2012) endeavor. Your talk was entitled *Densification and Renewal - Creating new and attractive living environments (Förtätning och förnyelse - så skapa nya attraktiva boendemiljöer)*. In the context of timber as a construction material, you addressed some of the sociological aspects of how we perceive the cities we inhabit and you referred to the children's story of the Three Little Pigs as a metaphor in how we have come to view building materials today. I am researching the application of advanced Scandinavian timber construction technologies in an Australian context. A part of this is investigating the perception of timber in the built environment by society and so your reference to the Three Little Pigs as a metaphor for the perception of construction intrigued me. Before we look into that, briefly explain what you do here at KTH and how you came to become involved in this seminar on timber construction.

ARO - This speech I gave was an odd assignment. I spoke previously at a workshop/seminar that was held by an organisation called the *Delegation for Sustainable Cities* (Delegationen för hållbara städer*) here in Sweden. This is a national commission that has been established as part of a Swedish tradition to provide money to assist projects which meet certain sustainable criteria. The moderator of that event was June Carlsson who is a television journalist and professional facilitator. She was the moderator at Nordbygg and she asked me to present. My research is in institutional theory as it relates to town planning. Institutional theory looks at structures of rules and also the behaviour within those rules. I am a public policy analyst as it relates to planning, not a physical planner, and so I focus my research on the forms that are possible for coordinating different interests. Planning, as you know, has a normative goal where we want to involve lots of different stake holders and we want to involve the people who live there, the developers, the municipality, the region, national interests and environmental groups and it's not easy coordinating all those interests. That's the focus of my research, what forms work, what forms don't and what will help or block cooperation. June called me and asked me to speak at Nordbygg during the seminar on wood construction. I don't know anything about building with wood but she said that it was the social aspects of construction and they are very interested in the coordination within the planning process. They have a group of municipalities that have signed on to building with wood and of course you're dealing with local area planning and so they are facing a lot of the issues I'm interested in. They have lot of ambitions for coordinating many different interests but don't necessarily know how to make it happen. When she came to me we started talking and I threw a bunch of ideas at her and I started to talk about planning and how the way we look at planning has changed pretty radically. One of the ways it has changed is that we now want to build for an innovative society and a creative society and we are starting to understand that that involves letting go of the reins a little bit and this is coupled with a practical change in Swedish society today and in fact most societies. When you look at the development of the Stockholm region for example, when you look at the building there is very clear evidence that it is developing along these radial corridors following the train lines. The reason it is doing that so elegantly is because the counties and City of Stockholm owned huge tracts of land. They decided after the Second World War to build outward because everyone was wanting their own homes and the conditions in the city were really bad. They built the rail and they built new towns all at the same time and the people settled there. So they sort of got lucky because they locked into transit oriented housing at a time when they had the

money and the mandate to do it. Now it is a very different story because almost all land is in private hands and you have a situation where municipalities are in competition with each other for people and so it's not so easy to just decide to develop. For example Hammarby Sjöstad (a new district to the south of Stockholm City developed on old industrial land that is often presented as how to develop inner city areas sustainably) is all very well, but it is land that was fully owned by the City of Stockholm. It was a brown field site and it was not difficult to get the last few straggling industries out and so they had free range to build a new city, but in most cases, it is difficult for planners to know what constitutes good planning when you have a city that is in constant flux. What's interesting about building with wood in this way is there is a certain amount of flexibility. She (June) was telling me how you can build more cheaply with wood because it's prefabricated, but you can also design for deconstruction in new ways. I'm not so sure how true that is, but it's interesting.

DB - That's part of the vision for new developments using timber construction. We haven't got to the point where we need to deconstruct them yet. Wait for 60 to 80 years time and I guess we will see if this is actually true.

ARO - This (design for deconstruction) is actually a problem. The challenge remains that we are working with fairly expensive capital infrastructure. We build for 100 years or more and if you put something in the wrong place you're in trouble. When planning you need to know how much is deterministic as in 'if you build it they will come' and how much is trying to build for demand and then Complexity Theory comes into it. While I don't know much about wood, I thought I would try and give a talk on planning and planning changes and how that relates to wood. It is also interesting to look back at history to European cities. The first land use plans and regulations for buildings came along as a response to the really horrendous fires that swept through cities that were built with wood and also to the first bad outbreaks of plagues. The first sewers were built in response to the horrible overcrowding, conditions and health. It is interesting to note that wood cities started developing this aura of being dangerous as the industrial revolution progressed and as waves of people started coming into them they became very dangerous places to exist. Using wood as a metaphor, I thought it was interesting when looking back at the story of the Three Little Pigs, I noticed that it was a story from around 1620 and that was right on the verge of industrialisation when cities started to get more dilapidated.

DB - So in this metaphor in the context of planning and cities, you're saying that the Wolf in the Three Little Pigs story represented the ills of the industrial revolution such as fires and disease and therefore as the story progresses, the wolf destroys the straw house and then the timber house but fails to destroy the brick house, but in fact is destroyed himself when trying to enter via the chimney. Is the inference here that anything other than brick is substandard and incapable of withstanding the challenges of the city?

ARO - Exactly, the story reflected very well the way planning went. Planning was to build for safety and for growing economic demands and it was supposed to provide for better society and it still is, but in the pursuit of those goals we started moving more and more to building for permanence and that's why we developed building codes and that is also why we wanted to build in brick. You build for safety and for permanence. In post World War reconstruction they went in a big way for what we call functional separation where you try to find out exactly where people were going to move everyday and you wanted to make it very efficient and you wanted to ensure that a person never came into contact with a car. A lot of the new towns reflect this as the norm. You wanted to keep housing affordable, but you wanted to keep functions separated.

AF - There are a lot of interesting threads here that you mention. They are definitely connected, maybe not at first glance, but they are definitely connected to development and the preconditions for the development of timber buildings. The way people have been living, the traditions, the way people look at different parts of the city, how they want to live and how they would like to develop their living. There are so many thoughts about timber construction but many people still think it's cheap, it's low quality and has bad acoustic. These opinions are still common even after 15 years significant technical developments in timber construction in Sweden following the change to performance based fire regulations in 1994. Once these changes happened, the timber industry was able to compete with steel and concrete. But the negative picture people have their minds of timber is lingering. It's still there, even though the attitude towards timber is changing as well, it is a much slower process. When looking at the preconditions (for development) in different areas and where to put efforts into getting things happening with timber, then these issues become very interesting. For example, there are two projects not far from here (KTH), Vetenskapsstaden I and II. Vetenskapsstaden I is the curved, slightly yellow rendered building which is an all-timber structure. It's rendered on the outside

and that was because it is so close to the National City Park and the so called 'Stone City' where they wanted to keep the rendered look of the area. The entire building system is timber, the walls, floors and stairs, everything you see is timber, but from the outside it looks like stone. (Refer to images of Vetenskapsstaden I and II in the Setra Case Study section). These issues are very tightly linked together. What you are saying pinpoints and helps look at these issues. The Nordbygg 2010 building fair had presentations from several Municipalities presenting their visions of timber cities of the future. Out in the smaller towns it is somehow easier to make these (large scale) planning changes because when they decide 'now we want to move forward and in this area, we want to develop it in this way or this way', it is easier to make it happen. In a context like Stockholm the political factors make it so much more delicate.

ARO - A colleague of mine's speciality is called 'City Marketing'. People always get it mixed up with advertising but it's actually the study of people's perceptions of the built environment. He originally trained as an architect but he is now working in cultural and social geography. He works with mental mapping of spatial contexts; I'm not sure but he may also deal with materials and how people relate to them. I can imagine that it is quite interesting to compare Sweden with some other countries. The Swedish romance with wood is undergoing a renaissance now because of the eco, natural feel of it. I live in a part of Stockholm, in Saltsjöbaden, that is associated with the natural, romantic style with wood from a century ago. There always has been this love affair with wood (in Sweden), but not so much in an urban context.

* <http://www.hallbarastader.gov.se/bazment/hallbarastader/en/start.aspx>

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David Bylund

(DB)

29 April 2010 - Tyréns - 118 86 Stockholm, Peter Myndes Backe 16

Interview Synopsis:

Mr Jensen introduces his doctoral research on the development of a high rise timber building system. He discusses the importance of designing stabilisation methods, dealing with deflection, compression and acoustics along with other additional associated issues specific to timber. The trial and error process of development used by some Swedish builders to build taller and taller timber structures after deregulation in 1994 is discussed along with some of the technical issues that were encountered at the time. The family owned nature of many Swedish timber companies is discussed and how some companies are having difficulty adapting their existing systems to modern industrialised construction philosophies such as Toyota's Lean. The importance of assessing a company's strengths and weakness and designing a product that responds to those along with gaining an understanding of regulatory constraints and opportunities is also discussed.

DB - Over the years I have developed an interest in timber construction but there are few opportunities to pursue this area in Australia. I am currently undertaking further study into new opportunities with timber with an Australian context. As part of this research I am here to investigate the Swedish timber, prefabrication and the construction industries as a point of reference for potential development and opportunities in Australia. Would you mind briefly explaining your background and position here at Tyréns?

PJ - I graduated from KTH as a mechanical timber engineer. I was studying sawmills and sawmill processes. I started at Tyréns five years ago as a structural engineer consulting on mostly small timber buildings and more recently I have been working on a development project between Tyréns and Derome. After being here for two years as a structural engineer, I was offered a position as a Ph.D. student at Luleå University focusing on technical platforms and building system development. I have been working on the LWEF or Lean Wood Engineering Program. In my Ph.D. research I have been working with small timber engineering companies building single housing and also with Derome. Along with Derome who own A-hus, we (Tyréns) established a goal of developing a high rise building system made of wood from four to eight storeys. In Sweden we have either volume elements or massive timber planar elements made with glulam. We had input from producers as we developed this system and also have several joint ventures between industry and academia. These are with Building-Living Dialogue* (Bygga-bo-dialogen) in the South of Sweden and the Timber Center** (Träcentrum) in the North. These organisations collect money from the timber industry and as they were financing the project we had to produce an open system that all different timber producers could use.

*www.byggabodialogen.se/templates/Page_____3477.aspx, **www.tracentrum.se/

DB - What are some of the basic issues you have addressed to develop this new structural timber system?

PJ - There are several criteria you need to keep in mind when designing such a system. These are not separate from any other type of building systems, but they are crucial. I don't rank these now, but you should start with how to stabilise the building. As you know, timber is a light weight material and the wind will tip it. Concrete is eight times heavier and the mass or the moment of the building prevents it from tipping because it's so heavy. With wood you don't have this weight and the building wants to tip so you need to fix it to the ground. You also get deflections in wood slabs. If you use ordinary sawn timber, you can't span further than 4m or 4.5m. That's a problem with the architecture that you need rooms that are closer to six metres. That is a big issue that we need to address. You can't have solid timber floors that are too deep. Another issue is compression in the structure as you are working with an orthogonal material that has fibres going in one direction. This is no problem with one and two storey houses, but with buildings that are eight storeys, if you put wood with the fibres in the wrong direction, the compression can be several centimetres. You also have the issue of fire

protection. It's not a problem, but you need to keep it in mind. We usually use gypsum layers to protect the wood. Then there is the acoustical issue. Stabilisation and fire are no problem as we have developed techniques to address these. But with sound, you have both sound traveling through apartments and flanking transmission. You have sound traveling through the floor slab from foot fall and airborne sound going between apartment separating walls. Because timber is a light weight material you have more sound transfer than concrete or brick. You have also have the moisture problem. It's a really crucial issue when you are working with prefabricated building elements during the construction. Because you have a prefabricated element containing gypsum and insulation etc you can't get any water in it. The usual way to address this is to build with tent structures providing protection.

DB - There is also the issue of damage to the structure from leaks within the structure after it is built.

PJ - That is true, but all building materials have this problem. The plumbing regulations here require pipes in pipes to protect against this.

AF - There have been trials and ideas that address that problem. There are prefabricated plastic boxes which contain the wet areas. You can isolate the wet areas in a shaft and in Austria I have seen the wet areas with a catchment basin that has an overflow pipe so if it does start to leak it can be detected.

PJ - The problem with timber building in Sweden has been that when the regulations in 1994 changed, they first started building timber high rise by just scaling up single housing and they found problems with compression and stabilisation. They developed problems and it is just because it was not an issue before and so they didn't take it into account. The stabilisation was also a problem at first. To avoid problems with sound transmission in two storey row houses, they simply separated each of the houses with a small air gap. The problem is when you use this same solution with eight storeys. If you put one apartment eight storeys up, when the wind blows you get stabilisation problems because you cannot just rely on gravity to hold it like you can with one and two storey row houses. You need to connect the houses by tying them down, but then you can have sound transmission problems. To overcome this we use a material called Sylomer. It's a high density type of plastic used as a dampener (vibration isolator). With this system we have been developing, we need to separate the apartments to address the acoustic issue, but we also need to connect the whole building to get a bigger

moment of inertia. To compare it with machine design, to avoid vibrations, there are two ways to address acoustic problems. One, you either use dense concrete or you use some kind of dampeners. In the construction industry, concrete is naturally dense, but with wood, it's relatively light weight so you must use dampeners. What we have done with our system is to construct something we call 'a house in a house'. So we isolate each unit by putting them together within a separate structure that can withstand the wind loads. We looked at the insulation of ceilings to address airborne sounds (from apartments above). We looked at foot fall, flanking sounds and noise sources from mechanical installations. We construct a core using dampeners with a structure that can also withstand wind forces. You have the problem of needing to connect the floors and adjoining walls of each apartment so you are dealing with one large plate, but acoustically you still want to also isolate them.

DB - You are working with Derome and they only make a prefabricated frame system. Have you investigated combining cross-laminated timber structure with the Derome prefabricated frames?

PJ - You're right, they only make frame structures because that is what they are set up to do so they didn't want any cross-laminated timber. It's a pity because that would be something really good. It would help overcome some of the structural cross-bracing issues we are finding with the multi-storey framed system. We have designed these framed wall elements that we call stabilising elements. We modularise them so we always have the same connections. In these elements we have tension rods in-built within them. There is risk here with this technique because it can't easily secure the building while it is being built. If a strong wind comes during construction, the individual elements are so light, they could fall over. It is not until they are all in place and the tensions rods are tightened that it becomes secure. The new way is to tighten it step by step as each floor is built up with the stabilising elements. These interconnect to each other and then are fixed into the concrete footings but there is more work that needs to be done in this area.

DB - Can you discuss the Swedish timber building prefabricated production line processes by describing how they are designed and their operational rationale?

PJ - Most of the factories that have been developed in Sweden have been done so by family businesses. They have the situation where they need jobs in a district and so they take a standard house, break it down into its wall elements in the same way as you would if you were building it on-site. So the technique was developed from ordinary

house construction methods. They have not modularised the building in the way other manufacturers have developed. Systems should be designed based on what the customer wants within the framework of the basic elements which are not changed.

AF - Many of the companies that are now starting to build multi-storey buildings are simply extending their existing factory lines that they use to construct single family homes. They use the same logistics as they have for small scale and they have just magnified it. The technologies are the same.

PJ - Yes it is basically the same, but we need to change this because of the higher loads.

AF - What would be interesting would be to turn the production line upside down to just see what is the main goal here.

PJ - Yes, what we need to look at is what the customer needs, how can we modularise this and how can we then build up a factory for production.

AF - I think that is the main issue that is happening here now. They are trying to apply the concept of Lean, adapted from the concept by Toyota, but they are striving to apply these principles on their existing production lines and it is not working well. It works, but it could be much better. With the philosophy of Lean, you should not have to stop the production when you want to change things or adapt things or when you want to remove problems. You should cut away things that are not optimised and you should produce more with less waste.

DB - So what you're saying is that typically, family owned companies are trying to adapt and apply the Lean concept to their existing production processes which are based on reverse engineering of the traditional house frame construction methods. There must be some companies that are not approaching things in this way?

AF - There are of course firms that have adapted to this very well. For example Lindbäcks are a family owned company that is managing this very well. They manufacture very efficiently produced volume modules, transporting all over Sweden from Piteå in the North.

DB - Are your views on this a general observation, and how much is your involvement being influenced by Derome's A-hus production methods?

PJ - Both, like I said, I have been looking at how small building companies work, but they are just the same. They have the same building system, all are built up on frames, the gypsum board gives the same distance between studs etc etc. They are basically the same. They haven't adapted their manufacturing processes according to customer segmentation, market niche etc. I think the frame construction system does have merits for example with the energy transmission through a wall. You can have a slimmer wall. But that is one of our problems in Sweden. The wall thickness is growing (to meet the energy ratings). The walls are complicated. This is my point. The industry has evolved from family businesses that have just cut an ordinary house into pieces, built it off site and then they just shift it. The thickness of walls were 100mm, but now the slimmest walls are 400mm. So what happened? Well, you can make sawn timber only so big, then you have to pack it out. They are just taking the old solutions from 40, 50 or 60 years ago and adapting them. You need to look at the criteria for a wall. What are the main purposes of the walls and how can you manufacture them in an economical way?

AF - The primary questions that need to be asked are what technical and constructional means do you have, what are the means for prefabrication, what are the means for transport, how sensitive do you wish your elements to be, how will you treat them on the way, what will be their function, what architectural needs will they fulfill? These are the questions that need to be asked. From my point of view, they are good at different things. It depends on the climate in the area and so there will be different needs for insulation. With the light timber frame, you can fill up the spaces between the structure with insulation and get very high ratings, but where the light frame is not so good, where it is particularly vulnerable is in transportation, you have to add things to stabilise it from both a montage point of view and when it is in place. Cross-Laminated timber plates are better in this respect as they are more stable and less sensitive to transport.

PJ - You need to see the pros and cons for different methods and see what are the market niche and segment you are working with. You need to see what criteria you are working with and then develop a solution. If you need a wall that gives the impression of solid construction, has good thermal performance, is economical to build, maybe some sort of montage, then you have to look for a solution before you proceed. The key to developing a new system is to understand the constraints, regulations and rules in the early part of its development.

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David Bylund

(DB)

20 May 2010 - Luleå Technical University - 971 87 Luleå, Sweden

Interview Synopsis:

Issues relating to establishing engineered timber as a trustworthy material are discussed along with Swedish progress in this area. The importance of combining design with the opportunities and constraints inherent in industrialised construction are discussed. Establishing a particular structural method and refining it to improve efficiencies and performance without allowing the method to dictate the project outcome disproportionately is also considered. Issues relating to establishing engineered timber and industrialised construction in Australia are discussed and how international collaborations could be one way of facilitating their development. Approval and liability issues are discussed in the context of sawmill companies taking on greater roles in constructing buildings using proprietary structural systems that largely negate the traditional role of the builder. Lean, 'Takt time' and 'Andon cords' are discussed in the context of developing industrialised construction facilities and systems along with trial and error processes.

DB - Before we start, I would like to contextualize my research for you. Australia's use of timber in construction is predominantly wall claddings, floor boards or stud framed residential buildings. There are few commercial buildings built with structural timber, although timber is often used for furniture, as a feature wall or floor lining and of course as form work. In residential construction, there are three primary methods used depending on the region. value-addingIn Perth, on Australia's western coast, houses are predominantly double brick walls with a framed timber or steel roof. On the east coast, they use either brick veneer or framed construction. Anecdotally, the general public often perceive timber as a lower quality material than brick. This perception exists for a variety of reasons, the main ones are concerns about its longevity, ongoing maintenance requirements, fire risk and susceptibility to insect attack. For the last 50 or so years, timber has been regarded in this way and so, not surprisingly, the perception

of timber has not kept pace with developments in timber's reliability and range of applications. Australia is a long way behind Sweden in that sense. Part of my research is aimed at exploring some of the Swedish developments in timber to test timber's potential to be used in new ways in Australia.

LS - From what you say, Australia is facing a dilemma if it wants to address the acceptance of timber as a trustworthy engineered material. You have to deal with many different layers of people with prejudices against the material and against this method of construction. Most people have a good knowledge of concrete construction and when presented with a new material, that is historically considered the poor man's material, they have huge difficulties understanding its benefits. It is my opinion that a huge cultural change is needed to alter the perception of timber. There is evidence of this now as the questions I get from the construction companies today are different than those asked 15 years ago. Back then we had to prove by technical verification that timber was a trustworthy material. The issue of reliability essentially evaporated several years ago. For example, they wanted to know about timber's fire performance, but now that is rarely queried as its properties in a fire are now understood and accepted in that respect. The questions now revolve around timber's capacity to be used structurally as we are now building six and seven storeys high with wood. Now we have verified its technical capacity to do this but it has taken a lot of effort to get to this point. My analysis of why Sweden's multi-storey timber industry has developed so well up to this point is this. There are two very successful factors that have influenced it. One of them is that since the 1950's, the builder's development of semi-industrialised, prefabricated processes manufacturing detached homes have allowed a new acceptance of timber in construction. Once there is acceptance of this for single storey houses, there is a natural progression or acceptance amongst people for larger buildings to be built this way. At least once a week, I get calls from building companies wanting to develop multi-storey timber housing and join our program. The second factor that has helped the development of timber is the focused attention from government and the state agencies. Even though concrete is a very powerful factor from a construction point of view, from a national perspective, the large amount of timber grown in Sweden means that politically it has a lot of influence. There are influential timber lobby organisations that try to convince the government to fund research and subsequently, there have been many large research programs over the last 50 years that have resulted in changing attitudes towards timber. These are the two driving forces that have had a snowballing effect which is now running under its own momentum.

If you look at the individual companies that have developed timber, all of them are prefabricating and are developing integrated building solutions where the technical and engineering solutions are integral. Once they have a solution from an engineering point of view, they stick to it. If they have a jointing detail that works for them, they don't need five different jointing techniques. They only use one joint solution and then they develop their value-adding by building as much as possible indoors, right down to installing the kitchen and hanging the wallpaper. The answer is not to have a multitude of timber engineering solutions, but to have one and a selling organisation that communicates with architects and clients explaining how to use their prefabricated solution. There are limitations of prefabrication that need to be overcome. The issue of how to combine the freedom of the architectural language with prefabrication is one important thing that has been overlooked in Sweden. That is where my interest in Lean and production efficiency comes to play. Companies develop one key solution and then build a factory around it. They don't change it (their 'key solution'), but if they were to do so, it would have a direct impact on the production machinery. What we do is to help refine their timber engineering practice and construction method. For example, by simply changing from one screw to two screws or increasing the diameter of a piece of timber from 10 mm to 12 mm members may give a company an important advantage. Whatever it is, we always try work to the method that they have adopted. There is the risk that you can get so involved in making critical and good engineering solutions, that you can lose market perspective. Companies do this all the time. Just last week, I entered into a cooperative agreement with a Finnish sawmilling company which is one of the largest sawmill companies in the world. The first thing I said to them was to be careful not to fall into the technology and factory design trap, yet despite this, they are doing exactly that right now. They are in love with CLT (cross-laminated timber) solutions and they are at risk of losing the benefit of prefabrication because of too great a focus on the technical aspects. It is a much faster method of construction, but the quality of the design from a technical and architectural perspective should be utilised to the maximum to offer value for the client. That is where you must put your focus. That is why I got involved in Lean. I am a structural engineer by training and I love calculating moment shear diagrams for beams etc, but it came to me that engineering alone is not the solution. It is the totality of the concept that is much more valuable to the market.

DB - One of Australia's biggest issues will be finding a building company or some organisation that is willing to do something that is new to the Australian domestic market because they, like Sweden's traditional sawmill companies, tend to be very conservative. There will be resistance to establishing large factories fitted out with

heavy lifting gantries, complicated and expensive production line equipment and also to the development of new technical solutions. I don't know where the answer to this is going to come from although I suspect it will be from outside the country - maybe someone from Scandinavia or central Europe. It could be in the form of a joint venture or partnership with an international company that wants to develop a new value-adding industry.

LS - Yes, that's a good solution. How long have you been here carrying out your research here in Sweden?

DB - About four months now.

LS - So then you may have had many conversations about this. I know of an Austrian company KLH (KLH Solid Wood Scandinavia in Sweden) that is looking at Australia.

DB - Yes, I've heard that.

LS - It could be said that the KLH experience in Sweden has not been that positive; they have had three CEOs in maybe two or three years and from a business point of view, it has not been a success story. There are a number of things they did wrong. They came to Sweden with a beautiful technical solution based on an Austrian business model. I know this because one of my Ph.D. students did a comparison between Austria and Sweden - we also looked at Austria to compare how to do business in Austria and Sweden to see what are the industry recipes for success. And so they (KLH Solid Wood Scandinavia) did everything wrong in my mind. Not from a technology point of view but from the business setup point of view. Forming a partnership, as you suggested, is a good solution, but they need to find a partner that understands the country's context.

DB - Absolutely. One contextual difference between Sweden and Australia is that Sweden is still essentially a monocultural nation whereas Australia has many varied cultural influences. Over the years, we have had large numbers of immigrants from many different countries. Can you imagine large numbers of Austrians moving to Sweden to live? Well in Australia, that's our situation. For a number of decades now, people with varied expertise and different approaches have moved to Australia and have adopted and adapted it as their own, generally being absorbed into the culture.

LS - Like the Italians after the war.

DB - Exactly, that's a classic example and there are many more. When an outside company comes to Australia and wants to establish a joint venture, we are generally open to the idea. Now it is predominantly China that is developing new business opportunities there. Australia does a lot of business with China and is now becoming accustomed to going outside its boundaries to develop partnerships.

LS - So you have different opportunities.

DB - Yes, I think from that perspective there are potentially many different opportunities. I interviewed KLH Austria's Managing Partner, Heimo de Monte, when he came to Sweden for Nordbygg 2010 (Nordic Building Fair 2010). I sat down with him for an hour and he discussed how difficult it has been for them here, but notwithstanding the setbacks, they are still trying. I will be visiting the KLH factory in Austria in about a month. I think that the symbiotic relationship, which is just beginning now between KLH and Australia could develop into something more. I understand they are just testing some of our plantation *Radiata pinus* timbers in their CLT panels. I imagine that any of Sweden's larger timber builders such as Martinsons, Linbäcks, or Derome would be interested in discussing similar inter-country collaborations that export their own engineered timber solutions.

LS - From my point of view, without having the responsibility of a company, I think that now is a good time for this type of collaboration. It could be franchising, it could be any form of business relationship. Notwithstanding this, Sweden's larger domestic timber building companies are really facing a dilemma at the moment. Martinsons is facing one kind of problem and Linbäcks is facing another type of problem. Martinsons is facing the issue of being too much of a sawmill, so much so that it is locked into that type of business culture. It is ingrained within the management, despite their CLT plant, they are still a sawmill. Maybe they should only be a sawmill company, I can't judge that. But what I mean is that if they are interested in developing the company and allowing it to grow, it is probably still too focused on being a sawmill.

DB - So you are saying is that their construction arm, which is making CLT, is existing only to provide a market for the sawmill as the sawmill business is the company's priority? Do you think they need to separate and so the CLT building side can say what they want independent of their parent company's needs?

LS - That's exactly what I'm saying. My opinion is based on how they respond to the building. I'm not a sawmill expert even though I have worked with sawmills for many years. I am primarily interested in construction. Here, at Luleå Tekniska Universitet, where we teach building, we now have many large construction companies participating in our program. From what I hear and see, when they enter into contracts within the construction industry, they are still struggling with their role as a subcontractor to the larger building contractors. They take on an increasing amount of responsibility for the structural system, but still there exist legal problems that they have to overcome in becoming a real partner in construction as they take on more responsibility for the structure and construction itself.

DB - I had this exact conversation yesterday with Håkan Risberg at Martinsons in Bygdsiljum. I asked him who is responsible for the structure of the building as they are now essentially building the entire building in their factory. What legal obligation do they have to ensure structural integrity and what role does the actual builder have in taking that responsibility? His response was that it is a grey area and that they don't really know exactly how to respond to this issue. Interestingly he did say that they have recently purchased a construction company to carry out the final onsite montage, allowing them to fabricate the entire structure off-site and then build it as the main contractor rather than as a subcontractor.

LS - Oh they have? Well, that's good, that's a positive step, but still they are going to face legal boundaries in the construction. You are pinpointing one key area that must be made clear.

DB - My thoughts on this issue are that technology and the rapid developments in the industry have moved forward so fast that the current regulations and the rules governing building and building permits haven't been able to keep up.

LS. - Yes, I agree again. Here in Sweden, people say to me that I shouldn't get involved in this issue. As I listen to those people, I think that this is about changing how building permits are given. It's the political aspect that I want to engage with. Traditionally, building permits are issued by the municipalities in Sweden and they have these monopolies of deciding what does and does not get built.

DB - We have the same thing.

LS - Often the final decision-making on approval is the responsibility of locally elected councillors. They are often really quite amateurish and do not understand the nature of building, especially this type. These types of decisions should be made by professionals as the issues at hand are too complicated for most elected councillors.

DB - Exactly, we have that same problem and as an architect, I have encountered the same issue many times in Australia.

LS - Yes, and it really is a hindrance for prefabrication. That's why I am getting involved in it. You can have a decision in one municipality, say where Linbäcks is situated, that is based on a good understanding of the issues at hand by the governing Authority. You can then just go to the next municipality where they don't have that level of understanding and there is a reluctance to issue building permits for prefabricated projects because they (Lindbäcks), for example, are not using local people (for the on-site construction) because they don't understand the system.

DB - You might be interested to know this. My Ph.D supervisor has been commissioned by a local municipality outside of the city in a rural area to design a series of houses for their employees using prefabricated timber buildings. The municipality themselves have commissioned these projects because they want more housing for their workers. They have circumvented a lot of these types of issues because they recognise the need to import expertise to get the type of projects they want and they understand the value and potential savings in using wood.

LS - Yes, but have the municipalities in Australia the possibility of being a client themselves? In Sweden they have.

DB - Well if it's for their own project, absolutely.

LS - We always have a communally owned municipality.

DB - No, no we don't have that, local councils are part of Australia's three tier governmental system. They are not 'owned' by the local community as such.

LS - So they act in two ways by commissioning projects and issuing permits.

So what else would you like for us to discuss - this is a favourite subject of mine even though I am not an architect. Because I'm involved in it and I see that this is one of the important issues for the timber building companies to really develop.

DB - I am also interested to talk about the Lean concept. Australia is a long way off setting up factories as they are here in Sweden. If and when this starts to happen in Australia, we will need to think about how to optimize the processes to allow maximum flexibility and still maintain viable economies of scale as an industrialised process.

LS - Yes, but the key really is that you have to be very much aware of what you are doing. It sounds obvious but it is true. The issue with construction in general in this respect is its variance; that is, the variability of each action is unknown. We try to manage it by putting measured estimates of how long each action takes. Installing a window for instance takes this much time, but still the variance across individual projects is very high. The main thing to try and achieve is to maintain control of production. To do that you need to measure the production flow that passes through the factory. This is known as the Takt time (Takt is derived from the German word Taktzeit which translates to cycle time. See the Terminology section for more information). Lindbäck's, even though they are a 'Lean' company, doesn't use Takt time yet but other prefabricated building companies do. Overseas, the Japanese automotive company Toyota also makes houses. They use Takt time on their production lines and everything centres around that. That is how you decrease the variability but it's not easily done. I don't know if you have heard about NCC's (Nordic Construction Company) failed attempt to establish a concrete housing factory based on Takt time some years ago. It was to be a Lean factory based on ideas from a white paper. They tried to establish it correctly from the beginning, including the set up of the factory and the design to get an even production flow. They also used standardised components which is also important. With the standardised components they were working with subcontractors like the car industry, where they bring the elements in as modules and, like lego pieces, just fit them together. Once they had set it all up, they failed after just four quarters. The reason for it was not the design but it was that NCC is a very big company that wanted revenues coming in quarterly and, after four quarters, they were not making their financial targets so they just closed it down.

DB - That's not a long time to allow a business pay its way.

LS - No it's not, but you have to find means to measure the flow to achieve the Takt time and that is difficult in construction because you don't sell 100,000 practically

similar cars where you have the opportunity to make small adjustments. You sell 20 houses of one type, and you then sell 14 of another type. You can even have, at the beginning of the factory production line, project A and in the end of the same factory project B and they can be completely different. It's not the same car type that you just value add at the end in a specific way. So that is the difficulty with Takt time in building. It's all about flow; measuring flow, achieving flow, having personnel doing self quality control of what they are doing and not leaving that to the last moment but rather detecting the problems when they occur. It is said that this was invented or adapted in Japan in the 1950s, post WWII. They went to the United States and looked at their mass customisation. They set up their own factories after this and to immediately identify a quality problem, they had a cord installed along the length of the production line called an 'Andon' cord. The idea being that when you pull the cord if you see a problem, the belt or production line stops. That is the beauty of it because, as a production line worker, if you acknowledge something that you did wrong, say you used the nail gun in the wrong way so that you have nailed into a plastic foil, when you discover it, you are the hero if you pull the Andon cord. Everybody is made aware there is a fault and collectively they try and fix it. This is not at all like the typical construction industry where people often try to hide their errors. In the Japanese philosophy, the hero is the guy who discovers a quality problem so everybody can see it, and everybody can work towards rectifying it. Today they don't use an actual Andon cord anymore to stop the line, instead, they press a button, a red light flashes and guys come rushing there to solve the problem as it occurs as a team.

DB - The Japanese are unique that way. I lived in Japan for a couple of years and they have a completely different approach to things where a collective approach is central to their world view.

LS - Yes. This is actually one of the criticisms that has been issued against Lean. It's a Japanese philosophy that can't be copied because nobody else can work the same way that the Japanese do.

DB - There is a difference there if you exclude the culturally ingrained collective work ethic.

LS - What I have tried to translate is the conceptual phase of this. You have to really put a lot of effort and thought into it before you set up a factory. That's why I am telling you about the experience of companies like NCC. These companies, including myself, are so much in love with the technical solutions that we can overlook the fact that it

might be sub optimisation to start with. We say to ourselves, 'Why should I look into this issue when I am focused on a beautiful technical timber engineering solution?' It may be the wrong solution within the big picture. This issue is where you should put more emphasis when comparing it to traditional construction techniques. Ask yourself, what is the aim of this? Where will it fit and what kind of market niche are we aiming for? It is a market niche we are discussing here because you are talking about prefabrication and you can't build everything this way.

DB - This is an interesting issue for me. I'm not an engineer, but I can appreciate a well resolved technical solution to a structural problem although I would hope not to the detriment of the whole scheme.

LS - For me it is possible to translate a lot of the Japanese philosophy. The actual design of a particular factory is not what I'm talking about but the philosophy behind it. You should have that conceptual thinking established as a way of working within the company and that requires a certain measure of experienced feedback. That's a crucial part. In the Japanese car industry, they have all these fancy programs for taking care of faulty reports and all those things that go wrong measuring it with micrometers; but that's not the way it is in construction. You need a system for experienced feedback. It's easily said, but the problem is to learn from the experience. You have to think of the house as a product and you have to think of it from the overall perspective: what went wrong in this project, why didn't it fit, why did we have to use more hours doing that when we still have a large variance. You need an experienced person or a group of persons to be able to do that; in my mind it should be the production engineer. It should be somebody who is responsible for the system. As you repeat it you learn and apply the lessons when you do it all over again. At the same time you run the projects traditionally as you have a superstructure to apply the experience to the design and into the production facilities.

DB - We all have to operate by learning from a measure of trial and error, I think. We can establish systems to operate and philosophies for production and ways of measuring markets and establishing the product to make but it still needs to be tested and that's the trial and error aspect.

LS - Yes, my point of view is that you should have them both. You need that common day business that you do and you are skilled in doing, but you need to capture that experience. If you have kids, you will know that they keep asking 'why?', even if at first you answer the question, they will keep asking why? The Japanese say that you

should ask five whys because if you ask five whys, at least three times the answer will come to the root cause. That's why kids are so good and also so annoying, because they ask, 'Why are we doing this' and 'Why are we doing that? Then you have to say, 'Yes we do it because Grandma wants us to', 'But why does she want us to do this'? 'Because she loves us'. 'Why does she love us'? So you come down to the core why, and then they are content. Questioning is something you should include at the conceptual phase. 'Why did we do it like that'? 'Because we have this contract with this guy', 'But why do we have this contract'? 'Because I know him'. 'Okay, but does he offer us the best quality work'? 'I don't know, but he's a good guy.' So that is the philosophy that the Japanese claim that they have on the production floor. It might be difficult for us that aren't Japanese, so my thinking is that we should at least be having this superstructure of personnel that are responsible for asking five whys all the time. For me, that is Lean.

DB - You claim that you don't have this Japanese philosophy and that the Swedes don't, but I think that they do, and I would state the example of Ikea. Ikea is a company that is an international company, now as well known as MacDonalds and Coca Cola, producing everything that we sit on and have around us in an incredibly coordinated and holistic measure. There has to be parallels there.

LS - Yes, there might be. We have a lot in common, at least the Japanese tell us that when we go to Japan for inspiration or they come here in delegations as they look at everything we do; it might be something in our cultures.

DB - My point is that I see similarities. I can't quite put my finger on it yet but I'm definitely seeing similarities between the Swedes and the Japanese in certain areas. I don't think it's anything to do with individual rights, or democracy or anything like that. I think it's on another level, it has to be an appreciation for timber, you both have long histories of using timber; but it's also an appreciation I think for simplicity, for paring back layers. Now when we look at contemporary Scandinavian furniture it is generally beautifully optimised on many different levels. I go to Japan and I can sense the same thing. I can't put my finger exactly on it but there are similarities there. I sense things in common which I have not seen elsewhere.

LS - That's interesting. Thank you for sharing that. I really do appreciate you saying this.

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(DB)

20 May 2010, Lindbäck's Bygg AB, Hammarvägen 21, 941 28 Piteå, Sweden

Interview Synopsis:

Lindbäck's typical project typology and their aspirations for the future are discussed. The importance of designing with a particular structural system in mind and the difficulties of adapting an existing design to suit a new structural system are discussed. The adoption of Lean into Lindbäck's production system are reviewed along with a typical project's time frame.

DB - I am researching Sweden's timber construction industry with a specific focus on developments in the area of industrialised production. Australia's timber industry is much smaller than Sweden's. Our developments in timber value-adding, for the most part, are many years behind Sweden. At some point, I think there will be a number of developments in Australia that will change the way we approach the construction process and the materials we use. The purpose of our meeting today is for me to better understand Lindbäck Bygg's background, production philosophy and building processes.

HJ - Your topic is very interesting and I feel that it is important work that you are doing as both industry and government need to see, and be convinced, that this type of construction is actually possible. A good example is the project that I am currently working on. It is a six storey building in Stockholm, it has five standard floors and the sixth will have a special, larger apartment. At the moment I am calculating the horizontal wind loads so I can design the stabilising elements that will be required. This is probably the most difficult thing to deal with here because, as you can see, there are many windows but not many structural elements that we can use to resist these forces.

DB - Yes, I can see that. In addition to the general issues associated with developing and establishing engineered timber building solutions within the built environment, I am also interested in these kinds of practical issues. Firstly, could you tell me a little about Lindbäcks?

HJ - Relative to the Swedish building industry, Lindbäcks is a medium size company in terms of our staffing numbers and financial turnover but in the area of industrialised construction, we are the largest company in Sweden. We don't want to limit ourselves to being just industrialised builders because that is not how we would like to be perceived. We would like to compete with the large construction companies and be a real alternative but it is doubtful that we have actually achieved that as yet. Some customers still see us just as an economical solution to be used on lower budget projects. We are still struggling to be perceived as a real alternative for a range of building projects.

DB - If you were establishing yourselves in Australia, it would not just be your competitive construction costs, but also your ability to build quickly which would also be very attractive to many developers. Can you outline the typical process and associated time-line from when you are first commissioned through to completion?

HJ - We always want to be involved at a very early stage of a project, even before any plans are drawn. Initially the preliminary project negotiating stage can typically take 24 to 48 weeks. Sometimes we enter gradually and usually before pencil is put to paper. The network that our sales agents have is critical to us being considered for a project and it is their involvement at a project's early stage that creates opportunities for us. Once we are commissioned, the design phase is divided into two stages. These are the building envelope design and the internal circulation and services design. Once these are completed, we undertake the detailed design and the documentation for production. This stage can take about about 17 weeks and it can depend on the number of projects we are building at any one time and their scale. The documentation of a building is not carried out sequentially, but rather on our ability to design the various components depending on our work load. As you can see, we have many projects currently being designed and this affects our ability to prepare the drawings for the factory. If we have many small projects, it can take longer than when we have fewer large projects that might have a lot of repetition. Once a project is submitted to the factory, constructing the volume modules always takes four weeks regardless of the project scale and the documentation department always needs to work four times

faster than the factory as they can build much more rapidly than we can draw. Once we are ready to go to site, it takes one week to place the modules on top of each other and they are sent out to site from the factory every second day. I should mention that the site works and foundations are always completed before we start the assembly of the modules. Once the modules are in place, the internal finishing typically takes two to three weeks. In the stairwells and common areas there are joints and pipes that need to be connected and we also make some final adjustments to the modules as transporting them can result in minor adjustments being required. In total, a five or six storey project takes about a year from conception to completion depending on how long the initial negotiations take as you can see from this time-line.

• Stage	• Negotiation	• Design	• Factory Construction	• Site Assessment	• Completion
Time (weeks)	24-48	17	4	1	3

DB - It certainly demonstrates the similarities and differences between the standard construction process and the time savings that can be made with your approach. The first stages seem to be fairly similar, but the eight week build time, from the factory to the finished building clearly shows the gulf between traditional sequential on-site construction and off-site, industrial construction.

Are you involved in the architectural design in addition to a building’s structural engineering requirements, and do you work with any specific architects?

HJ - We don’t employ an architect on staff because we feel that we would not be able to design a project for a specific area or location in the same way a local architect can. An architect will generally have a much better feel for what is right for an area. We do have several architects that we work with regularly who are knowledgeable about designing with our system. We can be involved in gaining the necessary approvals and permits and there have been times when there has been a shortage of architects and we have had trouble getting skilled people which can make it difficult with this kind of building system.

DB - I can see the potential for developing a joint venture between Scandinavian companies and Australian architects and developers where the skills and knowledge developed here could be exported and incorporated with local materials and projects.

HJ - I think so too. There have been many discussions here about how to export our technology, but even between the Scandinavian countries there are differing standards. I think that would need to be addressed first when entering a new market.

DB - Can you describe the processes that are used to manage and operate production of the volume elements in the factory context?

HJ - Several years ago, the company decided to adopt the Lean concept. There are only five people working here who actually draft the buildings, and we employ two external draftsman to document the building services. There are two people who do our project management and specifications and in the factory there are about 100 people. With so few employees, we try to maximise our resources and reduce waste. We try to make things standard and everyone knows our typical structural solutions. We hold fifteen minute staff meetings on a daily basis where the current issues are discussed. These meetings are held on a hierarchical basis. The people at the lowest level meet first, discuss the relevant issues and then one person from that meeting attends the middle management meeting and then someone from the middle management attends the senior management meeting. Within one hour, the CEO knows the status of things here in the office, in the factory and at the assembly sites so where possible, he can make adjustments to the operation if required. The factory, with its 100 staff, is the most resource intensive part of our operation. Once on-site, we only need three people to complete the building's assembly. Two people do the fixing and one operates the crane. The staff that complete the montage are actually from the factory as well and they also carry out the final finishing. That is actually the key to modular construction. Our staff working in the factory can produce more efficiently here on the factory floor than they could by building on-site and they are multi-skilled so we rotate them between tasks.

DB - Can you describe the procurement process that you use to win building contracts?

HJ - In Sweden, there are different sorts of contracts. There is the general contract where a building is designed, all the drawings are completed and the building approvals are sought. The project is then submitted to tender and the winning tenderer builds the project. That method does not work well for this type of production. We always use Design and Construct contracts. In conjunction with an architect, we are involved with the structural design as well as the construction. That is the only way we can operate economically. Some of our competitors do use both types of contracts, but

non Design and Construct projects usually result in a loss because of the number of changes that can occur throughout the designing process. An example is if you have to increase the height of the building to accommodate the extra floor thicknesses required for this type of construction. It sounds simple, but in the real world it could have a consequence if a building height limitation is exceeded or the client was not expecting a change which results in extra costs. We also find that if an architect designs a plan without a modular system in mind, usually based on concrete structural systems, they are not aware that we need to have certain structural elements align all the way up throughout the building and it can be difficult to include these at a later stage of the design process. When we tour the factory, you will see a number of the volume modules at various stages of construction. You can appreciate the expense that would be involved if we were required to redesign or re-engineer them if changes were implemented after they started production.

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David Bylund

(DB)

25 May 2010, Moelven, SE-545 21 Töreboda, Sweden

Interview Synopsis:


Acoustic issues relating to timber construction with a focus on the Akulite program being run between Moelven and Swedish SP to provide more accurate acoustic measuring regimes specifically designed for assessing timber construction are discussed. The public's perception of high rise timber building is reviewed along with the justifiable general disinterest in methods of production exhibited by consumers. Swedish timber construction companies' interest in the automotive and white goods industry mass production techniques are also discussed. Moelven's Trä8 system is discussed along with its cost compared to steel and concrete structures.

DB - Moelven's system of timber construction is unique in the Swedish timber construction industry. Can you tell me how they address issues such as regulation compliance, building standards and government approvals?

JÅ - The general building regulations in Sweden apply to us in the same way as they apply to other Swedish building companies. The main compliance matter that we are addressing now is not the fire issue, but acoustics. We know how to solve fire compliance by either over-sizing the timber dimensions or by painting the timber with fire resistant paint or by fitting gypsum boards. This matter is well documented and the regulations clearly prescribe how to deal with this to gain compliance. Sound transmission in light-weight construction remains a challenge. Complicating this issue is the bias between the limitations of the equipment used to measure sound and the subjective nature of our senses and expectations when in a building. For example, if you are in a building such as this and my colleague walks past, you can hear something. That sound is his feet on the floor which may or may not be disturbing to you despite the fact that, according to the impact sound measuring equipment, the acoustics still meet the regulations. Due to this specific issue, we are deeply involved in

a research program called AkuLite* which is being run by *Swedish SP* in conjunction with a number of other companies in Sweden. This program is intended to allow light weight structures to compete with more well known materials such as concrete and steel in terms of their acoustics and vibration. Akulite's main aim is to reassess the way we measure and test vibrations in these timber structures. For example, you may live in a multi-storey timber building that has an excellent acoustic environment, yet the acoustic tests may still say that it does not comply. In terms of the building regulations, we have three different sound regulation classes. These are Class A, B or C. Residential buildings are Class B and offices and commercial buildings are Class C. Currently, many timber manufacturers hesitate a little when tendering for a Class B building because it can be difficult for them to provide calculations demonstrating that a building will fulfill this aspect of the regulations. There are a number of different criteria that need to be measured such as air, flanking transmission and echo performance. In timber buildings, the echo performance is very good and they generally out-perform concrete structures when measuring reverberation time. Likewise, if somebody walks with high heels on a laminated solid timber floor, a high frequency pulse is generated. Timber structures also perform favorably when subject to this type of sound. However, if a larger person walks bare foot, the sound impact is in the lower frequency range and light structures perform worse in this range. In the lower frequencies, concrete structures generally outperform timber given that the easiest way to minimise lower frequency sounds is to add mass. Wooden structures perform well in some areas, but not so well in others. The AkuLite program aims to learn more about this issue and to also modify the regulations, creating a fairer regulation regime in which timber structures can compete with other materials. Currently timber is being assessed by a system that was created a long time ago for other types of structures. When you introduce a new type of light weight structure into an existing market, you could have a situation where the customer could be disappointed if they were expecting the same performance as a concrete building. A wooden structure is something completely different. It's not that we don't have ways to address this although there is a temptation to simply incorporate mass by adding a layer of concrete on top of the timber structure. If we do this, then we can risk stumbling on our own environmental arguments for using timber if we say, 'Think about the environment, build out of wood, but before you can move into it, add a 100mm screed of concrete'. If that's the end product that we deliver, maybe it is not so environmentally friendly and therefore, it is something we should be careful with. Rather than simply adding mass, we try to design better solutions for the timber floor-cassette connections. When fitting a floor-cassette into a wooden frame and then attaching it to the structure of the building, you must ensure that you can

minimise transmitting acoustic vibrations from that structure via the beam into other parts of the building. One way to do this is to use the synthetic compound Silomer between the elements to act as a vibration dampener. We are trying a different method. We attempt to create as firm a connection as possible by fixing the elements tightly to the beam. This utilises the mass of the beam as part of the system through the connection. The acoustic vibrations in the cassette are minimised because they are dampened by the huge mass and stiffness of the beam.

*  - AkuLite is a three-year project led by SP Trätekt. It is being implemented in cooperation with a number of the Swedish research and development agencies along with four universities, thirty industrial companies and consultants. 'Flats with light frames are becoming more common and they can be subject to unwanted noise and vibrations even if the requirements of building regulations have been met. The recently initiated project AkuLite intends to address this. The goal is to develop sound and vibration criteria that is consistent with people's perception of light buildings, rather than the current acoustic criteria which is designed for heavy construction systems.' Klas Hagberg, Project Manager, SP Trätekt (SP Technical Research Institute of Sweden 2010).

DB - How have you found the public's perception of your multi-storey timber buildings?

JÅ - They often ask if fire resistance is a problem, they want to know if you can really build that high, will it stand and is it safe? These are typical of the responses we have from the public. It is not difficult to convince them otherwise when we explain that we have built these buildings and tested them and we can show that these issues are not a problem. They quickly accept the idea of timber high rise and they often say that they would love to live in a building like that especially as they regard them as a better environmental choice. It is easy to present these issues to them as they are very personal arguments that appeal to the heart of the consumer. As soon as you start talking about wood, it has a strong connection with us as human beings in a way that is difficult to explain. It speaks to you in a way that is hard to define, but that's the way I have experienced it.

It's an easy product to promote and you rarely get questions like the concrete and steel industry are asked such as, 'Doesn't that consume a lot of energy to produce?' or 'What about pollution?'

DB - When proposing the use of substantial amounts of timber in large scale buildings, do you find clients asking about the issue of supply and the importance of sustainable forest management?

JÅ - That's not an issue at all in our market. We live in a timber country and it is such a big part of our history. Almost every Swede knows just what timber production means

to Sweden. When these issues are discussed, it is always referred to in the context of places like South America or maybe Africa or where you have poorly managed rain forests. It is never in connection with the way we produce timber in Sweden.

DB - Australia is not the same as Sweden in that respect. We don't view ourselves as a particularly large timber producing country. Products like wheat, wool, gold and iron ore come to mind before timber. I would expect it will need to be demonstrated to the public that building larger timber buildings is not only more economical than steel, concrete or masonry, but that there are sustainably managed programs enshrined in law ensuring adequate timber supply into the future. Unlike Sweden, Australia does not have legislation ensuring mandatory tree planting for every log that is harvested. I suspect that it will take initiatives such as this from both the public and private sectors to ensure that supply is not only secure, but that the public can feel assured that building with timber does not simply mean deforestation. It would make sense that when building with timber, it should automatically mean that more trees will be planted. An integrated cycle of planting and harvesting that ensures a sustainable supply well into the future that provides certainty for the public, would be one of the best ways to counter criticisms of Australia's timber building industry. Simply pointing out the unsustainable nature of steel or concrete production does not provide more trees and does nothing to convince people that timber is not just a more environmentally appropriate option, but also a sustainable one.

On a different note, since Moelven's Trä8 or Timber8 is unique in Sweden, can we discuss some of its architectural and engineering opportunities and also some of its limitations?

JÅ - The Trä8 system refers to a wooden pillar and beam system that allows for a gridded 8m x 8m span. The intent is to provide a timber option to the market, serving as a natural alternative for architects and engineers when designing a shopping centre, school or office building. We wanted to provide an alternative to concrete and steel using pillars and beams that could be rationally produced, with few variants within the components, and which is simple to stabilise. Soon after developing the system we spoke to a number of architects and we realised that when we invite them to consider our system, but restrict them to 8m x 8m modules and limit the height, we add too many limitations that were inhibiting the personal touches by making it too standardised. Now, we not only promote the Trä8 brand to architects who are designing fairly standard buildings where 8m x 8m spans can be easily achieved and suit the design, but we also encourage the system's use outside of this 8m x 8m grid. The

important thing to realise is that when designing outside of this standard size, we should be consulted early on in the planning process so we maximise the system within an individual design. That is probably one of our biggest challenges; countering the industry's habit of pulling a file out of a drawer for an old steel and concrete building, and then asking us to try to use that frame work for a new timber building. This approach does not work as we need to be involved in the project from the beginning. For example, let's say you have been commissioned to design a six storey office building in a city centre. The city architect has said that you need to work within prescribed finished floor heights. If your initial intent is to build a concrete building, the floors might need to be 280mm thick to achieve an 8m span and so it is designed on that basis. At some point later, it may be decided to use our structural system, but for us to fit with the given wall arrangement, depending on the spans required, we may need a floor thickness of 450mm. With some projects, it may be too late to accommodate this difference so you can see the problems that can develop. We have been asked a number of times to be involved in some really interesting projects, but we were not approached until it was too late to modify the design to work within our system. If they had only spoken to us early on, we could have found a solution that would have worked for all of us.

DB - From what you have described, the traditional procurement methods for building design will not really work at this stage of timber's progression into multi-storey construction. If you are being asked to tender on a project that has been designed based on assumptions informed from another structural system, I can see that it would be very difficult for structural timber to compete fairly. Have you established a height limit for Trä8?

JÅ - We have designed the system to comfortably reach four storeys, but seven or eight could easily be achieved. You must remember that the higher you build, the more challenges for stabilisation there are and for building above four storeys, we would need to be involved in the initial design to ensure that we could adequately achieve stability within your concept. It is a very easy system to work with, especially for three and four storey buildings. We work with stabilising elements between the floors and as the building goes higher, the momentum between the floors becomes larger at the connection to the ground so we need to ensure that there is sufficient width at the base to tie the building down. Using steel rods to cross brace and tie the building down is another way to deal with this.

DB - You had a large display at *Nordbygg 2010* (Nordic Building Fair, held at Stockholmsmassan [Stockholm International Fairs], 23-26 March) where you built a full scale example of the Trä8 system, complete with pillars, beams and stabilising elements. How did the public respond to your system?

JÅ - It was received very well and I think we made our point of demonstrating the simplicity and scale of the system. The market in Sweden is rapidly changing so it was a matter of showing people just what 8m x 8m using timber really is.

DB - Can you describe the infrastructure required to produce this type of system?

JÅ - As you have seen, we are extending our facility with a new laminating production line, but what we are doing there is not actually required to build this system as you don't need to be highly automated to produce it. In Sweden, you cannot talk about modern timber construction without discussing the topic of how to manufacture it. All of the suppliers, and even more so, *Skogsindustrierna*, our umbrella organisation, are talking about modern production techniques, Lean production and the automotive industry. I have come from the automotive industry and I think we are being a bit over ambitious because what the consumer wants is not a building that is produced in a specific way. I would argue that they don't care what the level of automation is used to produce it in the factory or whether it was built by a machine or not. Another thing that is very important is maintaining the level of freedom for the architect. A house is not like a car. We know that a car has four seats, a steering wheel and where the engine sits is more or less determined. A house is an expression of who you are and what you stand for. You create a very specific environment that is intended to make you feel good and which suits you. I think that it is simpleminded to think that you can produce a house like a car. I'm not alone in this thinking, but there are also a lot of people who disagree. I agree that we need to be a lot more efficient in the way we produce buildings, but not to the extent where everything is built as a catalogue product because I don't think that is what the market wants.

DB - In Australia, the public is basically already buying their house from a catalogue now. Our 'catalogues' come in the form of a row of display homes and slick web pages. Most houses are being built by building companies that produce a standard range and the consumer simply picks one from the range. There is no architect involved, no significant site-specific environmental considerations taken into account and compared to Sweden, fitted with very little insulation. The difference is that, while there are

already 'catalogue' houses, there is almost no rationalisation of the production process, and thus no benefits to the consumer from more efficient construction. When the minor differences between houses are peeled away, there is a very limited range amongst the designs and they also are produced very inefficiently. Houses are built on-site in a sequential process that has not changed in 50 years. People are not always aware of just how limited their options really are until they try and stray from what is offered.

JÅ - Too many people in our industry are looking into the automotive or white goods industries or other traditional metal industry here in Sweden. These industries produce huge quantities of products. Previously I worked for Saab and also Electrolux. Not far from here, they produce 500,000 refrigerators a year. These are huge industries. If we, at Moelven produced even 500 apartments a year here in Töreboda, it would be an extreme year for us. The quantities are completely different between our industry and these metal industries. People are wanting to transform the timber housing industry into automated factories with robots and production lines. We can do this to a certain extent to produce standard components, but maybe not for whole rooms or standard houses because people will not want to buy this level of standardisation out of the catalogue to justify the massive investment that it would take to create such a production line. The idea of making things more rational and effective is of course correct and we should never stop developing what we do, but not to the extent that some are envisioning. I think it is more important for the timber industry to teach the market that wood is just as good as other building materials and not focus too much on how we produce it. We don't sell buildings by discussing how they are produced.

DB - I had a similar discussion with Dr Tomas Nord at Linköping University. He also made the point that people are not so concerned about the production process, but rather, can they find a house that suits them and is affordable? The timber housing industry will need to decide which market they intend to produce for and devise products to fit that market. How they produce the buildings themselves should not be at the forefront of this process.

JÅ - If you look at cars, a few years ago some people were concerned about where they were produced. If they were patriotic they bought a Saab or a Volvo. But this is not so critical now as there are plenty of cars available that are just as good. The Swedes are becoming increasingly liberal when it comes to this issue. Another example is with electronic goods. Take iPods. You probably know that it is produced in Malaysia, but it's an iPod and since you like your iPod, you don't really care where it is produced.

DB - I think there can be a benefit in keeping people broadly informed about how and where their buildings are produced, especially if it has the potential to reduce the cost of construction and improve the quality. In Australia, industrialised production of buildings has not started in any meaningful way. If a particular building company is moving towards more rational means of building and they are on the leading edge of this movement, then there probably are benefits to promoting the fact. But it is not a reason to do it in and of itself.

JÅ - When talking about standard, straight-forward housing that corresponds to the normal, average family's requirements in terms of space and utilities, there is nothing more effective to build than modules where everything, including the finishes, are all done in the factory. You might think that I am discussing the production line concept again, in a way yes, but this is not the same as the production line in Volvo's factory. This type of production is practiced by Lindbäcks, Setra and A-hus. They all produce modules that are about 4m wide, 3m high and 12m long. This is the most rationalised way to build that we have in Sweden at the moment. If you want to step out of this frame defined by the 4 x 3 x 12 modules, then you have to look at other systems and it is harder to prefabricate elements larger than this. You need to use systems like ours or maybe Derome's new flat pack system. We believe our approach is the simplest to produce and assemble. Large elements are lifted into place with a crane and then they are fixed with a simple connection. It's cLean, you don't get wet, there is no concreting and no waste. Each step required is easy, simple and fast.

DB - Can we finish with a discussion on cost of construction. Can you describe how the Trä8 system compares with traditional construction?

JÅ - We recently designed a four storey, 3,000m² office office building in Skövde, just south of here. The total cost, based on trade quotations including the architect's fees and land purchase was 12,000SEK/m² (\$1800 AUS/m²). We also commissioned a bench mark cost analysis of the building using traditional steel and concrete. The traditional method cost was only one or two percent cheaper, but we were able to finish the building three months earlier and this gave our method a significant time advantage. From this, we know that we can be cost competitive, but being faster to build and more environmentally friendly etc is often not enough to encourage developers to shift from building the same way that they have been doing for the past 40 years and that is a struggle for us. Sometimes we manage to do it, some times not.

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Interview Synopsis:

The increasingly prohibitive nature of Scandinavian thermal performance has resulted in overly complicated insulation solutions to some timber framed systems. Buildings are sealed to such an extent that they do not perform well in warmer weather without extensive air-conditioning requirements. The change from proscriptive to performance based building regulation in 1994 in Sweden are discussed. The high level of sophistication exhibited by today's multi-storey engineered timber buildings is helping the public accept them as a reliable building solution. Architectural and engineering opportunities and constraints of engineered timber buildings are also reviewed.

DB - Thanks for the opportunity to meet with you again and to continue discussing issues relating to my research. It is the middle of summer in Sweden now and the temperature is getting warm with some days up to 30° Celsius. I have noticed that many of the buildings here are not air-conditioned and are becoming very uncomfortable to be in. They performed very well last winter against the cold, with their highly insulated walls and centrally heated floors, but it would appear that these same insulated, well sealed buildings are not coping so well with the heat.

AH - Yes that's right, the regulatory developments in Sweden now require that the sealing of the buildings be so efficient that in the hotter months you have to rely on artificial ventilation to keep them cool.

DB - It's not such a problem if you can ventilate using evaporative air-conditioning but of course, you cannot seal the building to the same extent as your regulations require, as air must be allowed to flow out to allow the evaporative system to operate.

AH - The insulation developments here are starting to become prohibitive, especially in the timber frame developments where they have so many specialised layers which almost only perform one function. If one of the layers fails, it can lead to the failure of the entire wall. That is one reason why, here in the Swedish climate, the cross-layered timber works so well as you don't need the additional layers to act as moisture barriers and the like. If you can allow the building to breathe, you don't require the same level of air-tightness as framed walls. With cross-laminated timber, you can potentially develop a more economical and robust system.

DB - In Australia, the public has come to expect buildings to be air-conditioned in order for them to be habitable, much like our sealed, air-conditioned cars. As much as people no longer tend to wind down the window of their car if it's hot, they won't open a building's windows to allow for cross ventilation.

Can we discuss the issue of building regulations, approvals and standards for the new timber construction in Sweden and how the Authorities are responding to the industrialised production of buildings?

AH - Regulation and bureaucracy is a very strong characteristic of the Swedish mentality and you must also understand the way we view our timber traditions as they relate to our expectations of buildings today. We want to see the wood's natural surface but we also want the building to perform in a certain way in relation to our climatic conditions combined with our expectations of sound levels to be below a certain range. The problem is that leaving parts of the timber visible can lead to difficulties in some of these areas. We need to strive for even more improved systems, and regulating every single part of the building in relation to these issues is how we are attempting to achieve that. As you heard from KLH (refer to KLH Massivholz GmbH interviews with Heimo de Monte on the 26th March 2010 and Johannes Habenbacher on the 24th March 2010), the levels of approvals and regulations needing to be met in the UK for example, are far, far below the Swedish standards. I think the Swedes are more particular in how we live. You have seen the procedures and the processes here and you have seen how we deal with timber structures along with the development of timber systems of construction and the aspects we consider as crucial. You could simply transplant the various Swedish systems of production to Australia, but you would still need to focus on the qualities that are core to the various Australian markets and adapt the output to suit them.

DB - Can you describe the paradigm shift that occurred in 1994 when the Swedish building regulations changed from prescriptive to performance based standards?

AF - During that time, I was working in the office of SP Trätekt (SP is the Technical Research Institute of Sweden. Trätekt is the Timber Technology department with SP) where the elite of Swedish fire experts sit. I was just starting my studies at that time, but I think that it was being recognised that there was a capacity within timber to perform better in those areas that hadn't been possible to utilise before due to the restrictive nature of the old regulations but I don't think there was much discussion about the historical factors that had initiated the restrictions, in the first place. The former Swedish Social Democrat Government felt that much was owed to the timber industry since, for so many years, there had been restrictive regulations preventing timber from developing beyond the cottage construction industry. From this, they initiated the National Timber Building Agenda. Nicolas Svenson, now the Chief of Sveriges Träbyggnadskansli was part of that. With the development of new timber technologies in other countries, along with encouragement from within the industry here, they started to push the technology further than just milling plain boards and building simple single panel one and two storey houses. I also think that they were having discussions on how to view, regard and treat materials differently. For example, previously, the practice has been to simply over-clad a combustible timber structure with other non combustible layers. There was no reflection on how the very structure itself would perform so no additional research had been carried out on its own combustive resistant properties. From a resource point of view, these were some of the issues that were being considered. We now know that you can design a timber structure to perform well in a fire. Tests, historical examples and experience from fire departments entering a well designed timber building demonstrate that they do perform very well. Even though they do get damaged, they don't collapse easily if they are well designed. In addition to this, the way we build concrete structures is quite ridiculous from a resource point of view. You build the structure once in timber, then you cast the concrete, then you tear the timber away.

DB - It's been approximately 15 years since Sweden's regulations changed allowing high rise timber buildings. Most of the timber buildings being developed today are residential buildings that are often six or seven storeys high. How do you think the public have reacted to this type of construction? Have they readily accepted it or has there been some resistance?

AF - I think that if you ask them, yes, they are a bit wary, but many times they don't think about it. They just accept it and often are not even aware that a building has been built with timber. For example, Lindbäck's, who build many of the volume modules for

multi-storey student homes and residential blocks here in the Stockholm region, build buildings that look as if they have been cast in concrete from the outside. I don't actually think that people reflect on it much. If you tell them it's made of timber, they seem quite sceptical. They often think of the low quality temporary pavilion style school buildings from their school days which were very noisy to be in. They had a plinth foundation and you could easily hear people's footsteps as they walked around. They were temporary, often being built and torn down as required. If you ask them what they think of timber for high rise, they are still quite sceptical because they still think of these temporary school buildings as they were once very common. Notwithstanding this, many people have now experienced the good qualities of these new timber buildings without even being aware of them. The core issue has been acoustics, and the design of the floors has been critical to overcoming people's concerns. Acoustics and floor properties of timber structures have been the most difficult points to address, even over fire safety concerns. This has been the biggest challenge for the timber construction industry, and they have succeeded even though it still can cost more compared to conventional concrete floors. They have now succeeded in achieving very high standards in this area.

DB - Can we discuss the architectural and engineering opportunities and limitations with engineered and industrially produced timber buildings? In Sweden there appears to be three main systems of construction. The stud framed, volume elements such as those built by Lindbäck's, the cross-laminated timber planar elements that Martinsons constructs and the post and beam systems such as Moelven's Trä8 system for commercial buildings.

AF - The introduction of cross-laminated timber in Sweden has meant a lot to the timber construction industry as a whole. Not in the sense that the share of cross-laminated timber products will be enormously big, but the creativity and further development of timber when used to create cross-laminated timber products is important. The use of cross-laminated timber has started to demonstrate that you can create other types of architecture and other types of structures with timber that were not possible before. For one hundred years, the Swedish industry has not wanted to invest money into the development of anything other than saw blades, cutting angles and how to saw more boards out of a trunk. What is very important is to make not just one step in the development of product or system, but two and three and four steps. Vetenskapsstaden I & II, the two guest researcher accommodation projects here at KTH are, unfortunately an example of this one step approach using prefabricated

volume modules. The first project, while externally quite uninteresting from a production and architectural point of view, was much more interesting and promising than the second project. The first project used a range of different module sizes to create differentially designed apartments within the same block. In the second project, they rationalised the process and only used one standard volume module for all of the apartments and that was their way of entering the market. They wanted rational, low cost, one volume modules, and in the second project were not so concerned about providing architectural variety as they had with layouts of the first apartment. When the Swedish timber industry makes the effort to develop something, they don't seem to dare take the next step. That is very typically Swedish. The Finnish are much more drastic and they often try something new as with the Norwegians also. They are always looking forward towards the next development of a particular technology or system. Having said that, the cross-laminated product has so many interesting properties and potential, I hope that they can start to develop combinations of volume elements and cross-laminated timber panels to provide architectural variety as well as remaining economically competitive. What I think would be sustainable in the building market would be to have the stud and beam volume module system in combination with the cross-laminated timber. You could use the cross-laminated timber for certain types of span, for cantilevering actions in building when you want something architecturally special and when the production means gives you the benefit of having robust floor elements.

DB - I believe that Martinsons and Lindbäcks are currently building a project called Älvsbacka Strand that is utilising both stud and beam based volume modules and cross-laminated timber floor elements.

AF - I think that about five years ago, there were solutions developed to combine these elements, but they were not promoting it or presenting it as part of their selling arguments. Vetenskapsstaden II though, had been developed to use planer elements in between the stacks of volume modules, which I think is clever. In Sundsvall, Martinsons had started to deliver cross-laminated timber floor elements for a project which, for reasons of production capacity, they combined with prefabricated light timber frame walls. This was very clever, because they had a very good cross-laminated timber floor solution. The solutions and trials are already there in the market, but the timber industry needs to open their eyes to the benefits of selling these possibilities and really show that things other than the typical red Swedish house can be produced. I spoke with Niclas Svensson from Sveriges Träbyggnadskansli on the phone last July

about this issue and he briefly reflected that architectural issues relating to this had been dealt with far too little as part of the national timber agenda. Until a few years ago when the performance based regulations came into effect, suddenly the need arose to develop timber; previously we had the situation where there had not been any need to do further research in in this area.

DB - When considering the future of engineered timber structures it would seem that the sky is the limit. What are your thoughts on the potential for larger developments and greater spans in timber?

AF - I think it is important to choose the right context for such efforts and to signal the right reasons to do it. I think it would be ridiculous to do it just for the sake of doing it. In the past ten years, I've seen that you can do all kinds of structures when you have architects who don't care about material issues. They just design it because they like the idea and they don't work it through properly. They fancy things that don't perform very well. The timber industry here has been very keen to do these things. They say, 'Look, we built this high tower', but it looks terrible. Quite early in Skellefteå in Sweden's north, they built a six storey building in timber and clad with red panel. It looked like they had taken the red paneled Swedish cottage, extruded it up six storeys, and put a roof on it. They put these red panels from the base up to the eaves and it looked ridiculous. You can't sell these new technologies by doing that. They should focus their efforts in the right places, then it can stand for maybe one or two hundred years and it will be accepted quite well. This especially applies to cross-laminated timber technology. So many Swedish architects are being attracted to this, but few know how to deal with it; they want to have the picture they have in their head realised at any price, even though it doesn't always work that way. An architecture student at KTH that I taught recently wanted to take a cross-laminated timber panel and drill holes all over it. It was a fantastic graphic pattern, but it would allow moisture into the panel making it rot away in half a year, yet they didn't want to understand or realise that. They say, 'I want to do this; anyway, it won't be that bad, it can't be that bad'. I think that to create a successful and really good object, you need to consider such things and take away the idiotic ideas. I said to them that it would be fine indoors, because it would be in a protected environment, but not outdoors.

DB - What are your thoughts on the move towards the industrialised production of buildings, and what implications has this for architecture and building?

AF - There has already been a lot happening in the area of single family house production lines. It will be interesting to see how things develop further. There has been a lot of discussion about the entire factory production idea and the work environment needed for efficient production. The Lean philosophy that is often imbedded into industrialised production wants to move the entire production into the plant and then distribute elements out to the site. You also have the situation where planar elements are transported to the site and assembled there and there is also on-site production as well. You need to adjust the production to suit the conditions from building to building. It's a positive thing that in the building sector so many objects are unique, even though there are now high capacity production lines producing volume elements. On the site, you still have so many factors that need to be adapted for, including transport and logistics.

DB - What issues do you see are important to consider when looking at issues relating to the assembly of industrially produced buildings?

AF- It really depends on how you value the products. You can develop exacting and very high performing joint solutions where everything fits together in a very rationalised manner, but this jointing will cost money. In a national or regional context, where timber is valued for its properties and treated as a costly material, it's not strange to include these costs for specialised jointing details.

In Sweden, we don't have so many of the refined timber products such as OSB or plywood. The slotted-in steel plates are becoming more common. These fit into a slot that is cut into the end of the beam and then fitted into a similar one on the wall or stud, but that is also quite costly. Apparently the Swedish market is not quite prepared for those type of details. Not so long ago SP Träteknik invited a Japanese researcher to spend two years in Skellefteå. He had a joint solution that made it possible to join beams in the longitudinal direction. I think that it is quite an interesting type of joint and that it should be developed here in Sweden; unfortunately at the time, it was too expensive. Maybe in five years the market here might be ready for it.

Moisture content has been discussed quite a lot here in Sweden too. What happens within the timber during drying? At certain temperatures, nutrition within the timber follows the moisture during the drying out process. The sugars in the timber follow this moisture to the surface and are left there when the water evaporates. This has been found to increase the risk of fungi and mould formation on the timber's surface. They have seen it on the lower side of carports and on sawn panels. It can simply depend at what stage the timber is planed. If you have dried sawn board, then if you plane the

surface, the top several millimetres that are holding these sugars are removed and you can decrease the risks of mould and fungus. These things should be discussed in the context of how we treat the material and what quality of material we put into the built environment. We should not build in moisture, so you need to properly protect the material when transporting to site. If you put cement into one part of a building, where will that moisture go into the timber structure as it cures?

The issue of deflection and compression of timber has also been discussed a lot recently. Of course timber's highest strength is in the longitudinal direction which is also the direction that suffers from compression when it is under structural load. When you use timber for multi-storey buildings, the sum of the compression must be accounted for to ensure that the difference in overall dimension does not cause any problems. Timber is so easy to cut with very small tolerances, but from that point of view it is not naturally form stable. You do have to deal with the compression factor, but I'm not sure how much affect it actually has.

DB - When in the south of Sweden, in the city of Växjö, I met with representatives of Södra. When we were discussing this issue, they related an example where one of the first four or five storey timber buildings in the area was found to be suffering from compression and it was affecting the gypsum wall cladding, causing it to buckle. It was found that the builder had simply increased the dimensions of some of the wall studs, from those used in standard two storey construction, which was subsequently found to be insufficient to carry the sum of the load without suffering from minor compression that was being compounded over the height of the building.

AF - Back to the issue of element connections, when discussing the design of open and closed systems, for example with cross-laminated timber structures, of primary importance is that the dimensions are correct. Where you put the screws or steel plates is not so important. If you have cast or slotted-in steel plates, screws or bolts, the very nature of timber is such that it is very flexible to accommodate many jointing solutions. The efficiency of the joints and of these various system details is important. To have one single system would seem to be a waste of resources. As long as the elements have the correct dimensions, cantilevering and correct distance between the walls or floors, the jointing between these elements is very straight forward.

The other issue we should discuss is the fire performance of cross-laminated timber. Jörgen Kernish, who I think is retired now, had been looking at what happens when one of the structural layers of the panel is charred off. The vertical layers carry the compressive load and in a typical five layered plate for a wall, you orientate it to have

three standing layers and two horizontal layers. If you burn off one of the 18 mm or 22 mm standing layers, you remove one third of the panel's structural strength. He has been quite critical of the testing of the KLH panels because of this. He has also been critical of the wall developed for the second Vetenskapsstaden project, where, for acoustic reasons, they built in air gaps into the structure, where the vertical layers are tight and the horizontal layers are spaced. If one of these surface layers is burnt off then a chimney effect can develop through the wall structure. You can tailor the build up of the layers to suit the purpose of the panel, but you must also think of the potential affects as well.

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8 June 2011 - Perth, Boral Head Office, Perth

Interview Synopsis:

Boral's reluctance to undertake research and development involving timber products is discussed. Both successful and unsuccessful attempts by other companies to operate viable value-added timber operations are considered along with some of the contributing factors influencing the success or otherwise of the ventures. The effect of issues such as local weather patterns and labour costs are explored as well as the quality of timber produced when plantations are planted in rows. Attempts to produce engineered timber products from low grade and juvenile timber are also considered.

DB - Patrick Beale is my supervisor and I am about halfway through the Ph.D. The first half has been spent investigating engineered timber in industrialised construction in Scandinavia.

MB - So would this be the manufacturing of the timber product or the building?

DB - Both, actually. The idea that I am investigating is ways to increase domestically produced and developed engineered timber products for building in Australia. I have been investigating Sweden's domestic model to learn about and perhaps apply their experiences here. I am not sure what you know about what's happening over there, it's a long way away, but timber in Sweden is a very common building product and they are probably one of the most advanced producers of timber and engineered timber products in the world.

Over the last 15 years they have had a significant increase in technical developments using timber to build multi storey buildings, 6,7,8 storeys high, all timber, and they are either using volume module type construction inside a factory and then they take each of the modules of the larger building and stack them on top of each other, or they are

using the cross laminated timber panels. I think you probably would have heard of them.

MB - I have heard of them; I don't really understand why they are so good, but anyway ...

DB - As far as I am aware, and I have been to some of the manufacturers and seen some buildings, the advantage is that they can find a market for second grade timber, and lots of it, and they can make a very structurally sound product.

MB - So how many laminates wide are they?

DB - They range between three and seven: three, five or seven, and they use timber similar to a batten I suppose.

MB - Just plywood, really.

DB - The nickname is jumbo ply so they will have a flat bed press that might be 2.4m wide +15m long on which small timber pieces are lay out in a cross laminated order and to form large solid panels.

MB - There is glue in between (the layers)?

DB - Gluing is the most common fixing method, sometimes the panels are fixed with nails or dowels and some are dove tailed together without any mechanical or chemical fixing at all.

MB - Are all the layers structural?

DB - No, it depends on whether you are using it to span distances such as a floor or a roof or whether it's a vertical element such as a wall. The application determines the cross section.

MB - And they actually panelise houses in that way, do they?

DB - More commonly for mid rise apartments, typically three to eight storeys.

MB - So it's not done in housing?

DB - Yes, they do use this technology in housing but in Sweden, the volume module concept is more common than in one and two and three storey buildings.

MB - That's interesting, because the WA housing industry doesn't believe that that concept works and I have always struggled with that because I don't see why it shouldn't, really. We could do it in concrete, we could do it in timber house panels but we have been trying for ages to make it work in housing and it's just not working. It's hard to know why.

DB - Yes, I think if it can be made to work here. If it became accepted and popular then it would work anywhere in the country.

MB - Yes, it's a question of leading the market.

DB - I think if it is going to take off here there will have to be a company willing to take some risks and I think it will happen in partnership with some European companies.

MB - So who's making those panels in Western Australia?

DB - There have been a few larger sawmill companies looking into this type of manufacturing such as Carter Holt Harvey and Wespine, but I am not aware of any commercial manufacturing as yet.

MB - And what is the technology required to manufacture these panels?

DB - Primarily you need a finger jointing machine, a large laminating flat bed press, a method of applying the glue or fixing the nails and heavy lifting gantries to pick the panels.

MB - So it's pressed and heated is it?

DB - Yes, they use high frequency press technology as a heating source to cure the glue. The high frequency process induces the water molecules within the glue to move intensively causing friction that creates instant heat making the water vaporize and bonding the glue.

MB - So who's the labour in Europe? Do they have a lower tier of labourers they can pay less money to?

DB - No, not particularly. The factories that I went to just employed locals. The thing with it is that the forests are predominantly owned privately there and they have been in the same families for generations. This sort of thing started to be developed because they were looking for ways to value-add to their sawmill industry so family businesses would add additional construction capacity to their sawmill and they would just feed into their next stage. Austria and Germany are also leading the way in that they have a very similar model. In our situation, most of our forests are state forests, or we have got blue gums down south in WA but that's only been in existence for 40 or so years so is a fairly recent recent phenomena compared the European managed forests.

MB - There would be a whole lot of technology trying to get it proved up because it's hard to prove.

DB - Yes, well the thing with it is that there is nothing in the Australian Standards or the BCA that deals with these types of products and if you wanted to make a building that is more than three storeys high out of timber the BCAs are restrictive at the moment so you might be looking at a hybrid building where you might have the ground floor as masonry and you might have three floors as one of these and you can even have something else on top perhaps. There are ways to work around that as a stepped approach to getting to the point where legislation is keeping up with it.

MB - Well, you have to get it it engineered right.

DB - That's right. There are a number of people now starting to look at this quite seriously, mostly on the east coast that I am aware of.

MB - Are we one of them?

DB - Boral? Not that I am aware of.

MB - That's a pity. I believe we are very interested in the the Grocon Pixel building.

DB - There is a lot of talk around about this type of thing but until someone actually gets in and puts a building up and it becomes a case that we can study it's incredibly conservative and hard to get people to move outside of what they know. But it seems to me that we've got the knowledge to deal with large panels because we have the tilt up concrete industry now so as far as how to deal with this sort of thing and transport it and lift it up to great heights there is nothing new there and the actual construction of these panels is not difficult at all. In one of these battens, in Scandinavia and greater Europe as well, they finger joint out all the knots so they get solid lengths, continuous lengths. There's really not too many things left to work out; there are a lot of buildings built like this now. So the reason I have come to see you is to ask you the question: what's Boral doing to be involved in some of the new technologies that are starting to appear?

MB - Yes, well nothing is the answer. You would be better placed to speak to the innovations manager and have those conversations. He's not based in WA though, I can get you his name. In WA we don't even sell timber. It just doesn't pay to try and transport it across and bring it to market. It adds too much to the product so we just don't sell it.

DB - Yes. So what's your role?

MB - Well, the Market Development, so that definition of market development is existing products to new markets, as opposed to product development so innovation falls within my area of responsibility but mainly to feed ideas through to our Innovation Management. Boral is really only just getting on top of things. But I know they are quite interested in the Grocon building (Grocon Delta Building yet to be built on the old Carlton & United Breweries site in Swanston Street, Melbourne) so the timber business unit is interested. I like it because it sequesters carbon and at least in the short term that's a good thing but in terms of building a business case that would be a big job. Boral would probably buy a company that had already done the R&D. Probably a Dad and Dave company that has it got it all working and then we would just come and buy the company. Most people just sell and then go into retirement and Boral picks it up and commercialises it. I am not saying that is necessarily the case but it is the easy way. Get someone to manage the building part of the risk where risk is greatest and then we grab it. Have you read Lyndall Bull's Ph.D.: *International Market Intelligence For Wood Products*? It was out of the CRC for Wood Innovations (Corporate Research Centre for Wood Innovations). She studied the adoption of technologies like Scrimber

and ValWood (Value Added Wood). Have you had a chat with anyone from the Forest Products Commission?

DB - Not as yet, but I am going to meet with Bob Pearce from FIFWA (Forest Industries Federation of Western Australia) soon.

MB - He really wouldn't know much about this sort of thing. It would someone like Terry Jones at the Forests Products Commission. But there were some innovative products in cross laminating and glue laminating but they weren't structural.

DB - That seems to be a bit of an issue here. You get a big head of steam and some great idea but it just doesn't get taken up by industry.

MB - Scrimber spent \$60 million before it got canned by the South Australian Timber Company which was a government company. In those days what used to happen was the government used to start commercialising things hoping someone would buy it and no one bought it. Actually that's not quite right. Scrimber was bought by someone but they couldn't commercialise it and CSIRO wasn't going to help out unless they paid so it got into a stalemate and they closed it down. The government just pulled its funding. So I don't think I am going to be able to help you much other than just put you in touch with the Innovations Manager at Boral and it will be difficult dealing with him in the east when you are here but I suppose that is just the way it goes. I think he is based in Sydney. I don't know anything of his background. I will give you the Timber Manager's name as well. The problem with Perth is you have got this moat around it and that's a huge impediment in competing in these markets. It would be best if Wespine made it. Have they shown any interest?

DB - I am speaking to them a bit later on.

MB - As I understand Wespine wouldn't be keen on developing a market for it. You would have no problem with the engineers and architects I don't think. I reckon you could sell it if you could get a building happening in Perth, especially through a company like Grocon that's already done it in other states but I just can't help thinking that the cost of transport if it's imported would just add a significant amount to it.

DB - Yes. The only way I think it would work here would be almost boutique manufacturers, fairly small operations able to move what they produce and develop

fairly quickly without too much of a momentum shift and because of the dominance of brick it would be hard to ...

MB - But there is no dominance of brick in this market.

DB - Not in this market, no but I think it has to have an interest into both. That's the aspect that allows the industrial production of large components of our residential market.

MB - I don't think that would work, personally. The residential market is wed to it. Until someone comes up with something cheaper they don't care about sustainability.

DB - It's not just the notion of hitting a solid wall and feeling ...

MB - That's not going to sway the housing industry. If you were talking to Dale Alcock now, it would need to be cheaper. All the other things would be nice, however in the commercial sector if you could produce a ten or greater star building because it sequestered carbon for as long as energy is sourced from fossil fuel you would be on a winner. Any of the major architectural practices, particularly the ones with experience in timber here or overseas would be keen. I would think there would be a developer, there has got to be plenty of developers around - even the developer who is Grocon's builder, the developer who employed Grocon to build this building, say you've got the architects, you would have the developer, then the issue is manufacturing and I suspect that that would blow the project out - it would make it fail in cost in comparison to other products. But it's a great story, it's a great narrative, it is just that we don't have the (necessary) timber industry. And if we do the labour it's just exorbitant. Because there are other models of the timber industry prefabricating buildings. In the mid 70s to the mid 90s they had a large truss plant at Bunnings Forest Products. They used to manufacture large span trusses. The only company left is the World Wide Timber Traders. So there have been other companies that have had a shot at it. I don't know the cost of timber and whether that would be practical. There's a lot of timber in there, isn't there.

DB - Yes, compared to frame, there is a lot of timber. Because it can use lower grade timber, the material costs are significantly reduced. That is what make it viable and results in a value-added product.

MB - So they don't need structurally graded timber?

DB - Yes, it is graded, just at the lower end of the spectrum.

MB - So what grade of timber goes into it?

DB - Typically F5.

MB - You would need to have a manufacturing plant that was capable of producing that economically which means economies of scale. Because we tried to make streets laminated bridges in the mid 1990s and we just found that even through some of the high tech hardened sawmills they couldn't saw accurately enough. Do you know what a streets laminated bridge is?

DB - Yes. That's another thing the Scandinavians do a lot of.

MB - But you've got to cut it right. Bunnings couldn't do it. They did it, but it just wasn't very good. The tolerances were too great. It worked, but not well; whereas you couldn't have those sort of problems.

DB - Have you heard about the Murray Fields development?

MB - No.

DB - It's in the UK. I think it's a nine storey building. The ground floor is mainstream and then CLT panels on top of that. As I understand it, when they finished putting all the panels up they dropped a plumb line from the top down to the bottom and it was 4 mm out over the entire high rise building. No one can get even near that with any other construction method. It took something like three guys to put the thing up.

MB - So I think that's where it fits is that you would need to talk to our Innovations Manager and maybe the Timber Manager and they would just need to think it through, from start to finish. I know I would be thinking that it needs to be a pretty sophisticated sawmill to produce it. But we may have that capability. I have no idea what they do in the eastern states.

DB - To produce the battens, any sawmill would be able to do that without any problems.

MB - Are they planed battens

DB - I'm not sure if they plane them, but they do not appear to be as rough sawn as the roofing battens commonly used in Australia. I only refer to them as roof battens because they are a similar size to the individual members that are used in making a CLT panel.

MB - If they are planed, that's an additional process.

DB - Well, if they are planed and also finger jointed, there are two processes there.

MB - I'm not aware of any finger jointing facilities locally in Australia.

DB - I don't know whether there is or not. You do see a lot of smaller finger jointed timber in Bunnings and the like.

MB - Unless they finger joint at the Neerabup plant.

DB - In Sweden, I visited several sawmills that incorporated the finger jointing process seamlessly into the production line and had been doing so for some time.

MB - But it's not easy to set those things up.

DB - They have invested a lot of money into their machinery but it's there now, squirting the stuff out like there's no tomorrow.

MB - Yes. When they work well they are good but it is hard to get them working. It's hard to get the glue durable, it's hard to get everything working properly. But once you do of course, off it goes and it runs for a long time but you shouldn't underestimate the set up, the complexities of getting these things set up and running. Midland Brick is still trying to get their brick line running, it's about two or three months overdue. It's just the oddest little curiosities that cause the trouble, things that you probably didn't even see coming when you designed the plant. So it is a big undertaking. Boral is very keen to

invest in new technology, it's just that I have no feeling for whether or not they would think this is a good idea. I think it's a good idea.

DB - But like I said, it's not just about the CLT type construction. Industrialised processors use Lean techniques to set their factories up, and whether it's CLT or volume modules when they finish the entire module down to wallpaper and tiles ...

MB - Yes, I was keen on that in the late 70s and early 80s but it doesn't seem to have progressed very far.

DB - Not here; there, I think in their residential construction, something like 90% of all buildings are now built in a factory.

MB - Is that right. The weather probably plays a part.

DB - Yes, that would play a part, but they just work right through. Winter and summer, they will put up special scaffolding with plastic film and just work right through, regardless of the weather. That is certainly something that we don't do much of in Australia, probably because of the cost.

MB - Yes, we are up against it, because we pay too much. I'm paying \$150 a linear metre for a fence. So the person who is labouring is earning a better hourly rate than me. It's a super six made of fibre cement. But they don't want to dig and I'm not entirely critical of it because I don't want to dig either but it's not going to work when the employee earns more than the employer. It just can't work, so I don't know how people on a lower salary than me pay to get things done. It costs too much. My father wanted a set of double doors to fill a hole in his garage, it was \$3,000 for two doors. That's the problem, that the blue collar workers are earning \$100,000 a year and people who are earning \$50, \$60, \$70 thousand dollars a year are employing them. I don't know how it works. I put in a new kitchen and it cost \$26,000 for the whole kitchen and the electrician and plumber cost me \$2,000 each. It was literally just running a wire through the ceiling and I got so angry with the electrician I cabled it myself because he was too lazy. He wouldn't Lean up behind the oven to push the cables through. He wanted to bash a hole with a screwdriver through my ceiling, he just wanted to take the easy way out. So I'm a bit jaundiced, I have a jaundiced view about the capability in Perth to fabricate anything like a commercial rate.

DB - So that's probably a reason why this might well work because you bring all of your labour under one roof and you can use a lot less skilled labour because you can have one tradesman supervising ten or 15 or 20 guys, and there's the automation, so that's probably what will make this work. The cost of having some guy doing it in a bespoke manner is just exorbitant, absolutely exorbitant. And I think that's what the Scandinavians are finding too, they were having to pay serious money to people and they had timber to use ...

MB - Is there a glut of timber over there (in Scandinavia)?

DB - No, I wouldn't say so. It's really well managed and they even export it. It's very tightly controlled by the government. Their forest industry is really well managed. It's managed for the future. They have got laws in place that you can't cut a tree down without planting again in a certain period of time.

MB - It would be a massive operation.

DB - Yes, it's something like 56% of the country is managed forest.

MB - I think our biggest sawmill is about about 400,000 cubic metres a year. That's Wespine, and their's would triple that. So there's the benefit of economies of scale.

DB - Yes, and the proximity to other markets as well. They send a lot of stuff over to Latvia, or those sort of places that are within cooee.

So you will give me the names of the Innovation Manager and the Timber Manager?

MB - Yes. Just have a chat with them. What is the scope of the Ph.D.? What is your hypothesis?

DB

The hypothesis is, "Can industrialised construction in engineered timber, that is construction methodology, be developed for the Australian market?" That is the question, and the phase I am in right now is getting a better idea about the local participants.

MB - Will you be looking into the economic modeling?

DB - I will be discussing a number of economic issues, but only in the context of testing the concepts I am exploring.

MB - So I gave you Peter Law's name, didn't I, and Bruce Hutchings. These are the guys who were early pioneers of this sort of thing. Peter Law was the technical manager of Neerabup Wesbeam plant. He is very knowledgeable of the technology and all that sort of thing. Bruce Hutching was another one. I don't think they are at retirement age yet, but getting there. And then there's Geoff Boughton. He's kind of a font of all knowledge but he's not particularly an expert on this.

DB - Because I am an architect, I don't need the nuts and bolts detail really outside of what is my area of expertise and it's a strange one because there is an element of marketing and there is an element of public perceptions and then there's an element of the capacity of the industry to actually to take something like this on. They are almost all outside of my area of expertise but one way or another that's the way it's heading. But Geoff is interesting. I have met with him a few times now.

MB - Yes, he's a dynamic guy, that's for sure. Incredible, and he's very good on structural engineering, very experienced lecturer, But I don't think he will be able to give you any tips on the potential difficulties of, neither can I by the way, whether it's going to glue properly, what our capabilities are to produce it ...

DB - I have recently read a paper that was the final thesis for an undergraduate degree for a Bachelor of Civil Engineering at the University of South Queensland. It was investigating the use of Slash Pine in CLT. It's the first paper that I have come across that investigates the use of an Australian grown timber for CLT.

MB - There are a number of theses that came out of CRC for Wood Innovations. There was one on the bending of timber, there was stacks, actually. It might be a good source to have a look at. I will ferret around and send you some information you might find helpful.

DB - I think that the main point that you made, which was how it is going to work here is a big issue. Can we make it sustainable as far as the economic argument goes and then are they actually going to want to build with it because of the comfort zones.

MB - Well, the Forest Products Commission is worth talking to, because they grow pine. The problem with them is they will say you have got to use farm grown timber. It takes on a religious fervour, it's not right. They have a terrible track record of commercialising things. So listen to what they say but bear in mind you are listening to bureaucrats that have tried about three times to make it happen and couldn't make it work. So the bottom line is that they grow the pine, and they could if they got enthusiastic, I think they are pretty much on the bones of their bum now financially but in their heyday they would have got right behind this sort of stuff. Terry for example, used to be marketing manager when I was there and he would have hopped on a plane and gone across, got the engineers out to see the viability of setting up a plant. There are quite a few of these technical innovations; have you heard of Laminated Strand Lumber? That was a good one. They came out and they evaluated the timbers and we were sending back and forth to them to evaluate, but it didn't ever come to anything.

DB - There is a company called Lignor who have been trying to establish a production plant to manufacture what they call OSL (Orientated Strand Lumber) and OSB (Orientated Strand Board) from locally farmed blue gums in Albany.

MB - Well there you go, I take it all back.

DB - It hasn't been built, and I think that the GFC has put a big dampener on it. I have had a chat to their chief engineer on the phone and we are going to have a site conference in a week or so and talk in more detail about that but they are going to be using the blue gums.

MB - Look, I take it all back then. They've pulled it off.

DB - The work hasn't been done yet. The R&D is done and they are ready to build the plant but they GFC has stalled them.

MB - That's kind of where they (the Forest Products Commission) got to in most of their other projects. They used to manufacture value added wood in Harvey, and it was quite ludicrous really that a government department would be running a business manufacturing something they invented, and it just couldn't continue because they just didn't have anyone who was going to take up the technology. There are quite a few times that that's happened. People believe they lose their sense of perspective and just believe in it and that's why I left Forest Products Commission because I just don't

believe in farmed forestry. I just don't believe in it. Timber is supposed to grow in a forest, not down strips in a farm. I think you get crap timber out of it. I used to say to them, this is just not right, and they would tell me I needed to decide whose side I was on because if I was on their team I had to believe in it. And no, I don't. It's insanity to think you can establish something like the Lignor plant out in the boondocks and then think you can ship it overseas from here to distant markets and be anything like competitive financially but there is a social imperative to do it and to maintain jobs in the regions. That's not enough; it's great to feel sorry for people but it's not going to work and farmed forestry is not going to work. Closing the sawmills down in Manjimup and thinking you can purchase timber from around Jarrahdale and the like was never going to work either and that's going to go out as well. They are nonsense decisions that the politicians make based on feeling sorry for people who have been displaced but it's just never going to work. The sawmills in the southwest are built in and around the forests so to try and keep them running by "close that forest because the public doesn't believe it's sustainable forest management" and then to provide access to a forest up here with all those transport costs and everything, it was never going to work. And the same thing with Scrimber. Scrimber was taking the branches of trees, so you're talking about timber with branches, the properties of the wood are not that great. The wood that goes into the timber product is not that great, and then it was branded F14, so you are taking crap timber, that's less than F14, putting it into a block and suddenly thinking it's going to become F14. It's almost like believing in fairies, it was just never going to happen. You can take something strong, put it into a block and the block will be strong. You can't take something weak and make it strong. Branches and little scrim are scrim, they are not strong structural timber, they are juvenile wood cells so I would have to say I never believed that that product was going to work either for that reason. So you do have to have a firm footing for the developmental project, it can't just be a belief in something that you would like to happen, but it would be good if it did. It's just the reality, unfortunately. I mean, I would like it to happen, I would have liked the timber industry to survive but it was never going to happen. The only reason in my mind that Wespine survives is that it costs competitors too much to bring it across the Nullabor and they have just slowly tried but not successfully. Austim used to sell quite good timber in Perth but they don't really sell a lot now. At one stage you could buy American oregon in Perth cheaper than you could buy pine. As a matter of fact they built the Denmark High School out of oregon, the roof anyway - the primary school it was I think and the local sawmiller over the road, which has now gone broke, he was saying well how can this be right. I can manufacture the product over the road from the school. You are using oregon because it's cheaper from another country. I don't know

how that happened but I suppose it was just a case of at that time America had a glut of timber or something and didn't need to make much of a markup on it. So I think its economics. I mean there is technology as well but there is a large chunk of economics in there.

DB - It's interesting that you bring up that point about farmed forestry and growing trees in straight lines doesn't really work.

MB - Not in my opinion, unless someone could convince me otherwise.

DB - So what actually is it about the lineal planting of trees that concerns you?

MB - It is the resultant resin, you know, like resin in fibre glass, but when you put it in a tree and the wind blows on it and then it splits internally then those splits allow sap to accumulate, it's the tree's natural defense mechanism because if it didn't, bugs would get in there. So if you have a tree in isolation. The old foresters will tell you that if you've got a grove of trees then all the trees around the outside are crap and the trees in the middle are the good ones because they are sheltered from the wind. By producing farmed forestry they are all perimeter trees so they have all been whipped around by the wind. They are all scarred internally and so when you cut them open they are just full of sap, and low quality timber. Then there is the fertilizer in the soil and the fact that the pastures have been farmed for so many generations and they are not like the soil in the forest so maybe you have got low grade timber, low density timber. But any of the trees that I cut open just looked like rubbish inside. I used to get frustrated because the CSIRO didn't used to say that; the CSIRO used to say it was quite good timber but I couldn't quite understand how because the timber was graded visually by people, and just the variations in attitude between one grader and another was quite high and then you couple that with a belief in what you are doing and so you get quite skewed results, in my view, and their results in my opinion were too optimistic.

DB - You might be interested to know that in Sweden they don't plant in lines and they don't plant single species. They clear fell a block - and it looks quite barren for the first few years. After about ten years time, till it's harvested in 60 to 80 years time, as a passer by, you would be struggling to pick it from anything other than native forest. The country's forests were devastated during the industrial revolution when they over harvested. The governments of the day were able to put these laws in place to protect - well not so much to protect but just to invest and help establish the forests again - and

so there are now long standing mandatory government requirements ensuring that they continue planting. It would seem that that they don't even need that level of regulation any more because the families now are in the third, fourth and fifth generation and what they plant today they are planting for their grandchildren and they are harvesting what their grandfathers planted and there is now a well established culture of sustaining and expanding their forests.

MB - That's not what I'm talking about when I say tree farming. I'm talking about a sheep farmer growing trees in the paddock that traditionally has farmed sheep. Tree farming is forestry, I don't question that.

DB - I have heard it said as well that the single species mentality that we have here and the straight line mentality is being driven by the Green movement because a farm lot that looks like native forest, or resembles it, has a moratorium on it as far as logging it goes and so the intent is to make it look as sterile as possible, hence the straight lines and the single species.

MB - I think its also about how to get the logging equipment up the middle.

DB - I've wondered about that. The Scandinavian don't plant straight lines. I have been in many forests now and you stand in the middle of it and there are no avenues. You can't pick it. And they've got undergrowth, it looks natural.

MB - Like a native forest. Well that sort of culture I don't really know much about. My expertise is just in science, not tree science. So once it is cut out of the tree I am not really interested in it. I've never really tried to understand forestry except to say that I have looked at the timber grown on farms and I just don't think it's good timber. I looked at quite a bit of timber from rehabilitated bauxite mines too and that's pretty crap timber. Alright, well I will do what I said.

Bob Pearce - FIFWA

(BP)

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David Bylund

(DB)

26 March 2011 - FIFWA Head Office, Technology Park

Interview Synopsis:

The merits of structural solid wood products along with their relative availability versus engineered timber elements are discussed. Architects and their apparent reluctance to specify timber in large scale projects are considered. The role of Australian timber lobby groups such as FIFWA and the FWPA and their attempts at improving timber's image within the construction industry are also discussed. Examples of European developments in commercial and large scale, multi-storey residential projects and the effect these types of projects are having on Australian architecture are canvassed. The role that marketing plays in establishing industry acceptance of new building products and the difficulty of forging inroads into established culturally ingrained presuppositional market environments are also considered.

DB

I'm half way through a Ph.D. under Patrick Beale, at UWA, and my topic is Engineered Timber and Industrialised Production Methods. I'm looking at the Scandinavian model of operations currently, seeing how they might apply to the Australian context, more specifically WA. I spent some time last year in Sweden, interviewing the forestry industry, construction industry, and academia; and looking at how they operate there. I'm back here in Perth now and trying to get my head around the Australian context outside of the reports and other things that I have been reading. Now I'm going around and speaking to people like yourself.

The question I am addressing is: "Can the industrialised production of engineered timber buildings be established in Australia?" To explore this, I have been investigating

laminated timber planar elements, engineered strand lumber and volume module construction.

BP

I have made the point a number of times in public speeches that one of the ironies about engineered wood products is that we are trying to do what trees do quite naturally by themselves. If you take a large tree, you can get a large wood section. A lot of the engineered wood products we are now producing are a result of the fact that more and large trees in our native forests are being protected so we are forced to use smaller and smaller trees. To make larger wood sections; we take a lot of smaller trees and put them together through lamination. If we left the trees alone they would do it on their own. As I'm sure as you know, Wesbeam uses laminations of pine to glue together, and that runs a little against just what I have said because you do get quite large pine trees in WA. They are seeking to establish a market for their product. I think it's a pretty tough area in WA for the product that they are producing.

DB

Can you expand on that?

BP

As I understand it, it's a difficult market area to get into, there's a lot of competition. Even in Australia, I know James Malone, have got a good operation; I've been up there several times, a very effective factory and they produce a good product, but it's a very competitive market and getting a foothold from somewhere like Perth is not easy because there is not a huge local market for that product. They produce more than for the local market, they are looking at the eastern states markets and into some south east Asian markets.

One of the problems of engineered wood products, it's more expensive to have an engineered wood product than it is to have a base timber product, so you are competing in two different ways. You are competing against, in the case of straight LVL, the straight pine products and with steel. You can produce quite large beams out of pine; but they are not in a competitive situation there because the cost of engineering is greater. So you can't compete easily in that area; what you have to do is have a product that you can say that the beams are larger or stronger or they have got an advantage that straight wooden products can't match, and then you are up against other people who are doing the same. It's an issue that James has for himself, that Wesbeam has, they have got to compete against people. For engineered wood

products you need, as you do I might say for wood products these days, a big flow through of product. In the pine business, just the straight pine, not the engineered one, these days you get people who put hundreds of thousands of tonnes through a plant in a year to be competitive, because it's a relatively low value product in terms of its cost per cubic metre, and to get economies of scale is really important so world wide plants get bigger and bigger and bigger, and I think it's the same with engineered wood products; because you are engineering it you need to have a large turnover to compensate for the cost that goes into building your plant in the first place. So James is in a position where Wesbeam really have to produce more product than they can sell on the local market and we come back to the issue then of Perth's distance from every other market, even south east Asia, eastern states, it's a big distance and I think that's one of the disadvantages that engineered wood products production in Western Australia is going to have. If you are going to go into that you probably need to be supplying to a market that is greater than the local market. And that means you are facing up to transport costs. In areas like timber production, where timber is a relatively low cost low value product, particularly in the large structural applications that you would use engineered wood products mostly for, then the transport component can become a very large part of your total cost and make you uncompetitive with everyone else. Mind you, I think Wesbeam are holding their own. I know they have had to work really hard to get a foothold in the market.

DB

So you are going into hard wood as well ...

BP

There's been not much. I was on the advisory panel for the FWPA Research and Development Committee some years ago. They were looking at various ways of having laminated products in the hard wood area and that's been more because in the past, in the native hard wood forests you get quite large trees, so you can basically produce very large structural beams very easily straight from trees. You look around at some of the old buildings in Perth, the Fremantle Port have just done up the B shed there. It's a beautiful old building, and it's made up of huge natural beams. These days, and in more modern buildings, they would be laminated because you would find it very hard to get a beam of that size. But as far as I know it's never really come to much in terms of laminating hard wood. There were issues about gluing, how you actually put the hard wood stuff together, but I think it's just been probably an issue that there's been a declining base of just how much hard wood is around, and no one that I am aware of

has been able to put together a commercial proposition. I'm talking about the straight laminating of beams, a kind of hard wood LVL, I don't know anybody who is doing that in Australia. Maybe my knowledge is deficient.

DB

Is that because of supply, or are there technical issues?

BP

I think it's probably a combination. Again I'm not an Authority on this, I don't want to sound Authoritative because I am not, but my recollection of it is that there were issues, particularly with jarrah, there were issues with gluing jarrah, it is very dense wood, it wasn't easy to find glues that would hold up to the strength, whereas the soft woods are more absorbent so I think gluing is probably an easier proposition for them; then there are issues of supply as well because the amount of native hard wood that you could get across Australia has declined dramatically. People have looked at it though, because with the decline of the volumes of native hardwood there has been a decline in size, quite a dramatic decline in size, so you would think that there is room there for hard wood structuraly, particularly to be done by laminating smaller trees together into larger ones, but whether there is an insufficient supply to make the volume that you would need is probably a factor. There is a real sovereign risk in the native forest areas because there are governments all over the place looking over this, you can't guarantee a supply from one year to the next, even for straight millers, they have got a mill they have amortized the cost of over time so it's almost free processing for the capital cost, and they still struggle so I think the money that would go into the engineered product is probably very difficult to put together unless you had a very clear view that you could get some certainty of supply. That's probably an issue as well. There was a crowd trying to get established down in Albany a few years ago called Lignor. They were trying to use the German concept of shredding timber and gluing it back together, which looked quite a workable product, to me, but they have never been able to assemble the capital to make that thing go. They are still alive, they were members of ours but they dropped out. They keep in touch every now and then but I haven't heard from them for a year or two. They say they are still going, they are still trying to work up a proposal but they have not been successful in doing it. Their timing was unfortunate. They got hit, they were starting to move at the time the global financial crisis came along and it was hard to raise money for anything then but they were struggling to get that underwritten. I went to several meetings where the then general manager came along and gave optimistic talks about markets in the United

States and markets here and markets there, how they had pre sold so much of their potential production but that has not ever come to anything. I'm not aware of anything around Australia that is actually likely to get established in the hard wood engineered product area apart from things like Plantation Energy who are pelletising, basically using sawdust glued together into pellets to sell to Europe for heating. That's been quite a successful venture but I imagine that's on the edge of the range of stuff you are looking at.

DB

It is a little bit. That's a very common practise in Scandinavia. I think all the sawmills that I went to got their energy from their own sawmill waste and were selling excess to run the town.

BP

What Plantation Energy do is take a sawdust product and glue together pellets and sell them for home heating I think. In Europe you can buy a bag of it and feed your fire.

DB

I have had a look through your web page prior to coming in to talk to you, and just looked at some of your members, trying to gain a better understanding of FIFWA's role. I guess it's a peak body, would that be how to describe it?

BP

Yes, we are the industry association peak body for the timber industry in WA. We cover the native forests, processors, we are basically a processors' organisation. Native forest processors, pine processors, panel - say Wesbeam, Laminex who use a more engineered product, and native forest loggers. We look after them as well. That's who we are. Fundamentally our job is government public relations. It's a very political area that we are in so a good part of our job is making sure that the government understands the needs of the industry. We try and influence the decisions that they make, and when stuff like that surfaces, it's our job to go and argue the case for the industry in the press.

DB

My main interest at this point is exploring the development of industrialised production in the local building industry. Potentially, using increasing amounts of timber highlights an inconsistency in the perception of timber as a material that is suitable to use and

that's one of the things that I think is also going to be difficult to overcome. Not just our isolation, not just our relatively small population but people's perceptions.

BP

Perception is important, particularly in specification. Architects have been some of the biggest problems with regard to using timber in buildings, particularly when you go back to when the big argument was going on about the Forest Management plan and the Gallop government at the turn of the century. We ran a couple of meetings for architects and some very aggressive people turned up to them. They just would not specify native timber under any circumstances. Part of it was maybe personal belief but a lot of it was to do with the fact that there were public image issues, so they just go for glass and plastic and steel and concrete and those things, and leave timber aside. The industry has done a bit to try and overcome that, the FPC's connection with Patrick is one example where we are trying to work together to overcome those difficulties. There is a bloke called Greg Nolan down in the University of Tasmania who is doing an excellent job in terms of trying to turn those sorts of perceptions around. But you are dead right, that is one of the issues. West Australians love their jarrah, particularly. We did a lot of research into that when this argument was going on, to try and get people thinking about timber, not just trees. But there is a contradiction. People like their jarrah floors but they don't want the trees to get cut down to produce them. It's like cattle. People want their steak but they don't want to see a cow killed. People have to learn to come to terms with those contradictions I guess. But public perception is an issue and it has a direct affect because it has effectively stopped industry getting access to the large trees and that means that if you want big size timber for structural reasons you will probably have to move to the engineered product in the longer term rather than the short term. What's happening in WA, as I'm sure you are aware, is that because of the government's refusal to allow green sawn hard woods to be used effectively, it really doesn't allow them to be produced to any large extent so the whole building industry has switched over to using pine for structural purposes.

DB

Are you referring to roofing timbers for stick roofs ...

BP

Yes, but we are also talking framing as well. Going back a few years we had a house that Patrick was involved in. We had a timber framed house, almost a totally timber

house, a display house, over in Homebase Subiaco where our offices were, going back five years, over nine years since we had the house built, and it was architect designed, a beautiful house actually, it was timber framed, timber clad. The whole thing showed what you can do with timber framed product, trying to get away from the old double brick and concrete pad proposition. It did use pine fairly extensively but that was about the time when the changes were taking place. I grew up in a house that was timber framed, asbestos cladding I suppose, probably a concrete sheet rather than straight asbestos. I'm a baby boomer, born in 1946, my father bought the house straight after the war and a lot of those post war houses were actually timber framed. In the eastern states it is much more common to have timber framed houses than it is here, where brick is so plentiful and cheap, and the brick industry has done an excellent job of getting support for their product. I met a guy who works in the timber industry who used to work in the brick industry and he said they ran a campaign. The brick guys would go around on the weekend to the timber framed display homes while they were full of people, and they would knock on the walls, and the people would look and say it's hollow so they would go off and buy a brick house. In that sense, I suppose that now most of the timber is in the roof but there are still timber framed houses being built. I think it is probably increasing a little bit, maybe not hugely, steel frame likewise, there has been clear competition between pine and steel in the roof area. Steel is making gradual inroads, not huge but gradually picking up market share and in the fully framed houses there is probably the same result.

DB

Part of my research is looking into these types of issues and the other part is to design a building using some of these technologies. I'm still looking at the type of building, it would probably be three storey residential block of apartments similar to what they are doing in Scandinavia as commonplace now, possibly using a combination of planar timber elements and volume modules.

BP

I'm sure the Forest Wood Products Research and Development Commission, probably going back eight or nine years, did a fair bit of work about multi storey housing construction in wood; you may be aware of it, maybe not, but if you are not it would be worth getting in touch with them. I've lost touch with that because we're not on their advisory committee any more. FWPA puts in a bit extra for running programs, mostly advertising, to try and get acceptance for wood products. I don't see much of what they do in a research sense, they don't report back to us directly. We have asked them

to come over here this year and give us a rundown on some of their key initiatives. About three or four years ago they came and did that day long seminar in Bunbury. They brought over three or four of their key researchers, each presented on the area that they are working in. A lot of people came to it, but they haven't done it since. We have asked them to do that again this year, at a price, looking at dates in two or three months time. I don't know where they got with that business about multi storey wooden, but they had a lot of work done on that.

DB

They have put out a series of publications, with the intent to inform people about the issues as far as BCA and Australian Standards go. When I look at the prescriptive emphasis of the BCA, it just highlights the limitations rather than the potential. The performance based approach is not usually chosen here. About fifteen years ago they removed the prescriptive approach and are predominantly performance based. I'm sure you are aware that eight or nine storeys in timber is common in Sweden now.

BP

They are mainly soft woods, aren't they?

DB

Yes. So that's the issue that I think is going to slow progress here because no one knows how to deal with compliance and the cost of performance based approvals can be prohibitive.

BP

One of the differences between Scandinavia and here, and you probably know more about this than I do, but their soft woods are just obtainable from their forests aren't they, effectively, their native forest harvesting is in soft woods, and they have got lots of it. Here all the pines are plantation based as you know, and there has been no real growth in the pine plantation base for a good long time. That's one of the issues that we have had, we've batted our heads up against the government for the last ten or twelve years, because there has really been no growth in West Australian pine plantations since the late 1970s when the Court government quarantined areas of native forest and started putting in large pine plantations. That was stopped in the early 1980s and since that time the plantation base has not expanded. The state's population has grown exponentially and with the shift away from the use of native hard woods, particularly in

roofs, and the use of pine we are going to come up against a supply issue of pine pretty shortly.

DB

The Scandinavian supply issue was addressed a hundred years ago. They regulated that for every tree you harvest, you must put one back within a certain time frame. The other issue is that most of the forests are privately owned by families and they are harvesting trees their grandfathers and great grandfathers put in, and they are planting trees that their grandchildren and great grandchildren will harvest.

BP

But they don't have a great population growth, as I understand it, in Scandinavian countries. The issue with us is that we do the same thing, not quite the same thing, but in the plantations a tree comes out and another one goes back, and they replant most years, but they get nibbled away at the edges, and a bit of land is wanted for this or that, and there is a bit of nibbling away at the plantation base. But our problem is the population is expanding at such a great rate.

DB

Yes, but it's countered by the fact that they are close to other markets, and so they produce more than their local market needs but they send it over into eastern Europe or even down into middle Europe quite commonly, and that makes it that much easier.

Lindsay Hesketh - Australian Conservation Foundation

(LH)

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David Bylund

(DB)

Telephone Interview 20 June 2011

Interview Synopsis:

The influence that conservation groups play have in native and plantation forestry practices in the context of maintaining log supplies to Australian sawmills is discussed. Australia's past land clearing practices and the effect this has had on the national vegetation coverage post colonisation is also considered. The relative merits of mixed species plantations versus monocultural plantations on the environment and the similarities and differences between Australian and Swedish practices are also explored. The importance of maintaining a broad range of timber products into the future is also considered in the context of value-added and engineered timber manufacture.

DB

I'm an Australian architect with about ten years' experience in small and medium size firms. Over the years I have developed an interest in timber construction but there are few opportunities to pursue this area in Australia. I am currently undertaking further study into new opportunities with timber with an Australian context. To understand timber supply issues, I would like to talk with you about ACF's approach to the management of trees in Australia.

LH

Farm forestry is a significant part of Australian forest management but it could be improved. In the sort of products that I guess you are looking toward, supply would be coming out of that sort of operation? We see a benefit in having wood processed locally into products, pulp and paper, veneer, OSB, maybe even sawn wood. It would just depend what the market wants. Having the flexibility of selecting sites for different

rotations to produce different products and all of the thought going into that down there as well as into future options. Everybody recognises that there is a risk with just aiming for one product outcome. If there's a downfall in that market you will have a crash in the whole region so to spread the risk across a broad spectrum of products, pulp and paper right through to a solid wood product gives us the flexibility of being able to maintain strength in that industry and the regional economy when you might see a certain component of that collapse because of a new competitor who turns up. There must be something overseas of course, you would be a lot more familiar with this than I am but I just had a family barbecue yesterday, my father was a house builder and his father was trained as a cabinet maker when he was a young man in Windsor in metropolitan Melbourne, with a very large cabinet manufacturing firm, so I've had an interest in wood production and also I have lived in the upper Yarra in Victoria's central highlands all my life and I am very interested in the natural environment. Watching where industry is moving to is something that I've been very curious about as well, not just around the issues of nature protection. ACF's major goal is supporting new renewable industries. I was discussing that yesterday with one guy who had been a carpenter all his life, a very good builder. He had been checking out the importation of bamboo from China for flooring systems and the solid bamboo products out now that clicks together, it's a click-lock type system and he is quite amazed by it, it's an outstanding product, and he wants to go and get into using it so you are seeing traditional carpenters who are very skilled at traditional carpentry now looking at the future of the building industry. I think we have just got to make sure we can compete because if something is coming in from China, any local manufacturing and processing we do here in Australia is going to be at risk from those sorts of products, so that's why I am interested in making sure that a new industry that ACF would support it is going to look at a spread of options rather than just going to put all its eggs in one basket.

DB

Lester, one thing that I have had said to me is there is resistance amongst the various conservation groups to diversifying structure within plantation forestry itself and by way of example, I have grown up in the south west of Western Australia and seen the pine plantations there and that's how I always thought that plantations were, anywhere across the world, single species, grown in rows and I had my eyes opened when I went to Sweden. Their forestry industry is definitely not single species, they will mix their species for harvestable timber, and they definitely do not grow in rows. They are almost randomly dispersed. Their crop rotation cycle is a sixty to eighty year type schedule, a combination of growing conditions and species, and their forests are

predominantly owned by families rather than corporations or government, so what they are harvesting now was put in by their great grandfathers and what they are planting themselves their great grandchildren will harvest. So they have got a much longer view, it would seem, and less driven by share-holders, and to be quite honest, walking through those forests, unless you have actually been to one of their old growth forests, and even then there is not much difference, it is a completely different experience to walking through our plantation industry forests.

I have had it said to me by a few people in the timber industry here that generally, conservation groups will try and lock away a plantation forest if it is mixed species and if it is not in straight rows, the reason being that if it takes on the resemblance of a native forest, and I guess time goes past and in the memories of the local people they forget that it was actually planted. There becomes a moratorium on harvesting it and therefore there is less incentive for companies to plant in anything other than this very sterile single species and in row format. Have you got a comment on that?

LH

Yes, it's an interesting observation and I don't doubt there is an element of truth in it, but I think you have got to look at things a bit more broadly than just, okay, if we go out and plant things for biodiversity then we will end up getting done over because of its biodiversity rather than its wood values. You have got to remember in Australia it is a bit different to the majority of forests of the northern hemisphere. I've never actually been to Sweden but I understand that most of their forests, and you say they are plantations but a lot of it is actually intensively managed regrowth that becomes more like plantations being replanted so it is a plantation, but they certainly are indigenous species and they will use a number of them, because they have gone into multi species with intensively managed forests, but they don't have much biodiversity attached to them as much as they might if they were an ecologically mature form. Just in terms of Australia, you've got to be pretty cognisant there is a very strong need for restoration in Australia. We know since European settlement, back to the 1750 vegetation mapping that was done back in the early 90s called The National Forest Policy Statement. National vegetation maps were done by the Commonwealth. Some very high quality work was done back then to show a coverage of vegetation in Australia in 1750 pre European settlement, and when you look at the current mapping of what remains, we've had an enormous impact on a very large areas in terms of the removal of vegetation.

DB

I understand it's in the order of two thirds? Two thirds has gone?

LB

We know that on balance three quarters of the woodlands has gone, three quarters of our rain forest coverage has gone, and half the forest area, of closed forest types have gone. So there's an enormous impact on eco system processes right across the landscape that we are now starting to see the impact of, with species extinctions that have occurred since the turn of the century, or recorded since the turn of the century. Now most of this has happened because of land clearing for farming of course, not around forestry as much although in unplanned systems, it worked hand in hand with forest operations; they took the timber and then milled it. You can look at north Queensland as a classic case of that; also Gippsland as well in Victoria, where land clearing and forestry were working hand in hand with one taking the wood off to get the land and the other using the wood as a commodity to process for the building industry. We've had an enormous impact because of land clearing. That's the reality and anyone who gets into reestablishing native vegetation for an ecological outcome is being well supported in Australia for that sort of ambition, well supported in terms of spirit and policy but not much financial support. People have tried to do it with a forestry spin off on the back of it as some way of getting a financial return for doing so but the problematic part of that on a case by case basis, you will find if you are connecting up areas for eco systems you don't want to have those areas then clear felled, for example, when you are trying to actually create corridors so there is a challenge there, and I'm not saying it's wrong to say that environmental interests would want to stop people from conducting forestry in those areas but it's been pretty ad hoc too.

I'm not suggesting to you that it doesn't happen, I know of an area up in the central highlands of Victoria that was replanted after the 1939 wildfires, and actually planted - you can still see the rows of it. That forest is now part of the national park. When it was replanted it would have been intended that one day it may have been harvested, but given the location that it's in, in the middle of a major tourism area, an area of quality habitat for a number of nationally threatened species, there is no interest in conducting clear fells in an environment like that.

I don't think it is true to say, to draw the conclusion out of that, that people have gone and produced mono cultures specifically so they will be able to maintain the argument for their logging rights. In a pinus radiata plantation, pinus radiata wasn't the species of choice because it kept the greenies away, it was a species of choice because it actually

produced the best timber outcome. Once it was found, and it was discovered pretty much in Australia, that you could kiln dry pinus radiata in a matter of an hour and maintain a stable timber outcome, it was never known to have occurred until it was discovered in the 1960s. The Commonwealth then poured an enormous amount of money into putting in pinus radiata plantations in the 60s and 70s, and into the early 1980s, so it wasn't around the fact that it grew so quickly. Pinus radiata certainly did well in high rainfall, rich soil areas which had once been rain forest; trees grew at enormous rates. It has a 30 year rotation and that runs the whole timber building industry now. All monocultures, arguable you could plant in the same way. All the blue gums are planted in the same way because they don't want anything competing against them, they proactively get rid of what they call woody weeds using some pretty horrific chemicals when they put their seedlings in purely because they don't want competition for water against the seedlings or the globulus. It's not because they are worried about the fact that somebody is going to point the finger when they are going to clear fell it in ten years anyway. They are focused on a bottom line financial outcome and so anything that is going to be taking up water or using soil nutrients there is going to be a product.

DB

This issue about clear felling and bottom line, I think there is a point of differentiation between here and Scandinavia as well because of the return cycle. They will clear fell their forest as well, and then for ten years the place looks pretty sparse, but then for the next sixty or seventy years it looks like a forest just going through its natural cycle whereas here of course crop rotation is much more intense and so we are getting this clear felled look a couple of times over one generation instead of just once over one generation in one particular patch. The issue you mentioned earlier about Scandinavia having indigenous species that they are growing is in part true, they certainly don't need to import, for example, the pinus radiata you mentioned. They have expanded into areas that those timbers have never been before but interestingly enough the industrial revolution is what ripped the timbers out of Sweden, anyway, and at the time they pared back to only about 15 or 20 per cent of their land mass having forest on it and it got to a pretty dire situation, but thankfully the government of the day legislated that for every tree you pull out you must plant another one and there is strict control over young forest areas about what can go on in that space to give them a chance to establish and those two combinations, we are talking about the one hundred plus years ago now, have made what their forestry industry is today, for better or for worse, and I would say in the big picture, for better, it would seem to me anyway. But it's a very different situation to us. We were clearing, as you said, for farming predominantly, and

that's really what's ripped most of our trees out and then when they go to replant, with such lower rainfalls obviously we are restricted in the species that will work well here within people's expectations of getting a return on them.

LH

Yes, and I think we don't know enough about the way, or we didn't know enough, about the way the natural forest systems worked in Australia. We still don't know. They have been conducting a level of forestry in Scandinavia for a very very long time, they are pretty aware of the characteristics of the species they are working with, but you have to look at natural forests here and see what's happened to them since 1750 and look at it now, for what we have got out of it, we probably would have done it in a very different way. The land clearing that I mentioned earlier on was really running at its peak at the turn of the century, I suppose arguably. We then saw a lot of then Forest Commissions set up that actually pushed back against the land clearing agenda, against farmers who were land clearing, and the best defense they had was a balance of forestry producing timber and maintaining natural eco system processes because they realised that those processes or ecological systems were an important part of ensuring the health of the timber so there was a strong push back then to say we had to maintain these natural forests, you can't clear, because of the need to maintain a wood supply. That certainly happened in Victoria, and I think it happened in Western Australia probably about the same time, the turn of the century, but then everyone was at a different state of play. No, come to think of it, there was a lot synergy there, with clearing the wheat belt in Western Australia, the clearing of south Gippsland and much of the west for post 1890s for farming and that continued again post First World War and the soldier settlement schemes. So it was all about land clearing and pushing back, and foresters became proactive in maintaining state forest areas and setting up strong state forest agencies who actually had a political say in the government processes at a time when farming interests were all powering. And there is a legacy there, we've got to thank foresters for that push back because land clearing would have continued unabated in some areas that would have been hopeless and the farming practises failed because the land was incapable of sustaining what was being done to it. But still, in the natural forest systems where production forestry has occurred it has turned out to be relatively unsustainable, certainly ecologically, but also on a resource basis as well, with just regrowth, and that has never been as vibrant as would have been hoped. And you can see that in the west, in the jarrah forestry, there has always been a massive overestimation of the recovery rates of jarrah, we've seen that in recent closures such as Deans Mill near Manjimup there, people have been hopeful, although there has

been extensive drought periods in Western Australia. I think that's been a big impact for any forester who's trying to work forward long term. Whether they have those challenges in Scandinavia as much as we have I'm not sure, but we certainly do get it here. I know in central Victoria we have just had a fire in 2009, there might have been one in 2006 and one in 2003; we are just copping a larger number of wildfire events that would once have been in an ecologically mature system, the large old trees would have been fire affected, but there was not as much fuel load in there as there is today and those systems would have just recovered pretty well; well they have because there is still one hundred year old and five hundred year old trees in there in the ecologically mature stands of forest in eastern Victoria, whether you are talking central highlands, Warburton, Healesville, right through to east Gippsland. But where there has been extensive clear fells historically, and there were after the '39 fires where it was clear felled en masse, it put pulp wood into the Australian paper industry and this went on for about thirty years. They were taking out a lot of dead trees but still it opened the whole place up and it has become one big massive regrowth. Now we have got a major fire problem on our hands where when a fire comes through it now, instead of it being a major perturbation but actually leaving a large stand of trees remaining which then coppice and then regrow again and within five years you can hardly tell a fire has been there. Now you have got a whole mass of dead sticks of young regrowth forest of half the original canopy height that's just been exploded and crowned and killed. So we have completely changed the way that the ecological dynamics are occurring in these areas and we have certainly changed the way fire operates when it comes into these domains. So we are still in the very infancy of learning how to manage these areas and unfortunately that's a debate we got involved in 2009 and 2010 after those fires because what they went out and completely clear fell those areas so we had large amounts of trees that were killed, and went in there over beds of ash with heavy machinery knocking all this stuff down so all of the undergrowth, ferns and all the wet lush under storey, which would have recovered because it comes from rhizomes and a seed bed that's lying deep down in the soil and they failed to recover. So we are a long way from managing natural systems.

DB

Interestingly enough, the issue of fire in Scandinavia is catastrophic because their forests don't take the heat well at all but when it comes to a natural event which destroys a forest I think, around about ten years ago, there was a very large series of storms that went through large forested areas and knocked very large sections of forest over and trees were just lying on the ground left right and centre and the industry

mobilised almost instantly and raced in there and pulled all these trees out that had fallen over so that they weren't wasted and then went into their cycle of replanting in those areas and they are now back in the system again. So they seem to be very proactive and know how to respond when a non planned disaster event happens and I think that might be a combination of the fact that they have got the longer term view and because they are working with family groups. And like you said, they have got that experience.

LH

When they replanted, did they replant as a mixed species replant, or as a monoculture?

DB

No, mixed species. You mentioned a controlled managed forest system. If you and I jumped in the car and drove across Scandinavia, across Sweden anyway, we would look in the forests and we would probably have trouble picking what was plantation and what wasn't. I don't even think the word "plantation" is really quite right because of our own image of what plantations are. They just don't look like plantations. You can't see any rows, you have different species, non producing species at the lower levels, so you don't get this openness that we have. You have got a lower level, mid level and upper level growth and so they just let them grow. They don't actually retard them in the way that they are here. They still go through and they will thin their forests, and they will manage them so they get the trunk lengths that they are wanting for that particular area, and I guess the new technologies allow them to harvest the trees with a lot less damage. They have done some very interesting research into big six legged walking machines that will actually walk into the forest rather than roll in on tracks or tyres. Their harvesting head will drop the tree, pull all the branches and bark off it and chop it into lengths, and it's all done remotely. The operator is not even in the machine. He stands in the forest himself and controls all of this remotely. They are pushing ahead a long way in the technology side, how to get trees out minimising the impact. It is probably because they have got a good understanding of the need of maintaining soil integrity.

LH

Well, different soils. There are younger soils here and just more of a dynamic going on compared to here, a different dynamic going on compared to here.

DB

Lester, we have actually covered a number of things that I was wanting to talk to you about anyway, plus a few extras.

LH

Send me an email and I'll catch up in the next couple of weeks.

DB

Yes, I appreciate that. I've been taking notes as we go, and I will put a few more things together and drop you an email.

LH

It's so broad a subject that you can pull up specific examples, and we need to pull up a lot of them, and it's very difficult for individual people, because of the complexities and different forest types and systems in different countries. All things work differently in different places.

DB

Absolutely. Ultimately from what I'm looking at, because it's not actually the forests themselves, obviously they are critical because you are not going to have a value-adding timber industry unless you can actually grow forests and then harvest them and then grow them again, but it's an interesting feeder into what I am doing and so I have been wanting to try and get my head around it a bit more and so far talking to mostly architects, engineers, who are involved in timber, and educators, but I haven't really had a chance to talk to people from a conservation point of view because I think without getting my head around where that's at, the different spectrums of opinion there, I'm not going to get a really good understanding of the dynamic as it is at the moment. So that's what I'm doing right now. Thank you again for your time.

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Interview Synopsis:

The FWPA's role, along with its various timber promotional ventures are considered. The approach of sawmilling and value-adding taken by Wespine are discussed. The conservative nature of the Western Australian residential construction sector and the resultant effect this has on the sawn wood industry relative to their current suite of timber products is considered. The relative merits of this, along with perceived disincentives associated with exploring new products by the sawmill industry are reviewed. The industry's past reluctance to establish large scale value-added engineered timber products in the context of the contractor and sub contractor system of construction are reviewed. Climatic difference between Australia and Sweden and the ease and difficulties associated with regular inclement weather patterns are discussed in the context of off-site and on-site construction scenarios. Rising regulatory standards intended to respond to more stringent environmental, acoustic and fire standards within the construction industry are also considered. The potential effect the resultant escalation in constructional complexity will have on the independent contractor's ability to construct these increasingly technically complex wall, floor and roof systems on-site are also considered.

DB

My Ph.D. is investigating Engineered Timber and Industrialised Production Processes. I'm looking at the Scandinavian model and their application in Australia, and specifically Western Australia. I undertook some field research last year in Sweden and met with various members of the timber industry there including plantations, sawmills and construction companies. Looking at what they are doing and how they are doing it was a very interesting experience.

RA

What led you to have this interest in this particular field? Do you have a background in timber? Are you an engineer, or an architect ?

DB

I'm an architect, and have had a small practice for about ten or 12 years, and I also worked for Sandover Pinder Architects at a senior level for a while before starting the Ph.D.. I was interested in learning more about timber. I started my journey by looking for short post grad courses just to improve my knowledge of timber and there really wasn't anything available at that time. I completed my Bachelor of Environmental Design at UWA and my Bachelor of Architecture at Curtin, but am probably keeping stronger links with UWA. I met with Patrick Beale from UWA who is running the Advanced Timber Research there thinking maybe I should do a Masters in something to with timber. He said that really there was not much point, and went through a number of reasons which I think I agreed with, and he asked me what I thought about doing a Ph.D..

RA

Perhaps I should give you a little bit of my background just to help you put that into perspective. I'm a mechanical engineer and have spent all of my life in the timber industry, in fact my father was in the timber industry and my grandfather was in the timber industry so it's probably three generations so there's a reasonable background in forestry and forest industries in Western Australia. My passion, I suppose, has been involved in technology and innovation, not so much in pure engineering, that's obviously where I started from but my interest has really been in innovation and technology and obviously in the marketing part; hence my other role besides being the Managing Director of Wespine is Chairman of Forest and Wood Products Australia.

DB

Yes, I am sure you are aware I have received a scholarship from them.

RA

Very good. Some of the advertisements you see on the wall are from the Forests and Wood Products and the program they are running to promote the *Wood. Naturally Better* initiative. This program looks at the sorts of things that you are talking about; where is the industry going to be running to, where is the industry internationally, what's

relevant to the Australian context rather than just the West Australian context. So we are quite interested in the particular project that you are dealing with.

DB

Good. The way it is structuring from here, I've written a fairly detailed report based on what I learnt in Scandinavia and that's in the order of thirty to thirty five thousand words; it's a reasonable sized report, and I'm not going to do the same thing as such for what I'm doing at the moment by interviewing people like yourself; that will probably feed more directly into the Ph.D. I'm going to be looking at a case study building that I've identified at UWA; it's the new student accommodation block there which is a typical three storey masonry building. I'm looking at how we might approach building that building using engineered timber. There is no reason structurally why we can't build that using engineered timber; so it might be a laminated timber planar system, perhaps with some volume module elements. The issue that I'm coming up against is that I'm sure I could draw that up and it would look quite nice but what would be the likelihood of that actually happening and what type of issues would we be up against if someone wanted to do that, so there would be resistance I suppose from the perceptions point of view that this is a multi-storey timber building, there would be resistance from the regulations point of view getting it through Councils which would not be familiar with that, then of course there is BCA compliance. Then of course how would we actually get the thing built, who would build it? Using the current method of subcontracting trades working in a sequential manner on a building site doesn't really work with the idea of fabricating large scale elements of the building almost entirely in a factory.

I've come to Wespine to discuss timber and supply issues in WA. I understand that Wespine is not supplying any engineered value-added products?

RA

Yes, that's true. And I think that you have summarised it quite well. Basically Wespine has seen itself as a manufacturing wholesaler for basically building timber components in the simplest form so we would see that we are the saw-milling wholesaler, using those terminologies, where we are not supplying directly to the building trade. We are supplying to merchants whether it be Bunnings or Cullity Timbers or other timber supplier businesses. We have been putting a package together. We produce structural timber components. We have on staff very competent engineering people who understand engineering design and engineering demands of a piece of timber. The

Australian Standards, the BCA assist us with supplying timber that is compliant with, or fit for the purpose, for builders to then package that together and utilise that into their building design. We work quite closely with Professor Geoff Boughton at Curtin. Geoff consults to us regularly to make certain of our quality control systems and working with our in-house engineering people to make certain our quality systems are where we want them to be.

I suppose our particular focus has been to be good at that. Some companies have tried to be involved in multiple things and then finish up being mediocre in a lot of things but not particularly good at any one in particular. We have determined that we want to be good at this particular issue of being able to be principally a supplier of structural timbers and packaging timbers more recently; probably that's pallets and whatever that's not particularly in your field but there is obviously a portion of the log that doesn't suit the structural application. The analogy of the T-bone steak is a good way of understanding our way of handling higher and lower grade timbers. The T-bone steaks are obviously the main structural components but you are going to have some mince meat that is going to come out of that and you are going to have to find a market for that. The traditional market for that has been one of two; one either you export that and that is what a lot of other guys are doing; you would export that to China or Vietnam or somewhere else and they would endeavour to make furniture out of that using short pieces and a lot of labour intensive to produce a piece of timber that fits the purpose in that instance; or a packaging industry which is basically carcassing pallets and those sorts of things. We don't get involved in doing that ourselves but we supply that sector.

So you are quite right. I think Wespine has positioned itself as very much a manufacturing wholesaler. Is that where we see the industry moving to in the longer term? I suppose it's an issue that we are spending some time analysing right now. We've got a guy in the office who we have just engaged with who is back trying to understand and look at where the future opportunities are. Where do we think constraints are going to come from, and where threats are going to come from and there are many of those as well as opportunities. I suppose you have put together some of the issues that you are looking at in domestic construction. Western Australia is double brick so we supply just the timber that is just the hat if you like, the roof timber. Is that going to continue? Or is there going to be a change in that? I think we are already seeing some changes occurring in that space now. Not that there is likely to be a wholesale change to timber frame construction but greater prevalence of two storey, two storey double brick, scaffolding leads to construction issues, more and more

people are now saying, “let’s put a light frame upstairs; we can be a little bit more architecturally creative with a light frame than we can using double brick”. Secondly, I think the West Australian market has moved from having a facade that is exposed brick to now wanting to rendered. People are moving to different facades and having a rendered brick with a bit of timber shuttering up here and flat panel over there in different colours and rock and stone and everything else is all part of this, and that obviously leads you to a different structure. So potentially you could see a greater opportunity in utilising timber in the structure of the building itself as against a solid two storey double brick home. So what does that mean for Wespine? That’s what we are trying to understand.

The other issue, of course, is roof truss versus stick frame. Western Australia is a very unique market in that it is probably the only state in the country that would still use the stick roof method. Some of that is leveraged off, in my opinion, because we use double brick; so you have got a cottage custom built lower storey, you are going to put a roof on that, you try and do a factory built engineering designed roof that doesn’t always fit. Bricks aren’t always exactly perpendicular; brickies decide to put half a brick out here for whatever reason so the roof doesn’t fit. If you are going to have a custom built wall frame that you put a custom built roof on, obviously the two are going to fit. If you try and build the factory built engineered design with the custom built it sometimes doesn’t fit. The steel boys found that out with steel trusses. You can go onto building sites and there are quite a few steel trusses that had to be cut and shut to get them to fit. Bricks aren’t quite as forgiving as that. Do we think that is going to continue as against a formal engineering package, which is the truss and frame model on the east coast where you would have a factory built structural envelope; the frame and the truss all fits together, it’s all come out of the one factory so it just goes together, is that likely to evolve in Western Australia? Possibly, but that’s been talked about for twenty years and it hasn’t made too big inroads at the moment but maybe the two storey thing with different facades, maybe that will open up some opportunities that haven’t occurred over the last fifteen or twenty years. I can’t foresee where that’s going to go but obviously it is something that we need to be aware of.

DB

I imagine that the thing that would help that greatly would be cost; if you could demonstrate that your building envelope, if that pre-engineered from a factory was significantly cheaper than double brick, in today’s market with what things are costing now we would probably have half a chance to do that but obviously the brick

companies are not just going to lie down and let that happen and there would be a huge price war.

RA

That's right. As it happened in the early 80s and it happened again some time in the 1990s.

DB

And not just a price war but I think the advertising and the mud slinging. Or should I say clay slinging.

RA

The solid knock campaign, this was supposed to prove it was solidly built and still is remembered by many people. So yes, I think you are right. The thing that the Western Australian market contends with, or has to contend with, is we are a relatively small market and we are an isolated small market. If you go to Scandinavia, if you go to Europe, you are talking about millions of people within five hundred kilometre distance so you can build yourself a factory of some size and you can be supplying frames to Sweden, Norway, Denmark, from one factory located somewhere in Sweden. It's not that far to cart. You build a factory in Perth, the market in Perth is flat, you are a long way away from Sydney. So the two million or whatever we have got in Perth is a pretty small market. And that obviously then comes back to achieving the cost position that you were referring to. It implies that you can achieve world economy scale which is hard to do in a market of two million people. So that is a fundamental issue for component manufacturing. Even a very simple component manufacture is timber roof trusses. I have probably closed two timber roof truss plants in my career because the issue that you need to contend with is that the stick built on-site construction in Western Australia is very efficient. At a level it does not look efficient, but how can you have a house sitting there and one trade comes in and next week nothing happens until Thursday, Friday. I have a great interest in housing. I renovated both my houses, I have just finished a construction down on the south coast which is a majority of timber and renovated our house here in Perth, so I work quite closely both passionately and personally with builders and looking at house designs. Probably every weekend my wife and I would go walking through a house under construction. Where we live in Applecross there is quite a bit of infill going on. I walk around and have a look at what's going on, why is it happening. I have a great interest and a personal passion in building styles and techniques. And while you can look at it, and people can say that

this house has been sitting here and I haven't seen a trade and nothing has happened for the last week and a half, and that's true, it takes a period of time so over a duration capital efficiency is not at a high level in my opinion. The trade efficiency is very efficient because it takes the overs and unders of capacity out. Whereas if you build a factory, it all becomes capital cost and one of the big issues with truss and frame manufacturing is those guys make money when the market is going up. When the market goes through this capacity band they lose money at the top of the cycle, they will make money when the cycle comes down, and it goes back through their capacity band again they will lose money again. So these guys, when the cycle goes like that make money in these two spots. The rest of the time they lose money. That's my experience of factory manufacturing in this state. And the reason why it is a cyclical demand and you build a factory for a particular amount of capacity and if you are not utilising that capacity you are either over capitalised and therefore you have got yourself a huge fixed cost, or you have got under capacity and so you try and fix your under capacity by working overtime etc which is double time and you tend to find you've got all of the additional efficiency costs in basically running a plant at a high level because most factories will run, they have got a tolerance band where they are efficient. You go over or underneath that and most of these factories don't have the flexibility for up sides and down sides where on-site labour does because the guys manage it themselves. The guys themselves will go out, the carpenters, the stick built carpenters go out and do other things so the project builder doesn't have to manage that cycle. He doesn't have to manage the elasticity of his supply and demand. The trade does that for him because he sub contracts that for him and they will go and build, presumably, pergolas or they will go and do home handyman projects, they will go surfing and fishing or something, but they will manage that themselves and so in my opinion the contract trade is the elasticity that takes out and keeps that balance whereas if you build a factory and it is particularly the case when you get a big project and ramp up your factory, you go and add another line on then it's three months before you get another project that utilises so many employees and now you've overcapitalised, you've got fixed costs in there, you've got supervision, you've got fixed costs in your labour because they are already locked in, it's hard to have elasticity in that. You've got yourself a yard, you've got buildings, you've got toilet blocks, you've got all of that. None of these occurs on on-site labour contracts. That's significant.

DB

One comment on that, obviously moving away from the sub contractor paradigm to an employee workforce paradigm, the cost of labourers seems to decrease because you

can have a a greater number of semi-skilled employees with one or two tradesmen supervising. In Sweden, 90 per cent of their houses are now built in a factory. Typically they have one tradesman and a number of semi skilled labourers doing the repetitive low skilled tasks. But it's still an expensive component because employing low skilled labourers can still be a significant cost.

RA

You are right in identifying that and there is a real issue about the one off, the trades probably being paid at a higher level whereas you can go to basically a factory issue where you are going to employ lower skilled people at lower rates but you've got absolute flexibility with sub contractors and you have got fixed costs with employees. So it comes back to a risk determinant, quite frankly over here it's higher rates, no risk. Over here, lower rates, all the risk. And so there is a risk profile in there that needs to be balanced and I suppose that in part has supported the rationale of saying, less so now in my opinion, but basically anybody who had a ute and a trailer and a hammer and an air gun or whatever could become a builder because basically he is a project manager; if he had some building knowledge and skill, he might have been a carpenter or a brick layer, he could basically became a builder because he knew an electrician and he knew a plumber, he knew a brick layer or whatever, he was a builder; he was set to go. At no fixed cost. He knew someone who could draw up some plans, he was out there, reacting to an architect who had done a plan and he was out there becoming a builder with one or two employees. He was in the building industry. Now that in part meant that could be quite efficient because maybe he didn't need an office. He could work from home, and he was working out the back of his four wheel drive and it was a pretty low cost structure in that sense and as long as you can pass those costs on, whatever they are, to your market, he's got a low cost position so he's got a margin that can be quite narrow.

DB

I still can't help but wonder that with the massive increase in costs to get into the residential market now, the last five years it has gone up maybe three times, some phenomenal amount, that's got to have an effect on this particular model. And who would have thought ten years ago that things would have gone up as high as they have and I guess there is a unique position in WA with our mining income source which brings a lot of people with a lot of new money, rushing off and buying or building new suburban homes. There is no precedent to demonstrate the sustainability of that.

RA

This is uncharted waters as you rightly say.

DB

And because it is uncharted no one is going to rush off and build a factory, other than going to wonder if there are going to be opportunities here.

RA

And you can probably put Wespine directly in that camp, just saying, “well, sniff the breeze, there are some differences happening.” There are new technologies, vis-a-vis Scandinavian laminated panels, probably a greater push to go into factory built component built housing.

DB

The potential appears to be there, and the Scandinavians have really developed that but the people who own the sawmills are in a quite different position than sawmills here because they are third, fourth, fifth generation family operations. They own their own plantations and they are planting on an 80 - 90 year cycle. So they are harvesting trees that their grandfathers put in, and the trees they are putting in, which legislation ensures are replanted; here you can cut a tree down in the forest and there is no real obligation to plant another one in its place. That locks in the perpetuity of that particular model and the fruit of that is now in what their industry is doing.

RA

Where the market is; yes, you are right. I suppose just carrying on with that is that you have got the issue in Western Australia, if I looked at the key differences between Western Australia and Scandinavia and I have been there a few times and we utilise some Scandinavian equipment, and you look at what are the similarities, what at the differences, what drives the factory built component built housing in a market sense. I think one of those issues has been obviously climate; you can't get too many trades out building houses in the middle of winter in Sweden, you would be ten feet under snow or it would be very cold if it was not under snow. You don't have that issue in Western Australia. You can build houses all year around. OK, there are a few rainy days and during the day in the middle of summer it might get a bit hot but guys accommodate that and so we have a perfect outdoor climate in which to construct things so you don't need to build indoors in enclosed heated or air conditioned buildings so you can actually build out in the outdoors.

DB

I agree with your climate point, but interestingly enough the building doesn't stop in winter in Sweden. They put up a type of scaffold around the building site and then they run the plastic sheeting and have a little micro climate in there. We don't have that. In commercial building there is obviously the option to scaffold and close it in but that's an additional cost that they have to factor in which we don't.

RA

That also that lends itself to building as many components inside a factory as you possibly can so they just have to truck it to the site and then you would have the bare minimum number of people there to assemble rather than to actually construct, most of the construction can take place over here so you do as much as you can in a predetermined fixed building. If you look at our building sites, the places where we deliver our raw materials to, then the guys actually construct and direct and assemble all the components on-site. I'm talking residential now, I suppose you can't do that to the same degree in commercial building.

DB

There is one other factor which I think is going to put the current model here under more pressure, which is the need to have higher and higher star rating, building efficiencies; double brick, aluminium frame, stick roof, tile, aluminium windows and the like are just not going to perform as well. That means you need to put a lot more work into the actual building envelope and I can't help but think that that's going to become very very difficult on-site; to manage, subcontractors on-site, to higher and higher standards will be difficult. The sub contractors are going to need to learn new skills and I don't think they are going to be real keen on that.

RA

I quite agree with you. I think there will be a change in, without being derogatory I suppose, to the skills we have learned, the precision to which we build these houses. You can get anyone from the northern hemisphere come out and look at our houses and they would say, "look at the gaps here, the aluminium windows ..." and we have got a climate in which we can get away with that. Now the regulations we are going to rely on will say no, we are not going to get away with it. There is going to be a change in design and a change in material and the precision to which our accommodation is built and I think that is going to drive whether you can achieve that degree of precision

in a custom built, home built, erected and manufactured on-site is up for question. I agree with you.

The climate of basically constructing the home or the building is one issue. I think the other one of course is this whole climate change debate. The Wood for Good program run by the FWPA is about highlighting the low carbon footprint of timber construction as against steel and concrete along with the imbedded energy.

DB

The experts are telling us that this is something that's important and that's starting to get some traction but it doesn't have enough yet. But it's building up a head of steam, I think.

RA

I agree with you. The role timber plays in that is actually a very interesting. Most people, because of their schooling, understand that trees take carbon dioxide out of the air and that's good and so we all acknowledge that we want some trees out there, and we say, "let's cut that tree down and produce some timber product and lock that carbon up in a building or furniture as the case may well be"; but hang on, we cut down the tree and that's not good. Doesn't that release carbon again, so well excuse me? When the tree's standing up it's got carbon in it, when the tree's laying on the ground it hasn't got any carbon in it any more? I don't know about that. Where did the carbon go, if suddenly cutting the tree down it has released all the carbon. Tell me, what have you got left if you cut it down? It's all still there. Now pick that up and put it into a building or into a piece of furniture, haven't you still got carbon? Grow another tree, by all means, that's what you want to do, you want to grow more trees but you don't want to not cut the tree down because at the end of the day the amount of carbon sequestered is going to stop, and surely the best thing we have is a vigorous forest consuming more carbon from the atmosphere. Now that's taking it to the next step, and not many people have actually thought about that, to be honest, and I have had some interesting discussions with architects on exactly that issue and they were saying, "that's logical but I've never actually thought of that, I just don't actually want to use timber because isn't timber bad for the environment?" I said well explain to me how it could be bad; well, we are cutting down trees and that's not good. I said but isn't growing trees good? Well yes. Well, eventually you are going to have to stop growing trees because there will be no land left to grow them. Shouldn't we be cutting the tree down and using it? They hadn't actually thought that bit, so we've got that far through the logic cycle and they are comfortable with that position but then when you push it

and that's what some of that's all about, you're trying to say help the environment and use wood.

DB

Looking more closely at Wespine, you mentioned you've got somebody looking at future directions. Does Wespine have its own sawmills, or are you sub contracting?

RA

We've got our own sawmill; just one.

DB

Just looking at what the Scandinavians are doing again, where they would have their one sawmill, it would be an interesting thing to follow up the notion of value-adding to the output of the sawmill for the second grade timbers; rather than looking at the packaging, or sending it overseas, to look at laminated timber. I can't help but wonder whether there's the potential for some sort of second stage processing to make simple laminated planar timber elements to order from lower grade wood. What do you think the capacity of Wespine is to start moving in that direction?

RA

That's on our radar, I guess, in part. In some degrees it's about, "are you a quick follower or are you trying to be a leader in there", and just how big do you think the market is going to be. I think we are watching with interest some development that is on the east coast, where my understanding is there several high rise building that are going to be built in Melbourne and Sydney in cross laminated timber.

I think our view is that people who go out there and fly the flyer and go, "we're looking at this" and then suddenly get to the reality from doing a feasibility study on something that has got to be built, find there is a bit of a gap between the two of those. Rick Sinclair from Forest and Wood Products Australia would certainly know. He's been following that quite closely. We (FWPA) sponsored Andrew Waugh from Waugh Thistleone Architects in the UK to come to and give a number of presentations on the Murray Fields CLT project to try and inspire the local industry to consider this type of construction.

DB

Yes, I heard his talks.

RA

Yes, and that was about from Forest and Wood Products Australia bringing in what we call renowned people who are a little bit out there obviously promoting timber and Andrew was very successful in that regard. He got a great deal of interest.

DB

Yes, he is also working for KLH now I think.

RA

Is that right! Oh well, there you go. So Rick is putting together a concept now where we are going to take a dozen designers and architects from Australia on a road show into the UK and Europe to go and look at a number of timber framed buildings and meet with architects who are picking up this whole timber thing with a bit more of a passion, whether it be because they have clicked onto the environmental message of "let's try and lock up carbon in buildings", that's the best thing we can do; it's obviously a point of difference as well so if you want to differentiate yourself from the professional pack, I suppose, as you said steel and concrete, we can offer something a bit different. Probably in the commercial sense I would think being a bit different is a desirable thing. You don't want to be taking a huge risk but commercially you probably do want to set yourself up, you want your building to be different from everyone else's. Everybody's got a concrete building with a steel roof; you can go and do something a bit different - I want to set myself out on the road to be a bit different from everyone else, that's the usual way of doing it. There is probably a bigger market to be a little different I would have thought, without ever being in that position, and I could well appreciate that. From our point of view it's a matter of trying to understand the technology and asking, is this something Wespine should be participating in, and watching it very closely. I'm nervous, I've got to be honest, about the size of the market in WA, and whether there is a means of being able to ramp it up. Is it one of these things where unless you are building a factory that's got 100,000 cubic metres per annum? You have got to build a factory of that size to get the economies of scale to be able to buy the technology. The WA market is not that big to take that, and so they are therefore having to transport it at significant costs to get it into the big market. Any of those engineered technologies are going to face that problem.

DB

The other option is to build boutique factories aimed at pitching at a higher value market. I met with Martin Beel the other day, from Boral, and he basically said that

while they are not interested in investing in constructing big factories, they would let the boutique market develop products and if they came up with a product that was viable and showed potential, they would come in and buy them out. Let small things happen, then maybe come into the market once others have worn the risk.

RA

My experience has been from Bunnings Forests Products days, which is my former employer, on the other side of the road, and it had a large timber engineering factory. As you may be aware, most of the gluelam beams in Perth were manufactured in that factory. It was a business that struggled. The product was brilliant, using well accepted European technology. They brought people out from Europe, developed the plant, developed the technologies, supported it with design etc. Was it economical in a return sense? No. Basically it was all about boom or bust, there were a couple of big projects, let's build this whole thing in gluelam which was great, so you ramp the factory up to that capacity flat out for three months and then when that project was finished, the market was not big enough. You are laying off people and doing a whole lot of things to bring it back to this sort of level and then you try and do a little bit of the car port beams and a few foot bridges and a few other bits but they were all little odds and sods and so how do you have stock, how do you offer the marketing service, how do you put that stuff behind you? It's very hard.

DB

There is one market that I do see as having the potential here and that's the industrial construction sector. CLT would fit straight into that industry because of its similarity to tilt up concrete. The riggers already know how to deal with it, there are many companies that know how to lift it. The way it puts together is almost identical and that market doesn't seem to suffer from the residential bind.

RA

I agree. I think we could investigate the opportunity to make tilt up type products. It's the same tilt up panel. Instead of being reinforced concrete it would be in timber. I would agree.

DB

And that's one area where I think that it might get a foothold. As long as it doesn't get badged as being only for that, which to a certain extent has happened to concrete. But I don't think we have got the same issues as they have as far as being able to make it

that little bit nicer, to make it appear more 'residential' if you like. I think as buildings get higher and higher, especially if these east coast projects happen then the synergy is just to naturally move on to more commercial rather than just industrial.

RA

I suppose I would put all of those technologies together in one sort of component because you are still manufacturing a component of the building; you are doing more of it in a factory rather than doing it on-site and I suppose in all of those senses we would be endeavouring to work with our customers, whether it would be truss manufacturing or wall frames. At the end of the day we only produce a limited range of timber components that a builder needs to build a building. There is a position in the value chain for a merchant to pull all of those materials together, to offer the package, even if it just be the timber structural package, to a builder and so you will find that from a timber merchant, if you went and spoke to Timber Suppliers in Rockingham or WA Timbers in Malaga, very much the same, family businesses, and see that their role is that they source the timbers, and maybe 60 or 70 or 80% comes from Wespine, but the builder does want a gluelam beam, he does want some wall panelling or some eaves lining or something he wants to put together as part of that. Both of those businesses, and even I suppose Bunnings and Cullitys are in the same boat, have then gone and added truss plants on the side of that so they haven't put all their eggs into the manufacturing basket. They have been able to say that they needed a business model, let's just ride this cycle, that yes, we can offer a truss and maybe a wall frame and maybe the entire roof is not going to be trusses; in Western Australia we have a little bit of a west coast ideology that says we want to be different. Project homes in Western Australia are totally different from project homes on the east coast. We badge them as project homes, but they are not really project homes, basically each home is custom built in this state, and basically they are all custom designed. There are very few houses that are actually project homes, in my opinion. And certainly that was my experience when we looked at truss manufacture, and went out and started talking to builders, saying, "look, you advertised this house, now I'm going back a few years when it was \$29,999.00 for five bedrooms or whatever it was, and here's a house for that. You are promoting that very actively. Now we think that if you can let us know how many you are targeting for that, then we could do a truss design for that packaged up, and we can give you a much more competitive price than what you would be doing stick building. Guaranteed." And the builder almost looked at me in absolute shock and horror and said, "You think that every one of these houses will be exactly the same?" And I said, "Yes, that's what you have promoted." He said, "No, that's not what

we are selling. The only way we are making money out of this is the variations. This is just the base price. This is just a base house design. We actually want to accommodate changes in walls, so we don't want a standard roof on this thing." "And so, that's not actually a project home, is it?" "Well, no, not really."

DB

I think the public are somewhat having the wool pulled over their eyes because the scope for true variation is still very small, it is the same elements rearranged. Making these rearrangements often means a large price variation. These often do not really cost that much more to do, because they only rearrange within certain tolerances. Maybe our definition of project homes has to be a bit unique to WA, but as an architect, if I approach those guys to see if I might do a bespoke design for somebody, the project guys won't even look at it. And the other issue of course is now they are getting so big that they are not really making money out of the building, rather from the material supply. So they will also own companies that manufacture the windows, and make the tiles, whatever, and the insulation, and the land.

RA

I quite agree with you. I think the building culture, the building structure, the building industry structure is different from what it is on the east coast, in that you don't have so much of what I would call the "estate" project, where you have a land developer going and buying an estate, and does deals with two or three builders and the builder goes and builds ten homes on that estate, mirror image this one, paint the front door a different colour, but there are on that estate twenty homes that are absolutely identical. They are imaged off, but they are absolutely identical. Up until now, that hasn't been the model in Western Australia, as you know, but there are starting to be cracks. It's starting to change a little bit.

DB

Yes it is, because a lot of the developers are national.

RA

Yes, they are coming across here now, and the Dale Alcocks (a well known residential building company in Perth) of this world are now getting into land development themselves and they are starting sub divisions, and they say, well, the next step is to put a house on this and that can be our house whereas traditionally they left it up to consumers to go and buy a block of land and then go off and talk to numerous builders

to find the house they wanted and modify it to fit on that block. You tend to find then, and you have seen as I have, that people have gone out and bought the block of land, and like a particular house, and say they want that house on this block but it's the wrong shape, it's facing the wrong direction, but people like that house or the look of it or whatever it was, but putting those two together is just diabolical.

DB

And I think also that's part of the situation where we get away with it. Our climate allows us to do that. How many people walk into their air conditioned house, hop into their air conditioned car, go to their air conditioned office. So unless you have got that switch on the wall that allows you to condition these houses, people won't live in houses that may have fluctuations in temperatures like they may have once. So maybe that's maybe another marketing factor, I suppose, that will start to have an influence.

RA

So I suppose that in all these issues there are a number of drivers that are saying there are changes afoot. I suppose it's part of an evolution, and it's a matter of saying well okay, there is a bit more interest in timber, there is probably a market for different materials than what there has been, and timber has probably got back into the residential market through its decorative aspects which obviously comes back to timber flooring, timber panelling perhaps in some degrees, in a little bit more decorative sense which starts to warm people up, who'll say okay, I view timber as a material more favourably than I did a while ago. So we tend to think that there is a little bit more interest in timber generally and that leads to saying you are not going to use pine in that instance, it's too soft; but it's more acceptable then to say why don't we have a timber building, such as the frame can be timber, you can use timber in the structure.

DB

I think it would be a very interesting exercise for someone just to put up a building as an exhibition building using CLT and getting people to walk through that building and try and see the difference between that and brick, and they can do the tap on the wall. It's just unbelievably embedded in people's subconscious, unbelievably. Most of the public, unless they have been watching Grand Designs, have never heard of CLT, 99.9% probably, so there needs to be something put up somewhere at some point.

RA

We have been talking about the West Australian market, both the Perth metropolitan, and in the north where we are spending a bit of time trying to understand the northern market, and we can say well okay, state government policy is to try and build a city in Karratha, for instance, they want to develop Port Hedland and Broome, we want to see some population up there instead of this fly in fly out stuff, that will always exist but you do have to, if you want to have some cities in the north. We've had our marketing guys up there and talked to the shires and said where's the land, how do you think this is going to evolve, what's the building design, what are the limitations and criteria do you have or don't you have, well obviously it's a cyclone area so it's got to be cyclonically designed, so how does timber design fit into that? Probably those houses are not going to be built with sub contract labour on-site, because that labour doesn't exist, the expertise doesn't exist, and if guys are going to go up and live in Karratha they are probably going to work for the mines, they are not going to build houses. So there's going to be a classic case where I think the house construction is either going to be pre-fabbed or at least pre constructed, component construction, so frame is going to make some sense. Now what people are doing at the moment is steel frame. Why do you have steel frame? Well, we don't actually want to have steel frame but it's the product that's on the market. Well, what about timber frame, well there are pretty ferocious termites there so it needs to be termite protected. Well, that's easy, there are plenty of treatments around that will enable it to happen. I'm a bit concerned about CCA; well there are other things around rather than arsenic. There's a mickey mouse plant, how do you develop that up to get cost efficiencies. We are actually going through that process right now.

DB

Your product is like the blue pine, I imagine that as a CLT panel as well. Not to move away from frame, but I think ultimately it's going to be what's most appropriate for the actual application and this is where I think the hybrid solutions, where you might have CLT components, you might have frame components, and you might have LVL components, and you can make a very good building when you know what's the right thing for the right place.

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1 July 2011 - Advanced Timber Concepts Research Centre - The University of Western Australia

Interview Synopsis:

Developing methods to expand timber plantations into low rainfall and high salinity areas and the subsequent need to co-locate processing centers to reduce log transport costs are discussed. Government support for the timber industry along with points of similarity and difference between Australian and Swedish silviculture methods are considered. The importance of genetic diversity to equip an ecosystem's ability to maintain resilience and the potential effects more 'natural' looking plantations can have on public perceptions of the plantation industry.

DB

John and Patrick, thanks for your time. John I am undertaking a Ph.D. here at UWA that is investigating the potential for engineered timber and off-site manufacturing in Australia to develop along the lines of the Swedish industry. One of the pertinent issues that repeatably came up as part of Swedish research was ensuring of a stable and dependable timber supply. The Swedes go to significant expense managing their forests to secure the supply well into the future. With the emergence of leading edge engineering and manufacturing technologies, new opportunities to optimise more of their lower grade timbers have emerged. I would like to begin our discussion by hearing your thoughts on the potential for Australia's and specially Western Australia's plantations to expand to increase supply to keep up with demand into the future and if you could also address the types of challenges they are likely to encounter?

JMcG

Any likely plantation expansion in Western Australia and possibly most places in Australia is going to be into lower rainfall areas. Relative to our size, we don't have many high rainfall areas and that means that we are going to have to manage those trees in a different way than foresters like to manage plantations for high quality mature, close grown, small branches. That doesn't work when you have got a limited water resource, you have to have fewer trees. Whether you have got rainfall or not they will grow bigger branches if you give them wide spaces and that's the sort of issue that we are going to have to deal with. If we are going to have an expanding timber resource into the future from plantation grown material there is going to have to be with different species. Not necessarily out to places like Merredin (located in Western Australia's wheat belt region) where it would be extremely difficult, but you might be thinking of land north and east of where we currently grow trees in Western Australia. In Eastern Australia you have a mirror image of that, north and west where they currently have the same sort of issues that we run into and where your resource is going to be different; it's going to be that kind of approach that is absolutely the way forward. I was at a farm forestry forum down at Albany two Fridays ago and the guy from Wespine got up and said that this is going to be a problem for them because we are not quite sure how we will handle this resource that is likely to be produced. Well, it's time to start thinking about ways to do it. We are not always going to have big tall logs and straight trees.

PB

So if you take the radiata pine that Wespine are taking at the moment and say that you can't afford to plant them this far apart, you have got to plant it that far apart, how are you going to do that?

JMcG

You might be able to prune them up to some extent.

PB

You will be pruning every six months.

JMcG

That's where the suggestion has been with the forestry for years and years but the economics of that are really difficult so you will end up with a bole, maybe prune it up and it will be material above that, which is less desirable trying to find things that you can do with that, so you are going to be really critical. This is when engineered options

become really important in those environments. That's where, in my view, the expansion is likely to go.

DB

The issue is whether it is going to be financially viable, because there are obviously a lot less trees per hectare meaning that you are getting a lower yield and post mill engineered options add cost because they require more processing. This is one thing that I am discovering as I speak to people; that when you start to source logs further and further from the mill and you have got fewer logs per hectare to grow in dryer climates, you need larger areas to plant and that adds a cost. The timber produced could be a lower grade so you need to engineer it in some way. The added engineering costs should be offset somewhat by the lower supply costs that lower grade timber fetches.

JMcG

Yes, you raise some really salient issues. Whether we are talking high quality sawn material, reconstituted material or partially reconstituted that has been shredded and glued back together or whether you are going bioenergy kind of area. In all of those issues the logistics become more and more difficult and one of the things that people talk about to overcome that regional based initiatives so rather than try to transport material long distances, you do the value-adding in a regional based industries. If we are here talking about going to Merredin or Carnamah or somewhere like that, we are talking initially at least, that strip beyond where we currently plant trees so over the next few years we plant softwood and then harvest logs down to 750mm. In the production sense you took that 750mm log down to 500mm you are not going to want to cart it from Merredin to Perth, it's another 150 kms so you might want to put your new processing plants in areas where that extra 150mm diameter is not a penalty to start off with.

DB

I can't help but wonder one of our big issues is going to be ensuring the will to do it and ensuring a viable market to support it. It would appear that in Scandinavia the will to maintain forestry is very strong and a market for new timber products is expanding.

JMcG

What drives that?

DB

More than 50% of Sweden's forests are privately owned by families who get together and form big co-ops. The trees that they are logging now were planted by their grandfathers and the trees that they are planting now will be farmed by their grandchildren. A strong timber and forestry culture exists. There is a strong incentive to keep that culture. Villages exist there like our old sawmill towns but have existed for hundreds of years. There is a stronger connection to the land and an affinity with timber. There is also government policy in place that really encourages the industry to continue expanding and developing new products. Money is injected into areas of research that will broadly benefit the entire industry without seeming to advantage one particular aspect over another.

PB

The interesting thing about that government support came about through conditions that were not unlike the sort of conditions that we have got in the agricultural areas now where a lot of clearing had gone on and the soils had degraded quite rapidly.

JMcG

We are not there yet, even though I look at that landscape and I was out there yesterday and I see that this is in serious need of attention. It's yet to be a general feeling or general acceptance that our landscape is in trouble. Even though we have had salinity issues and water availability issues, people still haven't got that message.

PB

Last night I was up in Perenjori and there was a farming agriculture representative making a presentation to the town council saying that salinity was not their problem any more because it has dropped from 400 ml to 600, 700 or 800 ml. Because the reason it has dropped is another problem; it hasn't rained. The water is not there in the first place. But it is not like it has gone away.

JMcG

I agree that the salinity issue is still there and it's just waiting for the next wet period to become an issue again. In the south east of Australia they are now seeing rises in the water table which has been stagnant or gone backwards during the previous dry decade from that big deluge they have got in the south east. Nonetheless we still not seeing the political will to actually say that we need to do full-scale revegetation.

DB

The industrial revolution came late to Scandinavia and when it did come, a little bit over one hundred years ago, they effectively clear felled the land in an attempt to supply the massive fuel needs of the industry of the day.

PB

The percentage was huge, 75% or something was cleared.

DB

It was a massive amount. The Swedish Government stepped in at the beginning of last century and, with significant foresight, mandated that for every tree felled, another had to be planted and they also limited what could happen on that land while the forest was reestablishing. Those things that were put in place have saved and have made Scandinavia's contemporary timber and processing industry what it is today. Now they have something like 56% of the country covered in managed diverse forest.

JMcG

Can I just ask you a question. What kind of growth rates do they deal with; because it is very cold and for half the year nothing happens.

DB

It can be typically between 70 to 90 years before the trees are harvested.

JMcG

And at that stage, what type of volumes do they take off in 70 or 80 years?

PB

They are taking down the spruces earlier than that.

DB

I only have data from 2008, but it was about 17.5 million m³ of sawn product. Of course they also have a large paper pulp industry. The Swedish forests are generally a mix of Norway spruce, Scots pine and Swedish birch and interestingly they don't plant lineally. After they have clear felled a particular block, for the first few years or so it appears barren, but once the trees are established the forest appears to have a more natural appearance thanks to the non lineal planting and mix of primary species. I think this is possible, in part, because of the significantly higher precipitation levels in Sweden as

they don't have the same level of competition for water that we often have. It could also be said that there is not the same level of community back lash when the trees are harvested as you can sometimes encounter in Australia when our managed native forests are harvested nor do they don't seem to have the same level of politicisation to forestry as we have here. When I first travelled through the countryside I couldn't believe how natural their managed forest looked. I had to be taken to an area designated as 'old growth' before I could really see the difference. Typically there is a clear undergrowth storey with tall tree trunks interspersed with a dense canopy. There is not the apparent gulf between plantation and native forests that are typical in Australia. It goes beyond my area of expertise, but if it helped maintain supply I wonder if including a percentage of diversified native species within a test plantation, that can in some way contribute positively, of radiata or blue gums. Planted non lineally they may no longer look like the plantations of old. You could call them diversified, non-linear plantations. These would go a long way to addressing the concerns raised at Australian plantations being a monoculture that does not encourage biodiversity. I doubt native forests could be replicated, but this approach could encouraged greater diversity.

JMcG

Yes. Here in Western Australia the bluegum is not a native and so I agree, it's a big stretch to say even if you mix a few other species up with bluegum that you would end up with something that looked too much like a native forest. One of the interesting issues is that Australia's, and this is going back to native forestry rather than plantation which is not really what your question is, but it's interesting that we transferred the European view on old growth forests to Australia's forests which don't actually get to that old growth status. Eucalypt forests burn or die from drought somewhere between 250 and 500 years and there are not many Australian forests that are old growth in the sense that European and North American forests are and yet we have translated that expectation to here and so if it's happened elsewhere there is that expectation of a plantation having native-like characteristics could become a problem, yes. Technically, is there any issues? The issues I can see are that the different species might compete against each other and there are not terribly many species that really grow at the same rates and so if you have got them in either water or nutrient limited environments, of which many Australian environment is possibly one or both of those things, your best exploiter of the available resources will dominate, and I'm not sure how mixed species might manage under some fairly harsh conditions. Our native forests are not exclusively single species, but if you look at a jarrah forest in the areas where jarrah is

the dominant species, there is a little mixture of things like mallee etc but it's pretty sub-dominant. They are very strongly jarrah forests or karri forests. There are marginal areas of the karri forest and I don't mean economically marginal, where you get that intermixture of karri and again marri, but when karri is the dominant species it is almost pure standing karri and so that's a natural circumstance.

DB

The other thing that is different is that the undergrowth is not governed so much by the way they manage it in Sweden. There is a reasonable vibrant looking undergrowth. Once the trees get to a certain size there is really no need to clear it out, and it just naturally finds an equilibrium, what plants can survive with whatever light they can get. And so what happens is that there a lot of species that grow well in that darker atmosphere and so interestingly enough the animal population can survive there because they have got somewhere to hide and eat.

PB

Yes, I think that might be a characteristic of the northern evergreen forests. Because certainly the further you come into the deciduous forest that doesn't work any more. You have to take care of the under storey otherwise you just choke.

JMcG

And the interesting thing to do with resources utilised in the eco system, the reports from Western Australia discuss are what the forests looked like before colonisation and a lot of the reports talk about very open forests.

DB

That's interesting. A friend of mind who grew up in Bickley and his grandfather was one of the first European people to be establish there. He has recollections of talking with his grandfather being able to ride a horse through unlogged forest up there, flat tack - no roads, no paths, just through the trees, and he was describing a forest with hardly any undergrowth.

JMcG

It's an interesting thing. You hear that a lot and you also think about the explorers and how they actually plough their way through some of the forest. Not at all how we have to get through the forest now. They appear to have freely moved through that forest, which is again perhaps a bit of anecdotal evidence evidence that suggests that the

undergrowth was a lot thinner than it is now. That gets us to an issue of having very strong competition for resources and the strongest elements of the under storey dominates and it's not common in a lot of other circumstances. In Eastern Australia, the forests are much more mixed including the species in the over storey, you often get quite mixed forests but here in the West that hasn't happened.

DB

I guess the other issue is this idea of planting in rows because they are not planting in rows and I would question that this is a plantation, couldn't pick it because they are not in rows, and it is not a particularly hilly country. Sweden especially is pretty flat. So it's not like, here's a big hill so we have to go around it this way.

Tell me, why are we planting in rows?

JMcG

It has been mechanised, and I will go to the other end of the extreme. Our agriculture is now so mechanised that the cropping, if not the harvesting, is basically done on auto steer through a GPS so people sit there and do nothing, and the tractor looks after it all. So people have gone for those highly mechanised things, so why should we go that way? I don't know if there is any good reason except that it makes the establishing and harvesting very, very efficient, economically effective.

DB

I have had it said to me that that issue of growing in rows, not being a natural way that trees grow, means that you lose the buffer benefit where if you have got trees perhaps growing in a circular arrangement the outer rows deflect a lot of the wind load and they are pretty much written off but the trees that are in the middle are much stronger because there is less gum as the result of less flexing. Have you ever come across that type of argument?

JMcG

I am not a scientist, but the scientists that I have worked with almost say the opposite, that the stronger trees that you produce are the ones that aren't protected, because they sway, because they have got to develop their own resilience, that they actually end up producing a lot more lignin, basically in response to that movement so that in fact, if you want to get strong wood you get it by having trees that are exposed.

DB

I think this issue about multiple species and growing in rows and things are quite peripheral to what I'm doing, but nevertheless it's an interesting discussion to have because they do feed into the future of how trees are farm and that in turn informs that quality of wood of that is produced and the types of products and uses that timber is best suited for. Engineered timber products have come about because of the need to optimise lower quality timbers.

PB

You're right, you are not doing the thesis about forestry, you are doing the thesis about what the products of forestry are, so that's why you are having to step back to look at forestry, so I think all of that stuff is relevant because it does start to talk about the quality of material that you can expect to get out, doesn't it.

JMcG

Exactly. One thing that people talk about doing is mixing the species for the positive benefits you get between the species and the most obvious one is to put acacia trees in with other species so that the other trees can benefit from the atmospheric nitrogens that they put into the soil. That sort of stuff has been practiced more in poor countries than it has been in more affluent countries simply because in affluent countries people generally take the view that they can apply fertilisers. In terms of its sustainability though, that's not that great. Poorer countries plant them because it is an effective thing to do without spending money. One of the things that, and this is not exclusive, but relative to agricultural crops, in forestry crops or plantations are not as highly bred so that the level of genetic variation that you get in a plantation is still quite high. If you have got a cultivar of clover or wheat or something like that, they are not identical but they have got a very very narrow genetic base and they keep them within that pool by only crossing within that cultivar pool. Trees work a little differently. Generally trees will breed with whatever is going around but the level of selection is also much less and you end up with improved selections rather than highly bred genomes and so there is still within any of the genomes that we use there is still quite a high degree of variability and that partly offsets that issue. The greater variability you have got in an ecosystem the more resilient it is going to be.

APPENDIX C - MLB CONSULTING ENGINEERS DESIGN STATEMENT



MARK L BATCHELAR CONSULTING ENGINEERS

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Client: David Bylund
Project: Solid panel concept

Job Number: 11049
November 8, 2011 Page 1 / 4

Design Features Statement

1 Introduction

This submission covers the structural design of David Bylund's wall panel concept for the Currie Hall re-design. Details for the wall panels, floor-wall junctions, inter-storey and base fixings are provided. Two panel designs are considered, one for an internal wall and the other for an external wall.

2 Structural System

The wall panels are comprised of multiple Radiata Pine boards gun-nailed together to create a rigid panel. The panel provides both vertical and lateral load resistance to the building.

Lateral loads applied to the building are resisted by floor diaphragms, which are fastened to the top plate of the wall panels. The top plate is fastened to each wall panel using light gauge steel brackets, which transfer the lateral loads into the panels. The panels transfer the lateral load to the base of the walls. For ground floor walls the panels are fixed to bottom plates anchored to a concrete slab on grade. For upper level walls the panels are connected to the diaphragm floor, with wall end hold down anchors connected to top plates of walls below.

3 Structural Analysis and Design

Structural analysis and design conforms to the following standards:

AS1720.1:2010	Australian standard: Timber Structures. Part 1: Design methods
AS/NZS1170	Australian and New Zealand Standard: Structural design actions
AS3660:2001	Australian standard: Termite Management Set
AS1604.1:2010	Australian standard: Specification for preservative treatment – Sawn and round timber
AS4100:1998	Australian standard: Steel structures

4 Loading Summary

The following loads were assumed for the design of the wall panels.

Gravity load: G & Q

Floor dead load (G)	0.97kPa
Floor Live load (Q)	2.00kPa
Roof dead load (G)	0.36kPa
Roof Live load (Q)	0.25kPa

Wind load: WL

Design wind velocity	45 m/s
Wind pressure	0.84 kPa

Wind pressure coefficients are in accordance with AS1170.2:2002.

Seismic loads were also considered but were found to be non-critical.

5 Proposed construction sequence

The following simplified construction sequence is proposed using the wall panels:

- Cast the ground level concrete slab.
- Anchor the 190x35 wall bottom plates to the slab using HILTI injection anchors. The anchors are positioned at approximately 2m centers. Fasten anchors, with nuts and washers, to the 190x35 bottom plates. Note that the anchors at the ends of each wall panel also secure Rothoblass hold-down angle brackets.
- Lift the ground floor panel modules into position on top of the bottom plates. Starting at one end of a wall, fasten the first wall panel to the HILTI tie-down anchor using the Rothoblass angle bracket (15550). Fasten the wall-panel to the bottom plate using the MiTek Multi-grip brackets and nails or the MiTek CPC80 brackets and screws.
- Position the second wall panel module next to the first wall panel. Gun-nail or screw through the 120x35 edge trimmer member into the adjacent panel (using 3.15mm diameter nails at 250mm centers). Fasten the second panel to the bottom plate using the Multi-grip or CPC80 brackets.
- Repeat this process until the final wall panel is in place. Gun-nail or screw through the 120x35 trimmer member into a 190x35 end board. Fasten the final panel to the bottom plate using the Multi-grip or CPC80 brackets and fasten the 190x35 end board to the Rothoblass angle bracket (15550) with a HILTI anchor.
- Repeat this process until all wall panels on the first floor are in position. Provide a 190x35 top plate that runs along the top of the wall panels. Fasten each panel to the top plate using Multi-grip or CPC80 brackets.
- At the end of each wall provide thru-bolts to act as tie-downs for the wall panels above. Position Rothoblass angle brackets on the top plate and tighten the thru-bolt.

- For all the internal walls the second skin can be fastened to the 120x35 members using 10 gauge countersunk wood screws.
- Position the joists using MiTek Joist hangers and provide plywood floor panelling.
- Position the first panel for a wall above over the top plate and fasten the Rothoblass bracket to the 190x35 member using the standard Rothoblass screws. Provide Multi-grip or CPC80 brackets between the panel and the top plate.
- Position the other wall modules and fasten using the Multi-grip or CPC80 brackets.
- Repeat this process as described above.

6 Potential floor systems

A range of floor systems can be used in combination with the wall-panel system. These are listed below with general advantages and disadvantages:

Floor system	Description	Advantages	Disadvantages
Traditional Residential	Floor joists with plywood or particle board floor panels.	Commonly used for house construction.	Labour intensive. Difficulties with acoustics. Relatively structurally inefficient (large joists).
Timber-concrete composite	Floor joists with concrete topping. Concrete topping is connected to floor joists.	Some improvement in fire, acoustic and structural performance. Provides thermal mass (if required)	Concrete shrinkage induces sag. Wet trade on-site. Reduced construction speed. Difficult fabrication.
Stress-skin	Box sections. Composite timber flanges and webs.	Can incorporate (non-structural) concrete topping and acoustic barriers. Structurally efficient (shallow floor depth).	Difficult fabrication.

7 Services issues

The wall panel system can easily allow for services. It is recommended that the 190x35 studs, bottom plates and top plates are not offset, as shown in preliminary details from David Bylund. This would require drilling holes for services through the 190 members which may be labour intensive as well as compromising the strength of these wall end members..

Any (70x35mm) lamination can be offset by 20mm to allow for wiring. However, caution is advised as a tenant may damage wiring while hanging pictures or adding fixtures. Any wiring on the inside of the solid skins should be protected by steel tubing or similar.

It is recommended that all wiring should be on the inside of the solid skin. The 70x35 members and the 190x35 top plates could be drilled for wiring. For interior walls the wiring could be positioned before the second solid skin is screwed into place.

8 Material Specification

Materials to be used in construction.

8.1 Timber

New Zealand or Australian F7 Radiata Pine in accordance with AS1720.1:2010 is used for the wall panels, joists, top plates and bottom plates.

8.2 Timber Treatment

All timber is to be treated to a minimum of hazard category H2 in accordance with AS/NZS1604.1:2002 using Tanalith T (H2 Blue).

8.3 Structural steel

The following Standards and their related documents and subsequent amendments and other specifications shall form part of this Specification:

AS4100:1998	Australian standard: Steel structures
AS/NZS 1111:1996	ISO metric hexagonal commercial bolts and screws
AS/NZS 1112:1996	ISO metric hexagonal nuts, including nuts, slotted nuts and castle nuts.
AS/NZS 1252:1996	High Strength steel bolts with associated nuts and washers for structural engineering
AS/NZS 4680:1999	Hot-dip galvanized (zinc) coatings on fabricated ferrous articles

Bolts, anchors, nuts and washers. Unless otherwise specified all bolts and nuts shall be Isometric Hexagonal mild steel Grade 4.6 (commercial quality) complying with AS/NZS 1111 and AS/NZS 1112. Bolts, anchors, nuts and washers shall be hot dip galvanized. Washers shall be provided where the head or nut of bolts bears directly against timber.

Structural brackets. Structural steel MiTek and Rothoblass brackets shall be hot dip galvanized.

Nails and screws. All nails shall be hot dip galvanized. All standard Rothoblass screws shall be hot dip galvanized. All rib head screws shall be hot dip galvanized or Buildex Climaseal-3 coated.



Mark L Batchelar

BE ME FIPENZ CPEng (NZ) Int PE
MIEAust CPEng (Aust) NPER 44249

Principal

mlb Consulting Engineers



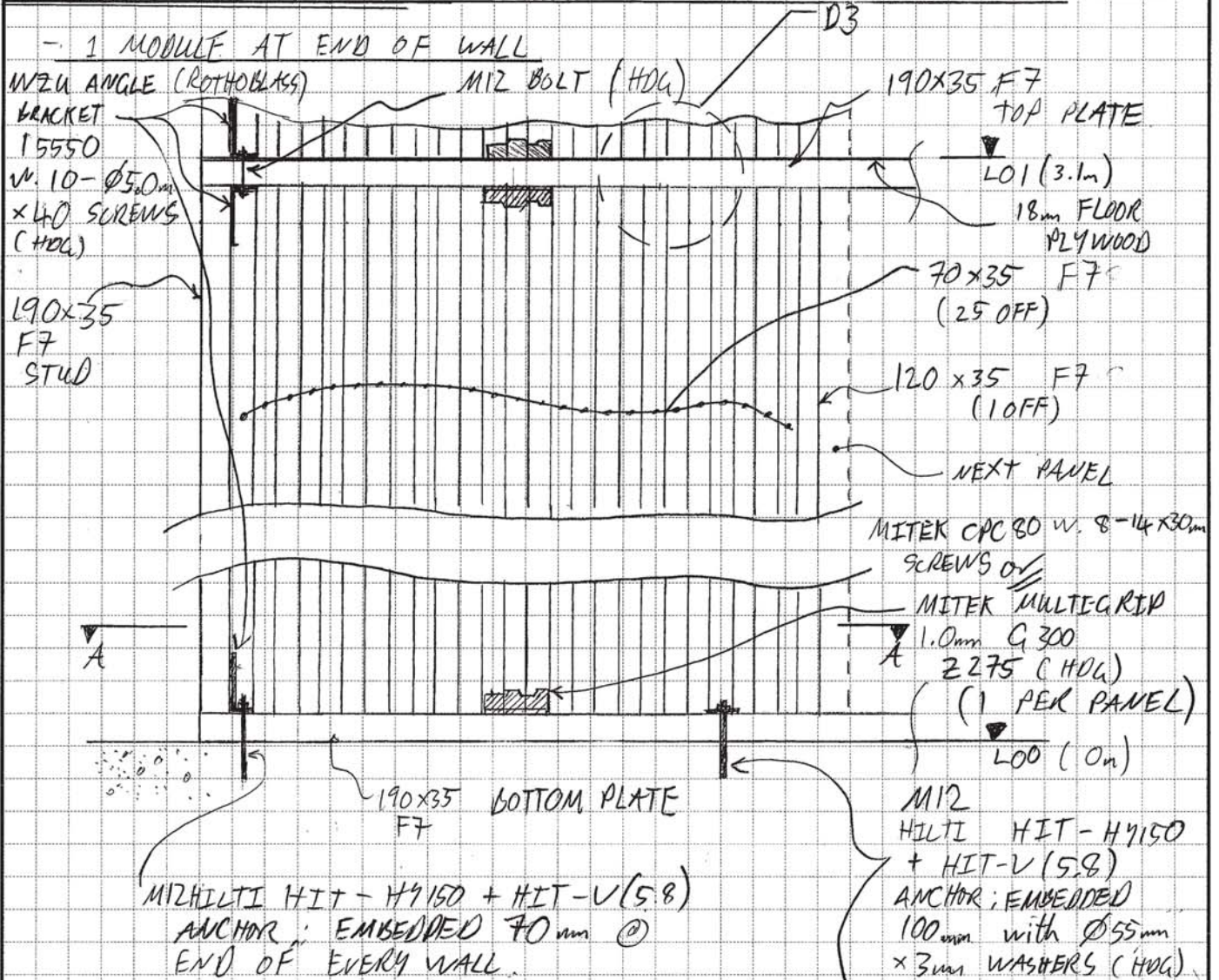
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Calcs for: David Bylund
Job: Solid Panel Concept
Designed: MPN

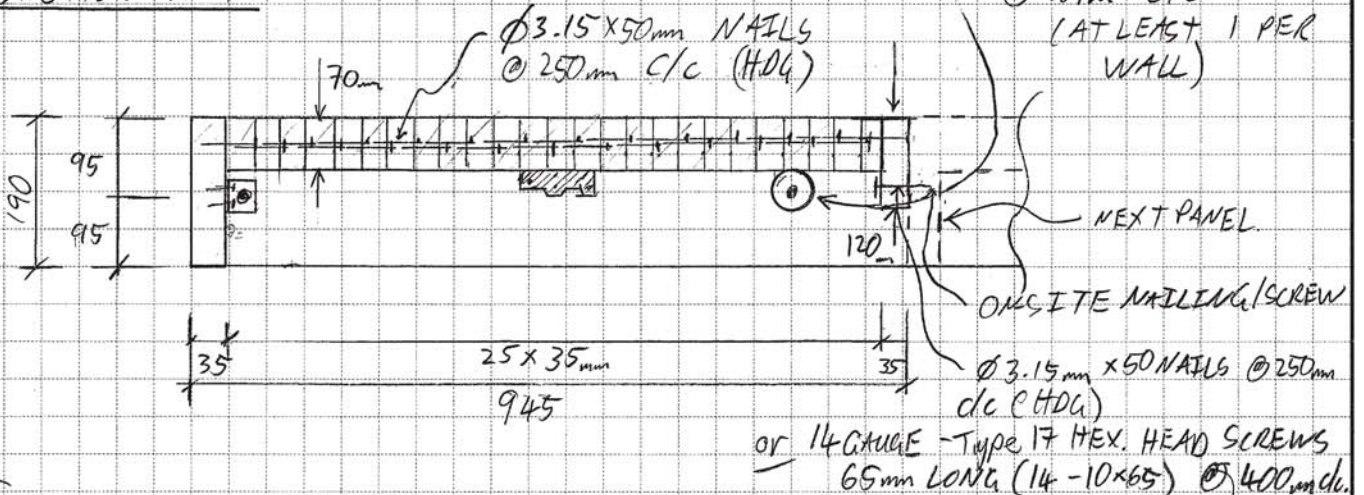
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Date: 31/10/2011

WALL PANEL SYSTEM: SINGLE SKIN EXTERNAL WALL



M12 HILTI HIT-H9150 + HIT-V(5.8) ANCHOR; EMBEDDED 100mm with $\phi 55_{mm}$ x 3mm WASHERS (HDG) ON TIMBER @ 1.9m c/c (AT LEAST 1 PER WALL)

SECTION A-A:



NB: - BOARDS ARE NAILED TOGETHER USING D-HEAD QW NAILS @ 250mm c/c. (HDG)

{SC.1:10}



CONSULTING ENGINEERS

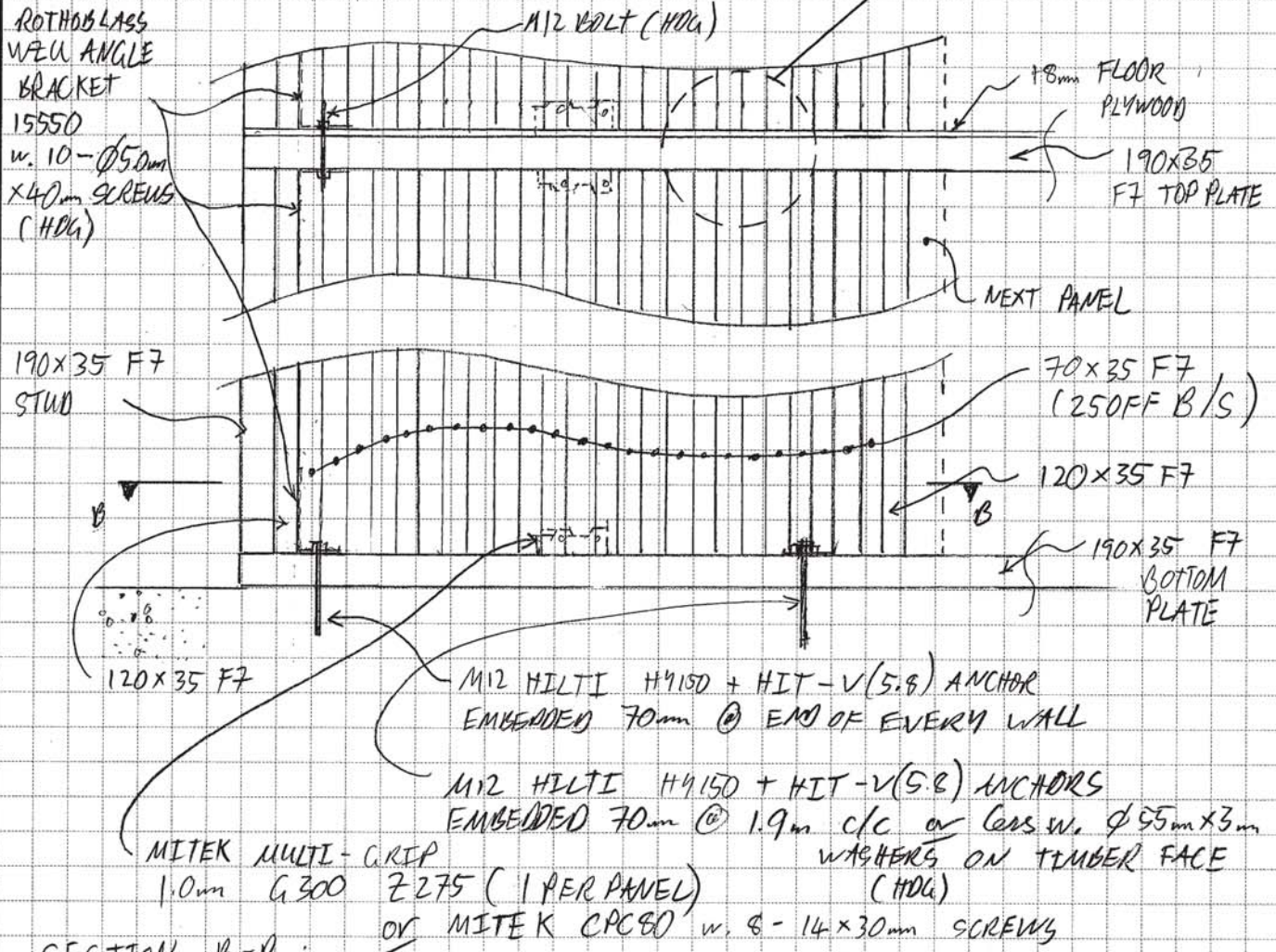
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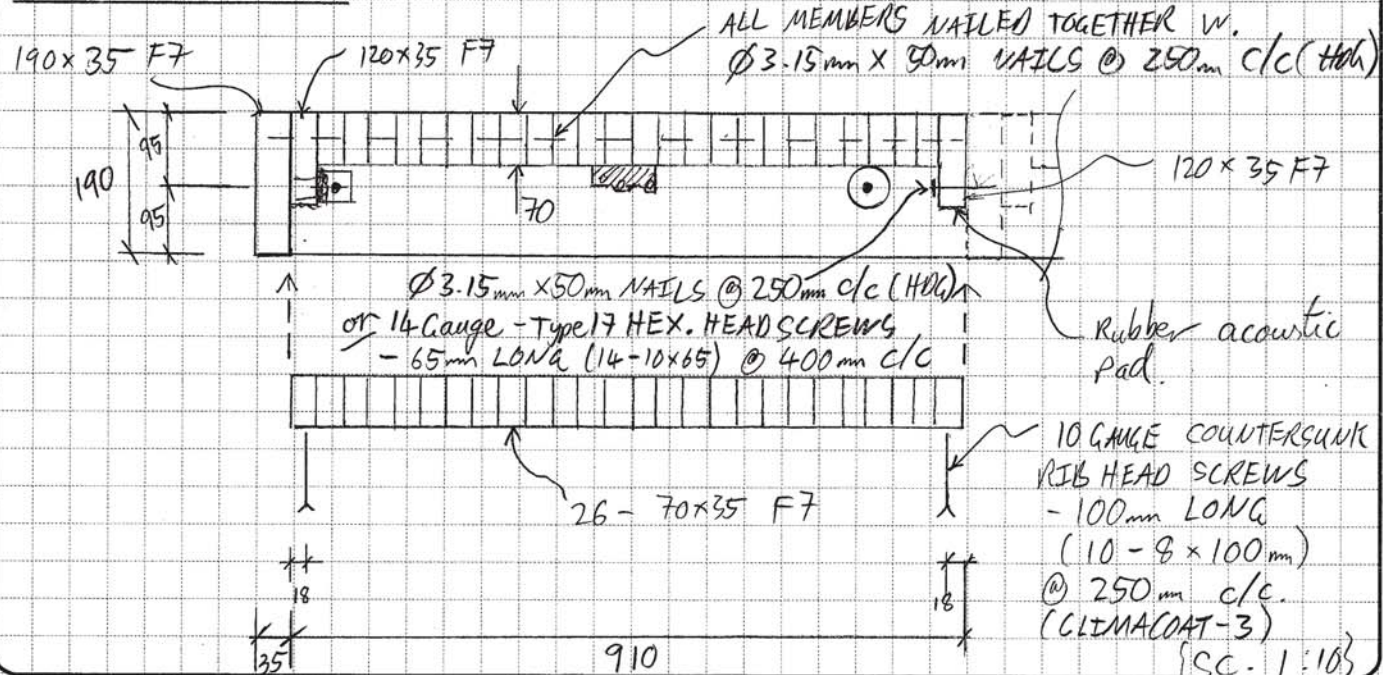
Job No: 11049
Page: 02
Date: 2/11/2011

WALL PANEL SYSTEM : DOUBLE SKIN INTERNAL WALL

1 MODULE AT END OF WALL



SECTION B-B :





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Calcs for: David Bylund

Job: Solid Panel Concept

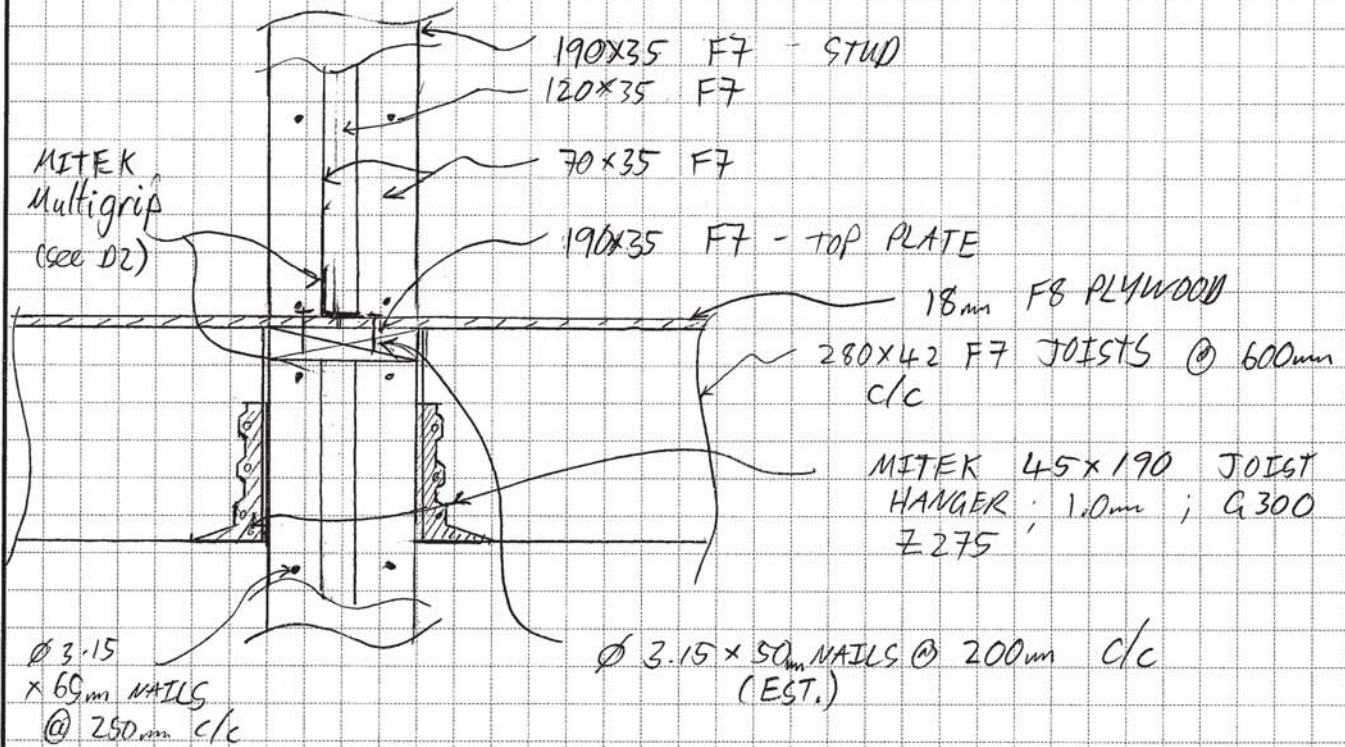
Designed: MPV

Job No. 11049

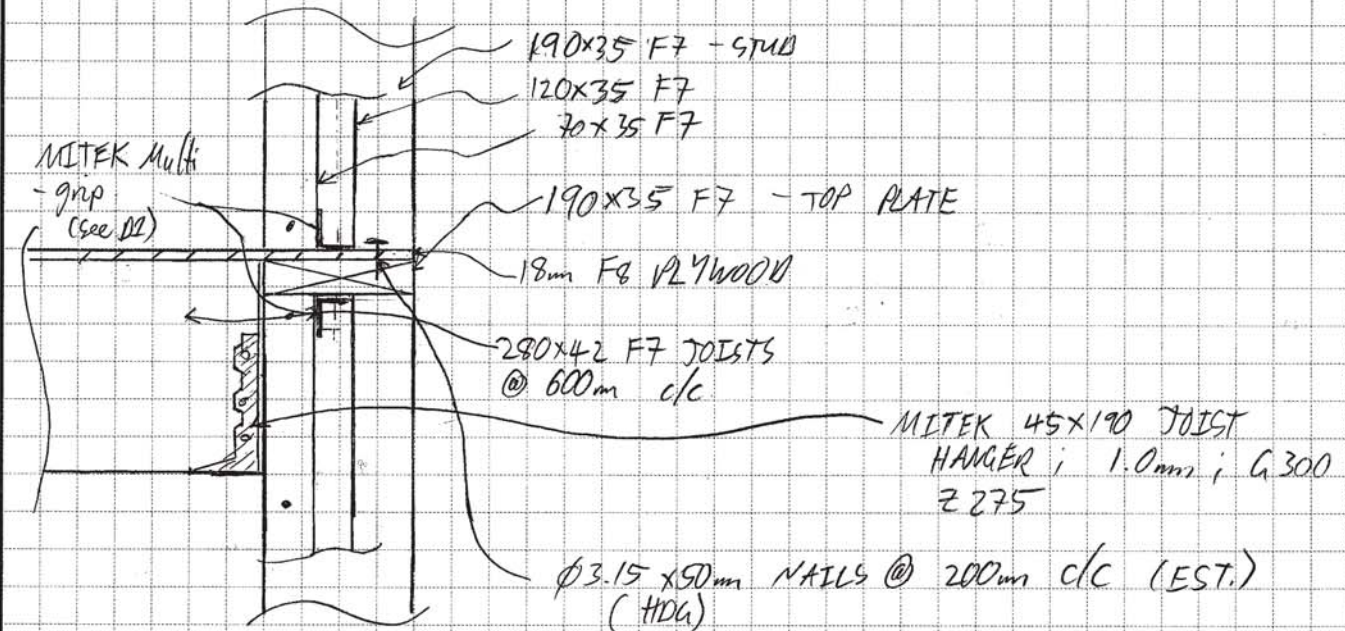
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Date: 31/10/2011

PROPOSED WALL - TO - FLOOR JUNCTION :



INTERNAL WALL



EXTERNAL WALL

GANG-NAIL[®]

Concealed Purlin Cleat

FOR HIDDEN TIE DOWN TO TOP OF SUPPORT

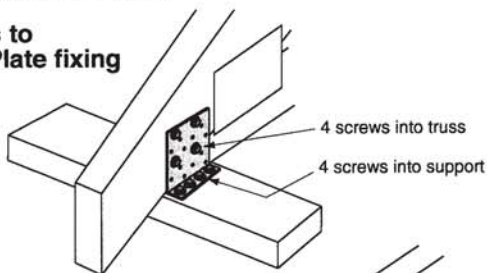
APPLICATION

The Concealed Purlin Cleat is an economical hidden bracket for fixing purlins to top of rafters, or trusses to top of walls to resist wind uplift.

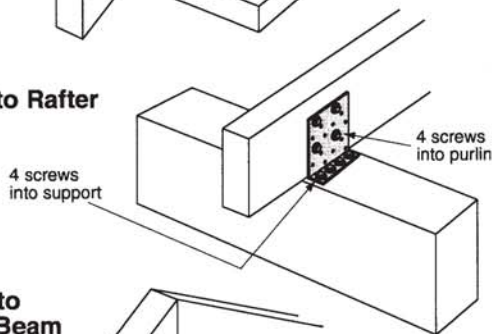
INSTALLATION:

1. Fix Concealed Purlin Cleat to side of rafter and top of support.
2. Fix 4 MiTek MSA1430 screws through the base of the cleat into the support. (use longer MiTek MSA1465 screws if fixing down to double top plates).
3. Fix 4 MiTek MSA1430 screws through large holes into the side of the rafter.

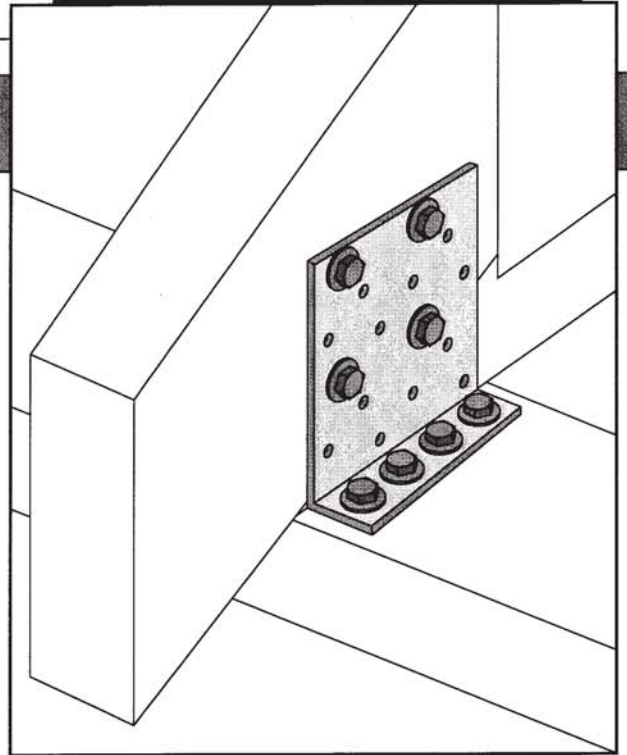
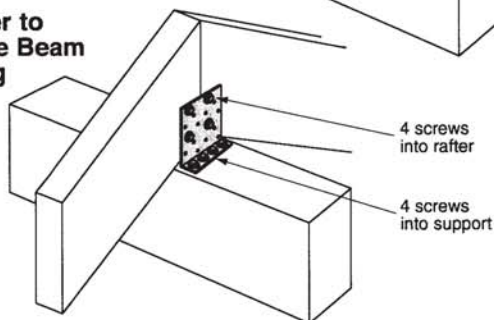
Truss to Top Plate fixing



Purlin to Rafter fixing



Rafter to Ridge Beam fixing



USES

Concealed Purlin Cleats provide a fast and easy method of anchoring purlins, rafters and trusses to the top of supports away from view.

They are also useful for fixing timber plates on top of block walls.

ADVANTAGES

- Quick and easy to apply, no nails required.
- No fixing to side of support required.
- Hidden from view.
- Resists wind uplift.

This Engineered Building Product complies with
AS/NZS 1170 Loading Code

MiTek[®]
MiTek[®]

creating the **advantage**

GANG-NAIL®

Concealed Purlin Cleat

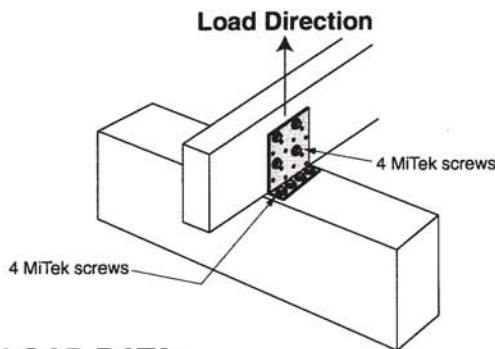
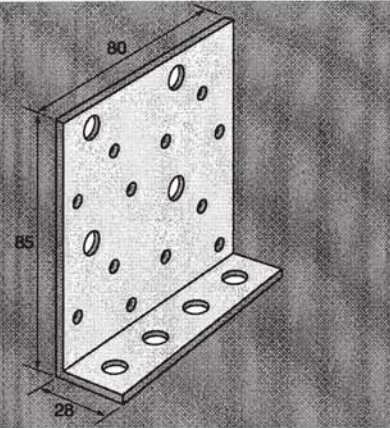
FOR FIXING PURLINS TO RAFTERS

SPECIFICATION:

Steel: Grade G300
Thickness 1.5mm TCT
Galvanized coating Z275

Screws: MSA1430 - MiTek No. 14 x 30mm anti-split self-drilling HD galvanized screws
MSA1465 - MiTek No. 14 x 65mm anti-split self-drilling HD galvanized screws for use in double top plates

Product Code: CPC80



LOAD DATA:

The design capacity is based on the weaker joint group of either member. The capacity is doubled when a pair of cleats is used in the connection.

Limit State Design Capacity per Concealed Purlin Cleat in Wind Uplift (kN)									
Screw Size	Joint Group								
	J2	J3	J4	J5	JD2	JD3	JD4	JD5	JD6
MSA1430	8.8	6.6	4.8	3.9	9.9	9.9	7.5	5.6	4.1
MSA1465	11.0	7.8	5.6	4.1	11.0	11.0	7.8	5.6	4.1

Values in this table incorporate the capacity factor (ϕ) for houses. For different building applications, multiply the design capacities by the following factors. Refer to AS1720.1 for a full definition of each category and building application.

Category	Building application	Adjustment factor
1	House	1.00
2	Commercial/Industrial	0.94
3	Post-disaster function	0.88

Design capacities have been obtained from laboratory testing and procedures given in AS1720.1.

MiTek Australia Ltd.

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MiTek
MiTek®

creating the advantage

APPENDIX D - WESPINE AND HYNE TIMBER CORRESPONDENCE

03/08/12

"Richard Schaffner" <RichardS@wespine.com>

To:

"DM.SY Bylund" <bylund@email.com>

Cc:

geofstri@hyne.com.au

G'day, David,

I absolutely agree with your line of argument. WESPINE has the same views, and has an abhorrence for statements that suggest inferiority or promote negative sentiment to any part of the timber grade spectrum! EVERY piece of sawn timber has structural properties. Some simply don't jump all of the hurdles to make it into existing "pigeon-holes"!

Just a couple of comments – hopefully you find them useful.

MGT – I think this term might draw the crabs. It is rather too close to MGP, I think. There are likely to be those who think it a "bit cute". There may be an assumed link to the MGP system, and whilst I don't see this as a bad thing per se, I think that the new structural plate products and building concepts could provide a vehicle for the industry to make a strong, positive statement in the market. A perceived link with MGP, and the continued availability of MGP10 and MGP12 may well send a message that "this new stuff is made with all of the stuff that doesn't make the main MGP grades". I believe that we should endeavour to avoid this at all costs! An entirely different name may *imply* a new and exciting, quite different approach to grading – even if it is really an evolutionary step rather than a revolution. XGrade, or XG Pine ? (I don't know....) Is there a name that fits with the plate concept? Maybe CLG (cross-laminating grade)?.....dunno.....will need to think about this!

Statement by industry – In line with the above, I think that we should avoid talking about under-utilised timber – too much of a hint to previous fall-down from MGP, I think! I prefer the angle that says something like:

"Utilising new and revolutionary timber grading and manufacturing techniques, we have improved our manufacturing processes to more fully utilise the inherent properties of our timber to produce a new range of high-quality engineered timber products. Load sharing between the pieces laminated together to make our new plate-laminated building elements enables us to optimise structural performance. This system creates new, economical and environmentally friendly solid timber wall, floor and roof panels and enables more efficient utilisation of our valuable resource."

Hopefully this statement (or something like it) would deliver a strong, positive message! Anyway, you probably get my drift.

Best regards,

Richard Schaffner

Business Development Manager

WESPINE Industries Pty Ltd

Telephone: +61 8 9725 5777

- WESPINE Industries Pty Ltd A.C.N. 88 052 954 337

07/31/12

RE: Timber Grading Terminology

"Geoff Stringer" <geofstri@hyne.com.au>

To:

"DM.SY Bylund" <bylund@email.com>

Cc:

"Richard Schaffner" <RichardS@wespine.com>

David,

A beautiful piece of work. You should be in marketing.

MGT is a good term and works for me.

I particularly liked your biomimicry paragraph.

I also liked your continual use of the word "plate" to describe the systems we are talking about.

The word "slab" also has some positive connotations although also has obvious links to concrete.

The only suggestion I would make might be to think about another paragraph between the problem and the solution paragraphs discussing options for other terms, before deciding on MGT.

The engineer in me would list all the options and discuss the strengths weaknesses of each. But that might complicate the simplicity of your suggestion. The document reads very well as it is.

Thank you.

Kind Regards

Geoff

APPENDIX E - WCTE2012 CONFERENCE PAPER

Full paper presented and published at the World Conference on Timber Engineer 2012 (WCTE2012) held in Auckland, New Zealand, 15-19 July, 2012.

INNOVATIONS IN THE USE OF ENGINEERED TIMBER IN AUSTRALIAN ARCHITECTURE:

ADVANCED SCANDINAVIAN ENGINEERED TIMBER AND INDUSTRIALISED CONSTRUCTION TECHNIQUES IN AN AUSTRALIAN CONTEXT

David Bylund¹

ABSTRACT: Advances in the Scandinavian industrially-produced engineered timber building sector are investigated to inform new Australian based architectural construction methodologies for single and multi storey engineered timber construction.

KEYWORDS: Engineered-timber products/systems, multi storey timber construction, industrialised construction, Gun-nailed Parallel Laminated timber (GPL), Cross Laminated Timber (CLT), Australian engineered-timber building design

1 INTRODUCTION

This research explores advances in the Scandinavian industrially-produced engineered timber building sector to inform prospective new Australian based architectural construction methodologies for single and multi storey timber construction. Four main types or systems of engineered, prefabricated timber methodologies have emerged in Sweden. These are Volume Module construction, Cross Laminated Timber Planar construction, LVL Post and Beam systems and composite web and flange elements using structural grade Masonite. A variant on the structural beam web and flange arrangement is also emerging utilizing Orientated Strand Board (OSB).

2 RESEARCH OBJECTIVE

Can industrially-produced, Scandinavian inspired, engineered-timber, as load bearing planar elements or volume modules for single and multi storey buildings, be developed for an Australian context?

3 SWEDEN & TIMBER

3.1 AN HISTORICAL OVERVIEW

Sweden has enjoyed a lengthy, rich and on occasion, vicissitudinous association with timber. An abundant

natural resource, timber exists ubiquitously in almost all aspects of Swedish society. As one of Scandinavia's most quintessentially recognisable materials, timber has helped define the essence of the Swedish built environment.

Sweden's long affiliation with its immediate neighbours has resulted in a recognisable commonality that is often perceived as simply 'Scandinavian' or 'Nordic'. Christoph Affentranger, in his book, *New Wood Architecture in Scandinavia*, comments on the historical connection Sweden has with the other Nordic countries where he states that traditionally, the use of timber in Sweden has much in common with its neighbour Norway [1]. This association continues to this day with the announcement in 2009 that the Norwegian architectural firm Reiulf Ramsrad Architects had been commissioned to design the High North Centre for the Barents Secretariat in the arctic town of Kirkenes, Norway, and has been described as "...the world's highest building ever constructed in wood" [2]. It is proposed to be 16 or 17 storeys high and has been inspired by "... traditional architecture from Russia, Sweden, Finland and Norway" [3]. Throughout the 19th and early 20th centuries, it was common practice to construct Sweden's provincial and suburban train stations entirely of wood and many of them continue to be functional civic buildings today. Architecturally, they are often an expression of typical Scandinavian timber construction techniques exemplifying stylistic sentiments representative of their era. These can be in the form of log cabins, expressed post and beam structures, timber stud frames clad in weather boards with ornate stylised trim detailing and even some of the modern era's first laminated beam structures. Examples of these are the

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Bodens Stationshus built in 1894 and Malmo Stationshus in 1924.

It is also worthy to note that timber roof structure in the main hall of Stockholm’s central train station, completed in 1928. Designed by Folke Zettervall, it features a repetitive series of expressed, impressively curved, laminated timber roof beams and are “... the main architectural feature (of a) generous, light filled central hall ... (that is) carried by elliptically-arched glue-laminated wood beams that spring powerfully from granite columns” [4]. The main hall is 119m long, 23m wide and 13m high; its arched timber beams dominate the interior and are a prime example of one of the world’s first curved, laminated timber roof structures.



Figure 1: Central Station in Stockholm (Centralen) (top), Ralph Erskine’s Stockholm University Frescati Campus additions (centre) and Timber multi storey apartment developments in Växjö (2010)(below)

In more recent times, noteworthy timber civic buildings are Ralph Erskine’s Stockholm University Frescati Campus additions. Erskine’s buildings contrast with the six original 1970’s multi storey concrete ‘slabs’ which were viewed “... as a symbol for the era’s despised large-scale approach to building” [ibid]. Erskine’s buildings feature timber prominently both structurally and aesthetically and collectively, they “... complemented in a refined way ... (the) ... originally sterile environment ...” [ibid]. These include the student union building, Allhuset (1981) which was awarded the Kasper Salin Prize of that year, the Aula Magna Auditorium (1996-97) and the distinctive all-timber sporting facility, Frescatihallen (1983).

Notwithstanding this, older surviving civic and institutional timber structures have been conspicuously absent from many Swedish cities and their relatively recent built environments. This can be primarily

attributed to Sweden’s prescriptive building regulations, enacted in 1888, limiting the use of structural timber in buildings over two storeys. This prescriptive approach to building materials created industry path dependencies reliant primarily on concrete and steel construction [5]. These controls were the direct result of a moratorium placed on the use of structural timbers following numerous disastrous fires in Sweden’s cities such as Uppsala in 1702 and Växjö in 1843. Restrictions on the use of structural timber were repealed in 1994. The effect of these restrictions has been to artificially constrain the technical development of timber in modern multi storey construction. Internal interest in emergent timber technologies and membership to the European Union [6] along with aspirations to develop more environmentally conscious building practices have played an important role in replacing what had become an antiquated, 19th century timber building code.

Following the new performance based codes being enacted in 1994, intense activity in the field of timber construction fast tracked technical developments in high rise timber building. An increasing number of architects, academics, engineers and developers have begun to utilise and rapidly progress new engineered timber construction techniques now seen in increasing numbers of Sweden’s multi storey buildings. One in seven new multi storey buildings in Sweden is now built with an engineered structural timber frame “... where 80% to 90% of the construction process is outsourced to a quality-assured factory environment” [7]. While this new multi storey timber construction industry could still be considered to be in a formative phase relative to concrete and steel, it is experiencing unparalleled growth as Sweden’s towns and cities create new developments that require timber-only construction, supplanting traditional heavyweight high rise construction methods.

4 AUSTRALIAN ENGINEERED TIMBER DESIGN SOLUTION

4.1 CURRIE HALL

Currie Hall (Stage One) student accommodation building was designed by local Perth architectural firm *Palassis Architects*. It is a three storey, double brick structure with two suspended concrete floor slabs. It is typical of materials, costs and construction processes used in Western Australia. Located on the University of Western Australia’s Crawley campus, this project was selected to act as a case study project for the purpose of comparing typical current (Western) Australian building practices with an alternate localised (Western) Australian engineered timber solution.



Figure 2: Currie Hall (stage 1) – Floor Plan and Under Construction

4.2 AN ALTERNATIVE CURRIE HALL

From the Currie Hall design, a proposal was developed as a theoretical alternative to test a localised variant of an engineered timber system used in Scandinavia. The project was investigated and through a process of reverse designing, a new brief was created that addressed the client’s requirements, while also providing a vehicle for the development of a new engineered timber building solution. As per the project objective, the aim was to develop an engineered timber concept that could be produced and constructed in Western Australia using currently available local materials, skills and equipment.

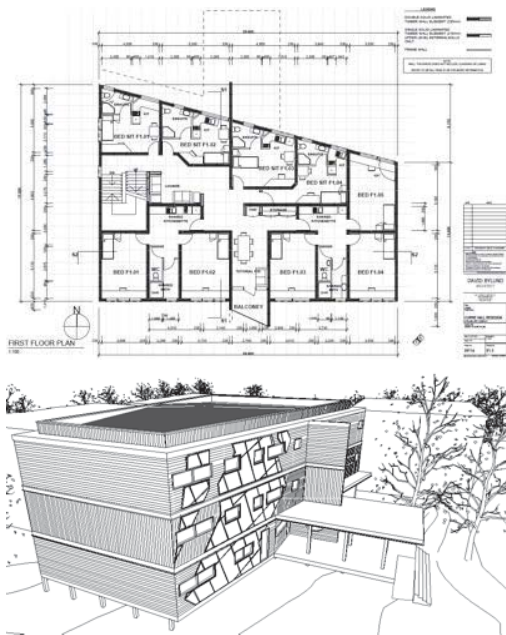


Figure 3: Redesigned Currie Hall. Upper floor Plan and Perspective

5 AN AUSTRALIAN ENGINEERED TIMBER WALL SOLUTION

5.1 AUSTRALIAN ENGINEERED AND VALUE ADDED TIMBER INDUSTRY

Australia does have a limited range of engineered timber and prefabricated systems commercialised and available. Carter Holt Harvey’s *Panelised Building System* (PBS) and Timberbuilt Solution’s engineered bespoke timber structures on Australia’s east coast are two examples of successful, well developed engineered timber products. In Western Australia there is a range of less developed engineered timber products currently being manufactured or fabricated. These are Particle board and Medium Density Fibreboard (MDF) manufactured by The Laminex Group in Dardanup; Laminated Veneer Lumber (LVL) posts and beams for low rise residential use by Wesbeam in Neerabup; residential wall frames and roof trusses by Timbercheck in Bunbury; Structurally Insulated Panels (SIPS) using imported Oriented Strand Board (OSB) skins in conjunction with

an Expanded Polystyrene (EPS) core by Smart Timber building systems in Kewdale and SIPS Industries in Bibra Lake. Of noteworthy inclusion to this list is the yet-to-be-realised Lignor ‘Engineered Strand Lumber’ (ESL) and ‘Engineered Strand Board’ (ESB) plant in Albany in Western Australia’s south west. The vast majority of residential construction undertaken in Perth, Western Australia, ignores these engineered timber products and systems and instead, uses a concrete ‘floating slab on ground’, double brick walls and a pitched ‘stick’ roof. In contrast to this, the prefabricated housing industry in Western Australia is perceived as a boutique, fringe method of construction. Juxtaposed with the Scandinavian prefabrication and off-site operations, Australian prefabrication companies build according to traditional sequential construction order, mirroring the build process of on-site construction. As yet, this sector has not made significant inroads into the mainstream suburban market. Commercial construction predominantly utilises tilt up and precast concrete and structural steel. Large scale high level prefabrication plants such as those found in Sweden do not exist. There are no turn key volume module systems being built on the scale of Linbäck’s Piteå factory, no Cross Laminated Timber (CLT) plants such as Martinsons in Bygdsiljum and no large scale glue laminated plants such as Moelven’s Töreboda operation.

5.2 WESTERN AUSTRALIAN SPECIFIC OPPORTUNITIES AND CONSTRAINTS

The above Australian engineered timber products and companies mentioned were considered for their potential to expand into larger scale prefabrication facilities that could create second and third tier value added building systems with the intent of escalating into larger scale building projects. While each sector may have the potential to expand into more sophisticated products and larger scale buildings, issues such as the need to increase investment in tooling and skills training are prohibitive without clear market prospects. It is reasonable to assume that significant expansion of the existing engineered timber sector beyond current levels is unlikely in the near to medium term.

With this in mind, an engineered, timber based structural system was developed specifically for the Western Australian context that utilised existing local timber supplies, skills and facilities without the need to invest in new facilities, or provide significant additional training to employees. The result was a system that reflected some of the early planar solid timber concepts pioneered in central Europe in the 1990s that predated the development of CLT. As the investigation progressed it became apparent that as a first step, a very simple parallel laminated timber wall panel system could be designed that could be easily fabricated by a roof truss and wall frame manufacturer. Parallel lamination, while not as structurally efficient as CLT, has demonstrated that it has the fundamental capacity to be used in three or four storey construction. By restricting the design parameters to existing standard timber working skills and equipment and with the aim of each panel being capable of being erected without the need for heavy

lifting equipment, a Western Australian specific parallel laminated timber concept was created that has the potential for use in Residential Class Buildings 1, 2, 3 and 9c and Commercial buildings 5, 6, 9a and 9b. Potentially taller buildings using the BCA's Alternative Solutions assessment method of demonstrating compliance to achieve Performance Requirements could also be achieved.

5.3 GUN-NAILED PARALLEL LAMINATED (GPL) TIMBER PANELS – A DESIGN EXPLORATION

Initially, the fixing methodology to secure each of the individual members together in a parallel laminated format utilising friction fitted Tasmanian Oak hardwood timber dowels was considered. Timber dowels allowed the use of CNC cutting and also simplified future panel modifications. This system was originally being considered because access to equipment such as a large scale flat bed press used to produce glue laminating panels was not readily available. Notwithstanding this, it became apparent that dowel fixing would not be feasible because of structural and production limitations. With both glue laminating and dowel fixing rejected, the only remaining feasible fixing method was a gun nail lamination process. Gun nailing also introduces some restrictions and reduces each individual panel's flexibility and ease of working, but is a relatively easy method of fixing and is readily achievable. The use of steel nails prohibits the cutting of the panels with standard saw blades and CNC cutters. This restriction ensures a minimum of timber wastage because each panel is made to size rather than produced as a large blank which is then cut out and trimmed to size as is common with standard CLT.



Figure 4: 1:10 Panel and wall element cut-a-way models

The gun nail concept was optimised with the assistance of MLB Consultation Engineers in Auckland, New Zealand. The panel's nailing pattern and the fixing requirements were calculated based on the loads required for the redesigned Currie Hall.

Radiata pine was chosen as the panel timber material because it is readily available in a range of standard sizes and is a relatively low cost locally grown plantation timber. Using standard 70x35 MGP10 graded Radiata Pine Dry Dressed sawn timber, milled at Wespine's West Dardanup sawmill, the panel's maximum width of 945mm was calculated on the assumption that it could potentially be tilted up into place by two workmen, each lifting a maximum of approximately 45kg. It was therefore determined that the panel's total weight could be within the range of 90kg to 110kg assuming that the

only manual lifting would be a 'tilting up' action rather than a dead lift. This limitation was imposed with the intent of minimising the need for mechanical heavy lifting equipment, either in the production facility or onsite. When the panel reached the building site, it would be lifted from a truck mounted lifter crane and either stacked onsite near its final location or moved directly into place using lifting trolleys.

The system of joining each panel to the next benefited from the existing modularity within standard timber sizes in Western Australia. The panel is comprised of a single 190x35 end piece fixed to a 120x35 trimmer which in turn was fixed to a series of 70x35 'core' timbers. At the opposite end, a second 120x35 end trimmer was added. By arranging the members in this way, a second 70x35 skin 'core' could be fixed to the two 120x35 trimmers to allow a double skin variant of this concept with a total thickness excluding external and internal linings of 190mm.

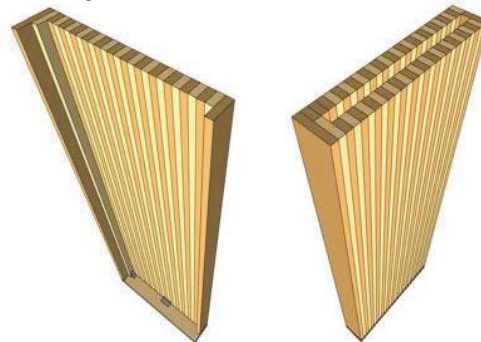


Figure 5: Computer generated concept view of single and double skin variants of the GPL panel

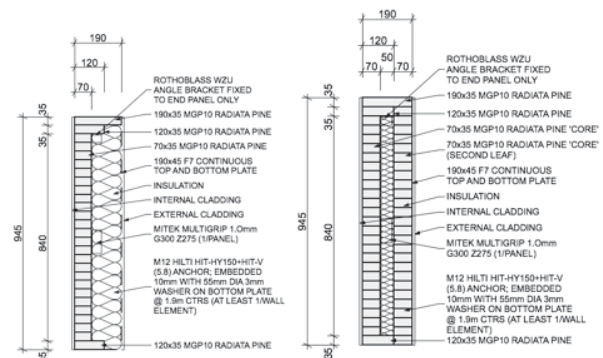


Figure 6: GPL single skin panel plan details (left) and double skin (right)

5.4 STRUCTURAL SYSTEM

The overall structural system can be described as a rigid panelised planar concept that, through the simultaneous co-action between conjoined members, provides both vertical and lateral load resistance to a building. The floor diaphragm resists lateral loads via fastenings fixed to the continuous top plate that is attached to the panels using light gauge steel brackets. The lateral loads are then transferred to the base of the walls via the panel. The ground floor wall panels are fixed to bottom plates anchored to a concrete slab on grade. Upper level wall panels are connected to the diaphragm floor via wall end

hold down anchors which are connected to the top plates of the walls below.

MLB Consulting Engineers have confirmed that the structural analysis and design conforms to the following Australian and New Zealand standards:

Standards

AS1720.1:2010	Australian Standard: Timber Structures. Part 1: Design Methods
AS/NZS 1170	Australian and New Zealand Standard: Structural Design Actions
AS3660:2001	Australian Standard: Termite Management Set
AS1604.1:2010	Australian Standard: Specification for preservative treatment – Sawn and round timber
AS4100:1998	Australian Standard: Steel Structures

5.5 LOAD SUMMARY

In developing the panels for a particular design application, the following gravity loads and wind loads were assumed. Seismic loads were also considered but were found to be non-critical:

Gravity Load: G & Q

Floor dead load (G)	0.97kPa
Floor live load (Q)	2.00kPa
Roof dead load (G)	0.36kPa
Roof live load (Q)	0.25kPa

Wind Load: WL

Design wind velocity	45 m/s
Wind pressure in accordance with AS1170.2:2002	0.84kpa

Figure 7: Load summaries

Following the structural calculations and design undertaken on the panel concept by MLB Consulting Engineers above, Professor Ken Kavanagh from the School of Civil and Resource Engineering at the University of Western Australia also undertook a review of the structural aspects of the GPL panel prior to its physical testing in the Civil Engineering testing facility. According to Professor Kavanagh, based on the expected loads in the Currie Hall design, each panel would be required to withstand a load of approximately 70kN. He concluded that each panel should be capable of withstanding a load of 250kN before buckling failure occurred. As is demonstrated below, the panel easily withstood the load of 70kN, but exhibited buckling to a degree greater than would be serviceable (13mm deflection) in a building application under a 250kN load. In his opinion, the use of solid timber in a panelised format for the Currie Hall project would result in a structural design that was over engineered by a factor of three. His view was that the conscientious application of a panelised web and flange arrangement where the outer face or sides of the panel could be separated via a

structural core would result in only a 10% loss in strength with up to 50% reduction in material.

5.5.1 Structural Prototype Testing – DDS - MGP10

Several full scale GPL prototype panels were made to test the nailing procedure, actual weight and balance during manufacture, handling and erection characteristics and to carry out simulated gravity load testing.



Figure 8: Full scale prototype (left). The author with prototype panel being prepared for load testing (right)

Load testing was undertaken at the University of Western Australia’s School of Civil and Resource Engineering. A 400mm x 2400mm high panel segment was tested to confirm load buckling failure. Under the application of a graduated load, the panel exhibited buckling characteristics consistent with the modelling but performed in a way that the modelling was not able to predict.

A laser was positioned to measure deflection in the centre of the panel. Initially, the panel gradually exhibited displacement of approximately 0.5mm to the left up until approximately 40kN. From 40kN to 80kN, it gradually returned to centre and then proceeded to progressively buckle to the right to a point that it was deemed as failure (13mm deflection) under 242kN of load.

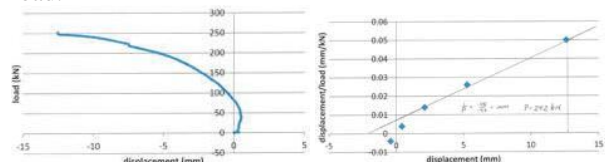


Figure 9: Load vs. Displacement test results (left), Southwell plot for buckling (right)

5.5.2 Structural Prototype Testing – DRS - Ungraded

The DRS GPL panel ungraded timber prototype was tested under the same conditions as the DDS MGP10 GPL panel. Being rough sawn, each individual 80mm x 40mm piece is approximately 23.5% larger by volume. The load test resulted in a buckling failure of 360kN (18mm deflection). This failure point load is 32% higher than the DDS MGP10 test results. The ungraded timber has the potential to contain wood that ranges from non structural through to MPG12. Notwithstanding this, the timber itself is back sawn from the log and is likely to have a high representation of MGP10 and even MGP12 timber. Conversely, the DDS MGP10 timber is unlikely to have a significant number of higher grade timber. This factor would explain the disproportionately higher test result.

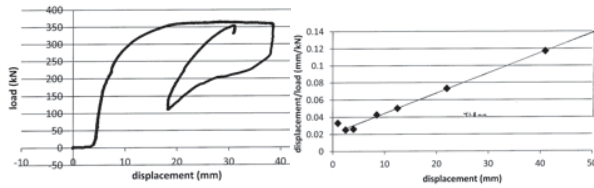


Figure 10: Load vs. Displacement test results (left), Southwell plot for buckling (right)

5.6 BUILDING CLASSIFICATION AND COMPLIANCE METHADOLOGIES

The Building Code of Australia (BCA) states that residential buildings other than one and two storey Class 1 dwellings must be constructed according to very stringent acoustic and fire standards. Depending on the type of construction and specifics of the building's design, these can usually be met by conforming to Deemed-to-Satisfy (DTS) provisions. If a building's characteristics are outside those applicable to the DTS provisions, demonstration of a particular performance requirement can be met by providing an 'Alternative Solution'.

The original Currie Hall project would be classified as a Class 3 building. The Building Code of Australia (BCA) 2011 states in Table C1.1 that Type A construction (the most fire resistant type of construction) is required for Fire Resistance and Stability for this class of structure.

Unless a conditional concession is applicable such as those granted to Class 2 timber framed buildings that are three storeys or less, all internal load bearing walls in three storey, Type A constructions buildings must be either concrete or masonry to be approved under the DTS provisions. This provision reflects a conservative approach to fire safety that the BCA adopts. One of the implications is that new technologies such as solid timber construction are excluded from being approved under the DTS provisions if intended for a project that is four or more storeys. The fire and acoustic performance of solid timber construction is yet to be accounted for in the BCA's DTS provisions and thus, projects that fall outside the DTS requirements must be assessed under the 'Alternate Solution' method. This puts solid timber construction at a disadvantage over concrete and masonry, despite being more similar in character and performance than to timber frame. This disadvantage has the potential to disproportionately bias against the advantages of solid timber construction such as significantly faster construction times and the significantly lower environmental impact of the use of renewable timbers.

As mentioned above, in contrast to three storey Class 3 buildings, a similar Class 2 building can be built using timber framing and approved under the DTS provisions, under Clause 3.10 of the BCA provided that the insulation used in the walls is non-combustible and automatic smoke alarms are fitted. It is reasonable to assume that an architect or developer is more likely to consider a solid timber structural system for a project similar to Currie Hall if it could be approved under the DTS provisions, alternatively, given the similarity between Class 2 and Class 3 buildings, it could be

argued that approval could be sought as a Class 2 building.

In the case of the alternative Currie Hall proposal as outlined in Section 6 above, demonstrating BCA compliance via the 'Alternative Solution' to the level required to obtain building approval is outside the scope of this research. Notwithstanding this, preliminary fire, acoustic, thermal and insect resistance characteristics are presented below.

5.7 EXPECTED FIRE RESISTANCE

As a composite wall panel system, GPL, as defined in this study, incorporates both an external cladding and internal lining. The alternate Currie Hall proposal's location relative to the surrounding buildings determines the necessary Fire Resistance Level (FRL) for the load bearing walls according to Section C1.1, Table 3. Assuming that the design is assessed as a Class 2 building, relative to the nearest building (on the southern side), the required external wall FRL is 90/60/60. The internal walls FRL is 90/90/90 for both load bearing stair shaft walls and loadbearing bounding walls between the sole occupancy units. Data specifically designed to demonstrate methods of achieving the required FRL in Australian timber construction is limited to timber framed construction in documents such as CSR's 'The Red Book' and Wood Solutions' 'Timber-framed Construction for Multi-residential Buildings Class 2, 3 & 9c'. Both publications utilize the Gyprock lining and Fibre Cement Wall board to achieve compliance. While these methods of compliance are applicable because of the composite nature of GPL, test results on European CLT would indicate that the solid nature of a panelized timber wall significantly improves a building's ability to maintain structural integrity in a fire because the charring effect is limited to only one continuous face. The burnt layer or 'char' that accumulates on the face of the timber acts as a protective element on the inner timber allowing the element to retain its structural integrity. The solid laminated arrangement of CLT and GPL means that there is no cavity or hollow core to the wall. This solid nature has the effect of restricting a fire's ability to burn through a wall as it only has access to one face of each of the laminated timbers within the wall. It is therefore reasonable to assume that a reduction in combustible surface area would result in the maintenance of a larger cross section of timber capable of retaining its structural properties.

5.8 ACOUSTIC PERFORMANCE

Solid timber panels have inherent airborne noise absorption properties as evidenced by the widespread use of timber panels in performance spaces. Anecdotal evidence from Sweden indicates that solid timber multi-residential buildings also out perform their calculated impact noise levels. One explanation for this is that the calculation methodologies used favour traditional forms of construction with an inherent bias towards steel and concrete. As the number of solid timber buildings have increased in Sweden, acoustic testing methods are being questioned and disparities between theoretical outcomes

and actual outcomes are emerging. Until a significant number of solid timber buildings are completed in Australia, it is yet to be determined if a similar trend will be exhibited here.

The BCA's list of acceptable forms of construction does not contain any directly comparable descriptions of wall types from which to apply a DTS solution to a GPL wall element. Notwithstanding this, the double skin variant of GPL as proposed in this paper is the closest to the BCA's discontinuous construction approach to noise transfer minimisation. Discontinuous construction in conjunction with double layers of fire and sound rated linings will achieve the DTS requirement of R_w+C_{tr} 50. The double skin variant of the GPL wall is estimated to achieve R_w+C_{tr} 40 when incorporated with double layers of fire and sound rated linings. This 10db difference is significant and is the result of the inclusion of the 190x35 end piece and the two 120x35 trimmers in each panel. These elements bridge the gap between the two leafs and in effect, create a bridge that has the potential to carry sound waves. A variant that removes the 190x35 end piece and replaces it with a Resilient Wall Tie such the MB01GA from *Matrix Industries Pty Ltd* should easily meet acoustic performance requirement of R_w+C_{tr} 50 and possibly even approach R_w+C_{tr} 60.

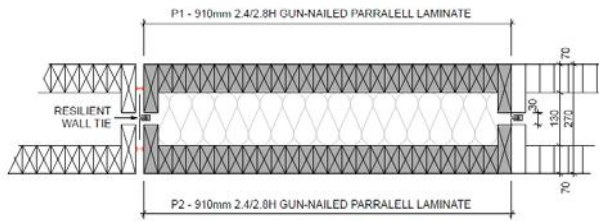


Figure 11: Plan of double skin acoustic GPL

5.9 THERMAL PERFORMANCE

Currie Hall is situated in the Perth suburb of Crawley. Perth and its urban surrounds are classified as Climate Zone 5 which refers to a warm temperate climate.

Table J1.5a Options for Each part of an External Wall that is Part of an Envelope of the BCA states that for Climate Zones 4, 5 and 6, external walls require a minimum total R-Value of 2.8. This can be reduced to R 2.3 if the density of the wall is 220 kg/m^2 or greater (clause - (a), (ii), (A)). According to BCA Table 2a Thermal Conductivity of Typical Wall, Roof/Ceiling and Floor Materials, a typical composite GPL wall incorporates external aluminium cladding ($2,680 \text{ kg/m}^3$ Surface Density of 10.72 kg/m^2), two leafs of GPL ($1,012 \text{ kg/m}^3 = 70.84 \text{ kg/m}^2$) and two internal layers of Gypsum ($1,160 \text{ kg/m}^3 = 22.8 \text{ kg/m}^2$). This equates to a cumulative Surface Density of 104.44 kg/m^2 . Being less than the 220 kg/m^2 required, the R 0.5 reduction would not apply. Notwithstanding this, a double leaf GPL wall's Total R-Value is estimated to be R 3.81 which easily meets the required R 2.6 minimum. The following table shows the accumulated materials used in an

external, aluminium clad GPL wall composite with their respective R-Values.

Item	Description	R-Value
1	Outdoor air film (t m/s)	0.04
2	4mm Alucabond Cladding	0.01
3	20mm airspace	0.17
4	70mm Radiata Pine solid panel	0.51
5	50mm Insulation	2.5
6	70mm Radiata pine solid panel	0.51
7	Plaster Board (13mm Gypsum)	0.07
TOTAL		3.81

Figure 12: Estimated double leaf GPL Total R-Value

5.10 INSECT RESISTANCE

Untreated softwood timber in Australia is vulnerable to attack from termites or 'white ants' and the European House Borer. The use of treated timber in conjunction with the judicious application of other preventative measures such as the inclusion of physical barriers into the structure and ensuring moisture cannot penetrate the structure, are part of well recognized and effective management strategies. To protect against potential insect attack, the GPL panels designed for Currie Hall feature readily available 'Blue Pine', a treated timber using an organic compound based on pyrethroids (found naturally in chrysanthemum daisies). This treatment accords with AS/NZS 1604.1: 2002 using Tanalith T (H2 Blue) for hazard category H2. This 'off the shelf approach' is cost effective and in keeping with the aim of utilising as many locally available materials and skills as possible.

5.11 JUNCTIONS AND FIXINGS

All junctions utilise a combination of commercially available off-the-shelf steel brackets, hot dipped galvanised gun driven nails and rib head, hot dipped galvanised or Climaseal® 3 coated screws. All bolts, anchors, nuts and washers are hot dipped galvanised Isometric Hexagonal mild steel Grade 4.6 complying to AS/NZS 1111 and AS/NZS 1112. All nuts or bolts that bear directly against timber have a washer to spread the contact load.

Fixing brackets are a combination of MiTek Multigrip timber framing anchors and Rothoblass WZU Angle Bracket 15550. The Multigrip brackets fix each individual panel to the continuous base and top plates. The WZU brackets fix at each end of the completed wall through the base plate into the structural substrate acting as hold down brackets.

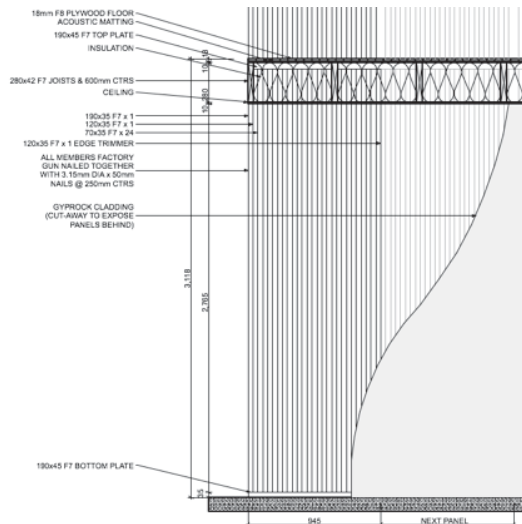


Figure 13: Typical Wall Section

5.12 CONSTRUCTION SEQUENCE

The following construction sequence outlines the typical panel erection process for Currie Hall. It assumes a standard engineered ground floor slab has been poured and that all suspended floors are standard timber joists with structural timber flooring. This process has been developed in conjunction with MLB Consulting Engineers.

- Ground level concrete slab is cast
- 190x35 wall bottom plate anchored to the slab using HILTI injection anchors at approximately 2m centres. Fasten to anchors using nut and washers to the bottom plate. Anchors at the end of each wall will also secure WZU hold down brackets.
- Tilt ground floor panels into position on top of the base plate starting at one end of the wall. Fix the first panel to the HILTI tie-down anchor using the WZU bracket. Fix the Multigrip bracket to the centre of the panel into the base plate.
- Position the second panel next to the first panel and gun nail through the first panel's 120x35 end trimmer into the second panel's 190x35 member. Fit the Multigrip bracket into the base plate.
- Repeat the above process until the final panel is in place to make up the entire wall element. Gun-nail through the last panel's 120x35 end trimmer into the 190x35 end board. Fix a WZU bracket to the end board with a HILTI anchor.
- Repeat process for all ground floor walls then fix 190x35 top plate along all walls with Multigrip anchors.
- At the end of each wall, provide through bolts to act as tie downs for the wall panels on the floor above. Position WZU angle brackets on the top plate and tighten through bolts.
- Fasten all walls with double GPL skins to their respective wall segments via the 120x35 trimmers using 10 gauge countersunk, ribbed head wood screws.
- Position floor joists using MiTek joist hangers and fit plywood floor panelling.

- Install floor panelling and commence positioning the first wall panel segment for the second storey over the adjacent first storey wall plate below and fasten with WZU bracket on the 190x35 member. Fit Multigrip bracket and proceed to fit all wall segments as per process described above.
- Proceed to lock up and fit-out.

5.13 CURRIE HALL BUILD COSTS

Five building companies submitted tenders which averaged \$2,930,709. The winning tender was \$2,940,100 which equates to \$3,565/m². For reference, the Davis Langdon building rates, as published in the Australian Institute of Architects 2010 3rd edition of *The Architect* state that medium rise apartments range from \$2,750/m² to \$3,250 m². It is assumed that all costs other than footings, walls and upper floor structure will be the same between both versions of Currie Hall.

Each tenderer supplied an itemised cost schedule and the masonry and block work ranged from \$260,476 to \$280,000 with an average of \$268,899. The winning tenderer's masonry and block work was \$277,740.

Excluding windows, each floor contains approximately 107m³ of masonry and block work, totalling 322m³ across all three levels. Based on the average tender price for the masonry and block work as outlined above, this equates to \$835/m³. The actual tender cost equals \$862/m³.

5.14 REDESIGNED CURRIE HALL BUILD COST ESTIMATES

The redesigned Currie Hall's total volume of wall using GPL panels is only 7m³ less than the actual Currie Hall (322 m³) at 315m³. The ground floor contains 94.9m³ of double leaf wall, the first floor has 110m³ of double leaf wall and the top floor has 71m³ of double leaf and 39m³ of single leaf wall.

Utilising costs provided by Wespine and Timbercheck Truss and Frame Manufacturer, the following calculations are intended to provide an indication of probable cost for the production and installation of the timber panels.

The supply cost estimates for the provision of Radiata Pine as Dry Dressed Sawn (DDS) and Dry Rough Sawn (DRS) ex Wespine's Dardanup mill, including Blue Pine treatment is (excludes the Australian 10% Goods and Services Tax (GST):

- DDS MGP10 timber - \$500/m³ x 315m³ = \$157,500.
- DRS ungraded timber - \$350/m³ x 315m³ = \$110,250.
- Transport costs to Perth from Dardanup equates @ \$15/m³ x 315 = \$4,725.

The panel fabrication costs have been calculated, excluding the initial set up of a jig on a flat bed table and the creation of the necessary shop drawings, to equate \$105 per hour for three semi skilled workmen and gun nail hardware. Based on the prototype build time, a fabrication time of 20 minutes per panel is assumed. Over a 7 hour day this equals 21 panels per day,

The redesigned Currie Hall has 522 panels. At 21 panels per day, this equates to 24 days fabrication or about five weeks at a total cost of \$18,375.

The combined timber supply, panel fabrication and transport costs plus 20% typical builders' margin and the inclusion of the 10% GST using DDS timber equates to \$175,875 + \$35,175 (builders' margin) = \$211,050 + 10% (GST) = \$232,155.

Using DRS equates to \$128,635 + \$25,725 = \$154,350 + 10% (GST) = \$169,785.

These figures reflect the accumulated cost of supply to the building site. Without precedent, it is difficult to calculate the onsite assembly time, but it could be assumed that it would be relatively fast compared to the laying of brickwork. According to the proposed Currie Hall building program 12 weeks had been allowed for laying and cleaning of the bricks. As GPL panels are prefabricated, actual onsite build should be considerably less, probably in the order of two weeks including the progressive installation of the upper floors' structure if they were prefabricated floor trusses. Assuming the onsite work would require three semi skilled workmen, (two fixing, one operating a light crane), the onsite cost would equate to \$9,702 at \$35 per hour per workman including builders' margin and GST.

The supply and installation of the panels would potentially range from \$241,857 (\$463/panel [averaged between double and single skin]) for MGP10 DDS panels to \$179,487 (\$343/panel [averaged between double and single skin]) for DRS ungraded panels. These figures reflect a reduction in cost over brickwork of \$35,883 and \$98,253 respectively. Further to this, a reduction in other expenditure items could be expected as follows:

- Smaller footing requirements. Radiata Pine (506kg/m³) weighs nearly three times less than masonry (1430 kg/m³).
- Hardwall internal linings are generally less expensive than render.
- Reduction in scaffolding costs due to majority internal build processes.

Additional cost considerations over masonry:

- External cladding layer, sarking and associated flashing. Had the original Currie Hall been rendered, as is often the case in buildings of this nature, then these cost would likely be negated.
- Insulation in the majority of walls fulfilling the role of acoustic and thermal insulation.

5.15 EXPECTED MAINTENANCE

GPL buildings should withstand typical wear and tear issues comparable to any other modern structure over the building's expected life span. Moisture exclusion is paramount and regular inspections of external water proofing elements and internal plumbing fixtures and fittings will be a significant factor in retaining structural integrity. Periodic white ant inspections and the provision of an effective chemical barrier in line with

standard practise for timber buildings will also be a key element of any preventative maintenance regime.

5.16 TRUSS AND FRAME FABRICATORS V AUTOMATED SAWMILL MANUFACTURE

The cost example given in Section 5.14 is based on the GPL panels being fabricated in an existing timber truss and frame manufacturer's facility. This method of manufacture, while relatively straight forward, could be greatly improved upon through the incorporation of panel prefabrication into a sawmilling facility via automated processes, as has become common in Scandinavia and central Europe.

5.17 PANEL TRANSPORT - ROAD AND RAIL

In contrast to both CLT panels and precast concrete, GPL panels are considerably smaller. Load arrangements on a semi trailer or rail car could easily accommodate the 2400/2800 x 945 dimensions of a standard GPL panel. A typical flat bed semi trailer can only carry one or two precast concrete panels because of their weight. As already demonstrated, GPL panels weigh significantly less than concrete. For example, a 100mm thick, 2.4m x 12m precast concrete panel might weigh as much as 6.9 tonnes, the comparable GPL wall, made up of 13 panels only weighs 1.4 tonne.

5.18 NAIL LAMINATED TIMBER AND ISSUES EFFECTING DECONSTRUCTION

As with gang nail trusses and walls frames, the use of gun nailing as a method of fixing GPL panels together could cause difficulty at the end of the building's life. Building material re-use regimes that take advantage of the panelised nature of GPL would be more appropriate than attempting to disassemble the panels into their most basic components. If the intended re-use did not require panel deconstruction down to a stick-by-stick basis, then the panels, subject to structural inspection, could be re used in the construction of a new building. If design for disassembly were to be a feature of a building, then substituting the panel's fixing method through the 120x35 end trimmers from gun nailing to wood screws would be required.

5.19 ISSUES FACING SOLID TIMBER CONSTRUCTION IN AUSTRALIA.

Residential construction techniques in Australia have developed and been informed according to, but not limited by, climate, available building materials and external influences such as building techniques imported by successive migration waves. On the eastern coast, timber frame and brick veneer have emerged as the dominant method of residential construction, while on the west coast, mainly in Perth, double brick is firmly established. Commercial construction is less governed by the above factors, resulting in a more homogeneous spread of construction techniques that have responded to internal developments in construction technologies. Typically, steel frame, precast or in-situ concrete and masonry or a combination of all are used.

The uptake of solid timber construction will be governed by many of the same factors that have influenced the

acceptance of previously unknown construction materials entering into the Australian construction sector. Cost will be a significant influence that will inform its ability to compete. Solid timber construction does have precedence in Australia's early history, but these methods were quickly overtaken, first by timber frame, then progressively by stone and masonry. The recent emergence of an increase in environmental consciousness has the potential to differentiate timber from other building materials. All construction materials are increasingly becoming subject to a certain amount of 'green washing', but few can match sustainably managed timber or plantation timber's environmental sustainability claims.

5.20 BESPOKE AND SCULPTURAL DESIGN OPPORTUNITIES

Planar building elements have the potential to create unique and interesting architectural forms. Timber also is unique in its ability to be worked and sculptured. It is therefore reasonable to assume that solid timber planar elements will be used to craft bespoke architectural designs and sculptural creations.

An architectural example of this is the London architectural practice, dRMM's *MK40 Tower*, winner of the 2008 Local Authority Building Control (LABC) Built in Quality – National Awards for Best Structural Project in England and Wales.

Another example is *The Termite Pavilion* by Softroom Architects. Here, CLT is layered to create a larger than life sculptural form that imitates a termite mound's interplay between solid and void.

As with CLT, GPL also has the potential to lend itself to folded plate structures. In Switzerland, architect, Dr Hani Buri, in conjunction with architect and engineer Professor Yves Weinand from Laboratory for Timber Constructions – IBOIS, authored a paper entitled, *ORIGAMI – Folded Plate Structures*. Here they explore origami pleating techniques to inform folded plate forms using CLT.



Figure 14: *MK40 Tower* (images: drmm.co.uk/projects/mk40-tower/ (above), *the Termite*

Pavilion (images: klhuk.com) (middle). *Folded plate chapel in Lausanne* (image: Hani Buri)

6 FURTHER RESEARCH

Suggested areas for further research are:

- GPL climatic response
- Provisions for use in earthquake prone areas
- Detailed production and construction cost
- Marketing and public perceptions
- Production transition from GPL to CLT
- Improving acoustic performance
- Improving structural performance through web and flange arrangements

7 CONCLUSIONS

Australia is significantly behind Sweden in developing its engineered timber building solutions, but signs are emerging of interest in the uptake of these technologies along with increased awareness in timber as an alternative to steel and concrete. Inclusion of new engineered timber standards in the National Construction Code as part of the Deemed-to-Satisfy provisions will help facilitate its acceptance. Demonstration of cost effective methods of manufacture and installation will also improve their acceptance amongst architects, engineers and developers.

ACKNOWLEDGEMENTS

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APPENDIX F - WESPINE KILN CONTROL FACILITY

This project is the first structure to be designed and built as a direct result of the work undertaken in this thesis. The author was commissioned by Wespine to further develop the gun nail lamination concept in conjunction with MLB Consulting Engineers as a two ply cross laminated variant of GPLT. The building was constructed under the supervision of local builder, Mr Paul Godsell. The panels were manufactured by two carpenters at the Wespine sawmill over a three day period using a similar jig and hand held nail gun as the one used in the manufacture of the panels for the cube structure. The panels were erected in one day with the entire build process taking two months.

"Not all those who wander are lost."

J.R.R. Tolkien, *The Fellowship of the Ring*