Wood in the urban context: Infill development using prefabricated timber construction systems

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Abstract

Wood is an important contemporary building resource due to its low embodied energy, rapid natural regrowth and unique attributes. The potential of prefabricated engineered solid wood panel systems, such as cross-laminated timber (CLT), as a sustainable building system, is only just being realized by the construction sector. Since timber is one of the few materials that has the capacity to store carbon in large quantities over a long period of time, solid wood panel construction offers the opportunity of carbon engineering, e.g. to turn buildings and districts into ‘carbon sinks’. Thus, some of the historically negative environmental impact of urban development and construction could be avoided. Given the many benefits of lightweight CLT construction, its introduction to the Australian construction sector is timely and relevant. The purpose of the study is to identify the barriers preventing a fast uptake and strategies for removing these barriers.

The author introduces a series of case studies of recently constructed inner-city residential timber buildings using CLT systems, exploring their levels of acceptance (post-occupancy evaluation). These precedents are in London, Vienna and Trondheim; while Australia’s first timber high-rise has recently been completed in Melbourne. First conclusions are discussed at the end of the paper, but further research will be necessary, based on in-depth post-occupancy evaluations that involve collecting information from owners, residents, neighbours, architects, real estate experts, construction managers and developers to better assess residential life in CLT multi-storey timber buildings.

Keywords: Engineered timber, **digital prefabrication**, **solid wood panels**, **low carbon construction**, **social acceptance**.

1. Introduction and problem definition

Expanding cities and the current rate of loss of agricultural land make a strong argument for urban infill and the need for consolidation and more sustainable urban development. Cities are the centre of consumption; they require an enormous concentration of energy, construction materials, water, food and land, which nature cannot provide (Mumford, 1961; Lyle, 1994; Brown, 2009). Brown (2009) notes that collecting masses of materials and later

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dispersing them in the form of garbage, sewage and pollutants in air, water and landfill is challenging municipalities worldwide.

Most of Australia's larger cities have recently developed master plans for the next 20 years, to cater for predicted population growth (Australia is currently predicted to grow from 23 million people in 2012 to 36 million by 2045: COAG, 2011), and to achieve this growth by increasing the proportion of urban infill from a current rate of around 35 per cent in Sydney, Melbourne and Adelaide to a nominated target of 60 to 70 per cent (with similar figures in Brisbane and Perth). These cities have identified transit-oriented development (TOD) sites and allow for higher density along transit corridors: thus, the master plans of all large Australian cities are strikingly similar in their aims and strategies. All this has urban design implications for housing typologies and densification strategies.

The renewed planning focus has led to the Australian government – through the Council of Australian Governments (COAG) and the federal government's Major City Unit – taking a much greater interest in the mechanisms whereby affordable and sustainable inner-city housing can be provided. However, the production of conventional apartment buildings using concrete and steel are one-way energy-intensive processes that release large amounts of greenhouse gases into the atmosphere. One strategy to achieve more sustainable inner-city housing is to design and manufacture 'green' assemblies for mass customization of buildings using modular prefabricated low-carbon construction systems with engineered timber. It is a way to get closer to ensuring the vision of 'making buildings without creating waste' finally becomes a reality (COAG, 2011). Mid-rise density infill projects, insertions within the existing urban fabric (not high-density or high-rise, but mid-rise, with 4 to 10 storey blocks), are gaining in popularity. The inner-city residential buildings of tomorrow will focus on construction speed, reduced carbon emissions and weight reduction by using low-carbon lightweight construction and cladding; these prefabricated systems will use high-performance timber panels such as cross-laminated (CLT) panels, as these can be easily handled on-site.

Behaviour change has frequently been listed as the number one barrier to reducing consumption towards pro-environmental behaviour and a more energy and material-efficient, low-carbon future (McKenzie-Mohr et al., 1995; Newton, 2011; Lehmann and Crocker, 2012). Tackling the carbon intensity of development and urban sprawl concurrently requires finding low-carbon alternatives for better urban infill development. Technology is always most effective if it is embedded into a societal framework. However, residents' motivation and commitment to aspire to sustainable living are still not well understood, i.e., how to best overcome social barriers to inner-city living in prefabricated timber towers.

The purpose of this study is to identify the barriers preventing a fast uptake of cross-laminated timber (CLT) in building construction and strategies for removing these barriers. The author introduces a series of case studies of recently constructed inner-city residential timber buildings using CLT systems; these precedents are in London, Vienna and Trondheim; while Australia's first timber high-rise has recently been built in Melbourne (the Forté apartment building in Docklands, see following case 5).

The research methodology includes an analysis of cases, structured around four inter-related themes: mapping of key low carbon timber construction concepts, providing an evidence base for policy and decision makers; investigating design standards for lightweight prefabricated timber buildings and their disassembly; describing how engineered wood construction systems could best be applied to Australian urban infill; synthesising the above to develop pathways to a construction system suitable for Australian conditions, e.g. its particular climate and supply chain. The availability and comparability of data will be assessed, gaps in the data identified. At a later stage, design-testing will be done for three Australian sites, including lifecycle analysis focusing on CO_2-equivalent global warming potential.

The paper is therefore structured in 3 parts: firstly, the benefits of solid wood construction are discussed; then the case studies presented; and, a concluding discussion considers what might have to happen for Australians to swap their backyard for a balcony.

2. Forests, trees, wood panels and carbon sinks

Timber has been described as materialized solar energy and an efficient CO_2 accumulator (Wegener, Pahler and Tratzmiller, 2010). Residential building construction with wood is now changing, focusing on green materials, local supply chains and resource-optimized engineered systems. Wood is to be sourced in a sustainable way from well-managed forests. Timber construction is an efficient method of CO_2 storage, as long as the material is obtained using responsible methods of forest cultivation (plantations) and from a certified source that is not too far away (to avoid transport-generated greenhouse gases).

The aim is to evolve systems and designs in engineered timber that tackle the significant negative environmental impact of buildings and offer new ways of constructing efficient and affordable structures that demand fewer resources and can be easily re-used/recycled. One cubic metre of timber can store up to one ton of CO_2. No doubt, steel and concrete are great building materials, until you consider their ecological footprint: over 5 per cent of all GhG emissions worldwide come from concrete, while each ton of solid wood panels has sequestered up to -1.6 tons of CO_2. New engineered timber panels can outperform both concrete and steel: during manufacture, a ton of steel emits up to 1,5 tons of carbon; and the production of a ton of cement emits over 1,1 tons (FP Innovations, 2011). Hence, fast growing softwoods will be the future, planted for laminating into large solid structural panels.

Contemporary technology has changed both the way in which timber buildings are converted and assembled (Vessby et al., 2009), and how these can be protected against fire, insects and decay (Frangi et al., 2009; Gereke et al., 2011). Given its carbon sequestration capacity, wood might well be *the* construction material of the twenty-first century.

> *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)

2.1 What exactly are the advantages of solid wood panel construction?

According to the Timber Development Association of New South Wales (TDA, 2011), a CLT construction system is a structural wood panel system fabricated by bonding together large timber boards with structural adhesives, alternating the grain directions of each layer, to produce a solid, load-bearing timber panel with each layer of the panel alternating between longitudinal and transverse lamellae. It's not a 'product', it's a recognised construction system increasingly used in Europe as an alternative to steel and concrete. Large-format solid timber panels are engineered wood products used as massive load-bearing walls, roofs and floor slabs. CLT panels are an extension of the technology that began with plywood and may be best described as 'jumbo plywood', where layers of timber are glued together with the grain alternating at 90 degree angles for each layer (thus different from LVL or glue-lam). Cross-laminating layers of wood veneer improve the structural properties by distributing the along-the-grain strength of wood in both directions. The advantages this offers are quite exciting – timber panels are much lighter than concrete, more easily worked and safer to erect (Sathre and Gustavsson, 2009; WoodWisdom-Net, 2009; Lehmann, 2011).

Two recent scoping studies identified the research needed and existing capacity to deliver solid wood panel buildings for infill development in Australia using CLT construction systems (Lehmann and Hamilton, 2011; Lehmann, 2012a). Key stakeholders were interviewed for their perspectives about CLT, including the perceived barriers to and/or opportunities for using CLT construction systems in Australia. However, there is still some confusion between acceptance and skepticism (consumer resistance) about the introduction of CLT apartment buildings in Australia. There are a number of clear benefits to solid wood panel buildings. The following list is drawn from the author's review of such buildings, a review of research papers, of wood product industry strategies and from discussions with architects, engineers and industry stakeholders in the supply chain:

- the speed with which the structure of CLT constructed buildings can be assembled on-site (built at least 30 per cent faster, because much of it is prefabricated and lighter);

- the acoustic and thermal performance of massive CLT panels, which reduce the level of additional insulation needed for energy efficiency and sound deadening;

- the 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);

- storage of carbon in the timber of each CLT building (CO_2 sequestration); and a reduced carbon footprint for timber buildings from responsibly sourced wood (reduced embodied energy);

- lighter: resource-reduced construction with only a quarter of the weight compared with a concrete building, and significantly reduced waste;

- 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).

3. CLT-constructed buildings in an urban context: some European cases and a first application in Australia

How can consumers be influenced to accept inner-city apartment buildings constructed entirely of timber? The use of post-occupancy evaluation (POE) of new CLT housing projects is a promising approach for analysing occupant comfort, user behaviour and energy consumption. It will enable researchers to develop and validate an 'ideal' model for CLT infill housing for Australian cities. In Europe, construction of solid wood panel multi-storey apartment buildings has increased recently, with several projects in European cities built or under way (including large projects in Austria, Switzerland, Germany, Italy, Norway, Finland and the UK). In Australia, only a few CLT buildings have been designed and submitted for development approval so far (proposals have been developed in Sydney, Melbourne and Adelaide). Construction costs for apartment buildings are still significantly higher than costs for suburban houses; however, increasing the scale of CLT construction would change this situation. There is still a lack of knowledge within the architectural design community about CLT buildings' design and the impact of various design features on infill developments' carbon footprints–as compared to other construction systems.
Figures 1 to 5 show some of the residential buildings recently constructed with CLT systems. These multi-storey apartment buildings were selected as case studies to provide an insight into the diversity of design possibilities using the wood panel system (for a more detailed analysis of them, see: Lehmann, 2012).

3.1 CLT case study 1: Bridport House, Hackney, London

The eight-storey Bridport House is, with 'Stadthaus' (also in Hackney), the tallest all cross-laminated timber building in the UK. It has pushed the boundaries of CLT construction up to eight storeys. Bridport House replaces an original 1950s block with 41 new apartments 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 in and supplied from Austria – including the lift shaft. Below ground level the raft, foundations and lift pit are of reinforced concrete. In the design phase, reinforced concrete and structural steel was compared in detail with the use of a CLT system (Eurban ran a detailed comparative analysis). There are several reasons why CLT was selected: one was weight. CLT is considerably lighter than the alternative structural materials, and a large Victorian sewer runs beneath the site and point loads had to be avoided. Speed of construction was another benefit, it can take as little as half the time to construct using CLT as a conventional reinforced concrete frame. In addition, the construction process is far less likely to be interrupted in bad weather conditions. Stephen Powney notes that, despite the transport, carbon saving over steel and concrete was 2,113 tons; the amount of sequestered carbon is a saving equivalent to providing 20 per cent of the building's operational energy requirement for 139 years (Powney, 2011).

Figure 1 a and b: Bridport House, Hackney, London, was completed in August 2012. (Source: Lehmann/architects, 2012)

3.2 CLT case study 2: Svartlamoen multi-apartment building in Trondheim, Norway

This development (architects: Brendeland and Kristoffersen, Trondheim, 2005) consists of two buildings with an overall area of around 1000 sqm. The main five-storey building also contains rooms that can be used commercially, and the four upper floors contain units of 120 sqm designed to accommodate 5 persons each. The entire construction was made out of solid CLT boards and clad with Norwegian larch (see Figures 2a, 2b). 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 on timber’s fire risks’ (Lattke and Lehmann, 2007). A post-occupancy evaluation for the building is currently underway. In April 2012, the author met with residents to discuss their lifestyle choices. He learnt that there is now a long waiting list to move into this building; it has become very popular to be associated with this green building. The occupants mentioned that they like the idea that the building materials are recyclable and all tenants are conscious of the building’s sustainability, appreciating its particular ‘timber qualities’, for example, the healthy indoor climate.

Figure 2 a and b: Svartlamoen project, Trondheim, Norway – exterior view with resident. (Source: S. Lehmann, 2012)

3.3 CLT case study 3: the Am Muehlweg complex, Vienna-Floridsdorf, Austria

The Am Muehlweg project was designed by Hubert Riess, Dietrich & Untertrifaller, and the construction cooperative Hermann & Johannes Kaufmann Architects. One hundred public-sector apartments were built on each of three interconnecting plots, 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. In total, the project provides 6,750 sqm in 70 dwellings in 13 buildings (a detailed description of the project is in Kaufmann and Nerdinger, 2011). The three-storey structures made from prefabricated CLT panels built on top of a concrete base were constructed in 15 months (see Figure 3). The entire four storeys of the building are clad in larch. The author interviewed residents to discuss their lifestyle choices and reasons for deciding to live in the building and the findings are similar to the Norwegian case.

Figure 3 a and b: Resident Barbara of the Am Muehlweg project in Vienna, Austria. (Source: S. Lehmann, 2012)

3.4 CLT case study 4: Wagramerstrasse public housing, Vienna

This is Austria's highest residential building constructed using CLT systems: 101 apartments in a 7-storey slab along Wagramerstrasse and three 3-storey fingers forming courtyards. Six storeys of CLT sit on top of a concrete podium (Brinkmann, 2012). The solution is the outcome of a 2009 design competition organized by the City of Vienna. The build is a composite structure of concrete cores with a CLT system; engineer Wolfgang Winter predicts that 'most large-scale multistorey timber buildings in future will be hybrid structures, where sound insulation is typically added via the use of concrete or screed' (personal communication, April 2012). The 2,400 cubic metre timber structure stores around 2,400 tons of CO_2, which equals the annual emissions of 1,600 cars. The project was completed in February 2013. The apartments are 2, 3 and 4 bedroom units of 60 to 105 sqm in size; some are maisonettes.

Figure 4 a and b: The Wagramerstrasse apartment complex, part of Vienna's 'Wood in the City' initiative, which now allows timber buildings up to 32 metres in height. Cores and ground floor podium are concrete. (Source: S. Lehmann, 2012).

3.5 CLT case study 5: the Forté apartment tower in Melbourne, Australia

Forté, the 10-storey timber residential building in Melbourne's Docklands, is Australia's first large CLT building and a landmark project for the timber industry in Australasia. 9 storeys in CLT sit on top of a concrete podium. The ground floor is used for retail space. The advantages of CLT were particularly relevant to the Docklands location, as its reduced weight generated substantial below-ground savings and the fast build suited the compact site. According to the developers, by using CLT, Forté reduces carbon emissions by more than 1,400 tons of CO_2, compared with building in concrete and steel. The advantages are likely to continue for residents too: the 23 apartments require 25 per cent less energy to heat and cool than a similar apartment built in reinforced concrete; they note that the building will be carbon neutral for at least 10 years. Construction of the building only took from February to October 2012 (see Figure 5). The tower is constructed from 760 CLT panels, which were shipped from Austria to Australia in 25 containers (panel length was limited to 12 metres due to container size). In the assembly process, around 20 panels per day were put in place. However, only a few timber surfaces are exposed internally, reduced to one 'feature wall' per unit. An earlier design option proposed that the entire building be wood clad, but 'it was then decided to reduce the timber aesthetic, to avoid marketing risks' (Hopkins, 2012). The developer decided on 'a more ordinary façade to have a building not completely out of the ordinary', and also decided that 'the building would be fully sprinklered to make it look safe and simplify the approval process, although this measure was not requested by the Fire Department' (Hopkins, 2012).

Figure 5 a, b and c: The 10-storey 'Forté' apartment building in Bourke Street, Melbourne Docklands, under construction (July 2012); CLT panels stored in a warehouse close to the site. (Source: C. Philpot, 2012; S. Lehmann, 2012)

4. Motivating people to swap backyards for balconies: a methodology for further research

High-rise timber building developments are now gaining recognition from designers and developers due to timber's many positive environmental attributes as well as construction benefits; being lightweight, having a known fire and thermal performance. This being said, there is still much work that needs to be done in demonstrating timber's benefits to regulatory and fire authorities as well as addressing social and cultural issues that arise from living in this new form of construction system. A fundamental question is the potential market penetration in Australia. The analysed cases show that not only technological but also social innovation is needed to introduce CLT systems more widely to Australians, who are used to having large backyards. Since the mid-1990s, CLT construction has been introduced in several European countries and more recently in Canada. Research from Canada indicates that 'a market penetration rate of up to 15 per cent in 5 to 7 years is realistic' (FPInnovations, 2011).

This ongoing study is a work in progress and findings are still emerging. Two problems require clarification: firstly, models of urban infill for intelligent densification; then the study of how the use of CLT systems can play an important role in achieving a more liveable city with better models of inner-city housing; the problems are intertwined. Three research strategies will be employed: in-depth analysis of case studies; a series of qualitative research interviews with residents and other stakeholders; and demonstration projects will help operationalizing concepts that can be measured over time and data extracted, with relevance to policy development. Further research is required to better understand the social acceptance of CLT multi-storey apartments in urban centres; what triggers people to choose a more urban lifestyle by moving back to the city centre, into timber high-rise. Researchers at the Zero Waste Centre for Sustainable Design and Behaviour are therefore aiming to increase the knowledge base required to introduce CLT construction systems into the Australian construction sector. This includes developing acceptable solutions for regulatory approval of CLT buildings and addressing the technical barriers required to ensure a safe, acceptable system for urban infill development.

5. Conclusion and further discussion

Better housing design can also significantly improve health outcomes. The integration of sustainability in housing is of crucial importance for the future development and re-development of Australian urban areas. The author found that the barriers and obstacles are not so much technical as human. Raising low-carbon construction systems to the top of our research agenda and transforming industry will move solid wood panel construction beyond being a niche innovation only carried out by a small network of pioneers.

For too long we have lacked real housing choices. Resistance to sprawl is growing. All future growth will have to be where abundant infrastructure and services already exist. Stopping the outer suburbs from further expansion means that the inner suburbs will have to accommodate more people; therefore more affordable, better typologies for inner-city living are necessary (Lehmann, 2013).

Australians will not swap their backyards for balconies just because of the construction material of an apartment. It is the cost savings from faster construction time and reduced cooling costs during hotter summers associated with CLT construction that might attract residents. Realistically, the wider sustainability issues are not sufficient to be major factors in the buyer's decision-making process; it would be overly simplistic to believe that sustainability credentials alone are sufficient. The discussion requires further delineation of the real barriers to acceptance of this interesting and innovative construction system.

One significant barrier is the slow uptake by industry and consumer resistance to denser inner-city living. It is necessary to find out whether residents are more likely to accept higher densities when they know that the density is created by green buildings. Proposing higher densities and multi-storey timber construction faces the general problem of Australians' historic resistance to apartment living (which has much to do with the apartments' poor design, small size, tall shape, lack of privacy, noise and high cost), and the lack of experience with infill sites in cities. The case studies reviewed make a strong argument for timber in the urban context. But the cases also show that there is still a need to instill confidence in the performance of solid wood panel buildings as designed, so that they will be accepted in Australia, by professionals required to certify construction to the country's standards and by the market. From the perspective of residents, social acceptance of CLT buildings will be influenced by public perception and factors affecting liveability, comfort and the consequent socio-economic outcomes.

Both the general public and the architectural community still lack knowledge about CLT construction and the impact of various design features on the carbon footprint of their use for infill development compared to other modern methods of construction. Education of architects and planners is therefore important, e.g. to develop new courses that focus on research methods into new materials and low carbon construction systems, aiming to reposition future architects as more knowledgeable (and again, as influential) in the construction industry. Government agencies and the building industry are involved throughout the research, as this will lead to an increased understanding and knowledge of the properties of CLT buildings and inform decision-making. The research will have to be tested on actual housing developments, delivering demonstration pilot projects. In conclusion, the author has identified the following actions that government and industry could pursue:

- modify building codes to make sustainable building practice and urban infill the norm, zoning out car-dependent greenfield developments on the city fringe, re-assess unrealistically high fire requirements for timber infill;

- demonstrate the benefits of CLT construction systems by using them to create exemplary housing projects that are affordable and sustainable, and work towards the delivery of demonstration buildings showcasing the capabilities of the system;

- use the opinions of committed investors, engaging owners and occupants of CLT buildings to promote a positive identity change of the city, enhancing awareness;

- accompany realisation with performance data monitoring;

- conduct in-depth research on behaviour change to facilitate and accelerate the move towards more inner-city housing that is fully embraced by residents;

- identify the facilitators of and barriers to CLT technology transfer with industry, university and government partners internationally and produce a road map for implementation;

- ensure longevity of the implemented strategy via suitable up-skilling of industry professionals (from architects and engineers to builders);

- support the Australian design, construction and timber industries in the uptake and adoption of emerging engineered timber technologies, establishing the production of a standardized quality assurance process for fabrication, details for construction and the creation of technical specification literature;

- establish a green supply chain for domestic CLT panel manufacturing, and instigate a strategy for the suitable uptake of CLT system fabrication in Australia relative to market requirements, available technology and sufficient wood resources;

- advance evidence-based policy and practices through a user-centred approach to housing occupancy evaluation and effective understanding of feedback;

- implement zero waste concepts with detailed targets for the construction sector, doing away with construction waste going to landfill;

- make embodied energy and resource/material efficiency a key focus of government policy, setting minimum standards of efficiency that buildings must meet;

- produce peer-reviewed published work ensuring market and product confidence including worldwide dissemination of standardized information on engineered timber, e.g., publish a technical handbook and associated launch event with a conference on solid cross-laminated timber production and construction in Australia.

In this paper the author has assessed the potential contribution of CLT construction to the creation of innovative and long-lasting housing types to increase the urban density of existing cities. Inner-city housing using engineered timber construction also offers the opportunity to re-establish a more meaningful concept of material culture and enduring value, thus underpinning a more profound notion of society itself. Furthermore, the scope of application of the system is to be extended to include commercial and public buildings.

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