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Transition strategies: Accelerating social acceptance and removing the barriers to prefabricated multi-storey timber urban infill developments in Australia using CLT construction systems.

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Transition strategies: Accelerating social acceptance and removing the barriers to prefabricated multi-storey timber urban infill developments in Australia using CLT construction systems.

Prepared for

Forest & Wood Products Australia

by

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Foreword: Setting the Scene

Wood works in the city

Professor Steffen Lehmann

Director, sd+b Research Centre, UniSA

Buildings should be like trees and cities like forests

Wood's technical and botanical history reflects the history of civilisation itself. Along with our historical, poetic and emotional connections to wood, as a construction material it offers several important environmental benefits. It is renewable; it stores carbon that has been sequestered from carbon dioxide in the atmosphere; it can be regrown; it provides excellent opportunities for re-use; and, when harvested from certified sustainable forestry and properly recycled, it can serve as a carbon-neutral source of energy.

'Timber' is wood that has been cut for use as a building material (the words 'wood' and 'timber' are often used interchangeably). Timber plays an important role in the debate about how our cities should evolve to accommodate what the Australian government hopes will be an increasing population in coming years—without irretrievably damaging the environment.

Arthur Lyons noted that, 'Timber, arguably the original building material, retains its prime importance within the construction industry because of its versatility, diversity and aesthetic properties' (Lyons, 2012, p. 105). One cubic metre of wood stores around one ton of CO_2, making timber the only construction material that can impact positively on the environment. Generally, timber buildings require less primary energy consumption and have a lower Global Warming Potential (GWP) than concrete or steel buildings. The difference between concrete/steel constructions and timber buildings' GWP can be 25 per cent or more.

Gerhard Wegener and his colleagues noted that 'the energy budgets of products and buildings made of wood show that they may use less energy over their total life cycle (manufacture, use, maintenance and disposal) than can be recovered from the waste products of their production and from their recycling potential at the end of their life cycle: they are energy-positive. No other construction material is so comprehensively energy-efficient and therefore climate effective as wood' (Wegener, Pahler and Tratzmiller, 2010, p. 4).

Just think of the many ecosystem services a forest provides! Every single tree gives us many essential benefits. Besides its aesthetic and emotional value—for me, there is something deeply satisfying about just seeing trees— a forest is the 'engine of nature', operating on a closed-loop metabolism, something we should aspire to in our urban design and architecture. Ideally, our buildings should be like trees, and our cities like forests.

Material culture: material-generated craftsmanship and design

'Material', in architecture, is the means of implementation and of expression.

Working with wood needs accuracy and forethought. Traditional wooden construction is extremely time- and material-consuming, and requires high levels of precision and craftsmanship. While the results can be mind-buzzing—for instance, traditional Japanese wooden architecture that has stood the test of time—today the process of handcrafting each wooden beam is simply too labour intensive. With an aging workforce, automation of the production process and using new, engineered-timber systems are essential to continuing and reinvigorating the tradition of timber construction.

As a sustainable and ecological material, wood has great potential to be an alternative construction material to concrete in urban areas, including for urban infill developments where there is little space to store materials on site. This efficient and sustainable prefabricated construction system could be used to build infill housing units, enabling us to achieve the Australian government's target of one million new homes by 2020.

We are at the beginning of a substantial ecological revolution leading to a new material culture where the complex interaction between, and performance of, form, structure and material can be designed, engineered and manufactured with specific performance characteristics. Engineered-timber systems will profoundly re-inform our material strategies in architectural engineering and construction in the next decade.

Is the 21st century the 'Wood Age'?

Just as glass, concrete, steel and plastics, each in turn, had an impact on the architecture of the 19th and 20th centuries, wood is set to do the same in the 21st century. This traditional material has re-emerged as the building material of the future, and we are at the start of a 'Wood Age'. Our ever-evolving relationship to this natural, regrowing material allows us to revisit the amazing qualities of wood, recognising that it provides superior insulation and easy handling.

The benefits of building with wood

Trees and forests are both a source of wood products and carbon sinks: grown by the sun, timber is materialised solar energy and an efficient CO_2 accumulator. Everything begins with the forest that provides the material and is a decisive climate factor. This is why wood needs to be sourced in a sustainable way from well-managed forests. Residential building construction with wood is now changing, focusing on green supply chains and resource-optimised engineered-wood products. Great emphasis is now placed on timber certification schemes, which track the whole supply chain from forest to site to recycling facility, ensuring the accuracy of environmental claims being made (such as FSC or PEFC schemes).

But there are more than technical benefits from building with wood. Cross-lam panels are well suited to internally exposed applications. Recent Canadian research established a direct link between wood and human health, and the restorative effect of using wood surfaces in buildings.[12] Architects have long known that architecturally exposed wood can have a similar effect on interior spaces, and that the experience of warm wood surfaces indoors can reduce stress or depression and promote health in a buildings' occupants

Conclusion

Because of the renaissance of wood in construction, we will need to plant more trees (a good thing in itself) and carbon accounting will further support this move. Finally, using engineered solid wood-panel systems on an urban scale means that we will have faster, safer construction and lighter, better-performing and more flexible buildings in the city. It looks like timber—the traditional construction material of the past—will become the construction material for the future. The 21st century might just well become the 'Wood Age'.

The aim is to evolve systems and designs in timber to tackle the significant negative environmental impact of buildings through innovative uses of wood technology that offer new ways of constructing efficient and affordable structures that demand less of the environment while maintaining functionality and aesthetic appeal.

The sd+b Research Centre explores a wide range of topics around consumption, material flows and solutions for better management of resources in regard to low carbon urban development. The Centre is a platform for the exchange of knowledge and ideas in these areas, bringing together representatives from academia with industry, government and local communities. Behaviour change has frequently been listed as the number one hurdle to reducing consumption towards a more energy- and material-efficient, low-carbon future. If we could only plan better cities and design better buildings and products that needed less energy, water, materials and other resources, thus generating less waste, and facilitating behaviour change simply through their design.

It is clear that things are going to change and we must make every effort to future-proof the built environment by designing more resilient urban systems. We will increasingly learn from nature's complex ecosystems and natural ordering principles, in redefining an industrial ecology that changes the way we produce and re-use products. We are about to embark on nothing less than a silent green revolution that has already started to transform our society, economy, energy and transport systems and the way we design, build, operate, renew and re-use cities, buildings and products. As sustainability activist Paul Gilding predicts, 'we will break our addiction to growth, accept that more stuff is not making our lives better and focus instead on what does' (Gilding, 2011; p.16).

Improving collaboration across the sector is critical, as is guiding research agendas and legislation. At the same time it is important to educate communities to encourage a groundswell of support for this type of construction and hence influence the developers to build what people want. Our researchers are collaborating with others to develop a responsive plan for the transformation of Australian cities as an important part of the solution. These efforts must support long-term planning and research in line with agreed national priorities, for holistic whole-of-lifecycle approaches. We therefore facilitate, support and continually evolve interdisciplinary, collaborative research and development capability in architectural and urban design and in sustainability knowledge for resilient urban systems and construction methods (Lehmann, 2012a, p. 4).

We are grateful for the ongoing interest and support of our work. The Research Centre's engagement with industry, government, community and other institutions supports a multidisciplinary and integrated approach to research and systems thinking. Such partnerships ensure that sd+b Centre's research has a high degree of relevance and societal benefit.

Executive Summary

This report was commissioned to review and formulate strategies for the accelerated uptake and social acceptance of living in multi-storey cross-laminated timber (CLT)-constructed buildings in infill developments to: remove cultural barriers, meet the sustainability expectations of potential buyers and obtain a better understanding of how we can facilitate the rapid introduction of this innovative construction technology in Australia.

An extensive review of literature within the field was conducted to gather an overview of the barriers that inhibit consumers, governments and industry in the uptake and acceptance of CLT-constructed buildings for infill development. Data was collected on CLT buildings worldwide, to build a comprehensive picture of multi-storey timber buildings using CLT-construction systems.

Throughout the research it was found that people do not necessarily make decisions in a logical way but, instead, behaviour is frequently governed by instinct, emotion, past events, current sociocultural beliefs and values, and one's peers of social ground. Changing housing-consumer behaviour is therefore a complicated process that requires in-depth knowledge of the way consumer attitudes are shaped and how their behaviours can most closely replicate these values. Therefore a range of information strategies, which provide knowledge, strengthen social values towards pro-environmental behaviours and strengthen social norms, should be employed. Their correlation to behaviour is strengthened when structural conditions provide easy pathways (access, affordability, varied options and so on). It was found that providing optimal structural factors is highly dependent on a range of factors reliant on external parties, such as government, industry and manufacturers. Living in multi-storey CLT-constructed buildings in infill developments is contingent on operating competitively with options such as living in the outer-suburbs or concrete-constructed buildings.

It was also found that barriers exist not only on a consumer level. The Australian construction industry and housing market present a range of barriers to the rapid uptake of CLT construction and multi-storey apartment infill living. For instance, the Grattan Institute cites cashflow as a barrier inhibiting developers from engaging in innovative projects. Pre-sale commitments of up to 50–60% are often needed for banks to finance projects, leading developers to stick with tried-and-tested building systems to ensure solid returns (Kelly, Weidmann and Walsh, 2011, p. 30). Costs associated with buildings four storeys and over (classified as commercial projects) discourage urban infill development, as they incur additional construction costs due to scaffolding, cranes and additional wages for building and construction workers (Kelly, Weidmann and Walsh, 2011, p. 34).

The recommendations at the end of this report therefore suggest employing a combination of both structural and information strategies when targeting consumers. Effective marketing techniques will be a large component of both these strategies. In-depth research on behaviour should be conducted in order to appeal to various market segments to facilitate and accelerate the move towards more inner-city housing that is fully embraced by residents in Australia. The integration of sustainability in housing, combined with holistic problem solving, is of crucial importance for the development and redevelopment of all urban areas. Key players in government and industry need to lead the way for innovative construction in CLT high-rise buildings.

Table of Contents

1. Introduction

Current models of urbanisation are based on the notion of continual urban growth. Australian's have few choices regarding types of dwelling and are slow to embrace urban infill apartment living. This unsustainable model destroys the ecosystem. This research seeks to influence the building and construction industry's systems and practices to respond innovatively to increased demand for inner-city housing and the need to build with low carbon systems minimising waste.

This report delivers strategies for influencing opinion formation and methods for better reconciling government targets for urban infill, CO_2 reductions, and community concerns.

At present half of the world's population lives in urban areas and all regions will be predominantly urban by 2050 (United Nations 2008). The urban areas of the world are expected to absorb all the population growth expected over the next four decades while at the same time drawing in some of the rural population. By 2050, more than 90% of Australia's population will reside in urban areas. The Australian Government's discussion paper *'Our Cities'* states that three-quarters of Australians currently live in our 18 major cities with over 100,000 people (Commonwealth of Australia, 2010). The discussion paper also notes the need for Australian cities to develop to accommodate growth and at the same time adapt to climate change, focusing on better design and management of urban systems to reduce the economic and environmental costs of current urban models which are contributing to high carbon emissions.

State governments in Australia are variously producing planning strategies which require a high percentage of new housing to be in existing urban areas (in-fill development) to accommodate an increase in urban populations in its main capital cities.

Australian cities Infill development targets
(Rowley and Phibbs, 2012, p. 6)

City	Strategic planning document	Timeframe	Total number of dwellings	Proportion from infill development
Sydney	*City of Cities: A Plan for Sydney's Future*	2005–31	640,000	60–70
Melbourne	*Melbourne 2030: A Planning Update—*	2009–30	600,000	53
South-East Queensland	*South East Queensland (SEQ)Regional Plan*	2009–31	754,000	50
Perth	*Directions 2031 Spatial Framework for Perth and Peel*	2009–31	328,000	47
Adelaide	*The 30-Year Plan for Greater Adelaide*	2010–40	258,000	50–70

These planning strategies have led to the Australian government through the Council of Australian Governments (COAG) taking a much greater interest in the mechanisms whereby housing can be provided that is affordable as well as sustainable.

Concerns remain about the traditional approach of the housing and construction industry producing conventional solutions rather than embracing innovative solutions that maximise the use of low carbon materials, allow rapid infill development on difficult sites, minimise construction waste and provide comfortable centrally located housing solutions. A recent report by Thinker in Residence, Professor Laura Lee, for the South Australian Government's Integrated Design Commission (Lee, 2011) recommends 'Manufactured assemblies for the mass customisation of buildings' which require 'expertise in the design and manufacturing of 'green' assemblies. Such solutions are said to provide an opportunity for 'transforming non-viable manufacturing industries into eco-innovation industries for diverse locations, populations and purposes in South Australia'.

Urban design and low carbon technologies have a key role in shaping the future of our cities. Planning strategies for Australian cities require a high percentage of new housing to be in existing urban areas. The Australian government through the Council of Australian Governments (COAG) is taking a much greater interest in the mechanisms whereby housing can be provided that is sustainable, focussing on its affordability, accessibility to services, and carbon emissions during construction and occupation. In Australia, the residential and commercial building sectors produce 23 per cent of the nation's GHG emissions, indirectly, as a result of materials used in construction, waste disposal, material inefficiencies and ongoing energy use (Green Building Council Australia, 2011). In addition the increasing cost of energy in Australia is driving the property and construction sector to look toward more energy-efficient products (Green Building Council Australia, 2011, pp. 4-5).

A study by the ZWSA Research Centre for Sustainable Design and Behaviour at the University of South Australia (Lehmann & Hamilton, 2011) was undertaken in consultation with nine Partner Organisations from industry and government. The study identified key factors preventing or enabling the adoption of solid engineered wood systems for prefabrication for infill development in Australia, reviewed literature relevant to design and construction of engineered wood buildings, and set priority areas for research. The key factors that affect the uptake for engineered wood product and investment certainty in Australia are:

- The social and cultural barriers inhibiting the acceptance of prefabricated engineered timber for multi-storey apartment living
- Australian industry capacity to supply prefabricated engineered timber utilising rapid assembly systems and digital design resulting in medium density (infill) development becoming more cost-competitive with greenfield development
- The contribution that digital design for disassembly, BIM, CNC processes and prefabricated engineered wood buildings can make toward sustainability objectives of urban development and the building and construction industry
- Lack of data on the cost of design, construction, operations and maintenance of prefabricated engineered wood buildings.
- Building code standards addressing acoustics, durability and fire, quality control, planning rules and urban design guidelines for prefabricated engineered wood buildings.

The production of concrete, aluminium and steel are one-way energy intensive processes that release large amounts of greenhouse gases (GHG) into the atmosphere. The carbon dioxide equivalent (CO_2-e) emissions associated with the production of these materials are progressively being documented and included in Australian building material life cycle inventories (e.g. SimaPro, AusLCI). Such databases are used to provide the necessary scientific analysis to underpin possible future Government policy initiatives (DCCEE 2010). The Australian Government's carbon pricing legislation will lead to an increased focus on the carbon emissions related to building materials. An expected outcome of such legislation is that industry will innovate, developing lower carbon alternatives to current practices and systems to minimise the carbon cost, investing in research to develop ideas into demonstration projects which can be studied for their performance in the Australian context.

The cost of energy from traditional energy sources such as coal in Australia is already increasing, a trend expected to continue into the future as carbon pricing mechanisms are passed through to consumers. These cost increases together with increasingly stringent energy efficiency standards for new buildings are also driving the property and construction sector to look toward new models of delivering more energy-efficient products using energy efficient systems that will combat rising costs of construction (Green Building Council Australia 2011). Through the growth and processing of each cubic metre of timber, research in Australia reports that 0.83t of carbon dioxide is stored (NSW Department of Primary Industries 2008). Engineers have calculated that by using timber structures, a 55 per cent reduction in carbon dioxide emissions can be achieved, compared to conventional construction methods in steel and concrete (Head 2008). These factors provide an ideal opportunity for evaluating the potential for using timber structural components to deliver a lower carbon alternative housing product for the urban infill development proposed in Australia's urban centres.

The shortage of affordable housing in Australian cities has emerged as a major concern. Housing has environmental impacts as well as economic implications and social dimensions. Sustainable housing tends to be unaffordable because of the dual costs of making such housing environmentally sound and the high price of inner-city land (Lehmann and Fitzgerald, in-press 2013, p. 3). The Australian lifestyle has evolved around the affordability of large bungalow-style houses with a garden in relatively functional suburbs for little money compared to Europe. In addition, the need to heat living space in Northern Europe has historically contributed to smaller dwellings as heating larger spaces is prohibitively expensive (Lehmann and Fitzgerald, in-press 2013, p. 23). It is essential to encourage new ideas about lifestyle that break with conventions, to question the 'out dated American/Australian dream' of living in a suburban one-storey house and test preconceptions and reframe our notions of urban lifestyle in post-industrial conditions (Lehmann and Fitzgerald, in-press 2013, p. 22).

The resistance to timber-built houses in Australia originates in a series of prejudices. Timber buildings are seen as less valuable compared to 'solid' construction in concrete or masonry, including perceptions of status and entrenched value systems (Lehmann and Fitzgerald, in-press 2013, p. 22).

Barriers to CLT constructions are perceived disadvantages of wood as a building material. People are afraid that the product may require higher maintenance and could lack durability, usual concerns include fire, acoustics, moisture and vermin protection and people believe wood products require protection from insects such as termites or fungi and it could be exposed to decay or rot (Lehmann and Fitzgerald, in-press 2013, p. 6).

For industry acceptance of prefabricated engineered wood construction in Australia, cultural, behavioural, organisational and policy changes are needed. Cultural shifts are essential for achieving project outcomes, while social acceptance also plays a vital role when implementing technological innovations (Pullen, 2010).

Managing change is a process of initiating and responding to change, and requires tools for implementing the change process and techniques to manage the cultural and human dimensions of the process (Davis and Dart, 2005).

To transform design and construction practice “requires a new understanding of our notion of ‘good’ residential design. Users’ expectations and needs frequently focus on: useability, affordability, comfort, cultural values, energy efficiency (and thereby cost reduction gains) and aspirational or ‘status’ goals’ (Lehmann & Fitzgerald, 2012, p.1). Much public policy work has been done in Australia to broaden the scope of what constitutes ‘good’ residential and urban design. An excellent example of which is the Green Star – Communities (pilot) rating tool developed by the Green Building Council Australia (GBCA) and launched in June 2012, is one of Australia’s first fully independent, national sustainability rating tools for communities. “This rating tool has the potential to support the Australian Governments National Urban Policy by providing nationally consistent benchmarks and deliverable outcomes at a project level … [allocating] additional recognition to those developments on infill sites where connection to existing utilities exist.” This kind of public policy initiative is indicative of the scale at which the FWPA should consider if it is to influence behavioural change. The rating tools ‘Liveability Indicators’ address both the material and psychological needs of residents to ensure that developments are designed so people may live and work in a community with a reduced ecological footprint and access well designed and well-connected places and spaces close to home and to work.

1.1 Background of the contemporary forestry and wood products industry

Australia produced 5.4 million cubic metres of sawn timber in 2007-08, 4.3 million cubic metres of which was softwood timber, nearly all derived from logs harvested from plantations (ABS 2010). About 95% of the softwood plantations are *Pinus radiata* (radiata pine) and other introduced pines. According to the Australian Bureau of Statistics Year Book Australia, 2012, the 'proportion of plantations owned and by managed investment scheme investors decreased substantially in 2010 as many were taken over by timber companies and other private investors and some have been written- off following drought and recurring disease problems' (ABS 2012). From 1999 to 2008, the proportion of private plantations increased from 46% to 62%, while public plantation reduced from 46% to 33%. The other 5% were jointly owned at that time. Exports of sawn wood totalled 338 000 cubic metres (6.3% of production), while imports totalled 784,000 cubic metres (ABS 2010). Hence there was a net import of timber products through trade.

Forest and Wood Products Australia (FWPA) has developed research priorities and investment strategies to support the industry. The research priorities address five key areas: climate change; water use efficiency and water resource management; genetics and tree improvement; industry statistics; and increasing the use of wood products in residential construction. While each of these research priorities may ultimately influence the development of CLT supply in Australia, the focus on increasing wood products used in residential construction is most relevant to this report.

An investment strategy for FWPA to increase the use of wood in residential construction in Australia (Mitchell & Tucker 2011) cited work by Kapambwe et al. (2009) which states that the average volume of wood per residential construction decreased from 24m^3 to 14m^3 between 1945 and 2008, despite an increase in the average size of Australian houses. Mitchell and Tucker (2011) also cited a study by Low & Mahendrarajah (2010) which states that, in Australia, structural wood use in the 2008 – 2009 period dropped 17% and use of wood based panel was down 11%. Timber structures are experiencing increased competition from steel framing and tilt-up concrete construction systems.

Mitchell and Tucker (2011) advise that a 30% increase in the use of wood (by volume) is possible through the introduction of innovative timber products, noting also that a 30% increase in value of wood products used may also take place through adding value to wood products used. They noted drivers favouring an increase in wood products used in residential construction, including: increased waste disposal costs, sustainability requirements, future timber availability and carbon storage potential of timber. Among the drivers influencing waste disposal costs are actions to reduce waste on site. The prefabrication of timber structural systems provides minimal on site waste. Sustainability factors include lighter-weight components that have reduced density compared to concrete and bricks. FWPA are promoting the incorporation of full life-cycle assessment into building rating schemes which will then result in an increased awareness of environmental impacts of building materials and a reflection of environmental costs in price of materials, including costs related to carbon emissions.

A major research commitment by FWPA is the Structural Timber Innovation Company (STIC). STIC is funded by $5 million cash from the New Zealand Government and $5 million from the Australian and New Zealand timber industries. In Australia STIC involves researchers at University Technology Sydney (UTS) and is led by Keith Crews. The deliverables of UTS and STIC (in Australia) are new design guidelines for timber & timber concrete composite (TCC) floors, design "calculators", and timber knowledgeable graduates. Hence STIC are focusing on specific aspects of timber buildings such as floors.

Discussion with forest and wood products industry stakeholders revealed that, while engineered glue laminated timber (Glulam) and laminated veneer lumber (LVL) are both manufactured in Australia, a manufacturing facility for CLT has yet to be established commercially in Australia. A discussion with the Timber Development Association of New South Wales (TDA of NSW) (Andrew Dunn, Pers comm. 2011) revealed that one Tasmanian timber company had made CLT, although not commercially, while another timber company in Queensland manufactured CLT using Slash pine and Caribbean pine for structural testing at the University of Southern Queensland during 2010 (see Harch 2010; Turner 2010; Lehmann and Hamilton, 2011).

The proximity, to communities in SA and Victoria, of softwood plantations (*Pinus radiata*) in the Green Triangle in the south east of SA provides an ideal opportunity for the establishment of a facility to manufacture CLT products for use locally. Assessments conducted by various companies have been completed to determine the feasibility of producing CLT in Australia.

According to the Timber Development Association of NSW and Precision Wood Machining (based at Lonsdale, SA), there are few fabricators with experience of precision CNC cutting of engineered timber products in South Australia and none with experience of the scale of CLT panels. Timberbuilt Solutions in Victoria indicated the ability to precision cut Glulam for modular kit form projects with rapid on-site construction (Leon Quinn, pers comm). Current access to CLT is via a limited number of distributors.

Current access the CLT is via a limited number of distributors and while there is currently no manufacturing facility, mechanisms are in place whereby CLT panels can be supplied from Europe.

Market penetration potential

CLT construction has now been introduced in several European countries and in North America (Canada). In Canada, CLT was used as a demonstration in the iHouse constructed for the 2010 Winter Olympics and has been used in hybrid structures such as in the Earth Sciences Building at University of British Columbia. The recent successful CLT introduction in Canada indicates that a market penetration rate of 5% to 15% is realistic. (FPInnovations, 2011).

The situation in Austria is similar: Finish saw miller Stora Enso has one large CLT production facility in St Leonhard in Austria, and has recently built a second CLT plant in Austria in 2011, costing Euro23m. 'The European CLT market has been growing by almost 20% per year over the last decade, and we expect the demand for CLT-based solutions to continue increasing rapidly', said Hannu Kasurinen, executive vice-president of Stora Enso's wood products division. This new CLT plant has an annual production capacity of 63,500 m^3, employing 59 people.

1.2 Purpose

The aim of this research collaboration is to support the FWPA's leadership in sustainability and new trends in residential developments. Timber, arguably the original building material, retains its prime importance within the construction industry because of its versatility, diversity and aesthetic properties', notes Arthur Lyons (2010, p. 105). Our shared goal is to transform building industry systems and practices through the adoption of cross-laminated timber (CLT) construction systems as a low carbon innovative solution to meet demand for infill development in inner-city and inner suburban centres.

This report examines the social, cultural, behavioural and structural drivers that will help or hinder the transformations needed to ensure the rapid adoption of CLT in the Australian housing and construction market. We propose that once the key barriers have been identified and overcome, an increase in CLT construction in Australia can be expected.

This report reviews and formulates strategies to accelerate social acceptance of living in multi-storey CLT-constructed buildings in infill developments, addresses the cultural barriers and explores the type of buildings that would meet the expectations of potential buyers of these dwellings.

This report answers the following key research questions:

1. Increase usage of CLT construction: How can we rapidly introduce CLT construction technology to urban infill development in Australia's housing market, ensure its uptake, and remove cultural barriers?

2. Effective communication: What are the favourable factors that would change consumer values and behaviour towards sustainable products such as CLT?

3. Selling apartments in CLT buildings: What quantifiable social benefits result from living in CLT buildings compared to traditional steel, concrete and masonry for infill development (e.g. healthier environment, reduction of heating/cooling costs, social benefits, etc)?

4. **Transforming industry:** How can adoption the of this new, material-efficient, low carbon technology help make the Australian wood products and construction industry more competitive and environmentally sensitive?

The report has four inter-related themes:

(i) mapping of key CLT construction concepts for relevant cases, providing an evidence base for decision makers to better understand inter-connections;
(ii) investigating how CLT systems can best be applied to Australian urban infill, to ensure their broader social acceptance;
(iii) investigating design standards for CLT buildings that potential occupants / buyers of apartments find culturally acceptable
(iv) synthesising the above to develop pathways to a CLT construction system's suitable for Australian conditions.

1.3 Definitions

Throughout this report a number of terms are used which require definition. This section discusses the various definitions for each term and provides a definition which is then used for the remainder of the document. Other terms used generally are included in the Glossary at the end of this document.

Wood, timber and lumber

The following definitions from Dehne and Krueger (2006) apply in this report:

- **Wood:** the hard, fibrous, lignified substance lying under the bark of trees. It consists largely of cellulose and lignin. Wood is a natural material and is therefore irregular by nature.
- **Timber:** the wood of trees cut and prepared for use as building material (e.g. beams, posts).
- **Lumber:** timber cut into marketable boards, planks or other structural members, and which is of standard or specified length.

Cross-laminated timber

According to Australia's Timber Development Association of New South Wales (TDA of NSW 2011a), cross-laminated timber (CLT) is a structural timber product fabricated by bonding together timber boards with structural adhesives to produce a solid timber panel with each layer of the panel alternating between longitudinal and transverse lamellae.

In the United States of America (US), CLT is a prefabricated solid engineered wood product made of at least three orthogonally bonded layers of solid sawn timber, and may also be made of structural composite lumber (SCL) (ANSI/APA 2011).

The Timber Development Association of New South Wales (TDA of NSW 2011a) notes that CLT comes in 3, 5 or 7 layers but that the width, length and thickness of CLT panels may vary between CLT production companies. It should be noted that CLT is not the same as Glue Laminated Timber (Glulam or GLT), nor is it the same as Laminated Veneer Lumber (LVL), nor is it panels of thin layers of plywood, although it has been described as 'jumbo' plywood.

2. The CLT story - an innovative system of manufacture and construction

FPInnovations (2011) note that CLT was first developed in Austria and Germany, although other sources indicate the first appearance of CLT was in Switzerland in the 1970s (Edinburgh Napier University cited in Robertson 2011). The development of the highly engineered product now known as CLT was the result of a joint research project in Austria in the mid-1990s. This research project involved the wood products industry and universities. The green building movement in Europe has since driven further manufacturing and distribution efficiencies and product approvals for CLT.

The process of manufacture of CLT and construction is part of a cycle (see Figure 1) which starts at the forest and ends with either the landfill disposal/storage or burning of timber at end of useful life. For more information about the CLT manufacturing process see X-Lam (2011) and Brain (2011).

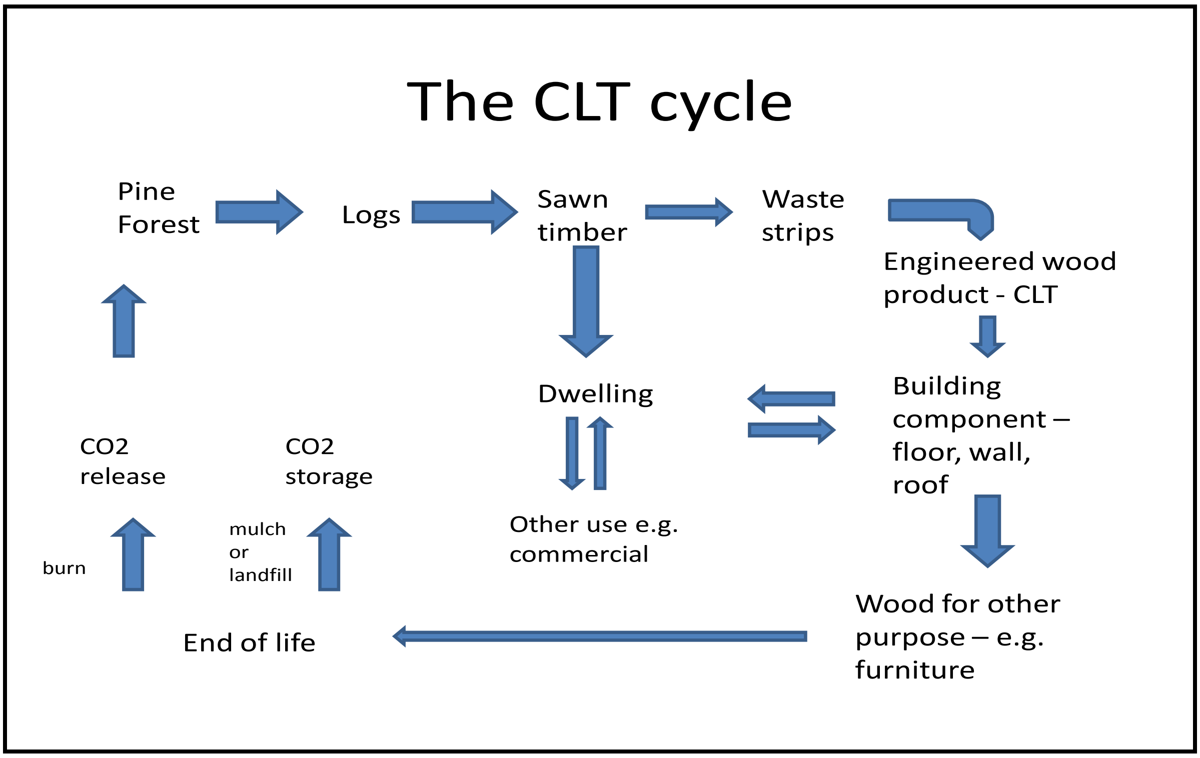

Figure 1: The lifecycle of the CLT product and storage or release of carbon

The European manufacturer KLH states that 'Cross-laminated timber (CLT) is produced from spruce strips that are stacked crosswise on top of each other and glued to each other with high pressing power to form large-format solid timber elements'. An example of the workflow of the manufacture, design and construction of a CLT building is depicted in Figure 2.

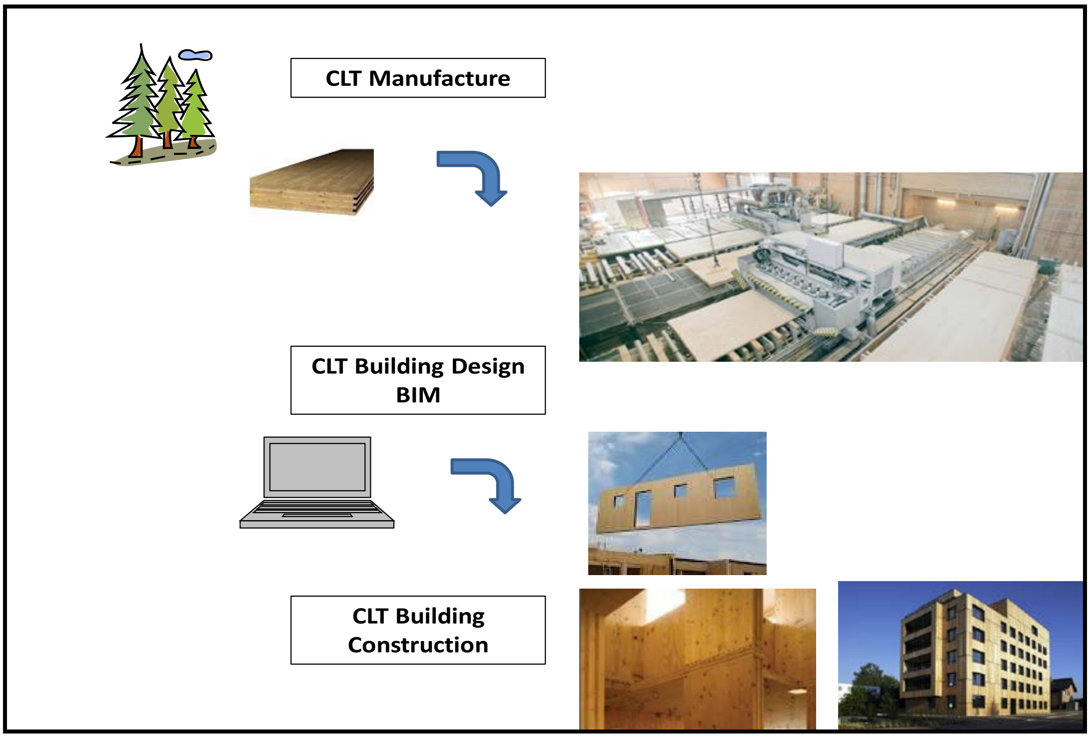

Figure 2: Example workflow for CLT building construction

2.1 Examples of buildings constructed using CLT

According to Lattke and Lehmann (2007), since the late-1990s, construction with CLT panels in Europe has resulted in some ground-breaking demonstration projects. They have analysed a number of these in detail (Lattke and Lehmann, 2007; Lehmann, 2010). A summary of some aspects of a selection of multi-storey CLT residential projects in Europe is presented in Table 1. six are discussed in more detail, here: Svartlamoen multi-apartment building in Trondheim, Norway; the Muehlweg project in Vienna, Austria; Holzhausen MFH in Steinhausen, Switzerland; Stadthaus multi-apartment building in Murray Grove, Hackney in London, UK; the eight-storey Bridport House building in Hackney, London, and the 'e3' multi-apartment building at 3 Esmarchstrasse, in Berlin Prenzlauer Berg.

CLT Building 1 Svartlamoen multi-apartment building in Trondheim, Norway, 2005 (Architects: Brendeland and Kristoffersen, Trondheim). This development consists of two buildings with an overall area of around 1000 square metres (sqm) (Lattke and Lehmann 2007). The main five-storey building, which measures 6 m x 22 m, also contains rooms that can be used commercially, and the four upper floors contain units of 120 sqm designed to accommodate 5 to 6 persons each. The entire construction was made out of solid CLT boards and clad with Norwegian larch. The untreated timber surfaces of the load-bearing elements are exposed on the inside (see Images in Figure 3). The use of prefabricated elements reduced total construction time significantly, to 9 months (about half the usual time). The efficient assembly of the timber elements allowed four workers to erect the main structure in just 10 working days. This project has provided student housing and was designed by two architects who were former students at the university in Trondheim. They entered the design in a competition set up by the city municipality, to draw on grants from the central government for sustainable and innovative buildings. The building was controversial and one of the architects (Brendeland) commented that ‘the day the Svartlamoen housing block was opened, concrete companies took out a full-page advert in the city newspaper showing a blazing timber building, a scare tactic focusing in on timber’s fire risks!’ (Fourth Door, 2010).

Figure 3 Images from Svartlamoen project, Norway – exterior and interior
(Source: Fourth Door, 2010)

CLT Building 2: Lattke and Lehmann (2007) describe the Am Muehlweg project designed by Hubert Riess, Dietrich/Untertrifaller, and the construction cooperative Hermann & Johannes Kaufmann architects. This building was an outcome of the 'Land Provision and Urban Renewal Fund' in Vienna, Austria, which invited tenders from developers for a construction project focusing on 'wood and mixed wood/concrete constructions'. One hundred public-sector apartments were to be built on each of three inter-connecting plots at the Muehlweg site, with the emphasis on the optimum exploitation of the ecological and economic benefits of timber and mixed constructions. Terraced houses and an L-shaped building surround an internal courtyard, creating a communal area. The three-storey superstructures made from prefabricated CLT panels built on top of the concrete base were constructed in 15 months. The four-storey buildings offer two different solutions. The north/south-oriented terraced concept, with its maisonettes, has a two-storey timber construction on the second floor erected on top of a ceiling of reinforced concrete. The three-storey superstructures made from pre-fabricated CLT elements are built on top of the concrete base of the east-west-oriented units (see Figure 4 for images of the project). The entire four storeys of the building are clad in larch. An obligatory fire protection belt was included in the design of the development.

Lattke and Lehmann (2007) noted that a major success of the project was the cooperative working relationships of planners and representatives of the public authorities, discussing and developing alternatives and sharing specific knowledge on timber construction.

Figure 4 Images from Muehlweg project, Austria – exterior following completion, during construction showing prefabrication panels and interior ready for occupation
(Source of images: http://www.trans-city.at/muehlweg.html)

CLT Building 3: The Holzhausen MFH in Steinhausen, Switzerland, designed by architects Scheitlin-Syfrig & Partner (in collaboration with manufacturer Holzbau Renggli AG), is Switzerland's first six-storey timber building (with a four-storey timber framed construction TFC on top of a concrete base). The project replaced an existing two-storey building and makes more intensive use of the 1600m² site area. The new fire protection standard in Switzerland, introduced in January 2005, permitted the construction of timber buildings of up to six storeys with a 60-minute fire-resistance capability. This is Switzerland's first six-storey timber building. Each floor accommodates two spacious apartments of 149 sqm and 166 sqm. Cedar wood, anthracite coloured windows, fibre cement cladding (produced by Eternit) and corrugated sheet panels on the balconies characterise the building's appearance (see Figure 5 for images of the project). The basement and ground floors are solid mineral constructions. From the first floor onwards only the central core, consisting of the staircase and the lift, are made from reinforced concrete, while the walls are a frame construction and the ceilings are acoustically decoupled, beamed constructions.

The timber-metal windows feature triple-glazing. The comfort ventilation system, with waste-heat recovery, reduces heat loss through ventilation, while, with correct usage by the inhabitants, an effective heat requirement ratio of just 20 kilowatt hours per square metre is achievable (Lattke and Lehmann 2007). A heat pump, with a geothermal probe, supports the heating and domestic warm water systems. Fine-tuning of individual measures meant that the development was able to surpass the criteria laid down by the stringent Swiss 'Minergy' standard.

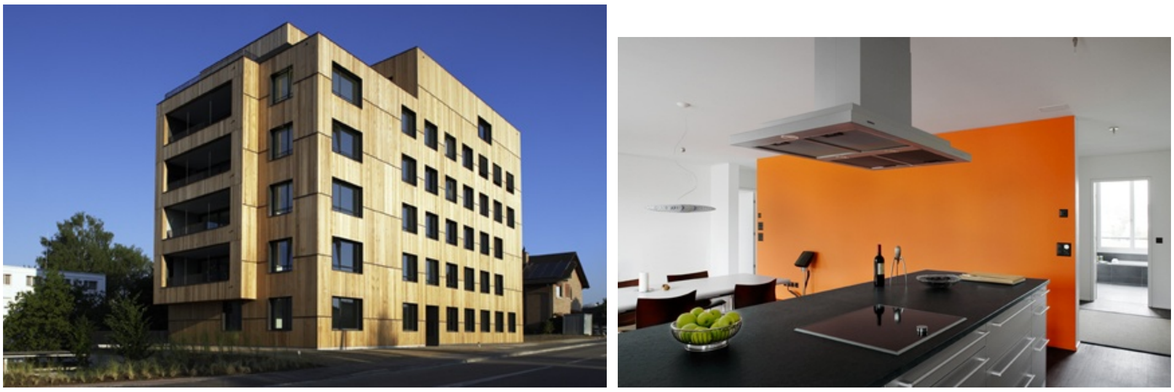

Figure 5 Images of Holzhausen MFH in Steinhausen, Switzerland – external and internal following second fix (Source of images: http://www.renggli-haus.ch/hausbau/referenzhaeuser/mehrfamilienhaus/steinhausen.html)

CLT Building 4: Stadthaus multi-apartment building in Murray Grove, Hackney, London, was designed by Waugh & Thistleton Architects with engineers Techniker Ltd. The 9 storey building is a project of Telford Homes and the Metropolitan Housing Association. There are 19 private for sale apartments, 10 social housing units and a residential housing office located in this building. The apartments are a mix of one, two and three bedroom accommodation. It is the tallest building of its kind yet to be built in the world (Wells 2011).

The site was confined but had access from two sides. After the ground floor was constructed the remaining construction was undertaken without a fixed crane in place, and each storey was able to be assembled in three days using four carpenters. The entire building process took 49 weeks with the construction of the 8 CLT storeys taking 12 weeks.

The CLT for walls and floors was sourced from Austria and constructed using the proprietary system of KLH UK Ltd. The CLT panels weighed a maximum of 15 tonnes and were limited by size for transport. The weight limit allowed use of a mobile crane. The rain screen and windows were added using an external scaffold. Images of the Stadthaus building are shown in Figure 6.

The foundations are bored, cast in situ concrete piles designed to accept the weight of a concrete framed building of similar size – a decision to ensure procurement alternatives (Wells 2011). The ground floor is cast in situ reinforced concrete framing. Wells (2011) notes that the lift core and stairwells are isolated from the surrounding core walls and perimeter, providing lateral stability. The building has been designed with redundancy - any single element can be removed without causing progressive collapse (Ward 2009).

The architect, Andrew Waugh stated that meeting building code requirements for fire was relatively straightforward, relying on the self-protecting properties of timber which retains its strength during fire for longer periods than steel or even concrete (Ward 2009; Waugh 2010).

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Figure 6 Images of Stadthaus, London, UK – following construction and during construction
(Source of images: http://www.e-architect.co.uk/images/jpgs/london/stadthaus_murray_grove_wt160709_wp1.jpg and http://www.structuremag.org/article.aspx?articleID=947

CLT Building 5: The eight-storey Bridport House, Hackney, London, is (at the time of writing), with Stadthaus, the tallest all cross-laminated timber (CLT) building in the UK (both were constructed for the same developer client and the London Borough of Hackney). Both have pushed the boundaries of CLT construction up to eight storeys, although Stadthaus is marginally taller at nine storeys, featuring a concrete ground floor, whereas Bridport House is CLT from the ground up, so it is a moot point which is technically the taller timber tower. Designed by Karakusevic Carson Architects as the first part of the regeneration of the Colville Estate, Bridport House replaces an original 1950s block with 41 new homes in two joined blocks, one eight storeys and the other five storeys high. All elements from the ground floor upwards are of cross-laminated timber, manufactured and supplied from Austria by Stora Enso Wood Products – including the lift shaft. Below ground level the raft, foundations and lift pit are of reinforced concrete. Stora Enso worked with specialist timber contractor Eurban. Often in such projects the ground floor will be concrete because it is used for retail and needs larger facade openings. At Bridport House, however, the lowest two floors are occupied by residential maisonettes that have been oriented in a different direction from the apartments above by changing the direction of the load-bearing walls.

In the design phase, reinforced concrete and structural steel was compared in detail with the use of CLT. There are several reasons why CLT was selected: one was weight. CLT is considerably lighter than the alternative structural materials. This was important, as a large Victorian sewer runs beneath the site and point loads needed to be avoided. Speed of construction was another benefit of CLT which can take as little as half the time to construct as a conventional reinforced concrete frame (Eurban ran a detailed comparative analysis). In addition, the construction process is far less likely to be interrupted in bad weather conditions. Engineering was completed and CLT boards were made from PEFC-certified spruce at Stora Enso‟s 65,000m³ CLT factory and adjacent fully integrated sawmill in Austria. Integration of factory and sawmill means raw material selection is greatly improved and CO2 emissions reduced because little transportation of raw materials between sawmill and factory is necessary. After manufacture, the boards were transported by truck to the UK.

Stephen Powney notes in *Timber & Sustainable Building Magazine* that, despite the transport, carbon saving over steel and concrete was 2,113 tonnes; the amount of sequestered carbon is the equivalent saving to providing 20 per cent of the building's energy requirement in use for 139 years (Powney, 2011). The accuracy of construction with CLT aids air tightness, as elements such as windows fit exactly in the assembly on site. Wayne Probert, of Stora Enso Timber UK, explains that their CLT boards were edge glued, which further increases air tightness and means that its three-layer CLT boards could achieve the same air tightness as non-edge-glued five-layer boards. The resulting air tightness of Bridport House, at 3 m³ per hour, is 60 per cent better than that demanded by UK building regulations. Edge gluing also increases the acoustic and fire performance of the CLT boards as well as making them watertight. This technique has the additional benefit of increasing the temporary weather protection when building during winter months. The building was completed in October 2011.

Probert explains that the faces of the visual (exposed interior) and non-visual boards are all sanded in the factory, which means any water blemishes incurred on site can also be sanded away. He also noted that CLT was becoming very competitive with UK construction companies, partly due to the carbon sequestration in the structures. Bridport House‟s main contractor, Willmott Dixon‟s in-house sustainability consultancy Re-Thinking, has been working with the Centre for Sustainable Development at the University of Cambridge, calculating the embodied carbon of Bridport House. Their calculation shows that, had the building had a conventional, reinforced concrete frame, the materials required would have incurred an additional 892 tonnes of carbon. This is equivalent to 12 years of operational energy required to heat and light all the Bridport House dwellings; alternatively it would take 61 years to save the same amount of carbon – based on the planning requirement of 20 per cent renewables. When the sequestered carbon locked up in this 1,576 m³ timber structure is added to the carbon avoided, the total figure is 2,113 tonnes of carbon – equivalent to 29 years operational energy. The construction sector focus on embodied energy and carbon storage has increased recently (Lehmann and Hamilton, 2011).

Figures 7a and b Bridport House, Hackney, London, was completed in August 2012 (source: Lehmann/architects, 2012)

CLT Building 6: The ‘e3’ multi-apartment building at 3 Esmarchstrasse, in Berlin Prenzlauer Berg, designed by architects Kaden and Klingbeil was only possible as a special exception to Berlin‟s building regulations. It is a seven-storey timber-frame building, something still uncommon in „stone-built Berlin‟; a hybrid construction using CLT panels and glue-lam elements; the majority of large multistorey timber structures are composites of different engineered timber building systems. A close cooperation with the fire brigade was necessary to obtain permission, since buildings in Berlin whose top storey has a floor level in excess of 13 metres must be constructed out of non-combustible materials. The building‟s design and fire safety measures (such as a short escape route), however, proved sufficient to satisfy the fire brigade. The most important fire safety measure is a free-standing, open, external staircase made of concrete, positioned along the fire wall of the adjacent building – offering a short escape route as it can neither catch fire nor fill with smoke. From this staircase, concrete walkways then provide access into the timber apartment building itself. The spacious loggias in front of the apartment doors are shared by all residents for communal use. The private balconies, which are attached lightweight steel constructions, fairly narrow and of little practical use, have been affixed somewhat carelessly to the rear facade of the building.

The external façade is plastered; the external white rendering makes it look like conventional urban infill and it is not immediately recognisable as a wooden building. It is a high-quality eco-home, with good insulation and a maximum annual energy consumption of only 40 KWh per square metre; a typical e3 apartment, with floor space of 140 sqm, generates heating bills of less than 500 Euros a year. The building is connected to a district heating network, and all rooms are equipped with under-floor heating. The structure is a hybrid: the wooden truss made of laminated beams is packaged in fire-retardant gypsum fibreboard, as are the solid wooden walls, made of CLT. The wood-concrete composite ceilings feature, on their underside, timber planks covered with a fire prevention glaze. Tenants have laid flooring of their choice on the concrete upper side – polished concrete, smoked oak or bamboo parquet. Apart from two concrete cores, which run the entire length of the building for stability and installation, the apartment layouts are flexible and can be subdivided and arranged as desired. The result is a loft-like space or small ateliers.

The building is connected to a district heating system, something very common in Berlin. The high degree of prefabrication resulted in an extremely short construction phase. The gross square metre prices of 1900 to 2400 Euros, which vary from floor to floor within the building, are less than or comparable to conventional developer projects. In Germany, the trend towards timber-framed and CLT buildings, advanced years ago by the Bavarian State Building Authority’s research, pilot projects and amended building regulations, has now arrived in densely populated inner cities (such as Berlin) in the form of infill prototypes. Whether or not this sustainable style of building will become more widespread will also depend on the wider acceptance and the willingness of relevant authorities to be flexible in approving new construction methods (Lehmann and Hamilton, 2011)

Figure 8. The ‘e3’ infill building, Esmarchstrasse, Berlin, a 7-storey residential urban infill building with a concrete staircase tower (source: architects)

Table 1 CLT buildings than 3 storeys in Europe

	Country	Case	Year	Height	Dwellings	Cost (million)	Architect	Comments
1.	Norway	Svartlamoen, Trondheim	2004 - 2005	5 storey building measures 6 x 22metres	2 buildings with an overall area of 1080sqm. Four upper floors contain units of 120sqm in size	€2.16 million	Brendeland & Kristoffersen, Trondheim	Contains commercial rooms Clad with Norwegian larch. Untreated timber surfaces of the load-bearing elements are exposed on the inside. Four workers managed to erect the main structure in just ten working days.
2.	Austria	Am Muehlweg, Vienna (new district built in CLT, involving various architects)	2005-2006	3 storey on concrete basement and 4 storey on concrete basement according to BBS	70 apartments in several CLT buildgs, 200 residents , Total approx. 7,000sqm	€11 million	Hubert Riess and Hermann & Johannes Kaufmann, Schwarzach, Vorarlberg Region	Three interconnecting sites, Optimum exploitation of ecological and economic benefits of timber and mixed constructions. Terraced houses and an L-shaped building surround an internal courtyard, offering a free area for communal use. Low energy standard according to BBS - performs at 30 kW/sq m/a (Passiv Haus Standard)
3.	Switzerland	Holzhausen, Steinhausen	2006	6 storey - 4 storey is CLT panel on concrete base	12 (2 spacious apartments per floor) 150sqm and 166sqm in size.		Scheitlin-Syfrig & Partner, Luzern	Switzerland's first six-storey timber building Fire protection standard in Switzerland, introduced in January 2005, 60-minute fire-resistance capability.
4.	UK	Stadthaus, Murray Grove, Hackney, London	Completed January 2009. Took 49 weeks in total Partially social housing	9 storey 8 storey in CLT	29 apartments	£3.5 million	Waugh & Thistleton Architects and Techniker Limited Engineers	Used KLH CLT - 926 cubic metres CLT walls, floor slabs; timber stair and lift cores Each apartment has its own internal balcony stores over 186 tonnes of carbon and 124 tonnes carbon saved by not using reinforced concrete frame exterior cladding made up of over 5,000 individual panels each 1200x230mm panels - made up of 70% waste timber Assembled using four carpenters in 12 weeks – one floor each 3 days. The potential for creep shortening due to compression under load is negligible for the walls and 0.6 millimetres (0.02 inches) for the floors. The potential for moisture expansion is negligible for the walls and 2 millimetres (0.07 inches) for the floors, resulting in maximum settlement for the

	Country	Case	Year	Height	Dwellings	Cost (million)	Architect	Comments
								entire building of less than one inch. clad inside and out to meet fire rating but no sprinklers required
5.	UK	Bridport House, Hackney, London	Completed end 2010	8 storey	41 1 - 4 bed residential units	£5.9	Karakusevic & Carson, London with Eurban	Code Level 4 and Lifetime Homes Construction time: 12 weeks, Oct-Nov 2010 CLT delivered by Stora Enso (30 deliveries to site)
6.	Germany	'e3', 3 Esmarch Street, Berlin Prenzlauer Berg	2008 (completed April 2008)	7 floors, urban infill (height 23m)	7 apartments (one large apartment p. floor)	Around Euro 2,000/sqm	Kaden + Klingbeil Architekten, Berlin	German building regulations changed in 2002, allowing timber construction up to 5 storeys. This 7 storey, fully sprinkled apartment infill building has been developed in close collaboration with the Berlin Fire Department; the escape staircase is separated from the main building. Calculated features: 40% less weight compared to concrete; performs at 27kWh/sqm/a. Building claims to be CO2 neutral. External façade is plastered. Apartment sizes 140sqm. Connected to district heating system. See also: www.e3berlin.de
7.	Sweden	'Lagerhuset' (warehouse), Eslöv, Skane	1916; 2008	10 floors (not in CLT)			Gunnar Asplund, Krook & Tjäder Arkitekter	34 m height - tallest wooden residential building in Sweden, possibly in Europe. Originally built as a grain silo, this is a conversion into apartments.
8.	Austria	Schuetzen Strasse, Innsbruck	2006	4 storey	34 apartments (3,500sqm)		Helmut Reitter, Innsbruck	low energy standard - energy consumption 33 kW/sq m/a
9.	Sweden	Portvakten, Soder, Vaxjo	2009	2 buildings each 8 floors	64 apartments, 32 per building		BSV Arkitekter & Ingenjörer AB structural engineer -Tyréns Temaplan	Built without traditional heating systems - designated passive houses. Electricity, as well as hot and cold water, is measured individually. The calculated energy use for heating and hot water is 38 kWh/sqm per year. There is a central heat exchanger installed with district heating as the source for the additional heat.

Table 2 CLT Buildings proposed for Australia

Case	Year	Height	Dwellings	Cost (million)	Architect	Ownership	Comments
'Forté', 807 Bourke Street, Victoria Harbour, Melbourne, Victoria, Australia, 2012	2012	10-storey residential tower (32.17 m high), 9 storeys of CLT on a concrete podium	23 apart-ments and retail in ground floor, fully sprinklered; no car parking space.	AUS$11		Lend Lease (Australia) in-house design	Australia‟s first CLT timber high-rise building. CLT panels manufactured and imported to Melbourne from KLH, Austria. Site work commenced in February and completed in October 2012 – a faster build than many stand-alone homes. Forté will comprise 7 one-bedroom apartments (59 square metres), 14 two-bedroom apartments (80 square metres) and two penthouse apartments with two bedrooms (102 square metres).
Delta, Melbourne	not yet built; still in concept phase	10 storey CLT - above 3 storey stone base heritage building	50	$100m estimated	Studio 505 (Dirk Zimmermann & Dylan Brady), Melbourne	Grocon	CLT proposed Originally designed to "Passive House" European Standard, Using shredded paper insulation, Fire safety standards 'met' – engineer assessed Uses 1000 cubic metres CLT
MacArthur Gardens, Campbelltown, Sydney West	not yet built; not yet approved	6 to 8 storeys 3 buildings proposed but unsure whether CLT is proposed	140 units? To date a development application for 75 units 15 x 1 bedroom; 48 x 2 bedrooms; and 12 x 3 bedrooms.	$28.26m for 75 units	Architectus Group Pty Ltd Arup - Engineers	Blue CHP Ltd (75 units)	Few details available for future buildings Higher density housing is proposed – and this higher density living is where CLT may be explored. The 75 apartments – 37 affordable and 38 will be sold 6,824.35 square metres residential floor space 1,943.32 square metres of retail/commercial space Designed around passive solar design principles with all apartments enjoying an optimal northerly orientation, 95% of apartments cross ventilated (Architectus 2010) 200 dwellings per hectare – 'superior access' to public transport, shopping and open space (Architectus 2010. "Provides a traditional 'inner residential suburb' with relatively dense housing. The mainly double-storey architect–designed homes in the early stages often have only a single garage, in recognition of the site's walkable proximity to many destinations" (ACNU conference 2010).

CLT Building 7: Forté, the 10-storey timber residential building in Melbourne's Docklands, is Australia's first large CLT building and a landmark project for the whole timber industry in Australasia. 9 storeys in CLT sit on top of a concrete podium. The ground floor will be used for retail space. The developer is Lend Lease, and its Australian CEO, Mark Menhinnitt, anticipates that 30 to 50 per cent of their residential projects in the pipeline could be executed in CLT. He noted "the project will unlock a new era for sustainable development by offering a viable alternative to traditional construction options, which are carbon intensive" (Hopkins, 2012). He expects CLT construction to be used in other applications, including educational, community and commercial buildings.

The advantages of CLT are particularly relevant to the Docklands location and the Victoria Harbour precinct, as its reduced weight generated substantial below-ground savings and the fast build suited the compact site. Forté aims to be Australia's first five-star GreenStar as-built certified residential building. By using CLT, Forté will reduce carbon emissions by more than 1,400 tonnes of CO2, compared with building in concrete and steel. The advantages continue for residents too: the 23 apartments will require 25 per cent less energy to heat and cool than a similar apartment built in concrete and steel. The building will be carbon neutral for at least 10 years.

Construction of the building took only from February to October 2012, constructed from 760 CLT panels, which were shipped from Austria to Australia in 25 containers (panel length limited to 12 metres due to container size). In the assembly process, around 25 panels per day were put in place. However, only a little of the timber is exposed in the final building, reduced to one "feature wall" per unit. An earlier design option proposed the entire building to be wood clad, but "it was then decided to reduce the timber aesthetic, to avoid marketing risks" (Menhinnitt, 2012). The developer decided on "a more ordinary façade to have a building not completely out of the ordinary." The developer also decided that the building would be fully sprinklered to make it look safe, although this was not requested by the Fire Department (Lehmann and Hamilton, 2011)

Figures 9 a and b The 10-storey 'Forté' apartment building in Bourke Street, Melbourne Docklands, under construction (2012); 760 CLT panels stored in a warehouse close to the site
(source: Woodsolutions/C. Philpot, 2012; S. Lehmann, 2012)

CLT Building 8 Delta, Melbourne, Australia. The Delta project is an initiative of Grocon, developers who were also responsible for the Eureka apartment building and Pixel zero carbon office building in Melbourne. The proposed building has been designed by Architect Dylan Brady together with Dirk Zimmerman of Studio 505. It will consist of 50 apartments most of which will be three bedroom size, and according to David Waldren of Grocon, are expected to be sold off the plan at approximately $1 million each, a premium of 10-15 per cent on the costs of an average apartment (Dobbin 2011). The pre-fabricated structure is proposed to be CLT. It will consist of 10 storeys above an existing bluestone heritage listed building (see the images in Figure 7). When built, Delta will exceed by one the number of storeys of any existing building constructed using this construction system anywhere in the world and will be the tallest CLT structure. It will have an airtight building envelope, be very well insulated with timber window frames and triple glazing. It will also have its own gas-fired electrical generator powered by waste woodchips, and a rainwater and grey-water recycling system. Sustainability consultants Umow Lai have provided input into the sustainability aspects of the design. David Waldren (pers. comm. 6 September 2011) advised that all CLT panels inside and out will be covered to address the fire resistance requirements of approving authorities and ensure the high quality features sought in the building.

Figure 10 Images of site on which Delta in Melbourne, Australia is proposed and the concept of the CLT building proposed, incorporating the heritage listed 3 storey fire station.
(Source: Dobbin 2011)

2.2 The benefits of CLT buildings

What quantifiable social benefits resulting from living in CLT buildings compared to traditional steel, concrete and masonry for infill development?

Cross-lam and other engineered timber panel systems will change the way we design, build and recycle buildings. The potential of CLT as a sustainable building system is only just being realised around the globe (Lattke and Lehmann, 2007; FPInnovations, 2011). Since timber is the only material that has the capacity to store carbon in large quantities over a long period of time, solid wood panel construction offers the opportunity to turn buildings into carbon sinks. Thus the historically negative environmental impact of urban development and construction can be turned around with CLT construction, especially on brownfield and inner-city sites (p8,3).

Recent Canadian research established the direct link between wood and human health, and the restorative effect of using wood surfaces in buildings (FPInnovations, 2012). The study Wood and Human Health establishes the direct link between the natural environment – especially trees and forests – and human well-being. Architects have long known that architecturally exposed wood can have a similar effect on interior spaces and that the experience of warm wood surfaces indoors can reduce stress or depression, and promote health in buildings' occupants. Australians spend around 88 per cent of their time indoors; six per cent is spent in the car, meaning only six per cent is spent outside. It makes sense then that the use of wooden surfaces in hospitals, schools, offices and homes should be a priority as we consider not just sustainability, but occupant health and well-being (p. 6, 3).

Timber stores 0.8 tonnes of CO2 within 1 cubic metre, making timber the only construction material that can impact positively on the environment. Timber is a replenishable material in comparison to the production of concrete, aluminium and steel are one-way energy-intensive processes that release large amounts of CO2 into the atmosphere (see AGO 2002; McKinsey 2008; BEIIC 2010; DCCEE 2011). Generally, timber buildings require less primary energy consumption (primary energy is the energy form that has not been subjected to any transformation process; it is energy contained in raw fuels and other forms of energy received as inputs to a system; it can be non-renewable or renewable) and have a lower Global Warming Potential (GWP) than concrete or steel buildings. (Lehmann, 2012a, p. 11) The difference between concrete/steel constructions and timber buildings GWP can be 25 per cent or more (Lehmann, in press, p. 1).

Wegener and his colleagues noted that the energy budgets of products and buildings made of wood show that they may use less energy over their total life cycle (manufacture, use, maintenance and disposal) than can be recovered from the waste products of their production and from their recycling potential at the end of their life cycle: they are energy-positive. No other construction material is so comprehensively energy-efficient and therefore climate effective as wood' (Wegener, Pahler and Tratzmiller, 2010, p.4; Lehmann, in press, p. 1).

Wood is the most sustainable structural material, growing abundantly through sustainably managed forestry practice. After having been neglected over the past 50 years as a primary structural material, wood has now been rediscovered with the development of new high-strength engineered timber systems. Wood construction systems have significant advantages over concrete or steel, such as their lower embodied energy (hence reduced emissions) and easier re-use/recyclability at end of life, as cradle-to-gate and cradle-to-grave scenarios show, when using life cycle assessment methods (Lehmann, in press, p.4).

Based on the environmental benefits of wood products, Planet Ark has joined with Forest and Wood Products Australia (FWPA), to encourage the use of sustainably sourced wood through a marketing campaign to raise the awareness of the carbon and environmental impacts of alternative building materials.

Brick, steel, glass, plasterboard, concrete and particularly aluminium, all use more energy in their production, thus contributing considerably to CO2 emissions. Concrete, steel and masonry construction can now be replaced more and more by timber load-bearing elements using these new engineered timber systems (Lehmann, in press, p. 3). Research of the Australian situation where radiata pine is widely used for timber framing, concluded that single detached housing constructed in timber uses less embodied energy than steel or concrete construction (Carre, 2010). FWPA have funded research at RMIT University to compare the life cycle impacts of alternative constructions of a typical Australian house (Carre, 2011) detached dwelling in Brisbane, Sydney and Melbourne (Australia), with some findings reproduced below in Table 3.

The FWPA also commissioned the CSIRO to produce an environmental impact assessment module (ECO_2) for AccuRate (FWPA 2011). The ECO_2 module allows the embodied CO_2 in a proposed housing design to be assessed. However this ECO_2 module does not apply to residential (Class 2) multi-storey buildings (Woodsolutions, 2011), emissions from the construction, operation, maintenance and the end of life disposal phases of the building life cycle (Bootle, 2006; NSW Department of Primary Industries, 2008).

	Elevated floor vs concrete slab		Timber frame vs steel frame		Weatherboard vs brick	
	Min	Max	Min	Max	Min	Max
Global Warming	-5%	1%	-17%	-5%	-12%	-5%
Photochemical oxidation	6%	19%	-30%	-10%	-1%	1%
Eutrophication	2%	10%	-13%	-2%	-4%	-4%
Land use	5%	10%	43%	44%	9%	10%
Water Use	-1%	12%	58%	63%	15%	17%
Solid waste	-30%	-20%	-13%	-5%	-47%	-46%
Resource depletion	-1%	6%	-16%	-4%	-12%	-6%
Cumulative Energy Demand	-1%	5%	-12%	-3%	-10%	-5%

Negative (shaded) indicates former impact less than latter.

Eg, -5% in first column means elevated floor less than concrete slab

Table 3 Comparison of impact of construction type on the environment through an LCA analysis of single family dwellings in Australia (from Carre 2011)

The New South Wales Department of Primary Industries (NSW DPI 2008) published a chart comparing the greenhouse gas (carbon dioxide equivalent) emissions associated with different materials used for building components of a typical single storey house in Sydney, New South Wales (see Figure 9). It is clear from this chart that timber provides significant benefits in relation to carbon emissions of materials used in housing. Data from Ferguson et al (1996) are also presented in Table 4 indicating that rough sawn timber stores a significant amount of carbon.

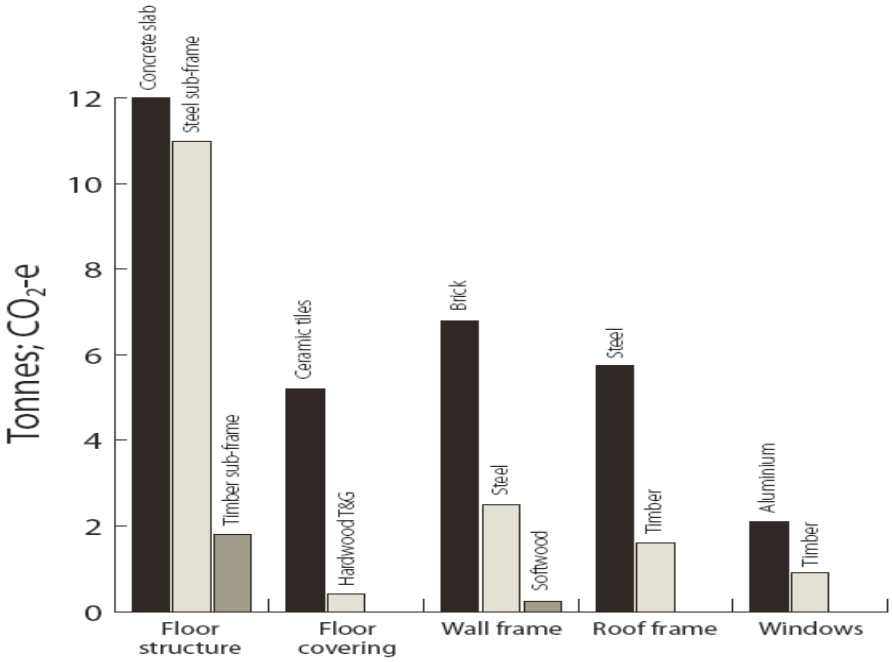
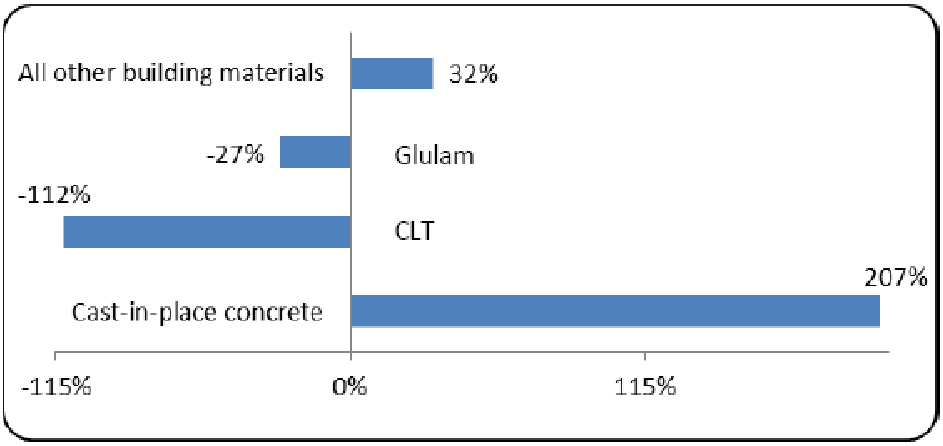


Figure 11 GHG emitted in the manufacture of building materials used in a range of construction components for a single storey house in Sydney, Australia
(From NSW DPI 2008)

There are currently no Australian studies comparing buildings constructed using CLT with other construction methods. The Building Products Innovation Council (BPIC) of Australia does not list CLT in its life cycle inventory of building products (AusLCI) as it is not currently manufactured in Australia (Tim Edwards, BPIC, pers. comm. August 2011). BPIC recommend using the global warming potential (GWP) of CLT from a report by Robertson (2011) which contains European GWP data for CLT obtained from Stora Enso, a CLT manufacturer located in Austria. The Robertson (2011) study also has GWP data from production at a North American CLT pilot plant (see Figure 10) which highlights the differences between CLT and other building materials including Glulam, and engineered uni-directional glue laminated timber product. BPIC also advised that, as manufacturing CLT is a similar process to manufacturing Glulam, the Australian manufacturing data in the database for Glulam could be used as a proxy. However, from Robertson's study, using the carbon storage data (from GWP) for Glulam significantly underestimates the carbon storage benefits that CLT provides.

Table 4 Carbon released and stored in the manufacture of building materials (from Ferguson et al 1996)

Material	Carbon released (kg/t)	Carbon released (kg/m3)	Carbon stored (kg/m3)
Rough sawn timber	30	15	250
Steel	700	5320	0
Concrete	50	120	0
Aluminium	8700	22000	0



**Negative percentage indicates net carbon storage*

Figure 12 Global Warming Potential (GWP) by building material (Source: Robertson 2011)

One area which is underreported in LCA analysis for timber is its impact on water resources. Carre's study (2010) concluded that:

Water use and land use represent key points of differentiation between the construction types considered. In general, water use and land use impacts for each construction type were driven by the timber content. Those construction types that minimise timber use tended to have lower results in these indicators.

For softwood timber, Carre (2010) noted that the estimation of water consumption is based on the difference in water use between a plantation forest and pasture, and not for other uses such as native vegetation or other agricultural crop. As water security and conservation are significant issues in Australia, further work needs to be undertaken to assess the impact of using CLT on water resources in Australia. In Australia CLT is expected to be manufactured using waste timber products, not structural grade timber according to industry representatives. Further study is needed to determine appropriate water use data for the life cycle analysis of an Australian-made CLT product. Feedback from industry is that Australian CLT materials are expected to be manufactured using waste timber products, not structural grade timber. Further study is still needed to determine appropriate water use data for the life cycle analysis of an Australian-made CLT product.

Prefabricated timber construction systems

Using resources more efficiently through CLT construction reduces the embodied carbon in materials and structures from around 550 kg CO2/sqm to 300 kg CO2/sqm, compared to conventional materials used for such construction. This is achieved by using a prefabricated timber construction system with lightweight facades with low-impact finishes. CLT panels have a high material efficiency, using around 0.75m3 of CLT per sqm of apartment. Using local timber will allow the entire supply chain to be controlled, developed, and its impacts minimised across the whole lifecycle of a building (Lehmann, 2012a p. 7)

Further advantages of prefabricated modular multistorey housing systems include integrated waste management which is a significant factor in the design and delivery process. This is enhanced as a consequence of building in a factory environment where one can achieve reduced site waste and environmental impact by:

- Designing to standard building material dimensions to minimise wastage (e.g., if a sheet comes in at 1.2 m wide, the product is designed at intervals of 1.2 m or 0.6 m, rather than 1.0 m and 0.5 m);
- Continuously recycling and streaming waste (factory waste is sorted into metals, timber, general waste and cardboard to optimise recycling opportunities);
- Minimisation of travel or transport emissions;
- Zero-waste construction and fast assembly on-site using mechanical jointing systems. (Lehmann, 2012a p. 10)
- CLT panels can be easily demounted for re-use, or used as an energy source at the end of the building's life (Lehmann, 2012a p.11)
- This technology offers construction systems for urban infill and narrow lots, where there is no or little storage space, therefore ideal for four-to-eight storey buildings (Lehmann, 2012a p. 11)

Off-site prefabrication of CLT panels enables modular construction and enhances the use of efficient techniques of digital design including Building Information Modelling (BIM). The CLT wall panels can be precision cut off-site to create window and door openings and in some cases have been fitted with insulation, external cladding and windows. Prefabricated panels are also used for floors, roof, ceilings, lift shafts and stairwells in some multi-storey buildings (Waugh 2010). The review of cases in this study highlights the rapid on-site construction which may be as short as three to four months for buildings of up to nine storeys. Such short construction times compared to traditional multi-storey construction methods reduces activity impacts such as noise and the need for traditional construction equipment such as fixed cranes. These benefits however are not limited to CLT buildings but will be a benefit of all modern methods of construction that utilise prefabricated wall, floor and roof construction elements.

Sathre and O'Connor (2010) reviewed scientific literature addressing the net life cycle greenhouse gas footprint of wood construction products. They also quantified greenhouse gas emission avoided per unit of wood used in place of other materials. They noted that all of the studies that they reviewed found that the production of wood based materials results in less greenhouse gas emission than the production of alternatives. Over the complete life cycle of building materials, wood materials also demonstrated lower total emissions, although the end of life management of wood was influential. They concluded that there is great benefit and a clear rationale for increasing wood substitution for other products, provided that forests are sustainably managed and that wood wastes and by-products are used responsibly. Sathre and Gustavsson (2009) compared two functionally equivalent four storey buildings made with a wooden frame and a reinforced concrete frame. They concluded that the manufacture of materials for the wooden building was estimated to use 28% less primary energy and emitted 45% less carbon than the manufacture of materials for the concrete building.

In a landmark study in New Zealand, John et al. (2009) compare the carbon emissions in construction and operation of a building constructed using four systems – Steel, Concrete, Timber and TimberPlus. The TimberPlus design which was clad in timber panels and had replaced aluminium window frames with timber, demonstrated the lowest environmental impacts (see Figure 8), whilst the steel building had the highest impacts. Of note is that increasing the amount of timber in buildings decreased the initial embodied energy and global warming potential (GWP) of materials and also decreased the total energy consumption and GWP over the building's assumed 60 year lifetime. John et al (2009) indicated that a significant benefit could be obtained in the steel, concrete and timber buildings by replacing high embodied energy components (especially aluminium windows and louvres) with timber.

John et al (2009) also noted that the final destination of deconstruction waste at the end of the 60 year life-cycle was extremely important. Land-filling of timber waste, with the permanent storage of most of the carbon in the timber, was slightly more beneficial than burning of wood waste for energy. Recycling of steel and concrete, however, is more beneficial for these materials than land-filling. The long-term storage in landfill of over 630 tonnes of carbon dioxide removed from the atmosphere more than cancels out all the GHG emitted in the manufacture of all of the other building materials used. John et al (2009) noted that, in this scenario, the TimberPlus building could be considered to be 'carbon-neutral' for at least the first 12 years of its operation.

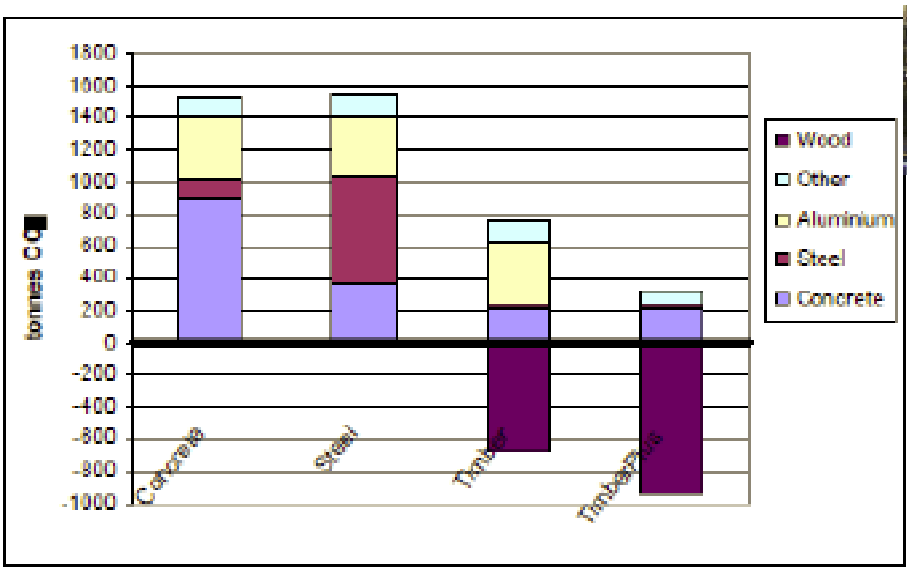


Figure 13 The comparison of carbon emissions associated with construction of concrete, steel, timber and timber plus buildings (from John et al 2009)

3. How to positively influence perceptions and address social barriers to achieve acceptance of new construction methods, materials and urban density

A number of reports published by the Grattan Institute investigate the challenges and opportunities Australian cities face brought about by population and social change, economic and environmental change, and resource constraints. In *'Getting the housing we want'* (Kelly, Breadon, Reichl, 2011, p.28) it is stated that "Innovation emerges in response to changing economic and social trends, and consumer preferences". However, because of the undersupply of housing [in Australia], developers are not always forced to respond to these changing factors. These challenges make it hard for new ideas to be tested and to spread between different companies. This is partly why construction is ranked as Australia's least innovative sector in recent studies". The report notes specifically "the lack of innovations in multi-unit dwelling design and construction. For example, Multi-Residential Timber Framed Construction was introduced to the Building Code of Australia in the 90s, but there have not been significant changes since then." (Kelly, Breadon, Reichl, 2011, p.29)

The Grattan Institute' analysis of Australians' housing choices (Kelly, Weidmann, Walsh, 2011, p.10) concurs with the broad consensus that most Australians aspire to own a large, detached house. Respondents had a range of concerns about apartments, all relating to factors affecting liveability. Apartments were seen as too small and lacking outdoor space, the proximity of neighbours (especially above and below) was a problem; they feared unwanted disturbance, or being forced to modify their own behaviour. Respondents had concerns about the quality of apartment stock assuming that very few apartments had any noise privacy. However, the results of a survey designed to explore the real world trade-offs people would make between houses of different type, size and location show a clear mismatch (the difference between the percentage of overall households who say they want a particular combination of house-type and location and the percentage of the overall stock represented by this house type/location option) between the current stock of housing in Sydney and Melbourne, and the mix of housing respondents say they would choose. In Sydney trade-off analysis suggests shortages of 60,000 apartments in buildings up to three storeys and shortages of 180,000 apartments in buildings four storeys and above. In Melbourne trade-off analysis suggests shortages of 125,000 apartments in buildings four storeys and above.

People, their motivations, values, and behaviours

Whilst the benefits for consumers inhabiting smaller housing in infill development are numerous (proximity to cultural institutions and amenities, time saving through shorter commutes, accessibility to transport) consumers attitudes towards urban infill apartment living are still not entirely positive. In order to change attitudes towards more sustainable practices it is first important to understand the ways in which attitudes are constructed. Cultural values play a large role in the construction of attitudes towards social and environmental issues. 'Values are important in thinking systemically about environmental problems, because they are understood to reflect higher-order motivations that organise the attitudes and behaviours that constitute many aspects of people's day-to-day lives' (Crompton, unpublished awaiting details, p. 2). It is generally acknowledged that cultural values sit within one of two categories; intrinsic values and extrinsic values. Intrinsic values 'refer to those things which are more inherently rewarding to pursue', such as affiliation to friends and family, self-development, altruism, and concern for the environment (Alexander, et al., 2011, p. 27). Extrinsic values are 'values that are contingent upon the perceptions of others', and relate to admiration of material wealth, power and authority, or envy of 'higher' social strata. (Alexander, et al., 2011, p. 27)

3.1 Value Mode Approach

Based on this understanding of cultural values, a number of marketing strategies and campaigning theories have been developed. The 'Value Modes' approach is one such marketing strategy, in which it is acknowledged that different people respond more effectively to either intrinsic or extrinsic motivations based on their values, and advocates that marketing strategies should be developed to appeal accordingly. Within a 'Values Modes' framework, users can be segmented into three key groups;

- Settlers, who are security driven, orientated towards safety and, identity and belonging;
- Prospectors, who are outer directed or esteem driven, orientated towards success,
- Pioneers, who are inner directed and orientated towards causes deemed as 'issues', often ones that have global importance (Rose and Dade, 2009).

The Value Modes approach stipulates that one user group will not be persuaded by tactics which appeal to another. For example, a Prospector could be more effectively persuaded to live in eco-friendly apartment living if the benefits appeal to one's self-interest, such as saving money and adding prestige to image, rather than appealing to pro-social values such as concern for the eco-system or facilitating a sense of community amongst residents. This means that whilst an extrinsically motivated person may not value the environmental merit of urban infill apartment living, marketing strategies geared towards self-interest based benefits (cost savings due to reduced operational energy needs and smaller energy bills, social power, social recognition) are more likely to convince them to adopt this way of living.

3.2 Common Cause Model

Whilst marketing that appeals to a person's extrinsic values can be used to motivate consumers to fulfil particular target behaviours, it can be counterproductive in trying to change overall attitudes towards more sustainable practices. This is the general premise of the Common Cause model, which suggests that advocating sustainable behaviours through extrinsic motivations, only serves to strengthen these values, thus undermining the general goal of creating a more environmentally aware and sustainably minded population. Whilst the uptake of target behaviour (in this case, apartment living) can be achieved, consumers are less like to participate in other sustainable and environmental practices (such as recycling).

However, people's values are not static; but rather, they operate on a continuum which can change over time. To further explain the way values operate in relation to one another, the Common Cause model utilises 'value mapping', where certain behaviours are grouped into value themes, whereby 'a particular value increases the frequency of behaviour associated with this value', thereby creating a bleed-over effect (Crompton, unpublished awaiting details, p. 9). For example, 'social justice' and 'protecting the environment' come under the broader heading of 'universalism', thus by advocating social justice as an important value, protecting the environment is also strengthened as to its association with the general theme of universalism, and lessen the importance of values such as wealth and social power (which are the most far from themes of universalism on the value map). The 'bleed-over effect' in the Common Cause model plays a significant role when developing marketing strategies for the adoption of new eco-friendly building systems and materials. Uptake will be seen more rapidly if consumers are already geared towards goals and behaviours that have similar values, thereby strengthening the probability of CLTs overall appeal.

Contextual Factors

While internal factors, such as values and attitudes play a significant role in a person's willingness to act in environmentally sustainable ways, they are just one aspect determining behaviour. Positive values towards a specific behaviour does not always equate to the person acting on that behaviour. This has been described as the 'value-action' gap (Crompton, unpublished awaiting details, p. 7) and acknowledges that behaviours will only be completed when a range of external factors are supportive of the said behaviour being carried out.

3.3 The 'ABC model' - Attitude, Behaviour, structural Conditions

The 'ABC model' (Attitude, Behaviour, structural Conditions), developed by Guagnano and colleagues (Csutora, 2012, p.147), see behaviour as contingent on both attitudes and contextual factors, such as time, money, and skills, to name a few. When contextual factors are highly supportive, even individuals with negative attitudes towards environmental issues tend to act in environmentally positive ways. Conversely, if contextual factors are not supportive, individuals with highly positive environmental attitudes will find it difficult to act in environmentally sound ways (Csutora, 2012, p. 147).

Providing appropriate opportunities and adequate resources is paramount when trying to increase the uptake of urban infill apartment living within Australian society. When making decisions, an individual will always consider 'the consequences of performing a behaviour and ones evaluation of those outcomes' (Axelrod, 1993, p. 150.). Factors such as ease of which a task can be completed, having access to appropriate resources and facilities, and financial risk and investments are all factors which can inhibit consumers from performing behaviours even if their attitudes are positive. For example, a person may have positive attitudes towards recycling, but if they do not have the facilities to do so in their area, the investment of time and money necessary to do so could be a cost that outweighs the perceived immediate benefits. In other words, if the sacrifice or cost is greater than the perceived outcomes for the individual, they are unlikely to participate in the behaviour. The costs and benefits of infill housing must be competitive with suburban living. The Australian Housing and Urban Research Institute states '...infill housing needs to be delivered at a price that attracts buyers who would traditionally opt for a detached house in the outer suburbs... the price of the product will be the key to demand' (Rowley and Phibbs, 2012, p. 25).

The role of social norms

In addition to contextual factors, social norms also play a huge role in the determination of whether people are likely to act in environmentally sustainable ways. Park and Sejin state that '...consumers tend to comply with social norms because they fear social pressure and/or because their referents provide them with guidance about appropriate or beneficial behaviour in their society (Park and Sejin, 2012, p. 393). In other words, people look to other individuals in society for directing and validating their own attitudes and behaviours. Hence the greater the social pressure to adopt environmental behaviours and attitudes, the more likely a person is to execute that behaviour. Additionally, Park and Sejin argue that intention to execute behaviours is strengthened due to moral obligations which are activated due to social norms. Acting environmentally becomes the default behaviour from which a strong moral obligation is attached, and a deviation from which triggers strong feelings guilt (Park and Sejin, 2012, p. 393). This information indicates campaigns must be well targeted to sections of the market identified as 'key influencers' in order to activate a sense of social pressure and obligation amongst general populations.

3.4 Informational and Structural Strategies

Based on evidence surrounding the construction of human values, attitudes, and behaviour patterns as discussed above, authors Linda Steg and Charles Vlek propose a general framework consisting of a four step process. The first of which is the 'identification of the behaviour to be changed'. In this case, this is the adoption of urban infill living in buildings made using CLT construction systems. Step two is 'examination of the main factors underlying this behaviour'. This pertains to the above discussion about people's values and attitudes, their housing preferences, and the contextual factors that are potential inhibitors of the target behaviour being adopted. The third step is the intervention phase, where strategies can be implemented to address the factors in step two in order to initiate change. The fourth step pertains to the evaluation of these interventions (Steg and Vlek, 2009, p. 309).

The strategies outlined below address step three in the framework, the intervention phase. What strategies for promoting pro-environmental behaviour can be implemented that will foster the necessary structural conditions for the uptake of multi-storey apartment infill living?

Informational strategies target motivational factors such as attitudes and values. Firstly, knowledge must be provided so people can make informed decisions and understand the impacts of their behaviour; secondly, strengthening social values towards pro-environmental behaviours, and; thirdly, strengthening social norms and providing information about the efficacy and benefits of other key influencers pro-environmental behaviours (Steg and Vlek, 2009, p. 313). The Grattan Institute's report *The housing we'd chose* states lack of privacy and autonomy as major concerns to individuals when considering multi-storey apart infill living. The proximity of neighbours meant residents feared 'unwanted disturbance or being forced to modify their own behaviour' (Kelly, Weidmann and Walsh, 2011, p. 10). Effective information strategies can address these kinds of preconceptions and dismantle these assumptions by providing information on the benefits of CLT construction materials such as the superior acoustic performance (Lehmann and Fitzgerald, in-press 2013, p. 6). The Australian Housing and Urban Research Institute (AHURI) note similar disparities between public perceptions about development projects and actual plans (Rowley and Phibbs, 2012, p. 24). There is still the tendency for the public to view infill development as residential towers with small, confining apartments. Authors Rowley and Phibbs suggest the necessity and importance of infill development, and the actual outcomes of such development properly be explained (Rowley and Phibbs, 2012, p. 47).

In order for behaviours to be successfully achieved, informational strategies are only effective if environmental and external factors facilitate action and are low cost, providing the right conditions, and therefore must be used in conjunction with structural strategies.

Structural strategies are aimed at 'changing contextual factors such as the availability and actual costs and benefits of behavioural alternatives' (Steg and Vlek, 2009, p. 313). Structural strategies aim to lessen the difficulty of acting in pro-environmental ways. It is also noted that they can aim to reward 'good' behaviours or punish 'bad' behaviour. (Steg and Vlek, 2009, 314). For example, governments may choose to incentivise the purchasing of eco-friendly homes with financial benefits similar to those of the first home-buyers grant. Systems such as measuring the environmentally friendly rating of homes adds to the integration of these concepts and standards into the everyday psyche, and an increased presence as a social norm (similar to that of 'energy ratings on electrical appliances).

Additionally, the Australian construction industry and housing market present a range of barriers to the uptake of CLT construction and multi-storey apartment infill living. The Grattan Institute cites cash flow as a barrier inhibiting developers from engaging in innovative projects. 'Pre-sale' commitments of up to 50-60% are often needed for banks to finance projects, leading developers to stick with tried-and-tested building systems to ensure solid returns (Kelly, Weidmann and Walsh, 2011, p. 30). Costs associated with buildings four storeys and over (classified as commercial projects) discourage urban infill development, as they incur additional construction costs due to scaffolding, cranes, and additional wages for building and construction workers (Kelly, Weidmann and Walsh, 2011, p. 34). Pre-fabricated CLT systems make on-site production more cost-effective, providing a potential financial incentive for developers.

The importance of collaboration

The Grattan Institute suggests that urban development projects should be a collaborative process between all key parties - State and Local governments, developers, and communities. It was found that the willingness to accept urban development proposals were most effective when communities felt as though they had a choice in the construction of culture within their community (Grattan Institute, Getting the housing we want, p. 12). Cities such as Seattle engaged neighbourhoods to identify the values that were core to their community in order to develop plans which fit within these value frameworks. Neighbourhoods in Vancouver were willing to allow higher density infill development in exchange for greater emphasis on the public facilities in their area, such as parks and schools (Grattan Institute, Getting the housing we want, p. 13). People need to be happy within their communities, and it is the responsibility of urban planners and developers to ensure that current residents are being accommodated for when making room for new ones. Such consultation and negotiation processes are important in addressing some of the major oppositions from communities towards higher density developments. There is a common perception that infill development adversely affects property values 'increasing traffic congestion, by placing pressure on infrastructure and by changing the characteristics of the area' (Rowley and Phibbs, 2012, p. 45). Conversely, 'up-zoning' often has financial benefits for neighbourhoods; therefore residents need to be supplied information on these types of changes and the pros and cons of each.

With these concerns in mind aesthetics too could be an important consideration in the planning process. Buildings must be able to aesthetically integrate into a neighbourhood. For example, an area heavily populated by heritage buildings might feel this important to their sense of community identity, making a modern complex apartment building inappropriate. However, smaller townhouses with similar ornamental features could provide higher density living while fitting more seamlessly into the already established characteristics of the community.

The Grattan Institute suggests that visualisation tools can be used for community engagement and provides reassurance that the community will maintain its integrity in times of change. A Statutory Planning Directive from Victoria stated that the use of visualisation tools were 'moving users from year-long to hour-long negotiations' (Grattan Institute, Getting the housing we want, p. 14). Visualisation tools are an innovative resource to be used in conjunction with political leadership to educate and reassure individuals of the benefits of higher density living in their neighbourhoods.

4. Stakeholder perspectives of the social, cultural, behavioural and structural drivers of change

This section of the report examines the social, cultural, behavioural and structural drivers that will help or hinder the transformations needed to ensure the rapid adoption of CLT in the Australian housing and construction market from the perspective of key stakeholder groups.

4.1 Opportunities for Architects as a result of new technologies

Roos et al (2010) researched the perceptions of architects and structural engineers as key stakeholders in the decision making process for selection of timber as a construction material in Sweden which, since 1995, has allowed timber buildings of height taller than two storey. They note that the main factors that positively influence attitude are building tradition, environmental considerations, and perceived structural advantages of wood; and negative attitude referred to concerns about movements, decay and sound transmission. Their study concludes that professional norms and perceptions in the building sector do not lead to a superior status for wood. They also note that behavioural control over wood construction is hampered by a superficial education on wood construction, and established practices and sunk investments in the sector that are adapted to concrete. (Lehmann and Fitzgerald, in-press 2013, p. 31)

Building Information Modelling (BIM) and related technologies will gradually change the way the building industry operates. There is potential to leverage its use for both marketing, design and offsite construction purposes. There is potential to develop BIM based case study buildings that visually showcase applications that the industry wishes to promote. … BIMs (of various building forms) can be dressed up with different timber systems. As such, the BIM becomes almost like a virtual shop to showcase various systems and can be used to explain and provide indicative component quantities and design details (including the use of timber product libraries).

Building Information Modelling is likely to change the nature of the procurement and delivery process of buildings in the future. At its core, it provides a base level technology that opens up new possibilities in the procurement, design and delivery processes – especially in terms of greater integration in the supply chain and an improved ability to interactively analyse design, cost and time information. The change point that BIM will bring, offers new opportunities for timber construction to move into new markets – such as the panellised construction mentioned above – because it will ultimately improve the ability to compare options, market integrated timber design and construction solutions and, simplify the uptake of offsite construction processes. (Forsythe, 2012, p. 13)

The extensive use of CNC-cutting and new 3-D software has allowed architects and engineers to push the boundaries, allowing them to move away from the constraints of building with conventional and material-intensive stick or frame systems. These conventional systems cover a fairly narrow realm given the possibilities that have become available through new engineered timber systems. (Lehmann, in press, p. 7)

A new generation of architects and engineers are exploring wood as part of their commitment to sustainability. Having established the direct link between wood and human health, the restorative effect of using wood surfaces in buildings will increasingly gain importance. (Lehmann, in press, p. 9)

Today, digital design allows for 'digital prefab', which can lead to a new form of 'sustainable prefab'. The building of today is designed with digital tools and is produced by means of digitally controlled production. This might lead to a revolution in the conception, design and realisation of multistorey apartment buildings. … A paradigm shift has taken place, from architecture based on mass production to architecture based on industrially produced made-to-measure components. Simultaneously, the role of the architect is changing as the context for development has entirely changed (Lehmann, 2012a, pp. 8-9)

4.2 Strategies to address the structural barriers faced by Developers

The Australian Housing and Urban Research Institute's (AHURI) report '*Delivering diverse and affordable housing on infill development sites'*, by Steven Rowley and Peter Phibbs (2012) is very instructive in highlighting the structural, social and cultural barriers to delivering diverse and affordable housing on infill development sites and argues for the need for three primary strategies:
1. Political leadership
2. Development approval certainty
3. Community engagement

The research project investigated the following broad themes, reviewing "a reasonably sparse literature on the issue". (Rowley and Phibbs, 2012, p. 9):

- Increasing the supply of housing through infill development
- Delivering a range of diverse housing products within infill developments
- Delivering affordable housing on infill developments
- Overcoming land supply and ownership issues preventing development
- Delivering infrastructure to support infill development

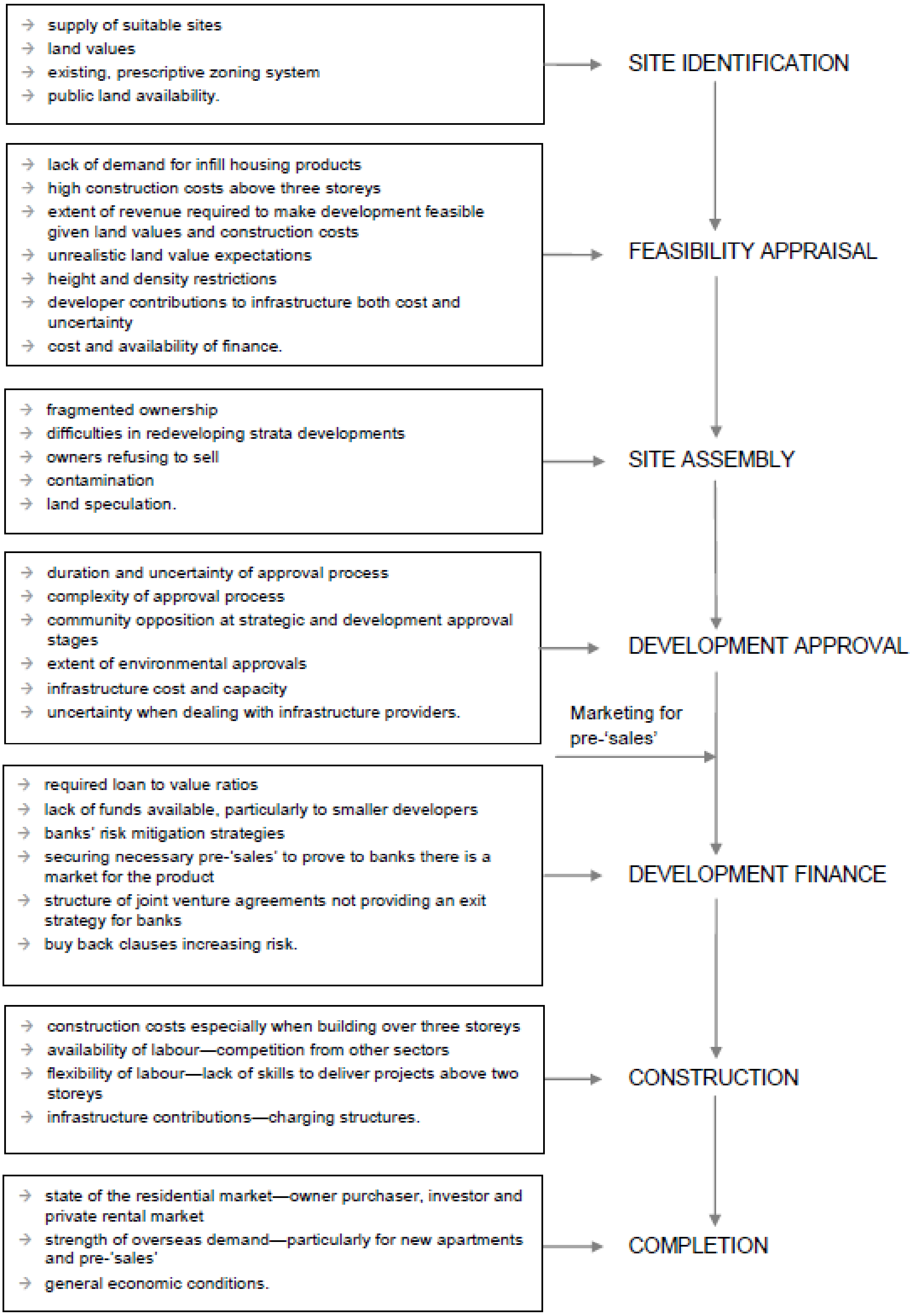
The report addresses a major public policy priority, infill housing to meet the housing needs of Australians. Fulfilling this need provides opportunities for the growth of the forest and wood products industry.

The National Housing Supply Council (NHSC) (Rowley and Phibbs, 2012, p. 10) identified the following barriers to infill development:

- Higher construction costs for medium and high density dwellings compared with those for detached dwellings, including land acquisition and demolition costs for landfill
- Difficulties aggregating and preparing land for construction
- Delays in securing development finance
- Lengthy and at times uncertain planning and development assessment processes
- Securing legal title to flats , units or apartments
- Community opposition to infill and to medium to high-density dwellings (NHSC, 2010, p.113)

The report found that the "development industry is not the risk-taking entity many like to believe; rather it is a conservative industry where the majority of developers are happy delivering the same type of product; low in risk, but with a high certainty of return. There are very few innovators in the industry due to the risks involved and the problems in obtaining funding. Indeed, the panels highlighted that many developers actually have an aversion to the built form and would much prefer to concentrate on land subdivision because the built form requires a much greater exposure to debt. This is problematic when trying to increase the capacity of the industry to deliver infill development." (Rowley and Phibbs, 2012, p.36)

The report says (Rowley and Phibbs, 2012, p.30) "developers crave certainty" recommending that the "development approval process should be structured in such a way that offers increased certainty for developers..." (Rowley and Phibbs, 2012, p.11). The Productivity Commission (2011) also found that these same barriers …. "may be so serious that many developers do not view infill development as a viable development option".



Barriers to Infill development in Australia, (S. Rowley and P. Phibbs, Australian Housing and Urban Research Institute, *Delivering diverse and affordable housing on infill development sites*, August 2012)

5. How the adoption of a new, material-efficient, low carbon technology will make the Australian wood products and construction industry more competitive and environmentally sensitive.

There are a number of clear benefits to solid wood panel buildings. The following list is drawn from a review of multi-storey buildings and discussions with industry stakeholders undertaken in the process of the in the supply chain: (Lehmann and Hamilton, 2011)

- the speed with which the structure of engineered wood panels-constructed buildings can be assembled on-site (they can be built at least 30 per cent faster, because much of it is prefabricated and lighter);
- the thermal performance of massive CLT panels, which potentially reduce the amount of additional insulation needed for energy efficiency;
- the expected higher fire performance of CLT compared to timber-framed buildings (high-density massive wood panels char rather than ignite, and the charring creates a fire barrier, as the charred layers protect the panels' load-bearing capacity) (Dehne and Krueger, 2006; Frangi et al., 2009);
- storage of carbon in the timber of each CLT building provides CO_2 sequestration;
- a reduced carbon footprint for timber buildings from responsibly sourced wood compared to steel, concrete and aluminium counterparts as the low energy used to make the building materials means reduced embodied energy;
- timber buildings are lighter: only a quarter of the weight compared with a concrete building;
- material efficiency: there is little waste in the production process;
- the ease and affordability of heating and cooling a CLT dwelling, providing a healthy indoor climate resulting in reduced operational energy and smaller energy bills for residents (Kaufmann, 2011). (Lehmann, in press, p. 6)

The advantage of timber is that it can easily be combined with other materials, either compositely or non-compositely, to form hybrid structures. It makes sense to combine wood where necessary with some steel or concrete, which leads to more efficient and architecturally elegant structures (Lehmann, in press, p. 5).

Off-site prefabrication of CLT panels enables modular construction and enhances the use of efficient techniques of digital design including Building Information Modelling (BIM). The CLT wall panels can be precision cut off-site to create window and door openings and in some cases have been fitted with insulation, external cladding and windows. Prefabricated panels are also used for floors, roof, ceilings, lift shafts and stairwells in some multi-storey buildings (Waugh 2010). The review of cases in this report highlighted the rapid on-site construction which may be as short as three to four months for buildings of up to nine storeys. Such short construction times compared to traditional multi-storey construction methods reduces activity impacts such as noise and the need for traditional construction equipment such as fixed cranes. These benefits however are not limited to CLT buildings but will be a benefit of all modern methods of construction that utilise prefabricated wall, floor and roof construction elements (Lehmann and Hamilton, 2011, p. 18).

The CLT panels are compatible with digital design and precision cutting techniques, enabling delivery of a prefabricated wall, floor or roof element for rapid on-site assembly; implementation shows that the system cuts construction times by more than half (Kaufmann, 2011; Waugh & Thistleton, 2011). Prefabricated CLT panels offer a number of advantages to delivering more sustainable buildings including modular, rapid on-site assembly (substantially faster and safer) which reduces cost, construction activity impacts and waste (Lehmann, 2010; Lehmann & Crocker, 2012; Lee, 2011). In

New Zealand, research has also highlighted the opportunity that timber structures, assembled on-site through bolt fixings, provide for integrating 'design for disassembly' principles (John et al, 2009). Such principles are said to allow reuse of load bearing timber panels and entire components on alternate sites at the end of the building's useful life (Lehmann, 2012a, p. 5).

Utilising specialised computer-controlled machinery, these panels are manufactured, factory cut, bored and grooved to suit any end use, and delivered just in time for assembly on-site. CAD and CNC computerised technology delivers perfect precision and allows building designers to interface directly with production. Manufacturing elements for mass customisation of buildings (e.g., using a 'kit of parts') will develop a manufacturing assemblies industry similar to the automotive industry, using digital fabrication and systems design of components, realising prototypes and demonstration projects. Applied research will drive this off-site fabrication.

The extent of factory prefabrication dramatically reduces construction time on-site. The panels can be used as a complete construction system (modular and demountable); components in conjunction with complementary engineered timber products, such as glue-laminated timber and laminated veneered lumber (GLT and LVL); and hybrid structures in combination with concrete and steel (Lehmann, 2012a, p. 9).

European experiences of CLT construction over the last decade will allow for significant technology transfer. Timber's flexibility makes it much more affordable to saw-cut a large piece of CLT panel into a particular geometry or complex shape, compared to laser-cutting a comparable piece of steel. The precision is impressive, as well as the speed on construction site: modular repetition is high and the elements are light-weight in comparison to concrete. For the nine -storey 'Stadthaus' project in London, the engineers estimated a 17 weeks' time saving (Waugh & Thistleton, 2011) (Lehmann, 2012a, p. 9) .

Extended Producer Responsibility (EPR) is an approach that seeks to designate responsibility for the impacts of products (or urban development) throughout their whole lifecycle. Applying this idea to the construction sector means when a building is made the consequences of its use and demolition (disposal) must be considered during its design. Adopting this approach across various industries would help to minimise waste and improve the efficiency of the resources used (Lehmann, 2012a, p. 5).

This is an important product benefit and a significant point of difference with other building construction materials. The FWPA could market this feature as a recyclable construction system with potential for carbon reduction.

To identify holistic approaches, such as principles for disassembly and reusability of entire building components, requires researchers in disciplines including economics, design and materials, to work together to enable the systemic environmental restructuring of consumption and provision in energy, water and waste systems. In the context of this change process, designers—architects, urban planners, industrial, interior or product designers—play a major part. To advance design knowledge one has to engage in designing. In Sustainable by design, Stuart Walker (2006) outlines a new understanding of the complexity and potential of sustainable design, extolling the contribution of design to the creation of a more meaningful material culture (Lehmann, 2012a, p. 6).

6. Design Standards for CLT buildings

Just as glass, concrete, steel and plastics, each, in turn, had an impact on the architecture of the nineteenth and twentieth centuries; wood is set to do the same in the twenty-first century. This traditional material has re-emerged as the building material of the future and we are at the start of a Wood Age. Our ever-evolving relationship to this natural, regenerating material allows us to revisit the amazing qualities of wood, recognising that it provides superior insulation and easy handling (Lehmann, in press, p. 6).

The technical solution or construction system is itself less important. Users' expectations and needs frequently focus on useability, affordability, comfort, cultural values and aspirational status goals. The shift to infill buildings constructed in CLT requires behaviour change, to ensure these buildings will be acceptable to occupants as an alternative approach based on ideas of environmental construction (such as new 'passive house' standards being slowly embraced by consumers (Lehmann and Fitzgerald, in-press 2013, p. 19).

Living close to work and access to public transport are now most important for Australians and experiencing a sense of community has grown in importance (Lehmann and Fitzgerald, in-press 2013, p. 3). Decisions made by providers of housing should directly relate to residents' needs, expectations and aspirations, and be appropriate in relation to their income, education, family and other social structures; as such relationships are likely to have a significant bearing on whether consumers continue to engage in sustainable practices in their homes once occupancy is established (Lehmann and Fitzgerald, in-press 2013, p. 23).

One incentive for occupants is that better housing design can significantly improve health outcomes and buildings that use timber internally and externally have demonstrated benefits for residents' well-being (Lehmann, in press, p. 8). Cross-lam panels are well suited to internally exposed applications. The study *Wood and Human Health* establishes the direct link between the natural environment – especially trees and forests – and human well-being. Architects have long known that architecturally exposed wood can have a similar effect on interior spaces and that the experience of warm wood surfaces indoors can reduce stress or depression, and promote health in buildings occupants (Lehmann, in press, p. 6).

6.1 The Role of Federal, State and Local Government

With carbon accounting in place, existing building materials' carbon lifecycles will be assessed, underpinning future government policy initiatives in the construction sector. High carbon intensity materials (such as steel, aluminium and concrete) have already been identified, and the Federal Government's low carbon legislation will motivate industry to develop low-carbon, high-performance alternatives and systems. Hence, there is an increasing importance of research in recycled construction materials (Lehmann, 2012a, p. 8).

The majority of carbon emissions and environmental impact comes from existing buildings. In the very near future, new low-carbon products and construction techniques will be developed and commercialised with industry partners to help industry reduce lifecycle carbon content and minimise embodied energy. The required market transformation will only be achieved when new government policy is implemented, underpinned by research into lifecycle carbon and the optimisation of local supply chains. This will transform the building construction, material supply chain, infrastructure and property development markets, such that there is consumer demand for low-carbon products and services, removing identified barriers (Garnaut 2008; PMEETF 2010). The ability of government at all levels to adopt new policy and planning settings will be vital to the success of these market transformations. It will also build the capacity and capability of industry such that the building and infrastructure design and construction industry is able to deliver the necessary low-carbon products and services (Lehmann, 2012a, p. 11).

Government Authorities provide standards for new development, including the policies for built form and urban design guidelines. They are also required to ensure that the structural properties of buildings are assessed as meeting appropriate standards, defined in the building code. Hence their attitudes towards new structural systems, such as CLT, will influence the speed with which such systems may be adopted in each jurisdiction.

In Australia, the Building Code of Australia (BCA) regulates materials which can be used for construction in buildings, taking into account the form of construction and design. Building Solutions are assessed against the performance requirements of the BCA. A Building Solution can be achieved through complying with the Deemed-to-Satisfy (DTS) Provisions, or by using an Alternative Solution to achieve the Performance Requirements.

The Assessment Methods described in the BCA are: Evidence of suitability, Verification Methods, Comparison with the DTS Provisions, and Expert Judgment.

- Evidence of suitability relates to the material proposed, the form of construction or the design. Suitable evidence consists of either a report from a Registered Testing Authority, a Certificate of Conformity or Certificate of Accreditation, a certificate from a professional engineer, a current certificate issued by a product certification body that has been accredited by the Joint Accreditation System of Australia and New Zealand (JAS-ANZ) or other document.
- Verification Methods include calculations (using analytical or mathematical models) and/or tests using a technical operation either on-site or in a laboratory to directly measure one or more performance criteria of a given solution. While lists of Verification Methods are provided, other methods are able to be considered.
- A comparison can be made between a DTS Provision and a proposed Building Solution. If it can be demonstrated to the authority having jurisdiction that the Building Solution complies in an equivalent or superior way to a DTS Provision, then it can be deemed to meet the relevant Performance Requirement.
- Expert Judgement is able to be used where physical criteria are unable to be tested or modelled by calculation. The person providing an Expert Judgement needs to demonstrate the qualifications and experience necessary to determine whether a Building Solution complies with the Performance Requirements.

For industry acceptance of CLT construction policy changes need to occur first (based on fire testing to building and planning legislation throughout Australia (England and Zillante, 2007). Regulatory changes are required to achieve this innovation as well as stakeholder engagement (Lehmann and Fitzgerald, in-press 2013, p. 18).

Currently the Building Code of Australia (BCA) only allows for 3 storeys of load-bearing timber construction under its 'deemed to comply' provisions, so if the building is higher an alternative fire-engineered solution is still required. But, as a consequence of new technological possibilities, building codes are under revision; in most European countries and Canada, they have recently been changed to allow for taller timber buildings. Today almost all EU countries regularly allow at least 4-storey buildings in timber, and demonstration projects built up to 10 storeys indicate what we will soon see: cities becoming forests (Lehmann, in press, pp. 4-5).

The process for approving a CLT building design for construction in Australia includes a number of steps which are outlined in Figure 15.

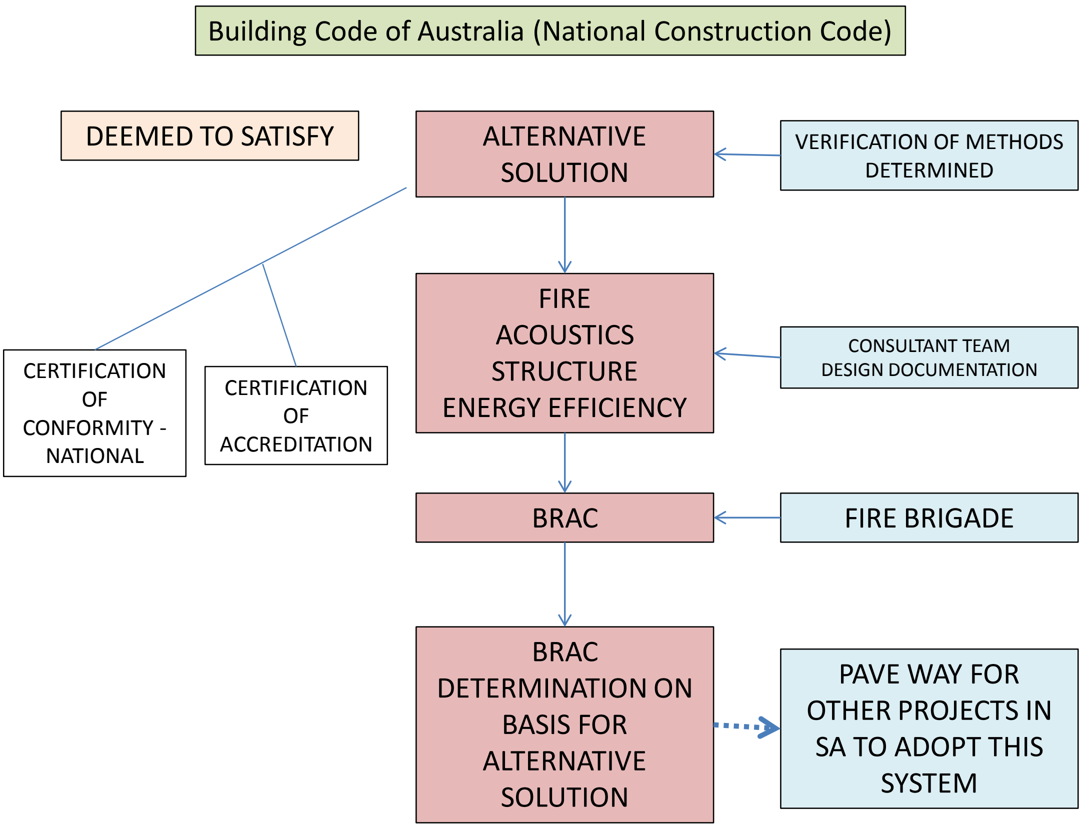


Figure 15 The process for approval of a Building Solution in South Australia

As the properties of CLT are determined by the type of timber used and the adhesive used to glue the layers together, the approval of a Building Solution designed for construction using CLT in South Australia for example, will only be possible once the properties of the CLT material has been determined. If the product is manufactured overseas and imported to Australia for use, its properties may be known through testing and certification in the country of manufacture. However the acceptance of this information will rely on the knowledge and skill of a building certifier in Australia to provide an Expert Judgement.

6.2 Design standards of timbers buildings in Australia

In an analysis of barriers identified by stakeholders to using CLT construction systems, Lehmann & Hamilton (2011) noted a number of aspects related to the lack of reference CLT in performance standards in building codes and regulations in Australia. One aspect relates to the permitted height of timber buildings generally, reflecting the expected performance of timber framed construction rather than engineered CLT construction.

The National Construction Code (NCC) also focuses on the combustibility of timber, classifying buildings constructed in timber as Type A. There are no *deemed to satisfy* provisions relating to CLT products or performance standards for these products, requiring expert opinion likely to be based on destructive testing. The NCC and its building codes are performance based and are similar to codes adopted in most European countries. (Lehmann, in press, p. 13)

As the BCA is a performance based construction code, in theory, timber buildings can be constructed to any height in Australia provided that performance standards stipulated in the BCA are met. However, in practice, the combustibility of timber in a building is taken into account in determining the maximum height of timber buildings, where timber is used as the main construction material. Hence, the DTS Provisions in the BCA currently allow only 2 storeys of timber framing in Class 3 buildings and 3 storeys of timber framing for Class 2 buildings. Forest and Wood Products Australia (FWPA 2010) provides design guidance for BCA compliant sound and fire-rated timber-framed construction for multi-residential buildings of Class 2, 3 and 9c. Their design guidance does not extend to CLT construction but, as a minimum, it may be assumed that CLT structural elements would need to meet similar performance standards to timber framing. An Expert Judgement would need to be made to provide this assessment or a Verification Method developed which may include testing of the CLT product to be used to ensure an acceptable level of performance can be achieved.

There are two major timber engineering Standards in Australia - *AS 1684, Residential timber-framed construction* which is a series of standards which outline the methods for design and construction of single and two-storey residential buildings using timber framing systems; and *AS 1720.1-2010, Timber structures - Design methods* which outlines the methods for all other types of structures. A review of these standards reveals that neither provides guidance for use of the CLT construction system or CLT structural elements.

Table 5 summarises two cases of multi-storey timber buildings which have been constructed using the Multi-Residential Timber Framed Construction (MRTFC) system requirements or similar in Australia, indicating some of the standards or specifications met by these buildings. Since that time however, the BCA has been modified and the standards required of these timber framed buildings may be different from that required of new development. In the current guidelines (FWPA 2010), issues of fire and sound performance are managed through considering the concept of a Sole Occupancy Unit in the buildings being designed which has not changed. In the absence of specific regulations and standards for CLT buildings in Australia, the following sections discuss the performance standards and building regulation relevant to timber buildings, focussing on structure, stabilisation, seismic design, durability, adhesives, acoustics, fire, and energy efficiency standards.

Table 5: 2 Examples of low rise timber framed buildings constructed in Australia

Case	Year	Height	Dwellings	Architect	Comments
Tower Apartments, Bundoora, Victoria	Completion October 2003	3 Storey plus concrete undercroft car park	108 units in total 54 class 2 units (serviced and nonserviced apartments) 4 class 3 units (1 and 2 bedroom hotel suites)	Walker and Yerondias Architects	MRTFC system used Double studs with 13 mm thickness, fire rated plasterboard, and a sprinkler system installed on all levels Incorporates both Class 2 and 3 construction Commercial uses included: · Restaurant · Gymnasium, pool, spa · Car park basement with 160 car spaces Stained treated pine lining boards and rendered base sheet were chosen for the external cladding on the building.

Case	Year	Height	Dwellings	Architect	Comments
Mansion on Burke, Melbourne, Victoria	Had been completed by 1999	3 storeys atop existing four storey structure built with concrete, timber and steel.	63 apartments	Reed HLS Architects	Load capacity of existing footings limited use of concrete Timber framed construction slightly cheaper than timber and steel combined options, 95% timber framed (with concrete lift and stair wells). Steel columns (90x90mm hollow sections) used in some wall construction Bourke Street façade - conventional glass/steel curtain wall system. Designers consulted Peter Luzinat and Partners P/L Building Surveyors from the first stage of design Ensured compliance with BCA 96. Fire Rating - The one hour fire rating achieved through installing sprinklers; smoke sealing apartment doors; smoke detection systems and early warning speaker systems in each apartment.

6.2.1 Structure and stabilisation

Information covering design, installation, fixing and erection requirements for timbers used for structural applications in residential buildings is included in the *AS 1684* series of standards which only address timber frames not CLT. The Timber Development Association of NSW (2011b) notes that timber frames should be constructed on slabs and footings that have been designed to *AS 2870-2011, Residential slabs and footings.* Other standards relevant to designing structurally sound and stable buildings in Australia include: *AS 1684.1-1999, Residential timber-framed construction – Design criteria; AS 1684.2-2010, Residential timber-framed construction – Non-cyclonic areas;* and *AS 1684.4-2010, Residential timber-framed construction – Simplified – Non-cyclonic areas.* Wind speeds for timber framed buildings can be calculated by following the methods described in either *AS/NZS 1170.2:2002, Structural design actions – Wind actions* or *AS 4055-2006, Wind loads for housing***.** The spans listed in the supplements to *AS 1684.2-2010, AS 1684.3-2010* and *AS 1684.4-2010* are linked to wind speeds and grades for visually (F) and mechanically (MGP) graded timbers.

Understanding the properties of CLT and how this material performs under specified wind conditions will be needed for designing CLT buildings.

Building with solid CLT panels will always have the likelihood of problems associated with wood's movement. There are several things one must take into account when working with wood. Wood is an anisotropic material, with different moisture movements along the three principal axes: tangential, radial and longitudinal. For instance, wood shrinkage, particularly in multi-storey construction or when combining wood and steel is an issue requiring careful attention; fire ratings and exposure to rain during construction also require consideration and all of these issues have to be dealt with early in the design phase (see Figure 3). (Lehmann, in press, p. 5)

The anisotropic nature of wood makes design and modelling of connections' load-bearing capacity complicated. This has been a constraint on the use of wood in general and, in particular, for larger constructions like bridges, large roof structures for sports arenas, agricultural buildings, industrial buildings and multi-storey residential buildings. (Lehmann, in press, p. 3)

6.2.2 Seismic Design

A new earthquake loading standard (AS1170.4) for designing buildings was developed in 2007 and elements of the new standard were discussed by Wilson, Lam and Pham (Wilson et al. 2008). They state that Australia is a low-moderate seismic region that is subject to low probability, high consequence earthquake events up to magnitude Mn=7. It is noted that while many standards for design of buildings are developed jointly with New Zealand, for the earthquake loading standard, Australia has developed its standard separately from that required in New Zealand as the latter is a high seismic country compared to Australia. Most structures in Australia, however, will have to be designed for some earthquake actions to ensure minimum levels of robustness (Wilson et al. 2008).

6.2.3 Durability and design

In 2003, the National Association of Forest Industries (NAFI 2003) noted that 'Assessing the potential durability of timber is assisted by relating the timber's required performance standards with historical and test data. This assessment relies on the knowledge and resources of the designer to correctly analyse the specific applications and to determine the performance and durability requirements.' See Figure 18 for process of design for durability.

The Timber Development Association of NSW (TDA of NSW 2011b) notes that the texture of Radiata Pine is fine, but uneven, and knots are common. The timber is fairly soft and has a low density, often with very wide annual growth rings. The sapwood is white to pale yellow, but often indistinguishable from the heartwood, which is light brown to yellow. The grain is usually straight, apart from a central core of 100mm, which can twist if the moisture content of the timber changes. Radiata Pine is easy to work, apart from the knots, and it readily accepts preservatives. Radiata Pine is not resistant to termites and preservative treatments are needed to increase its durability.

Designing timber buildings requires more careful detailing and precise planning than other construction methods … there is a need for a precise, correctly layered and high-quality construction envelope to protect the timber structure from rain and water condensation (Lehmann, in press p. 6).

6.2.4 Adhesives

The Australian Standard AS/NZ 4364 Timber – Bond performance of structural adhesives which was released in 2010 to supersede AS/NZS 4364:1996, Adhesives, phenolic and amino plastic for load-bearing timber structures—Classification and performance requirements, and the AS/NZS 4364(Int):2007 standard. The 2010 standard only covers testing procedures for adhesives to be used in the manufacture of structural finger jointed timber and Glulam. It states that it does not specify performance requirements for adhesive bonds between structural timber components in plywood, LVL, and wood-based panel products; however it notes that the adhesive bond requirements in AS/NZ 4364 may be applicable to these products. The standard states that it has been largely based on the Canadian Standards Association document CSA O112.9: Evaluation of adhesives for structural wood products (exterior exposure). However it acknowledges that alternative requirements from the European Standards have also been included. The 2010 standard is a performance based standard and has paved the way for new technology and applications of engineered timber according to European adhesive manufacturer Purbond AG (Purbond 2011). Purbond adhesives are widely used for the manufacture of CLT in Europe and Canada.

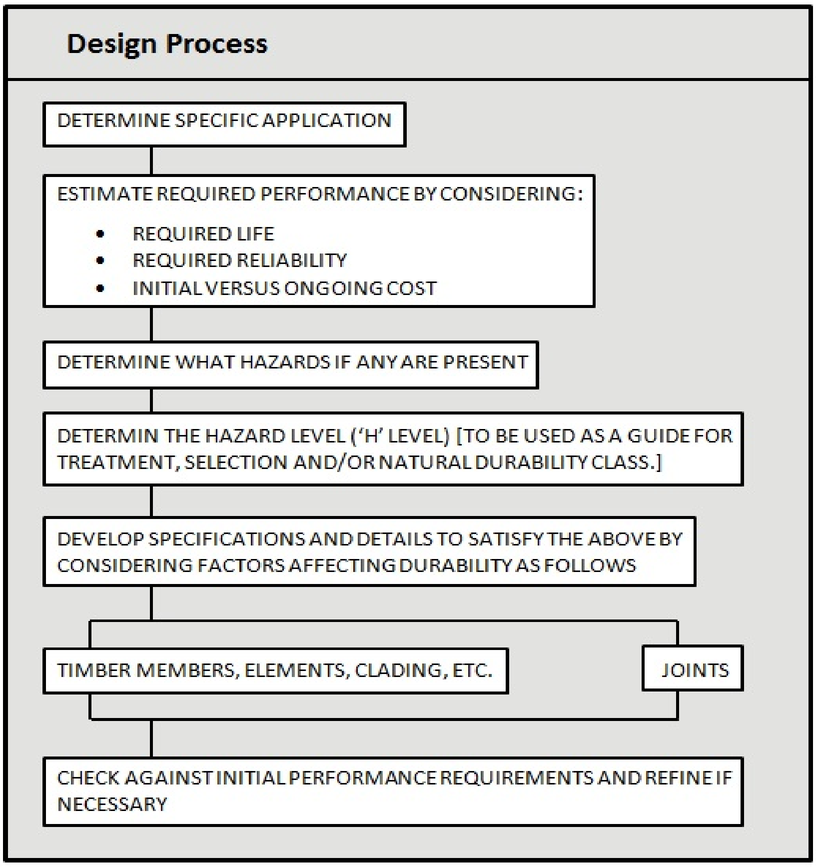


Figure 16 Process of design for durability

6.2.5 Acoustics and design

The BCA does not have specific requirements for noise for single family dwellings. However, it does provide specific minimum construction requirements related to the reduction of transmitted noise between adjoining dwellings in multi-unit and multi-level residential construction (Timber Development Association of NSW 2011b).

The ABCB (2011) has initiated a study to determine the need for a regulatory or non-regulatory solution to introduce acoustic requirements for buildings in inner city areas and for residential buildings adjacent to transport corridors.

In Australia, the Structural Timber Innovation Company (STIC) together with University of Technology Sydney (UTS) are studying acoustics for long-span timber flooring systems for commercial buildings, and are currently researching the bonds between timber and concrete (Sanfilippo 2010).

6.2.6 Fire performance and design

The BCA refers to fire performance in terms of *Fire Hazard Properties* (see reference clause C1.10 Fire Hazard Properties). Building materials used in Australia are required to conform to fire performance standards, the testing for which is detailed in the *AS 1530* series of standards. In addition, the Australian Standard *AS 1720.4 Timber Structures: Fire-resistance of structural timber members* provides a method of calculating fire resistance levels (FRL) for solid timber and provides a method of calculating a conservative char depth. While FRLs for building elements are required, the levels for CLT have yet to be incorporated into the BCA.

The Timber Development Association of NSW (2011b) provides some information about the fire resistance of CLT based on overseas studies which have assessed the rate of charring of CLT. The predictability of timber charring is critical to establishing building regulations for CLT structures that address fire performance. However, the rate at which timber chars varies between tree species and is predominately dependent on density and moisture content. Establishing standards for the quality of CLT for fire-safe use in Australia needs to address the density and moisture content of timber used in the manufacturing process.

Improving resistance to fire

Treatments of timber to improve its resistance to fire may include cladding with fire resistant materials or coating with a fire retardant. The use of fire retardant coatings is limited by the DTS provisions of the BCA, particularly the application of C1.10 (b). However, according to the ABCB, inconsistencies in the DTS Provisions for the use of fire retardant coatings have been noted between BCA Volume One and Volume Two. The ABCB have recently commissioned a Fire Code Reform Centre research project which will result in a paper for consultation.

A main concern with multistorey construction systems is fire behaviour. Design models of timber structures in fire usually take into account the loss in cross-section due to charring of wood. While there is little information available on charring of CLT panels (and their adhesives for bonding), recent extensive testing programmes on the fire behaviour of CLT panels has been conducted in Switzerland and the results are very promising (Frangi *et al*, 2009). For instance, the spread of flame and therefore fire safety is comparable to other established construction methods. Building designs for timber structures require fire engineering to be embodied in the architectural and structural design concepts from the beginning—to ensure integrated solutions that are cost effective and meet the requirements of the building code and regulatory authorities (Lehmann, in press, p. 7)

It is well-known that a timber-based construction can withstand fire far longer than a steel building, which when softened by heat might suddenly collapse, whereas a burning wooden beam can still support a cross-section of sufficient load-bearing capacity for long enough to evacuate a building (Lehmann and Fitzgerald, in-press 2013, p. 6).

While timber is combustible, it is predictable in fire and has a high degree of fire resistance; CLT panels are resistant to initial combustibility. The results of recent fire performance testing of CLT has provided sufficient evidence to force a review of Euro Codes and an update of building codes at a country level (Östman and Källsner, 2011). In respect of fire performance of CLT, the most influential fire research to date has been undertaken by Frangi et al. for the WoodWisdom-Net project in Europe. Their study found that the integrity of the CLT panels tested is reliant on both the rate of fire spread and speed with which the layer burns, and the type of adhesive used (Lehmann, 2012a, p. 14).

6.2.7 Energy efficiency and design

For multi-residential buildings (e.g. Class 2), BCA (2010) requires Building Solutions to address resistance to heat transfer through roof, walls, floor and glazing. The objective is to reduce greenhouse gas emissions. New multi-residential buildings are required to achieve a level of performance in line with the COAG target of a 2:1 benefit to cost ratio (ABCB 2011). At the same time, sole-occupancy units in Class 2 buildings have had to collectively achieve an average energy rating of at least 6 stars, and individually achieve an energy rating of at least 5 stars. The energy rating software used to determine the energy rating for sole occupancy units of a Class 2 building must comply with the ABCB Protocol for House Energy Rating Software.

Attention must be given to: heat flow and solar radiation; how well the building is sealed; air movement for free cooling (openings and breeze paths); the efficiency and energy saving features of heating, ventilation, air-conditioning systems and hot water supply; power allowances for lighting and electric power saving features; and access to certain energy efficiency equipment for the purposes of maintenance.

The design of CLT buildings would need to address each of these energy efficiency factors. The performance of CLT buildings in terms of thermal comfort and low energy requirements for heating of buildings designed for cold climates in Europe is encouraging. However, there is very little research related to the performance of CLT buildings in hot climates as is experienced in Australia.

The following sections address the design standards for CLT buildings in other countries in an effort to identify the main factors being addressed elsewhere that may inform the development of appropriate CLT building performance standards in Australia.

7. Design standards for CLT buildings in other countries

The use of CLT is progressively being recognised in the building regulations and codes of various countries. However, to date, the initial construction of CLT buildings in each country is often as a demonstration of the technology, and generally requires exemption from relevant national building codes (see Reimer 2010). Even so, there are strong indications that this technology is being heavily developed internationally, and general standards and guidelines are being devised in order to accommodate a more standardised use of this material (see discussion of international standards below). In some countries, such as in Europe and New Zealand, the use of timber as a sustainable building material is well established, and design guidelines are being modified to accommodate CLT.

7.1 International

Demand for standardisation of CLT for the construction industry has driven concerted efforts to provide established guidelines and principles for the design of CLT products (FPInnovations 2011). The International Organization for Standardization (ISO) is currently developing a draft standard specifically applicable to CLT entitled *ISO/WD 16696 -Timber structures – Cross-laminated timber -- Component performance and production requirements*. There is already an accepted standard for the use of adhesives for bonding structural timber components (ISO 20152). FPInnovations (2011) note the effort in both the short term (inside 1 year) and long term (5 year timeframe) to establish product standards, which integrate the drafts being considered in Europe, the US and other countries such as Australia and New Zealand. It is noted that the development of material design standards and building codes for CLT construction remains a responsibility of each country.

A review of design standards for CLT buildings and building regulations has been undertaken as part of the scoping study (Lehmann and Hamilton, 2011). The following sections discuss the findings of the review. For the purpose of this scoping report, nine countries were selected for analysis of individual building codes and regulations. The regulations affecting the use of CLT are presented and discussed following an explanation of the action to include CLT in construction standards in Europe, North America and New Zealand.

There is still much work that needs to be done in regard to international standardisation of new timber construction methods, and prefabrication of large timber components that can save material through the use of prefabricated elements. Material efficiency and embodied energy are increasingly recognised as two important criteria when assessing, in the move to lower GWP in building construction. (Lehmann, in press, p. 3)

7.2 Europe

Having been developed in Europe, CLT, and timber in general, is recognised to varying degrees in continental and national guidelines and building regulations. In understanding the use of CLT in the identified countries, one must understand the broader nature of construction and building within this continent. Administered by the European Union, the *Single European Act 1986* and more specifically, the *Construction Products Directive* (CPD) and the *Council Directive 89/106/EEC*, seek to integrate Europe’s internal market, by governing the operation of European institutions, while expanding the development and research fields and creating common foreign policy (EUROPA 2011). More specifically, the CPD contains six essential requirements for construction, relevant to Member States, relating to: stability; fire; health; noise protection; and energy economy (Östman and Kallsner 2011). This general ideal of standardisation is stressed through continuing research efforts into CLT in the future (see, for example, SP Trätek).

The key documents relevant to timber construction in Europe are the Eurocodes – especially *Eurocode 5 - Design of timber structures EN 1995*. This Eurocode '... applies to the design of buildings and other civil engineering works in timber (solid timber, sawn, planed or in pole form, glued laminated timber or wood-based structural products) or wood-based panels jointed together with adhesives or mechanical fasteners' (EUROPA 2011). Although not naming CLT specifically, various sources internationally refer to these documents directly for information relating to amending/creating their own timber and CLT building design guidelines, including references to fire, seismic and acoustic performance of timber (FPInnovations 2011). Further evidence of European standardisation is demonstrated in ISO and European Committee for Standardization Standards specifically related to the Eurocodes, such as *EN ISO 1363 Fire resistance tests.*

As noted previously, standards relating to wood products and use, including CLT, rather than regulations, provide perhaps the best indication of where the technology is positioned in both Europe, and internationally. In the United Kingdom (UK), for example, there is reference to standards relating to the structural work of timber, such as *BS 5268-2:2002 Structural Use of timber-Code of practice for permissible stress design, materials and workmanship* and *BS 5268-3:1998 Structural use of timber-. Code of practice for trussed rafter roofs*. Further standards relate to methods to be adopted for testing the fire resistance and durability of wooden structures, as well as expected performance outcomes of these buildings.

In the UK, *Approved documents* are subsidiary documents to the UK *Building Regulations.* Within the *Approved documents*, there is recognition of timber (timber framed and prefabricated timber) as an adequate alternative form of construction of buildings within legislation and supporting documentation. Within *Approved Document 1 – Structure*, it is noted that although having been 'in common use for a number of years' as well as 'hav(ing) demonstrated an adequate performance in compliance with the A1 requirement', a 'number of guidance documents relating to these alternative forms are presently being developed by industry', with these references to be included 'as soon as they become available' (UK Planning Portal 2004:4). While being created in 2004, this document was updated again in 2006, signifying the dynamic nature of technology development in this area and the need to rapidly amend relevant building regulations.

Institutions such as SP Trätek in Sweden, FTT Finland, Building Research Establishment (BRE) in the UK and Building with Wood (CEI-Bois), provide academic and industry-relevant papers relating to all the aspects of timber discussed above, as well as relating these aspects to various national building regulations and codes, which in turn are increasingly referencing Eurocodes. The development of continental-wide partnerships, with research industries, governments and practicing professionals in the building trade is seen as fundamental in developing CLT in the European context (CEI-Bois).

The WoodWisdom-Net project was established by CEI-Bois in Europe to address the need for more research to enable the standardisation of guidelines and Eurocodes, expand the knowledge base about the benefits of using wood, providing education and training in key skills, developing an understanding of construction processes using wood products and developing new markets for wood products. CEI-Bois has been working with a Roadmap (see Figure 19) for increasing the use of wood across various industries in Europe.

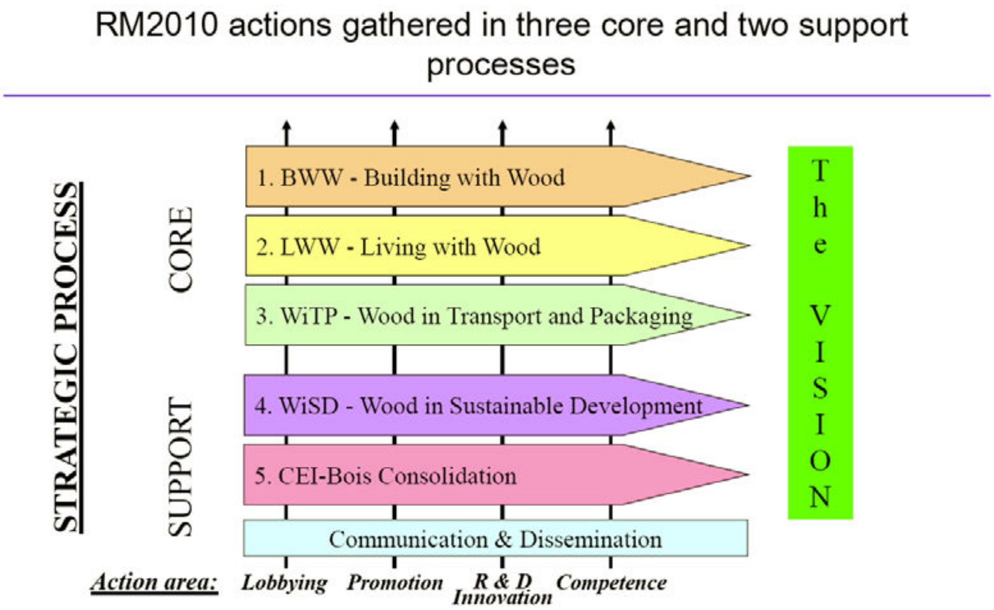


Figure 17 The CEI-Bois Roadmap RM2010

A recent report supported by the WoodWisdom-Net project reviewed the building regulations across countries in Europe affecting the construction of multi-storey wooden buildings (see Östman and Kallsner 2011). Their report identified and analysed five building requirements: fire safety; acoustics and vibrations; stabilisation; seismic design; and durability design. Of these, the main limitations from a regulatory perspective to the increase in use of wood for multi-storey buildings in Europe were noted to be fire and acoustic performance requirements. These aspects will be discussed in more detail, however, Östman and Kallsner (2011) noted other findings which they summarised as:

- regional differences in building regulations in some countries;
- a lack of codes and standards for many wood products, resulting in costly and time-consuming certification procedures for technical performance of these products;
- limited use of Eurocodes, although familiarity was increasing;
- uncertainty and lack of in-depth knowledge of building regulations relevant to use of wood in construction;
- limited external use of wood or wood products due to height of the building and distance between adjacent buildings – related to external spread of fire;
- variation in the maximum number of storeys permitted.

In respect of CLT, Östman and Kallsner (2011:17) note that under Eurocode 5, 'no specific rules for the design of Cross-Laminated Timber (CLT) elements are given.' However, 'within the Technical Committee CEN/TC124, Working Group 3 (WG 3), a working document for requirements on CLT products has been drafted'.

7.3 North America – USA and Canada

The North American Wood First Initiative (Wood First) has been developed aimed at supporting the increase of the 'use of wood products in North American non-residential construction'. The Canadian Government under its Economic Action Plan (EAP), aimed at 'support(ing) Canada's forest and wood products sectors' has also developed the Canada Wood Program, designed to expand Canada's wood product influence in the European and Asian markets. In addition there is a 'Value to Wood Program', an academic based incentive, aimed at encouraging wood use in the industry. Under the Transformative Technologies Program of Natural Resources Canada, FPInnovations launched its CLT program in 2005 (FPInnovations 2011, C1:2). Within the CLT program, FPInnovations has played an important role in promoting the expansion of wood use outside of the residential building sector. Various 5 to 6 storey residential and office buildings have resulted, as well as discussing alterations of national building codes to complement CLT use. For example, the British Columbia Building Code (BCBC) has already 'made a revision to allow platform wood-frame residential construction up to 6 storeys', while Quebec has recently allowed the 'construction of a heavy/timber/concrete hybrid office building' (FPInnovations 2011, C1:21)

Under Canadian law, the provinces and territories are responsible for regulating the construction industry (Surprenant 2010). These jurisdictions may, in turn, delegate their powers in this area to municipalities. The federal government is also entitled to regulate the construction industry to ensure compliance with the *National Housing Act* and the *Hazardous Products Act*.

Canada's construction industry is overseen by six codes which form the National Model Construction Codes (NMCC). Provincial and territorial authorities may decide to adopt the various codes developed in full, or they may adapt them to their needs, hence why they are referred to as model codes. Overall, they are of key importance to the construction industry, since they set out what is and is not permitted.

Specific legislation and policy has also been developed, and is in the process of implementation in parts of Canada and the United States of America (US). British Columbia (BC) is the first jurisdiction in the world to pass legislation requiring the use of wood materials for construction. Known as the *Wood First Act,* other states in the greater North American region, such as Oregon, in the US are adopting this act and similar policies (Wood Enterprise Coalition n.d.) The implementation of the *Wood First Act* in BC is consistent with the pan-Canadian policy towards greater wood use.

FPInnovations, which is based in Canada, has developed a CLT Handbook (FPInnovations 2011) which is divided into Chapters addressing CLT manufacture, structural performance, seismic performance, connections, dimension of load and creep factors, vibration, fire, acoustics, enclosure design and environmental performance.

The US has the International Building Code (IBC) which has been developed by the International Code Council (ICC 2006). The APA – Wood Engineering Group provides an extensive range of free guidelines for building with timber, including building energy efficient wood walls and creating wind resistant roofs. These documents aim to integrate the IBC with best wood practice within construction.

The American National Standards Institute (ANSI) and the APA are also developing an American National Standard – *ANSI/APA PRG 320-201x Standard for Performance-Rated Cross-Laminated Timber* (ANSI/APA 2011). The document was still in draft form (90% as of May 2011) at the time of writing.

Standards for product testing for the US and Canada are often joint exercises, developed concurrently to ensure consistency with each country adopting the standard within their system.

7.4 New Zealand

The Building Code in New Zealand (BCNZ) sets out performance standards that building work must meet. The *Building Act 2004* provides the law for building work. Schedule 1 of the supporting *Building Regulations 1992*, details BCNZ. The *Building Act* as it relates to buildings is implemented at the local level by district and city councils. BCNZ defines the minimum standards buildings must meet. It has 35 technical clauses covering requirements such as managing external moisture, structure and ventilation.

Some development is also required to be assessed under the New Zealand *Resource Management Act* (RMA). City or district councils prepare district plans that focus on managing aspects of subdivision and land use that can affect the environment, such as the height, appearance and location of buildings. As each city or district council prepares its own district plan the requirements of these reflect the aspirations of each community and are not consistent across the country. A resource consent is a formal approval and applies to the use or subdivision of land, the taking of water, the discharge of contaminants in water, soil or air, or the use or occupation of coastal space. Each council decides if a resource consent is required. In contrast to the plans prepared under the RMA, the BCNZ provides a common set of minimum rules for the whole of New Zealand.

In New Zealand, the building regulations are generally accommodating of timber construction. The standards for design of timber structures are applied by Standards New Zealand. Relevant standards include *NZS3603: 1993* – for multi-storey buildings and *NZS3604* for houses. Amendments have occurred to these standards since implementation, due in part to improved wood technology. John et al. (2009) state that, since 1992, the BCNZ has allowed timber buildings of unlimited height provided that performance requirements are met, whereas earlier codes limited height to only three storeys.

Further discussion of aspects of building regulations in Europe, North America and New Zealand relevant to timber buildings and more specifically CLT follows. This discussion draws heavily on the study of European building regulations conducted by Östman and Kallsner (2011) and the CLT Handbook of FPInnovations (2011). Other studies are referred to as appropriate.

7.5 Structural stabilisation

The CLT Handbook (FPInnovations 2011) reviews various investigations undertaken in Europe for the determination of design and structural properties of CLT, noting that these are both experimental and analytical in nature. Studies relating to, for example, the flexibility and stiffness of timber panels, are discussed and their application in the use of CLT is considered. Theories including Blass and Fellmoser's (2004) "Composite Theory" and Kreuzinger's (1999) "Shear Analogy" are reviewed, noting that many European studies have focused on 'predicting the stiffness and not the strength properties of CLT panels in flexure'. They also note there is little information on 'creep and vibration' behaviour of CLT panels, with further research needed to be undertaken in design properties in order to be compatible with North American building codes and regulations.

The CLT Handbook Chapter on dimension of load and creep factors reviews how the structural characteristics and design of CLT ensure that it is prone to 'time-dependent deformations under load' (known as 'creep') more so than other 'engineered wood products, such as glue-laminated timber' (FPInnovations 2011, C6:iii). As the load duration, creep factors and service factors of CLT are not identified in specific Canadian Standards, such as the Canadian Standard on Engineering Design in Wood (CSA O86-09), the authors propose two options, one of which is consistent with the format in the Canadian Standard on Engineering Design in Wood, the other is consistent with the format in the European Timber Design Standard. FPInnovations (2011 C6:9) notes that a parametric study is to be carried out on CLT slabs subjected to various load configurations and spans to verify the proposed options.

The CLT Handbook Chapter on Connections (FPInnovations 2011, C5) notes the need for structural efficiency for proprietary and conventional connector systems. It also discusses issues and advantages of connector systems. The chapter finally concludes that further studies are needed in the Canadian, and subsequently, international arena for the engineering design specifications in this area in order to comply with Canadian material design standards and the Canadian National Building Code. In North America, both the Canadian and US building codes address wind load.

In the context of Östman and Kallsner's article, 'stabilisation' refers to wind loads, with timber buildings having a low self-weight compared to concrete structures' (Östman and Kallsner 2011, p.17). In Europe, Eurocode 5 part 1-1, common European rules for design of timber buildings are given. In the present version of the code two simplified methods, A and B, for design of wall diaphragms (shear walls) exist. The main difference between the two methods is that in method A the vertical studs must be fully anchored with respect to uplift forces while in method B the bottom rails have to be anchored. Both methods can be applied for one-storey buildings but only method A can be used for multi-storey buildings. The recommended method in Eurocode 5 is method A, but method B may be given as a national choice. In Eurocode 5, no rules for design of CLT elements are given. Within the Technical Committee CEN/TC124, Working Group 3 (WG 3), as noted previously, a working document for requirements on CLT products has been drafted (Östman and Kallsner 2011, p.17). CLT has been identified directly as a means by which wall diaphragms (or shear walls) in tall timber buildings can be replaced in order to improve stiffness properties and load-carrying capacity (see Vessby 2008).

According to Chapman (2010), the CLT system relies on walls as the main elements for supporting both vertical and horizontal loads. Chapman has explored three timber based systems for resisting lateral loads for CLT buildings to six storeys in an effort to provide more 'open' floor spaces in commercial uses.

7.5.1 Seismic design

In the European region, Eurocode 5, *Design of timber structures*, and Eurocode 8, *Design provisions for earthquake resistance of structures*, are new design codes. Guidance on the use of Eurocodes in the seismic design of wooden residential buildings has been published (see Toratti 2001; Toratti 2006). In Italy, the SOFIE project (see FPInnovations 2011, C4:2) was undertaken by the IVALSA Institute of the National Research Council with the support of Provincia Autonoma di Trento. This project resulted in shake table testing of a seven storey CLT building in Miki Japan in 2007 (Franch 2007). Figure 20 shows an image from the setting up stage of the shake table- after earlier testing in laboratories (Ceccotti et al 2006). Franch (2007) notes that:

Wooden structures possess some inherent characteristics that make them particularly suited for the use in regions with a high seismic risk, both due to material properties (lightness and load bearing capacity) and to system properties (ductility and capacity of energy dissipation).

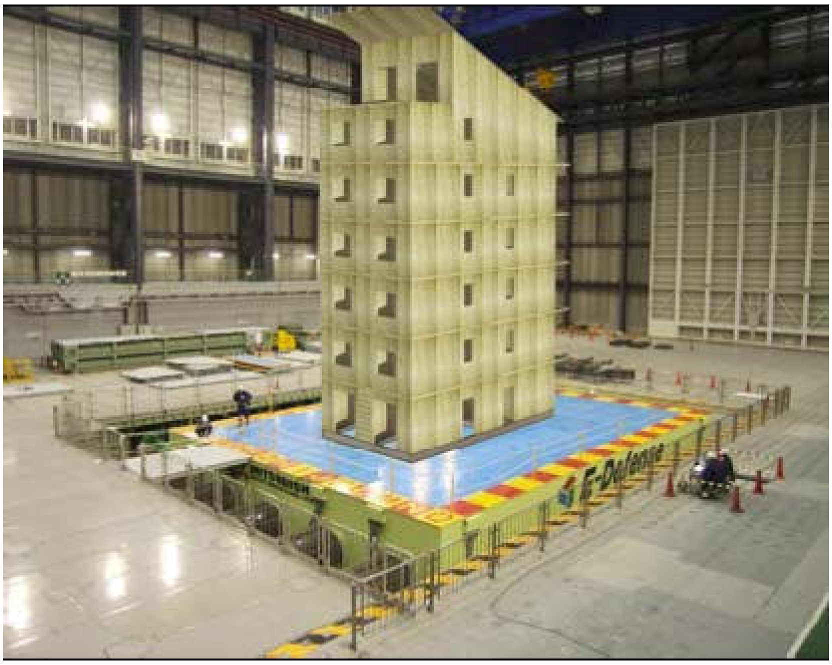


Figure 18 Setting up for the seven-storey CLT building shake table test in Miki, Japan (from Franch 2007)

The CLT Handbook (FPInnovations 2011) presents an overview of international studies relating to the seismic performance of CLT wall panels and structures in Chapter 4. Findings of a series of quasi-static tests undertaken by FPInnovations are also presented, aimed at testing various configurations and connection details of various CLT wall panels. They discovered that CLT wall panels have 'adequate' seismic performance 'when nails or screws…..with steel brackets' and 'timber rivets in small groups with custom made brackets' are used in high seismic zones. The authors also include a survey of the 'development and assessment of R-factors (such as the reduction of seismic force) for different structural systems'; the 'behaviour of European q-factor for CLT structures', and 'values of R-factors of CLT buildings' in relation to the National Building Code of Canada (NBCC). FPInnovations has developed tentative estimates for R-factors (force modification factors) for CLT structures within the NBCC, based upon tests that were conducted (FPInnovations 2011, C4:5).

Currently, building codes in North America 'account for the capacity of (a) structure to undergo ductile nonlinear response, which dissipates energy and increases the building period' (FPInnovations 2011, C4:26). This ultimately, allows the structure to 'be designed for seismic forces smaller than the forces that would be generated if the structure remained elastic, without increasing the displacement from seismic loads'. In response to the means in which different structures cope during past earthquakes, and their ability to 'undergo nonlinear response with limited loss of strength as (a) structure goes through several cycles of motion', different R-factors (the response modification coefficient, to reduce seismic design force) are assigned to different structural systems (FPInnovations 2011, C4:26). The Canadian NBCC has two factors to 'reduce elastic seismic load' – the Rd factor, relating to the 'durability of the structure' and the R0 factor which relates to the 'over-strength of the (structural) system' (FPInnovations 2011, C4:26). These R-factors are determined using various methods.

In the US, the IBC (ICC 2006) specifies R-factors. The IBC has employed the Equivalency Approach for assigning an R-factor to new prefabricated wood assemblies (FPInnovations 2011, C4:27). Furthermore, with the improvement of design codes internationally, there has been an 'expansion of code-approved seismic force resisting systems'. For example, the US Federal Emergency

Management Agency (FEMA) and the Applied Technology Council (ATC) development of the FEMA - 695 document (see FPInnovations 2011, C4:27).

Timber construction in New Zealand has been favoured due its performance during major earthquakes, which occur frequently as the country is a high seismic area. Tonks and Chapman (2009) explain that, from early experience in the 1840s, timber buildings have consistently outperformed masonry, stone and concrete structures. They describe the outcome of the first major earthquake of magnitude (M) 7 recorded in Wellington on 13 October 1848, quoting from the *Wellington Independent* (18 October 1848):

"...few brick or clay houses resisted the shock…and the earthquake has clearly demonstrated that wooden buildings are about the only class of habitations, which can be deemed secure against such dreadful shocks…"

A larger M8.2 earthquake in Wellington in 1855 also destroyed stone and brick buildings and lifted the harbour floor by 1.5 metres. Tonks and Chapman (2009) noted again that reports from the time indicate how well the timber buildings withstood the impact, commenting that confidence in timber structures was reinforced through such experiences.

7.5.2 Durability design

Durability concerns the 'capacity of the structure to give a required performance during an intended service period under the influence of degradation mechanisms', however, according to Englund (cited in Östman and Kallsner 2011, p.13) 'conventional durability design methods for wood do not correspond to this definition'. Östman and Kallsner (2011) identified a number of issues which affect the durability of a wooden construction, including decay fungi, the influence of moisture on wood and the service life (and life cycle) of a product. They also recognise that 'service life estimation efforts for wood and wood-based products are an area of research that so far has been given little attention in Europe', with 'generally no direct limitations (relating to durability) in building regulations (Östman and Kallsner 2011, p.21).

Guidelines in North America, such as the *Best Practice Guide for Wood-Frame Envelopes* (CMHC 1999) and the *Building Enclosure Design Guide – Wood-Frame Multi-Unit Residential Buildings* (HPO 2010) recognise that wood has durable features, although these depend on protection from moisture. In these guidelines, 'durability by design' requires shaping the construction and the detailing so that an efficient water protection is attained. Alternatively, or as an additional beneficial design feature, a design may be sought that allows for an efficient drying of wood components that have been wetted above critical levels of moisture. There is a recognised need to avoid creating 'water traps' as extended periods of increased wood moisture content causes decay.

For CLT, FPInnovations note that its moisture content should be less than 19% at any location (FPInnovations 2011, C10:21). The method of CLT manufacture and use as a structural material means that during and after construction CLT panels must be protected from rain and moisture through properly designed wall assemblies and covers. The CLT Handbook (FPInnovations 2011) devotes a Chapter to building enclosure design (Chapter 10) and refers to the *Best Practice Guide for Wood-Frame Envelopes* (CMHC 1999) and the *Building Enclosure Design Guide – Wood-Frame Multi-Unit Residential Buildings* (HPO 2010). It explores the best practices related to 'heat, air and moisture control strategies' for wall assemblies in the North American climate zones.

CLT is not a cladding material and not to be used for the exterior and must be protected from rain and other moisture sources (FPInnovations 2011, C10:1) Heat, air and moisture control design criteria for an exterior wall or roof assembly need special attention (FPInnovations 2011, C10:1). CLT panels are not resistant to termites and would need protection in areas of high termite activity. A barrier between the ground and CLT panels is required. The 90% Draft Standard for Performance-Rated Cross-Laminated Timber (ANSI/APA 2011) notes that CLT shall be used in dry service conditions where the mean equilibrium moisture content of solid-sawn lumber is less than 16% (p. 5 of 26). The draft standard specifies that installation requirements need to be prescribed by the manufacturer for products trademarked according to the standard. Product testing also requires that an average moisture content should not be less than 8% (ANSI/APA 2011, p. 17 of 26). Hence the properties of CLT are determined based on moisture contents ranging between 8% to 16%.

In New Zealand, Clause B2 of the Building Code is the technical clause for durability and includes timber treatment. It sets out the durability requirements for all building elements.

7.5.3 Adhesives

The 90% Draft Standard for Performance-Rated Cross-Laminated Timber (ANS/APA 2011) notes that adhesives used for CLT manufacturing shall meet requirements of AITC 405 in the US or CSA 0112.10 in Canada with minor exceptions. The standard also requires adhesives to be evaluated for heat performance in accordance with Section 6.1.3.4 of DOC PS1 and meet Service Class A (limited water exposure) requirements specified in ASTM D 2559. It is noted that the intent of the heat performance evaluation is to determine whether and adhesive has exhibited delamination characteristics. The 90% Draft Standard notes also that FPInnovations have explored heat durability testing for classifying adhesives in cross-layered wood products. The CLT Handbook notes that reference to ASTM D2559-10a Service class A in the US and CSA O112.10 in Canada and adding ASTM D7247 are being investigated (FPInnovations 2011, C8:11).

The proprietary nature of CLT products from Europe has been noted as a major reason for the Eurocodes in Europe to not specify its material properties such as duration of load and creep. Creep is significant in bonded surfaces under load, and FPInnovations (2011, C6:8) noted that creep in CLT under load is 30-40% greater than for Glulam, which has its surfaces laminated uni-directionally. They cite the work of Jobstl and Schickhofer (2007) who determined that deformation for CLT of 7 layers or less is 10% more than for plywood, but similar to plywood for CLT of 9 layers or more. Thus caution should be taken in using factors for Glulam or plywood to determine the behaviour of CLT (up to 7 layers) under load.

Custodio, Broughton and Cruz (2009) have identified a number of factors determining the durability of structural adhesive joints, grouping them into three categories: environment, materials and stresses. They state that the environmental factors are dominated by temperature and moisture. The materials category includes the ‘adherend’, the adhesive, and the inter-phase between them both. The stresses include those that the bond is subjected to during or after exposure to service environment, affecting both longevity and residual strength.
Other research on adhesives for CLT focus on its volatility, impact on indoor air quality and safe working environments. The CLT Handbook of FPInnovations reviews a study of 5 CLT products, with different thicknesses and glue lines for the presence of volatile organic compounds to help assist builders and engineers to better select construction materials.

7.5.4 Acoustics and vibration

Acoustics is another aspect of building in timber which is of concern to the construction industry and regulators, although unique characteristics of timber (especially CLT) differentiate it from light wood joisted floors and heavy concrete slab floors (Östman and Kallsner 2011:13, FPInnovations 2011, C9:11; Gagnon and Hu 2007).

BRE (2004) note that, in a survey of various stakeholders associated with building projects in European countries, wood-based products for multi-storey buildings were least popular in application in the acoustic and ceiling zones of floors. Their study noted that in internal and compartment floor constructions, limitations were generally related to providing adequate sound insulation, particularly in multi-occupancy dwelling applications. Wood-based product used in the acoustic zone was felt to be unsuitable and interviewees preferred other materials for use in this application, especially in combination with a lightweight structural floor system. However, in the majority of floor applications interviewees agreed that wood-based products are suitable, despite limitations to their use.

In Europe, the first regulatory sound insulation requirements appeared about 50 years ago, with many European countries adopting a typical or 'traditional' frequency range of 100-3150Hz for new developments. However, in countries where traditional light weight material and practices have been used in buildings (such as Norway and Sweden), lower frequency ranges, (below 100Hz) have been introduced within regulations (Östman and Kallsner 2011:13). Since 1996, Sweden now regulates a minimum requirement of frequency bands down to 50Hz in construction. No other country in Europe has adopted this regulation. However, there is evidence that in the past decade, 'low-frequency descriptors (down to 50 Hz) have been introduced in the criteria for the higher, voluntary quality classes in the classification schemes in all five Nordic countries and in Lithuania' (Östman and Kallsner 2011:13).

The study of Östman and Kallsner (2011) noted that the regulatory requirements for sound insulation between dwellings focuses on both airborne sound and impact sound. Figures 21 and 22 for a comparison of legal requirements for airborne sound and impact sound between dwellings for 24 European countries. For airborne sound insulation, differences between the minimum and maximum standards for multi-storey housing and row housing across 24 countries in Europe in 2008 were 5 dB for multi-storey and 10 dB for row housing. The strictest requirements are found in Austria while low-frequency descriptors applied only in Sweden. For impact sound insulation, the difference between the minimum and maximum was 17 dB for multi-storey and 22 dB for row housing. Again the strictest requirements were found in Austria and low-frequency descriptors applied only in Sweden (Östman and Kallsner 2011:14).

While Eurocode 5 provides a method for designing residential floors that considers vibration, stated to be applicable to multi-storey buildings, Östman and Kallsner (2011:14) consider that this aspect needs further attention.

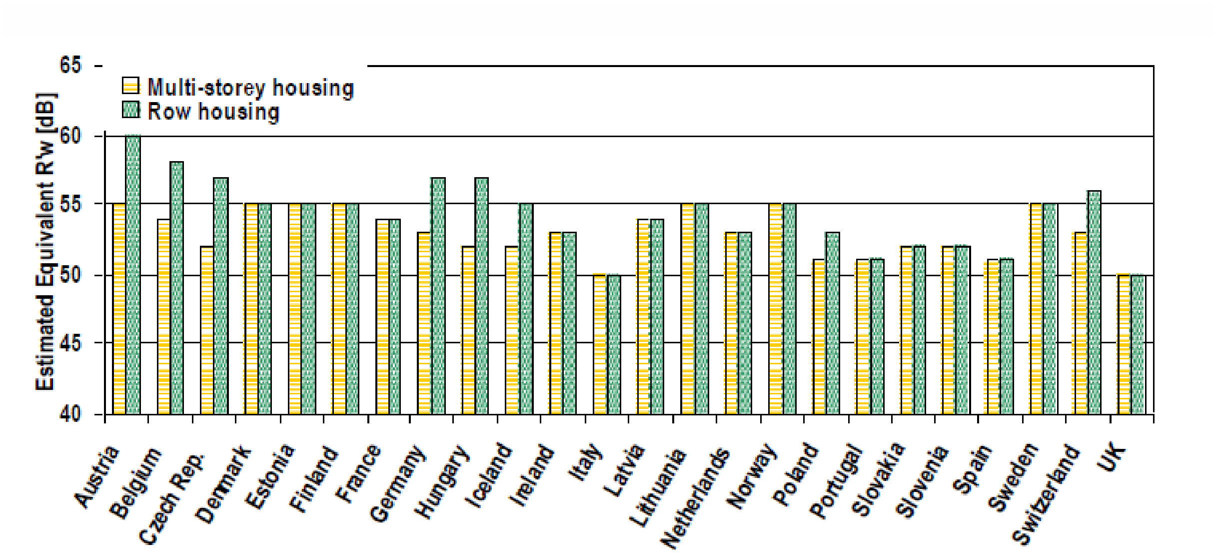


Figure 19 Airborne sound insulation between dwellings. Minimum legal requirements for 24 countries - 2008 (From Ostman and Kallsner 2011)

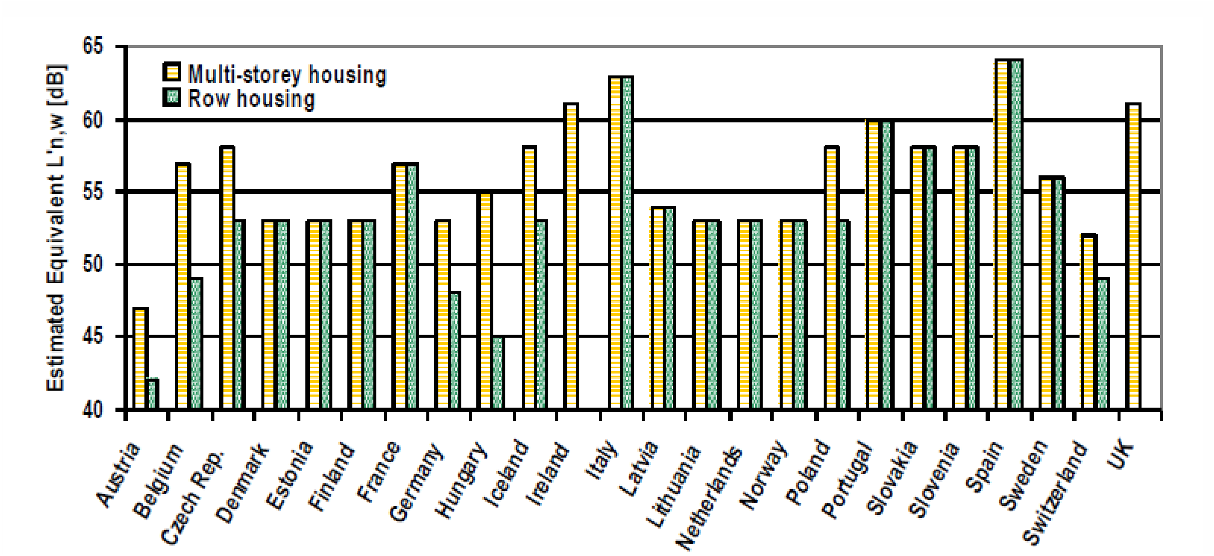


Figure 20 Impact sound insulation between dwellings. Maximum legal requirements for 24 countries - 2008 (From Ostman and Kallsner 2011)

In Canada and the US, adequate levels of noise/sound control in multi-family buildings are mandatory requirements of building codes (FPInnovations 2011, C9:4). In the NBCC, it is stipulated that 'a dwelling unit shall be separated from every other space in a building in which noise may be generated by construction providing a sound transmission class (STC) of at least 50dB. This level of performance shall be of 55 dB near elevators or refuse chute' (FPInnovations 2011, C9:4). Under the NBCC, there are no specific requirements for impact sound insulation class (IIC), however there is a recommendation that bare floors should achieve an IIC of 55dB or better (FPInnovations 2011, C9:4). The typical STC of generic wood-frame wall assemblies is stated to vary between 30dB to 65 dB (FPInnovations 2011, C9:5).

Hagberg, Larsson, Bard (2010) conducted research relating to strengthening light weight structures. This project had 'strong links to European standardization (sic) within the CEN (European Committee for Standardization)', such as reviewing CEN standards, including *FP0702 Net-Acoustics for Timber based Lightweight Buildings and Elements* and *TU 0901 Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions* (Östman and Kallsner 2011:13).

Research by the World Health Organisation (WHO) on building sound and living standards through an analysis of European housing has identified neighbour noise as a health problem, and now is receiving serious attention from the organisation (See WHO cited in Östman and Kallsner 2011).

There has been intercontinental collaboration between the French Institute of Technology for Forest-Based and Furniture Sectors (FCBA) of Bordeaux and FPInnovations in Canada, relating to the testing, predicting and enhancing sound transmission loss of wood construction, especially in relation to CLT panel floors and walls. The FCBA ultimately provided 'step by step guidance' for FPInnovations for the design of North American CLT floor systems (FPInnovations 2011, C9:7). This complemented work undertaken by FCBA in 2006, relating to different floor systems, using 5-layer CLT panels. Regardless of this research, FPInnovations notes that 'very little work has been done in Canada on the acoustic performance of CLT systems in construction' (FPInnovations 2011, C9:39).

7.5.5 Fire design

Last but perhaps of most concern to building designers, developers and government organisations including fire brigades, is the fire performance of CLT buildings. One of the key challenges in building in timber relates to fire safety and the combustibility of timber. In Europe, the standardisation of continental and national fire regulations has been a key area of research (Östman and Kallsner 2011). The majority of fire regulations in Europe are generally prescriptive, however, recent research and improved understanding of the fire design of timber buildings has meant many European countries are in the process of altering these regulations to be more performance-based (Östman and Kallsner 2011, p.9). The document *Fire safety in timber buildings: Technical guideline for Europe* (SP Tratek 2010) has been developed by leading experts and researchers from nine European countries and is being used to inform the review of the Eurocode 5 for fire safe design and principles of performance based design. Based on fire testing studies conducted in Europe, building regulations in European countries have eased over the past decade, and have been, or are being amended to allow multi-storey buildings up to 5 or 6 storeys to be constructed using CLT panels as structural members (See Östman et. al. 2010).

While the Structural Eurocodes specifically reference fire design under Part 5.1.2 – Fire Design, and efforts are directed towards their standardisation, Östman and Kallsner, and other researchers, have still discovered vast inconsistencies and limitations across countries in Europe. One of the main differences includes the number of storeys permitted in timber structures, (Östman & Rydholm cited in Östman and Kallsner 2011). Based on the concerns about fire, countries such as Sweden, Germany, and France limit the height of timber buildings to 5-6 storeys, whereas other countries, such as Finland have only allowed a maximum of two storeys (Östman and Kallsner 2011:9). Recent evidence, however, suggests that Finnish fire regulations have been relaxed to allow timber buildings up to 4 storeys.

Further limitations are evident when these multi-storey buildings contained exposed wood. The types and/or amounts of visible wood surfaces in interior and exterior applications has an effect on approval of timber buildings in some countries. While the United Kingdom's building regulations allow timber buildings of any height, the fire regulations allow a 2 storey maximum if timber ceiling and wall linings are exposed. Hence building regulations for multi-storey timber buildings in the UK require fire resistant linings and cladding. Figure 23 shows the change over time in the maximum number of storeys in timber allowed for buildings in countries across Europe. Figure 24 shows the status in 2006 of regulations that allow buildings to have exposed timber lining without sprinklers in terms of the maximum number of storeys in timber allowed. The differences are clear.

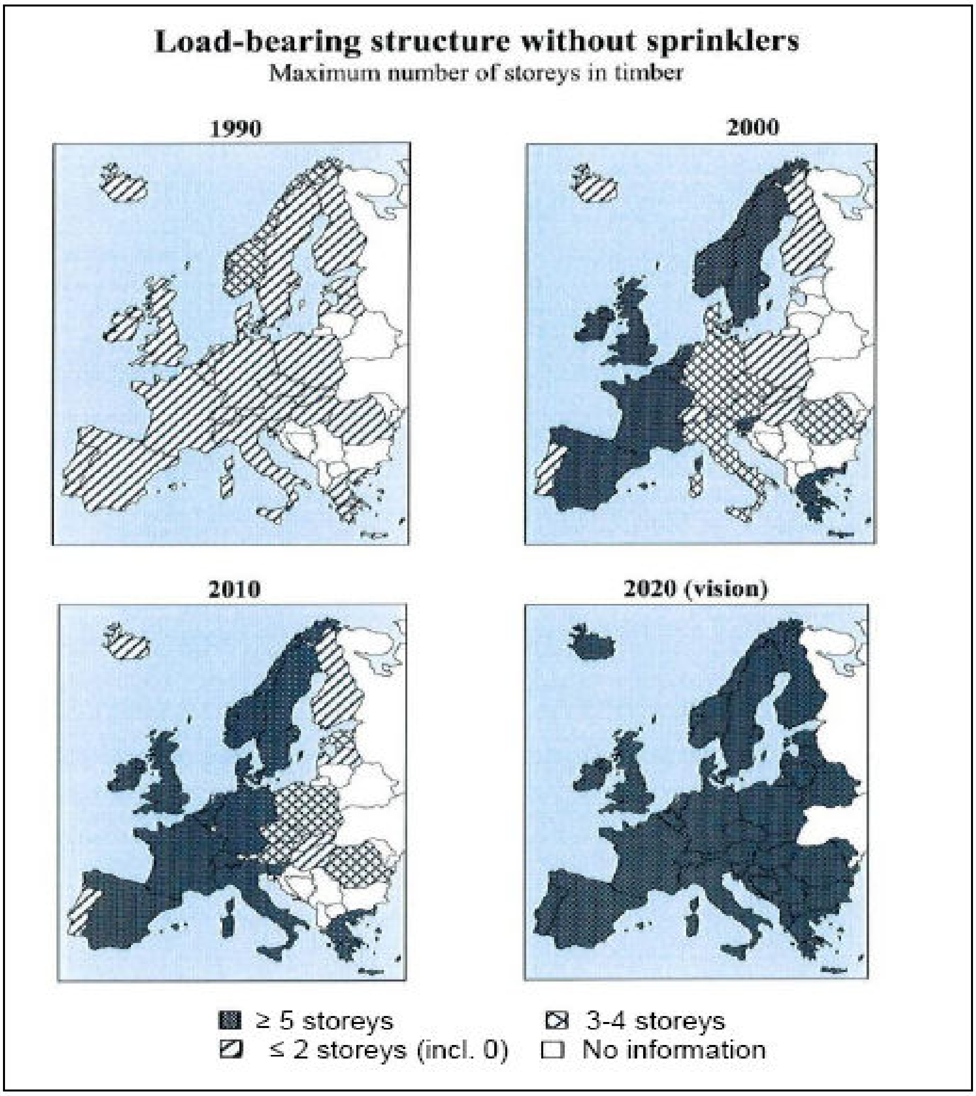


Figure 21 Differences in the maximum number of storeys of timber buildings without sprinklers (from Östman and Kallsner 2011)

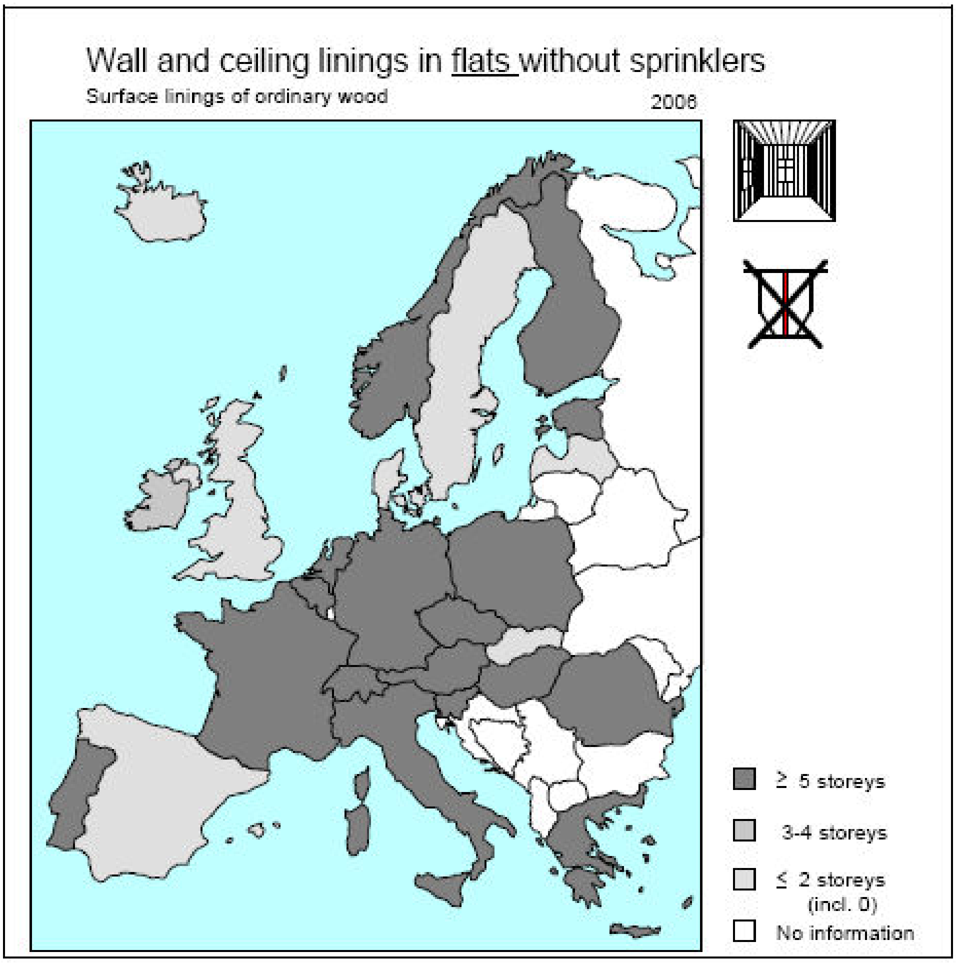


Figure 22 Differences in the need for wall and ceiling linings in apartments without sprinklers (from Östman and Kallsner 2011)

Currently, the *Construction Products Directive* (CPD) in Europe requires that buildings must be designed and built to: maintain loadbearing capacity during fire; limit the generation and spread of fire and smoke, particularly to neighbouring structures; ensure that occupants can leave a building safely or be rescued by another means; and consider the safety of rescue teams (Östman and Kallsner 2011:9). These CPD regulations are complemented by two European fire standards, implemented in national building regulations. The reaction to fire means the initial response of a material to fire exposure and the fire resistance (structural design) means that structural elements, e.g. wall elements, must withstand a fully developed fire and fulfil certain performance requirements, load-bearing capacity (R), integrity (E) and insulation (I). In Sweden, for example, fire resistance is currently expected to be provided for 30 minutes (REI 30) up to 2 storeys; 60 minutes (REI 60) for 3-4 storeys; and 90 minutes (REI 90) for 5-8 storeys.

The massive timber-constructed buildings comprising the Portvakten housing complex in Söder, Växjö Municipality (Sweden), completed in 2009, have been designed to comply with the Swedish Fire Protection Association's demands for a fire safe home (Swentec n.d.). Each of the 32 apartments in each building is equipped with both fire extinguisher and fire blanket in addition to fire detectors. Swentec also explain that the fire detectors are "intelligent" and turn off the power to the stove, dishwasher, washing machine and dryer should any of these become over-heated.

Compartmentation is a strategy being used to limit the spread of fire by containment within fire resisting walls and floors. Each country, apart from France and Germany (Hesse) has some requirements for the compartmentation of residential buildings, but only the Netherlands uses the additional concepts of 'sub-fire compartments' and 'smoke compartments' (Sheridan et al cited in Östman and Kallsner 2011).

In the United Kingdom (UK), full scale fire tests were undertaken on a six storey demonstration building, as part of the 'Timber Frame 2000' or TF2000 project (BRE 2003). The project, a collaboration between the UK Government, BRE, TRADA Technology Ltd and the UK timber industry, focused 'exploiting the UK's potential to become world leader in the provision of medium-rise timber frame buildings', as well as encouraging wide-spread market acceptance of timber frame constructions, by demonstrating the benefits of this form of construction. Although now completed, TF2000 project provided vital details relating to timber construction, including the production of authoritative guidance documents and a published design guide on the structural stability and robustness of timber, fire safety, differential movement and construction process and procedures (BRE 2003).

The UK Timber Frame Association (UKTFA) (2011:5) states that UK Building Regulations and fire safety regulations are among the most stringent in the world. However, one aspect of fire safety with timber buildings which has become increasingly prominent in the UK is fires during construction. The Approved Document B notes that the risk of fire during construction work in the UK is covered by the *Construction (Design and Management) Regulations 2006* and the *Regulatory Reform (Fire Safety) Order*. The Health and Safety Executive (HSE) is responsible for enforcement on the construction site if it is unoccupied and has published *HSG 168 Fire Safety in Construction*. However, where construction work may be undertaken on part of a building that is occupied, the Fire and Rescue Authority is responsible for enforcement of the regulations. A recent study on urban fires in London (Greater London Authority 2010) has highlighted the need to address fires during construction, particularly in early stages of construction which are not covered by building codes generally. The document *16 Steps to Fire Safety: Promoting best practice on Timber Frame construction sites* (UKTFA 2011) provides duty holders of these sites with guidelines about safe timber construction practices. This document notes that it should be read in conjunction with the *Joint Code of Practice on the Protection from Fire of Construction Sites and Buildings Undergoing Renovation*, published by the Construction Confederation and The Fire Protection Association and *HSG 168 Fire Safety in Construction* published by the (HSE).

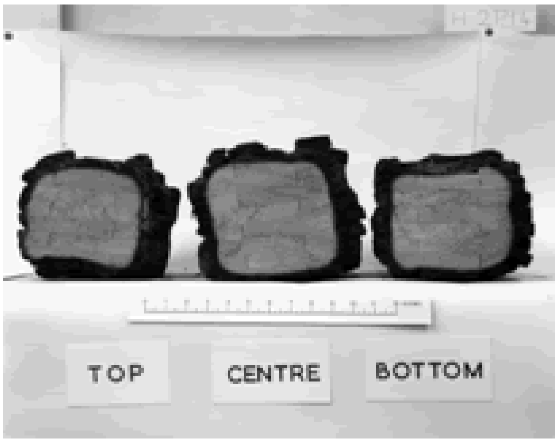
Research by Frangi, Fontana, Hugi and Jobstl (2009) for the *WoodWisdom-Net* Research project in Europe found that the char layer of timber is a good insulator and protects the remaining uncharred residual cross-section against heat. They noted that fire behaviour of CLT panels is strongly influenced by the behaviour of the adhesive used for bonding the cross-laminated timber panels and whether the char layer remains intact. Further research in the area has seen the development of glass wool insulation (instead of stone wool), to resist high temperatures caused by fire, which can be used for timber structures such as the ULTIMATE product range (See Andersson 2010).

In North America, the flammability of materials is regulated in the NBCC with flame spread rating limited to 150. This is measured using the standard test method CAN/ULC-S102-07 in Canada and ASTM E84-10 in the US. In Canada, following research undertaken in Europe, a research project was launched by FPInnovations in April 2010, to 'develop and validate a generic procedure to calculate the fire-resistance ratings of CLT wall and floor assemblies'. FPInnovations have since commenced a series of 'full-scale fire resistance experiments to allow a comparison between fire resistance rating measured during standard fire-resistance testing' and that of a procedure proposed by researchers of typically North American design CLT assemblies (FPInnovations 2011, C8:1-2). Although only recently commenced, this project is aimed at facilitating the 'acceptance of future code provisions (such as the National Building Code of Canada) for the design of CLT panels for fire resistance' (FPInnovations 2011, C8:2). FPInnovations note that CLT panels often deliver good fire resistance, stated to be comparable to massive assemblies of non-combustible construction. (FPInnovations 2011, C8:1). Current building standards in North America recognise the fire performance of solid wood assemblies. An example in the NBCC stipulates minimum thicknesses of both load bearing and non-load bearing solid wood walls and floors for fire resistance ratings of 30, 45, 60 & 90 minutes under Section 2.4 of Appendix D (FPInnovations 2011, C8:1). The building regulations require that 'key building assemblies exhibit sufficient fire resistance to allow time for occupants to escape and to minimize (sic) property losses' (FPInnovations 2011, C8:1)

Other standards and guidelines are consulted and procedures undertaken in order to calculate the fire resistance of timber and non-timber structures. Fire resistance is traditionally assessed by subjecting a replicate of the assembly to the standard fire-resistance test (CAN/ULC S101 in Canada and ASTM E110 in the US and ISO 834 internationally) (FPInnovations 2011, C8:1). In the case of CLT, for fire resistance, panels are subjected to the Canadian Standard for Engineering Design in Wood (CSA O86). A similar standard is also used for fire resistance rating for Glulam and 'heavy 'timber in the US, NZ and Europe (FPInnovations 2011, C8:4)

Based on similar research undertaken in Europe, a one-year research project was launched by FPInnovations in April 2010, to develop and validate a generic procedure to calculate the fire-resistance ratings of CLT wall and floor assemblies. They have since commenced full-scale fire resistance experiments to allow a comparison between fire resistance rating measured during standard fire resistance testing and that calculated using their proposed method (FPInnovations 2011, p. 17). FPInnovations (2011) state that fire resistance of CLT is calculated using 5 steps: calculation of char depth; determination of effective residual cross-section; find location of neutral axis and moment of inertia of the residual cross- section; calculation of structural resistance (calculation of the moment resistance (floors) or calculation of axial resistance (walls)); and comparison of residual resistance to calculated load. In 2010, Craft (of FPInnovations) reported that research was underway at Carleton University in Ottawa which was comparing the relative risk to occupants and property by using CLT construction in place of other traditional construction materials. The findings of this study have yet to be published.

The Building Research Establishment in the UK has documented the results of timber performance during fire tests which show that timber retains its structure (see Figure 23).



Cross-sections of a timber column after fire test.
(Photo: BRE)

Figure 23 Images of charred timber after fire tests in the UK
(Source: http://www.mace.manchester.ac.uk/project/research/structures/strucfire/materialInFire/Timber/Charring/charingRate.gif)

In New Zealand, while fire testing has been undertaken for a patented product (Pres-Lam) made from laminated *Pinus radiata* to inform its use in multi-storey timber commercial buildings (Buchanan et al. 2009), their research does not provide fire testing results of CLT panels for similar use. They state that floors in multi storey timber buildings will need to be carefully considered, and fire-rated suspended ceilings used if necessary to provide the required rating. Buchanan et al (2009) also state that the most effective and reliable means of fire protection in all buildings is an automatic sprinkler system. A review of fire safe design of multi-storey timber buildings in New Zealand by Thomas (2008) noted that the risk of fire in a timber building was highest during construction but that for “heavy” timber this was less of a problem. He compared “light” timber and “heavy” timber construction systems. Thomas noted that in fire rating terms, standard studs of 45 mm thickness are “light” timber and burn quickly. He commented that the cut-off point between “heavy” or “thermally thick” timber and “light” timber is about 75 mm for the lesser dimension (smaller of depth and breadth of the cross-section). He also noted that if the external heat source is removed from a piece of “heavy” timber it is likely to smoulder and then self-extinguish. However, smaller pieces of timber will continue to burn by themselves.

Thomas (2008) commented that it is usually not necessary to protect “heavy” timber using board products or intumescent paints. However, a study by Chapman (2010) assumed that 16 mm fire resistant plasterboard and three paint coats were needed for a 6 storey CLT building designed for commercial use. While theory may indicate that linings are not required to meet the fire safety requirements of the New Zealand building code, lining of “heavy” timber buildings clearly takes place in practice.

Table 6 Summary of height restrictions and fire standards relating to timber buildings (and CLT if specified)

Country	Height (in timber - general)	Fire performance	Regulation or standard
Australia	Deemed to satisfy provisions of the BCA for timber framed multi-residential buildings allow timber framing in: • All Class 1 buildings • Class 2 buildings to 3 storeys (4 storeys where ground storey is concrete masonry car-parking) • Class 3 building to 2 storeys No specific reference to CLT	The charring rate of a typical softwood having a density of 500kg/m3 is 0.76mm/minute (EWP 2009) Fire rating - 0.65 or 0.66mm/min for *P radiata* 'The BCA requires that compliance of the Fire Resistance Level (FRL) be provided in either a report from a Registered Testing Authority, stating that the material complies with the standard fire test, or alternatively is designed in accordance with AS1720.4 if it is a solid or glued laminated timber structure '. Turner (2010)	Australian Building Codes Board 2010, p.25 AS1720.4
New Zealand	Unlimited, although Banks (2000) noted that only 5 storey buildings had actually been built in timber	NZBC Clause C, requires architects and engineers to consider Fire Safety when designing a building or renovation. The general performance requirements for a passive fire rated element are: • Must prevent premature collapse of the structure • Must prevent premature passage of flame or hot gas • Must prevent significant transmission of heat Thomas (2008) notes difference in fire performance of light and heavy timber – based on thickness – 75mm minimum thickness for heavy timber Buchanan et al (2009) states that 'By far the most effective and reliable means of fire protection in all buildings is an automatic sprinkler system'. Chapman (2010) assumed that 16 mm fire resistant plasterboard and three paint coats may be required for commercial CLT building.	NZ Building Code Clause C
United Kingdom	Load-bearing structure **without** sprinkler: Unlimited Load-bearing structure **with** sprinkler: Unlimited (2009)	All dwelling houses need fire alarms New blocks taller than 30m need sprinkler systems	UK Building Regulations Approved Documents – Specifically Approved Document B EN ISO 1363 Fire resistance tests
Germany	No limit of Storeys for Multi-storey Wood-frame Buildings (Suprenant 2010) Load-bearing structure **without** sprinkler: 3-4 Load-bearing structure **with** sprinkler: 3-4 (2009)	Flats up to 2 storeys – 30 minutes Blocks of apartments between 2-7 storeys – 60 minutes Blocks of apartments of 8 storeys or more – 90 minutes All compartment walls up to 6 storeys – 60 minutes External walls as well as party walls must have two layers of plasterboard as fire protection	DIN 18334: VOB/C Charter fur Holtz EN ISO 1363 Fire resistance tests Model Guideline for Technical fire protection requirements - extremely flame-retardant for wooden construction components (Lattke and Lehmann 2007)

Country	Height (in timber - general)	Fire performance	Regulation or standard
Austria	Limit of 22 metres (Kaufman cited in Hopkins 2011)		OIB requirements EN ISO 1363 Fire resistance tests
Switzerland	Up to 6 storeys (Kaufman cited in Hopkins 2011)	Fire protection standard introduced in January 2005, 60-minute fire-resistance capability (Lehmann 2011)	EN ISO 1363 Fire resistance tests
Sweden	Load-bearing structure **without** sprinkler: Unlimited (unless ordinary framed wood; not fire retard wood – 2 storeys max.) Load-bearing structure **with** sprinkler: Unlimited (2009)	Automatic sprinklers	EN ISO 1363 Fire resistance tests
Norway	Unlimited (Kaufman cited in Hopkins 2011; Suprenant 2010))		EN ISO 1363 Fire resistance tests
France	Unlimited (Kaufman cited in Hopkins 2011)		EN ISO 1363 Fire resistance tests
Spain	Can exceed 5 storeys (Ostman and Kallsner 2011)		EN ISO 1363 Fire resistance tests
Canada	6 storeys: British Columbia Maximum 4 storeys for Multi-storey Wood-frame Buildings (Suprenant 2010) architects, engineers and developers may obtain an exemption to build higher than four storeys	Automatic sprinklers will relax NBCC requirements ie. height restrictions In March 2010, a representative of the Canadian Association of Fire Chiefs said that the use of wood products does not necessarily undermine fire safety, stating that he would consider wood, as well as steel and concrete, for multi-storey building construction, as long as the materials satisfied the provisions of the Code and the building was equipped with a sprinkler system (Suprenant 2010)	NBCC CSA Standard O86 " Engineering Design in Wood" British Columbia *Wood First Act*
United States of America	Maximum number of storeys set at five (IBC) if the building does not have automatic extinguishers for fire prevention. If a wood-frame building has extinguishers and meets the other requirements of the Code, the maximum number of storeys allowed rises to six (Suprenant 2010).		NFPA 5000 code : Building Construction and Safety Code & NFPA Code 1 Fire Code Wood First Act (State of Oregon) ANSI/APA Standard for Performance – Cross-Laminated Timber, 90% Draft (2011)

7.5.6 Building energy efficiency

Improved building energy efficiency is a priority issue in the European Union (EU) where the EU Energy Performance of Building Directive (EPBD) requires Member States to implement improved energy efficiency measures for buildings. The EPBD seeks to ensure that all new buildings will be nearly zero energy by 2020 (Dodoo et al 2011:1596). Kildsgaard (2010) explains that, in addition, the energy will be 'to a very large extent' from renewable sources and that public buildings will be required to meet these strict measures by 31 December 2018. They go on to say that, while no specific target has been set for the renovation of existing buildings, Member States are advised to take measures for stimulation of low energy refurbishments and there are minimum requirements for components for renovations and replacements. Energy performance certificates (EPCs) for buildings are already in use across Europe providing information about the energy used in operating the building compared to its designed performance (see Figure 26 for an example layout of the EU Energy certificate).

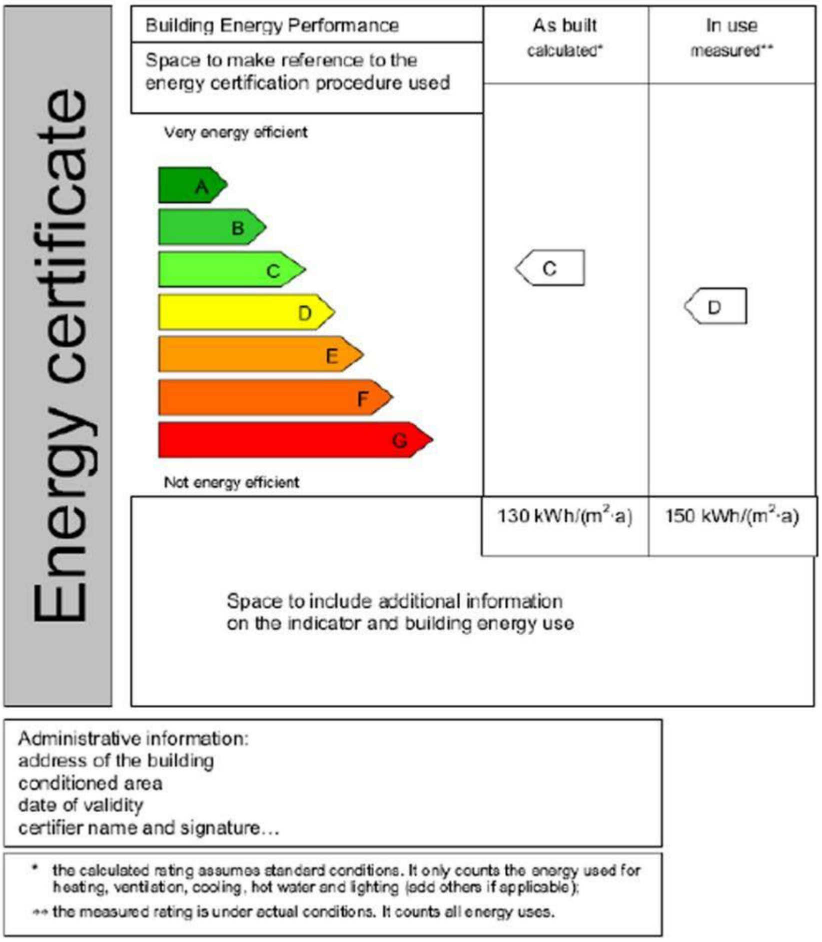


Figure 24 The layout of an Energy performance certificate specified by EU (From Kildsgaard 2010)

The EPBD, however, has been applied differently by each Member State as it is voluntary. In Sweden, Dodoo et al (2011) explain that a stringent building energy-efficiency standard was introduced in response to the EPBD, shifting the compliance criteria to the energy performance method from the average overall U-value method. They note that the energy performance method sets a maximum value per m^2 building area for energy use or CO2 emission based on energy supply, while the average overall U-value method sets a maximum thermal transmittance value for a building envelope. In Denmark, a new building energy-efficiency standard based on the energy frame method was introduced which sets a maximum energy loss value per m^2 building area. In the UK, the energy conservation section of the building code was revised, shifting the compliance criteria to the energy performance method from the elemental U-value method. In Spain, the maximum U-value for building elements was tightened, to further improve the energy performance of building envelopes.

Ostman and Kallsner (2011) conclude that there will be high demand for well insulated structures with very high air tightness and no thermal bridges. They comment that a study on a timber building built to passive house standard in Sweden (the Portvakten building in Vaxjo) has been undertaken that documents the critical points during the development, planning and building phases. They note that analysing energy performance of the building also extends to life cycle energy use, which takes into account choices about construction, building elements and technical systems. While this study is yet to be reported, a recent paper by Dodoo et al (2011) studied the life cycle energy use of a four storey multi-family timber building in Sweden using three energy directive regimes (BBR 1994; BBR 1999 and Passivhus), comparing it to concrete frame construction. Under the Passivhus regime, while the primary energy use during the operation phase dominates the life cycle primary energy use, the relative importance of the other life cycle phases increases with improved energy efficiency. Dodoo et al (2011) cite various other studies (Sartori & Hestnes; Thormark; Gustavsson & Joelsson; Citherlet & Defaux; and Verbeeck & Hens) that also found that building material choice becomes increasingly important for a building with lower primary energy use for operation.

In the UK, in 2010, the Code for Sustainable Homes (CSH) Level 3 (Energy) became a requirement of Building Regulations Part L. The standard of energy efficiency for new housing will rise to CSH 4 (Energy) in 2013, and by 2016, all new homes in the UK submitted for planning approval must be zero carbon (ahead of the 2020 target for the EU). The definition of zero carbon led by the Zero Carbon Hub (ZCH) has three components:

- Fabric Energy Efficiency
- On-site low/zero carbon energy (and connected heat)
- Allowable solutions

A recent ruling in the UK (in March 2011 Budget Statement) now requires a minimum of 70% of carbon emission reduction to be from Carbon Compliance – defined as ‘on-site solutions from energy efficiency of the fabric, the performance of heating, cooling and lighting systems, and low and zero carbon technologies’. The mitigation of the remaining carbon emissions from homes, set at an additional 30%, can be achieved via Allowable Solutions, which need to come from regulated energy sources which may be additional on-site initiatives or from off-site carbon reduction, preferably at the local level. The definition of an Allowable Solution had yet to be resolved and has been the subject of recent consultation (Zero Carbon Hub 2011).

To offset the need for low energy requirements on-site, the Stadthaus CLT building project in the UK was able to count the storage of carbon in the timber in the building in addition to low carbon emissions in energy used for manufacture of CLT and construction (Wells 2011; Waugh 2010). The precedent set by the Stadthaus building is still to be applied more broadly, although the carbon reduction through materials used in the building fabric is part of the CSH in the UK.

8. Summary of design factors

Building regulations, standards and other overarching legislation for a number of countries have been reviewed to better understand how regulations may have been applied to CLT buildings and how the CLT construction system may have forced changes in building regulations. The review has focused on structure and stability of CLT buildings, seismic design, durability design, adhesives, acoustics and vibrations, fire design and energy efficiency. Where there was no specific reference to CLT in building regulations, the review focused on timber multi-storey buildings more generally.

The strength of CLT buildings has been demonstrated by the construction of buildings up to nine storeys and the approval of CLT buildings of four or more storeys in most European countries as well as in North America. However, the regulations that differentiate between light and heavy timber are not well specified and standards for CLT product are required to ensure that light timber frame structures are not used in place of the heavy CLT product. CLT buildings have also been demonstrated to adequately withstand earthquakes. There are no impediments to the use of appropriate structural adhesives for CLT in Australia. The softwood used for CLT is generally not durable for exterior purposes and is generally clad to withstand weather.

Cladding of external surfaces is often undertaken with products which provide a fire resistant rating to the exterior of the CLT panels. In addition a number of countries require lining of walls with fire rated gypsum board panels which provide a quality painted finish for apartments. Building regulations tend to specify the fire performance rating required for stairs, lift shafts and other common areas and some regulations have recognised that CLT may be suitable for these areas if clad in a fire resistant material. Generally large areas of exposed timber are discouraged unless sprinkler systems are in place, and even for fully lined CLT buildings, some countries require sprinklers for buildings of four or more storeys. This review has shown that there is much variation in the regulations that apply in countries even within the same region (eg Europe). It has also shown that CLT buildings are classified as timber buildings, with the same restrictions placed on them as for light weight timber framed constructions systems. While fire safe design appears to be the most critical factor, attention should also be placed on acoustics, vibration and thermal performance, with the latter including liveability in hot and possible humid climates. Most of the examples of CLT buildings to date have been built in cooler climates where the warmth afforded buildings designed in timber is sought. In Australia in particular, the heat of summer may be a significant challenge to designing comfortable and structurally sound buildings in urban areas that also provide appropriate natural ventilation when desired

This report has shown that from a design perspective there is still a need to instil confidence that CLT buildings can perform as designed and that they will be accepted by professionals required to certify construction to respective country’s standards and the market.

9. Recommendations

Recommendations to review and formulate strategies for the acceleration of social acceptance of living in multi-storey CLT-constructed buildings in infill developments:

- Employ a combination of both structural and informational strategies when targeting consumers. Effective marketing techniques will be a large component of both these strategies. In-depth research on behaviour should be conducted in order to appeal to various market segments to facilitate and accelerate the move towards more inner-city housing that is fully embraced by residents in Australia.

- Demonstrate the benefits of CLT construction systems by using them to create exemplary housing projects that are affordable and sustainable. This is in line with structural strategies that aim to facilitate conditions allowing for ease of uptake by consumers, ensuring infill apartment living is competitive with suburban lifestyles.

- Work towards the delivery of an iconic demonstration building showcasing the capabilities of the product and enhancing awareness. As informational strategies suggest, increased use of CLT construction systems within the Australian context will aid the social acceptance of CLT construction systems and infill apartment living.

- Work towards modifying building codes to make sustainable building practice and urban infill the norms, zone out car-dependent greenfield developments on the city fringe and reassess fire safety.

- Prioritise the integration of sustainability in housing, combined with holistic problem solving, for the development and redevelopment of all urban areas. Consider opinions of committed investors to engage owners and occupants of CLT buildings to promote a positive greening identity change in the city in which they are located.

- Identify the facilitators of and barriers to solid CLT technology transfer with industry, university and government partners internationally and produce a feasibility report for investors identifying the most commercially viable solid timber solution for the determined market with a road map for implementation (for example, ensure a sufficient wood supply to deliver prefabricated panelised systems in high quantity) (Lehmann, 2012a, p. 17).

- Key players in all levels of government and industry need to lead the way for innovative construction in CLT high-rise buildings by implementing a grant scheme for construction of such buildings. Strategies such as incentivising the purchase of CLT apartments for urban infill could provide encouragement for consumers in the initial introductory phases of building with CLT construction systems.

- Implement zero waste concepts with detailed targets for the construction sector, doing away with construction waste going to landfill. To identify holistic approaches, such as principles for disassembly and reusability of entire building components, requires researchers in disciplines including economics, design and materials, to work together to enable the systemic environmental restructuring of consumption and provision in energy, water and waste systems. In the context of this change process, designers—architects, urban planners, industrial, interior or product—play a major part. To advance design knowledge one has to engage in designing (Lehmann, 2012a, p. 6).

- Extended Producer Responsibility (EPR) is an approach that seeks to designate responsibility for the impacts of products (or urban development) throughout their whole lifecycle. Applying this idea to the construction sector means when a building is made, the consequences of its use and demolition (disposal) must be considered during its design. Adopting this approach across various industries would help to minimise waste and improve the efficiency of the resources used (Lehmann, 2012a, p. 5). This is an important product benefit and a significant point of difference with other building construction materials. The FWPA could market this feature as a recyclable construction system with potential for carbon reduction.

- Make embodied energy and resource/material efficiency a key focus of government policy, setting minimum standards of efficiency that buildings must meet. This will support the Australian design, construction and timber industries in the uptake and adoption of emerging engineered timber technologies.

- Establish a green supply chain for domestic CLT panel manufacturing, instigating a strategy for the suitable uptake of CLT system fabrication in Australia relative to market requirements, available technology and wood resources. Founding such supple chains will also assist in establishing the production of a standardised quality assurance process for fabrication, details for construction and the creation of technical specification literature.

- Ensure longevity of the implemented strategy via suitable upskilling of industry professionals (from architects and engineers to builders) via continuous professional development (CPD) activities.

- Advance evidence-based policy and practices through a user-centred approach to housing occupancy evaluation and effective understanding of feedback. This will further our understanding of the social and cultural benefits of CLT living and help marketing strategies for future projects.

- Ensure market and product confidence by producing peer-reviewed published work, including worldwide dissemination of standardised information on engineered timber. This is in line with informational strategies as circulation of supporting evidence aids to support a culture of innovation and idea exchange.

- Publish a technical handbook and associated launch event with a conference on solid cross-laminated timber production and construction (for example, the technical barrier is not structural but the high fire requirements).

- An underreported area in LCA analysis for timber is its impact on water resources. Carre's study (2010) concluded that:

  > *Water use and land use represent key points of differentiation between the construction types considered. In general, water use and land use impacts for each construction type were driven by the timber content. Those construction types that minimise timber use tended to have lower results in these indicators.*

For softwood timber, Carre (2010) noted that the estimation of water consumption is based on the difference in water use between a plantation forest and pasture, and not for other uses such as native vegetation or other agricultural crops. As water security and conservation are significant issues in Australia, further work needs to be undertaken to assess the impact on water resources of using CLT in Australia. CLT is expected to be manufactured using waste timber products, not structural grade timber, according to Carter Holt Harvey and further study is needed to determine appropriate water use data for the life cycle analysis of an Australian-made CLT product.

10. Filling the Gaps - The Main Research Questions

This report makes recommendations designed to facilitate the increased use of engineered timber construction systems for multi-storey developments, delivering strategies for influencing opinion formation and methods for better reconciling government targets for urban infill, CO_2 reductions and community concerns.

Prefabricated engineered timber construction systems for multi-storey residential urban infill will deliver the sustainability objectives of urban development and the building industry whilst reducing GHG emissions. However, social acceptance and behaviour change play a vital role in the uptake of such technological innovations. The outstanding knowledge gaps are:

1. Technical and regulatory guidelines for the design of prefabricated engineered timber buildings utilising Australian plantation species.
2. Australian industry's capacity to supply prefabricated engineered timber utilising rapid assembly systems and digital design.
3. Life cycle cost analysis will include design and construction building expenses and long-term costs including utilities, operations and maintenance
4. And, whilst this report has sought to address the social and cultural barriers inhibiting the acceptance of prefabricated engineered timber for multi-storey apartment living, the industry will benefit from additional analysis.

To address these four knowledge gaps, the Centre for Sustainable Design and Behaviour at the university of South Australia has developed a research funding proposal - 'Low carbon prefabricated wood-based construction systems for residential urban infill: Addressing the technical, regulatory and cultural barriers to the rapid adoption of lightweight timber components in Australia' for submission to The Cooperative Research Centre (CRC) for Low Carbon Living, which brings together key property, planning and policy organisations with leading Australian researchers to develop new social, technological and policy tools for reducing greenhouse gas emissions in the built environment. The proposal which included the support of Partner Organisations sought funding of approximately $1.8 M.

The project will address the need for behaviour change and industry transformation to facilitate the adoption of design and construction techniques for residential urban infill development that utilise a sustainable low carbon construction system that has reduced GHG emissions, reduced Global Warming Potential and significantly minimises construction waste.

Engineered wood systems from certified sources (e.g. LVL, Glue Lam and Cross- Laminated Timber (CLT)) are using large format, modular, lightweight, load-bearing, prefabricated components of structural integrity that emit low levels of carbon in their manufacture and store and sequester CO_2 over their lifecycle.

This research will investigate the social, behavioural, economic and regulatory drivers needed to ensure the rapid adoption of new technologies and industry/market transformation and deliver new knowledge to increase the use of engineered timber construction systems for multi-storey developments, delivering strategies for influencing opinion formation and methods for better reconciling government targets for urban infill, CO_2 reductions and community concerns.

The outputs include:

- A set of guidelines that address the physical, social and cultural adaptations required to live in harmony with our fellow human beings in the denser, low carbon city.
- A model of prefabricated engineered wood housing construction for urban infill areas for the future delivery of affordable and sustainable housing in Australia.
- Life cycle cost analysis of prefabricated engineered wood housing construction which will include the cost of design and construction of the buildings and long-term costs, including utilities, operations, and maintenance.
- Technical guidelines for the design of prefabricated lightweight engineered wood buildings for infill development for submission to the Australian Building Codes Board and urban planning authorities.
- A feasibility report for investors identifying the most commercially viable solid wood solution for the determined market with a road map for implementation.
- Development of a strategy for the suitable uptake of lightweight engineered wood system fabrication in Australia relative to market requirement, available technology and wood resource.
- To ensure longevity of the implemented strategies, up skilling of industry professionals via continuing professional development activities and capacity development programs for stakeholders.
- Three completed PhD theses

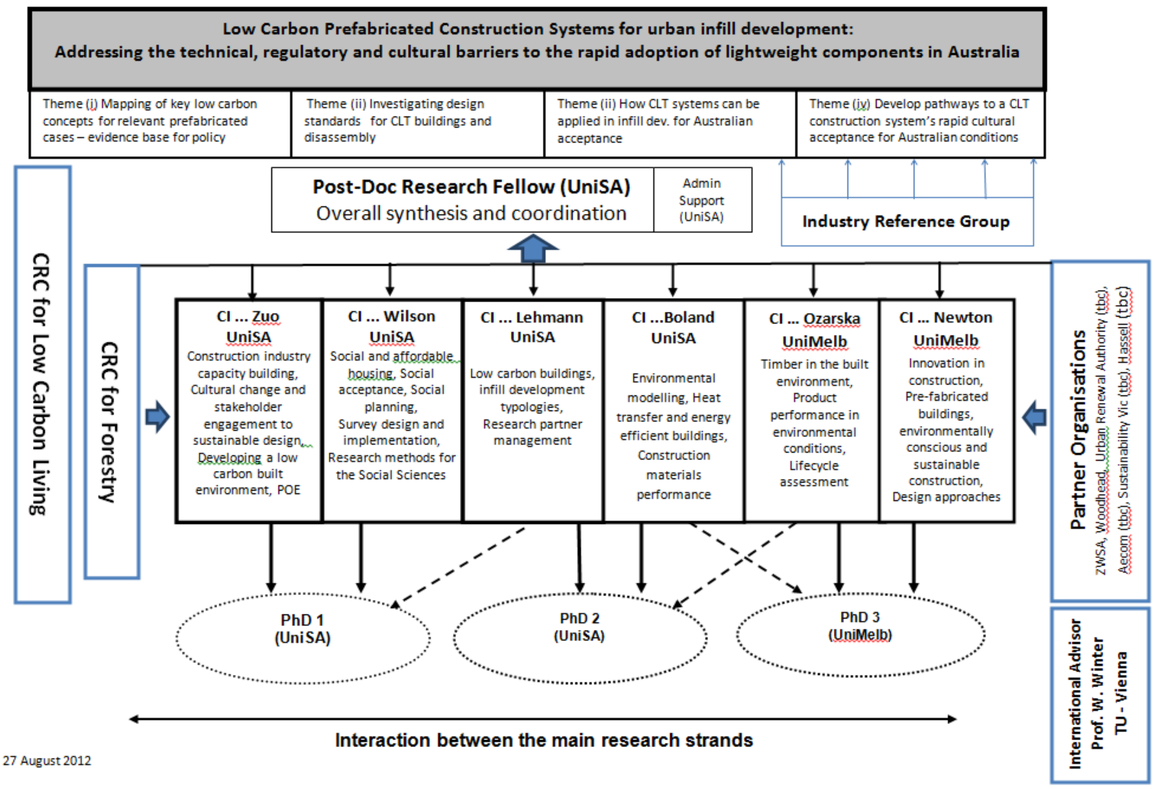


Figure 25 – CRC Research Framework

Original research will be undertaken throughout this project with findings documented in working papers disseminated through a project website and through peer reviewed conference/journal research papers. It is proposed to conduct regular meetings with Partner Organisations and forums for the industry reference group during the project to enable industry input and peer review of the technical guidelines and research findings.

Appendix A

A scoping study by the ZWSA Research Centre for Sustainable Design and Behaviour at the University of South Australia (Lehmann & Hamilton, 2011) was undertaken in consultation with nine Partner Organisations from industry and government. The study identified key factors preventing or enabling the adoption of solid engineered wood systems for prefabrication, in this instance, solid wood panel construction systems for infill development in Australia, reviewed literature relevant to design and construction of engineered wood buildings, and set priority areas for research.

This study revealed that architects are keen to design buildings in CLT, however, the benefits for developers and builders to pioneer this innovative technology are unclear. There is concern that a lack of local manufacture of the CLT product will erode benefits through increased transport costs, associated carbon emissions, time delays from design to supply, lack of industry experience in CLT construction systems; and uncertainty in the ease with which defective material can be replaced. In addition, there is significant uncertainty about the acceptance in Australia of fire rated CLT material from Europe or elsewhere. The flow on effects of a lack of regulations included low demand for CLT product which was delaying commitment of local wood products manufacturers to establish a CLT plant in Australia.

While there was concern about the fire load of timber buildings and the performance of CLT structural members under Australian conditions of heat or humidity, most stakeholders in this study had confidence in the procedures and standards in place by government authorities to ensure that a building would meet appropriate standards. It was assumed by the forest and wood products industry, through the example of the Grocon Delta building in Melbourne, that obtaining approvals from regulators in Australia to build up to ten storeys using CLT was procedural. This study, however noted that government authorities in South Australia including the building rules adviser in the Department of Planning and Local Government had concerns about urban fire-storms fuelled by the load of timber in CLT buildings. The Department for Communities and Social Inclusion, which is responsible for the provision of social and student housing in South Australia, was concerned at its ability to obtain certification, from building assessors and the fire brigade, of CLT buildings for safe occupation. Local government stakeholders were also interested in seeing the outcome of fire testing of CLT structural members and recommended that a research organisation provide appropriate advice to enable CLT designs to be assessed.

Hence, government decision makers at all levels need further information to enable CLT buildings to gain building approval. Of importance is the need to assure the community that accommodation in centres meets stringent safety standards and also liveability objectives which are currently under review through the structure planning process. Introducing CLT as a new system of design and construction of multi-storey buildings will need to satisfy the needs of many stakeholders in each community where such development is proposed.

This study identified the following key gaps:

- Currently, there is no Australian supplier of CLT panels.
- Fabricators in the precision woodcutting industry in Australia generally are not currently set up with the scale of CNC cutting equipment required for prefabrication.
- The BCA codes do not provide guidance or standards for: the use of CLT structural members in multi-storey buildings in Australia; the type of cladding (external or internal) or fire safety systems that may need to be included in the design of such buildings.
- There is a lack of knowledge within the architectural community about the design of CLT buildings and the impact of various design features on the carbon footprint of infill development compared to other modern methods of construction.

- While timber framed construction is a widely accepted method of construction for up to three storeys for Class 2 buildings in Australia, there is a lack of knowledge about the capacity in industry for adapting to deliver four to eight storey buildings using the CLT construction system.
- A lack of knowledge about the liveability and public perception of CLT buildings for infill development in Australian conditions including performance during heat waves.

Table 1: List of Stakeholders contributing to analysis of barriers and opportunities for the scoping study

Stakeholder Name	Stakeholder Group	Stakeholder input
Forest and Wood Products Australia	Industry Innovation Company	• Ric Sinclair • Chris Lafferty
Timber Development Association of NSW	Industry Association	• Andrew Dunn
Carter Holt Harvey	Wood products manufacturer	• Ron Green • Jim Snelson (now ex CEO)
Timber merchant	Timber products	• Name withheld
Timberbuilt Solutions	Precision wood design and cut – fabricator Distributor of CLT product	• Leon Quinn
Precision Wood Machining	Precision wood CNC cutting - fabricator	• Mark Daws
Property Council	Industry Association	• Nathan Paine
Buchan Lee	Developer	• Peter Buchan • Derek Lee • James Lee
Colliers International	Developer and Building Manager	• James Young
Monopoly Group	Developer	• Ben Howard
Woodhead International	Architect	• Karl Traeger • Kate Colligan
Russell and Yelland	Architect	• John Held • Alistair McHenry
Woods Bagot	Architect	• Gavin Kain
JPE Design Studio	Architect	• Tom Vinall
Land Management Corporation	State owned land manager and Master Planner	• Sandy Rix • Matt Rodda
Integrated Design Commission & Government Architect	State Government independent advisor	• Tim Horton • Ben Hewett
Department of Families and Communities -Housing SA	State Government policy - public & student housing	• Phil Fagan-Schmidt • David O'Loughlin • Ben Ward
Department of Planning and Local Government	Planning and Building rules assessment	• Donna Ferretti • Don Freeman
Metropolitan Fire Service	Fire brigade – emergency response	• Amy Seppelt
Adelaide City Council	Local Government	• Joe Kocy • Mike Philippou
City of Charles Sturt	Local Government	• Fiona Jenkins • Kym Wundersitz • Dennis Farrow • Henry Inat
Zero Waste SA	Waste policy - innovation in recycling	• Vaughan Levitztke
Department of Trade and Economic Development	State Government Economic Developer	• Mario Pegoli • Peter Hall
UniSA Zero Waste SA Research Centre for Sustainable Design and Behaviour	Research Institution	• Steffen Lehmann

Stakeholder Name	Stakeholder Group	Stakeholder input
UniSA NBE – Building and Construction	Research Institution	• George Zillante • Stephen Pullen • Nicholas Chileshe • Timothy O'Leary • Jian Zuo
UniSA School of Mathematics	Research Institution	• John Boland
UniSA Sustainable Energy Centre	Research Institution	• Brian Kirke
University of Melbourne	Research Institution	• Barbara Ozarska
University of Bath	Research Institution - UK	• Martin Ansell
Cambridge University	Research Institution – UK CLT Buildings	• Michael Ramage
TU Munich	Research Institution - Europe	• Prof Hermann Kaufmann • Frank Lattke

Stakeholder perspectives of the barriers and opportunities in relation to the capacity for adopting CLT construction systems in South Australia

Table 2 Stakeholder issues – timber and wood products – manufacturers and fabricators

Motivation	Barriers identified	Opportunities identified
Increase use of wood and wood products in residential construction Interested in carbon and energy efficiency Establish a CLT manufacturing plant Value add to current waste Develop capability – increase familiarity in building industry Promote CLT product - distributorship in Australia Develop capability	Deemed to satisfy for CLT always a struggle Fire, durability and water resistance - Fire regulations – biggest issue All CLT is structural – not durable – needs cladding Lack of industry capacity CLT not manufactured locally Insufficient demand for CLT in Australia (est. 30,000 cu m/yr) Cost of labour in Australia – too high Unions blocking Purbond adhesive – isocyanate content Low awareness of WoodWisdom-net research (Europe) Over-specifying requirements for timber buildings over three storey Not enough fabricators of heavy engineered timber in Australia New Zealand supply of X-Lam likely to be used for rebuilding Christchurch Lack of demand for CLT buildings in Australia Shareholder investment for CLT will be demand driven CLT too compartmentalised for commercial buildings – only suitable for residential apartments Issues of supply and risk if panels damaged during transport – how to overcome this issue Code Mark Certification cost No business case yet for building of CLT Need to import from overseas Industry competitive – not working collaboratively Need good quality crew on site No fabricator in SA with precision cutting capability for scale of CLT panels	Need a Building code and fire compendium to address all timber structure for multi-storey – i.e. timber stick frame not just CLT Carbon storage in wood Mount Gambier (SA) has source of low grade timber for CLT Need to look at economics of location of production CLT can be produced by processors as secondary remanufacture – does not need fabricators as do other Glulam pre-stressed timber box beams Broaden to other uses of CLT – e.g. school buildings as per UK industry Wood products industry invest in CLT demonstration to stimulate demand Cost comparison of CLT vs. conventional build system More collaboration between building industry and wood products manufacturers re CLT Import to improve familiarity – touch and feel CNC and BIM digital design– have ability to translate European engineering into suitable local product - structural design and prefabrication Acoustic design – complementary products already available Use existing expertise for early introductory projects Foundation for local market and supply chain development Compare output of CLT plant with demand – look at all Australia – eastern seaboard is majority of residential construction Market 'quality, technology and environmental responsibility' not 'cheap' Focus on sophisticated and technologically advanced system of building Cladding with recycled plastic product – locally

Motivation	Barriers identified	Opportunities identified
		made

Table 3 Stakeholder issues –Property developers and architects

Motivation	Barriers identified	Opportunities identified
Stimulate property development market in SA Gain approval for car park top developments Address construction waste Adopt innovation Wants to use CLT in regional project Want advantage of being first to design with CLT Want to gain experience in designing with CLT seeking knowledge Share knowledge about feasibility, affordability	Developers and builders unfamiliar with CLT product Have to break down barriers No CLT manufactured in Australia - need to import CLT panels from overseas Infill development solutions needed in inner-city location Financing of CLT projects through the banking sector is unclear CLT not 'affordable, social housing' material Public education lacking Fire engineering and meeting fire regulatory approvals Cost of fire testing Developer confidence in gaining approvals – no-one wants to be Pioneer with CLT Need to train industry Concern about quality of pine in Australia	Homeless Housing Government assistance to develop car park sites Locate infill development in centres – Adelaide CBD – infrastructure to service growth Timber houses: public still needs to be educated that it's better than brick. Needs to be pitched as a high-end market product Manufacture - Import from China? To reduce cost Use Minda project Undertake comparison of design in CLT with steel or concrete systems - LCA Use design from 41 Currie Street for fire testing research Need to address cost as part of Sustainability

Table 4 Stakeholder issues – Australia –State and Local Government

Motivation	Barriers identified	Opportunities identified
Develop innovative design in buildings – promote inner-city living Affordable Housing Building rules – code Planning Strategy Urban design guidelines Infill development – car park Infill development –Waste Minimisation Increase jobs and ongoing investment	Lack of CLT building for familiarity Developers and builders unfamiliar with CLT product No local manufacturer – import from overseas – adds to carbon footprint – affects sustainability Fire regulations and acoustics in dense development - expose timber? Cost? – comparison with steel systems and concrete flooring per sq m floor space Building code restrictions Strength of existing building important for car park top CLT construction No margin for error in highly engineered product Liveability in centres - generally BRAC do all building approvals for ACC No building rules established Establishing titles across timber walls Not enough information about the value to State Government – return on investment?	Stimulate interest in CLT – Potential for competition for CLT Building at Bowden (tbc) Fire test designs from competition – in-kind contribution to research Govt fast-track CLT building Govt to establish CLT manufacturing plant? Govt to pay for fire testing? undertake research with CSIRO re fire testing – unlock barriers Need to quantify jobs from CLT vs. other construction systems Undertake comparison with steel and concrete systems Review the plywood industry in the scoping study – capacity for CLT? Ensure fire department and building certifier concerns are addressed Map out the regulatory process Structure planning Resolve building rules issues LCA Reduce construction waste Need cost benefit analysis of establishing CLT manufacturing facility in Australia including buildings

Table 5 Issues raised by UniSA researchers

Motivation	Barriers identified	Opportunities identified
Identify research needs	No local supplier of CLT No buildings CLT built yet in Australia Need to satisfy fire regulations in building code Need to obtain finance to build CLT demonstration Need to manage stakeholder interest and expectations regarding CLT Need to manage community acceptance of CLT Need to translate European knowledge to demonstration projects in Australia Limit of three storeys for Class 2 - Type A buildings Lack of knowledge of materials performance during hot conditions – confined spaces Risk management - new construction techniques – capacity of building industry for rapid construction Lack of knowledge of performance of CLT building - energy rating tools No studies of CLT LCA for multi-storey Class 2 – lack of knowledge about carbon benefits Supply of timber from softwood plantations rather than native hardwood	Document scoping study findings and disseminate widely across Australia Follow up scoping study with ARC Linkage grant applications - wide multi-disciplinary approach Involve industry associations – make findings of ARC research more broadly available Ensure international input – build on overseas research and experience in manufacture, design and construction systems for CLT buildings Focus on imported CLT panels initially – document properties Seek Government support for demonstration projects Document ARC research findings and disseminate widely to spread knowledge Do research to establish deemed to satisfy provisions for Aust Building Codes Board to consider To satisfy provisions in building code –use expert opinion or test alternative solution to build confidence and knowledge Review thermal performance of CLT – adhesives in Australian climate, thermal comfort and energy efficiency Review timeframe for delivery of CLT building – manufacture, cutting transportation and assembly Review capacity of building industry – skills level required Review performance of CLT building in energy rating tools – how to assess? Undertake LCA of Class 2 prototypes following fire testing research Link to design typologies for infill development Thermal performance of CLT buildings Potential input in design of CLT buildings to address thermal mass and energy efficiency for Australian climate Lightweight timber construction better for seismic prone areas and areas suffering from soil movement due to dry cracking clays – timber likely to have good damping properties

Table 6 Issues raised by other researchers – not UniSA

Motivation	Barriers identified	Opportunities identified
Share knowledge International research collaboration on CLT in Australia	More severe extremes in weather in Australia than UK – impact on adhesives unknown Limited capacity in construction industry Limited capacity in Engineering Limited capacity in Manufacturing Limited capacity to design in CLT in Australia No CLT Manufacturer	Draw on positive experience with CLT high rise in the UK regarding adhesives Define main research area more clearly Draw on UK experience International research partner for ARC project Bring European design expertise to Australian study – in design phase of research Softwood adhesive properties much better than hardwood Ensure CLT acceptance in construction code Increase knowledge of systems, platform construction, acoustics Panel cutting, supply & waste, composite CLT/insulation panel properties etc

Table 7 Summary of potential research needs

Activity	Research need	Aspect in project scope	Priority
Forestry		Carbon intensity LCA materials input	L
Transport to processor		LCA input	L
Processing lumber	Pre-treatment Standards/Grading	LCA input	M
Identify site	Customer acceptance of apartments in timber; building standards - foundations	Developer - Market research – demand for apartments Learning from demonstration projects Specifications for foundations Urban design Planning restrictions	H
Design and costing	BIM for CLT Digital Design	Training for industry – architects, builders, planning requirements, building requirements	H
Obtain approvals	Fire Engineering standards	Local government, planning approval, building inspectors, building certifiers	H
Prepare site	Construction and Project Management skills for CLT building systems	Risk assessment of construction process	M
Manufacture CLT	Industry skills and capacity for manufacturing CLT in Australia	Training for industry, Equipment for manufacture Source of CLT – overseas or local Adhesive Standards Structural standards Fire resistance	H
Cut prefabricated panels	Transfer digital design to computer cutting systems - prefabrication	Training for industry, Equipment for prefabrication Source of CLT – overseas or local	M
Transport to site	Special equipment	Logistics and access to sites; permits for road closures etc for cranes	M
Erect on site	Construction and project management skills - Capacity of industry for on-site construction techniques	Training for industry, risk management – fire, safety	M
Second fix	Standards for second fix – building standards, fire rating impact on comfort and energy efficiency	Checklist for building standards, materials check, building inspection, handover Understanding of industry about the fire rating - conditions	H
Ready for occupation	Customer experience of CLT structures for apartment living	On-going Surveys of residents in demonstration sites Energy use Thermal comfort Acoustic properties Liveability	L

Glossary

Acoustics – both sound and vibration (Ostman & Kallsner 2011:13).
Built CLT projects show that good acoustic values of R'_w 55dB with a U-value $0.45W/m^2K$ for external walls are achievable (Kaufmann 2011).

Creep – 'an increase in the deformation of a material in time under constant loading' (FPInnovations 2011: C6:1)

Cross-laminated timber or CLT is a structural timber product fabricated by bonding together timber boards with structural adhesives to produce a solid timber panel with each layer of the panel alternating between longitudinal and transverse lamellae. (TDA of NSW 2011)

Durability – The capacity of the structure to give a required performance during an intended service period under the influence of degradation mechanisms. (Ostman & Kallsner 2011:17)

Load duration (or 'duration of load') – The duration of continuing application of a load or a series of periods of intermittent applications of the same load type (CSA O86-09, 2009. See FPInnovations 2011 C6:1)

Lumber - timber cut into marketable boards, planks or other structural members, and which is of standard or specified length. (Dehne and Krueger 2006)

Stabilisation – refers to' wind loads' (Ostman & Kallsner 2011:13)

Timber - the wood of trees cut and prepared for use as building material (e.g. beams, posts). (Dehne and Krueger 2006)

Wood -the hard, fibrous, lignified substance lying under the bark of trees. It consists largely of cellulose and lignin. Wood is a natural material and is, therefore, irregular by nature. (Dehne and Krueger 2006)

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sd+b Centre	www.unisa.edu.au/sustainable-design
Sohm Holzbautechnik	www.sohm-holzbau.at
Stora Enso Timber	www.storaenso.com/wood-forest
Structurlam, Canada	www.structurlam.com
Techniker Engineers, London	www.techniker.co.uk
Wolfgang Winter, TU Vienna	www.iti.tuwien.ac.at
WoodWisdom-Net	www.woodwisdom.net
Woodsolutions	www.woodsolutions.com.au