STUDY REPORT

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Cross-laminated Timber for Building Structures

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Preface

Cross-laminated timber (CLT) is an engineered wood product developed for structural applications. In recent years, it has gained significant interest from designers in New Zealand and worldwide for use in building structures. This report discusses the applications of CLT in New Zealand as well as potential and challenges for the future.

Acknowledgements

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Note

This report is intended for planners, architects, engineers, builders and others involved with the building industry.

Cross-laminated Timber for Building Structures

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Reference

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Abstract

Cross-laminated timber (CLT) has been the one of the latest and most significant types of engineered wood product developed for structural applications. In the last two decades, there has been some remarkable progress in the technology to use CLT in building structures. Although it arrived in the region later than in Europe and North America, CLT has quickly gained popularity within the engineering community in New Zealand. There are significant challenges in New Zealand applications, such as seismic demands. Some research has already been done locally to provide guidelines for applications. A number of projects involving CLT applications have been completed. With increased confidence and a positive economic outlook, CLT is set to be one of the main engineered wood products used in the region in the near future. There is also potential for the applications to extend into emerging markets in Asia. Recent research initiatives taken to facilitate further applications are elaborated on here.

Contents Page

1. INTRODUCTION 1
2. INITIAL RESEARCH, PRODUCTION AND APPLICATIONS 1
3. CURRENT MARKET SITUATION AND PROSPECTS 3
4. APPLICATION OUTLOOK 5
5. CHALLENGES FOR APPLICATIONS 5
6. RESEARCH NEEDS AND INITIATIVES 6
7. CONCLUSION 7
REFERENCES 7

Figures Page

Figure 1: Load deformation of pine CLT in a) perpendicular to grain compression (Millen and Carradine 2010) and b) flexure (Millen and Carradine 2011) 1
Figure 2: Post-tensioned CLT rocking walls – a) high seismic option and b) low seismic option (Dunbar et al. 2013) 2
Figure 3: Hysteretic behaviour of a high seismic option stairwell – a) single wall and b) coupled walls (Dunbar et al. 2014) 2
Figure 4: Kaikoura District Council Building (images courtesy DesignBASE/Andy Buchanan) 3
Figure 5: CLT uptake – a) manufacturing cost components and b) demand (Scion 2013a) 3
Figure 6: Building in upper Queen Street in Nelson (left) (image courtesy Progressive Building) and Tait Communications Building in Christchurch (right) (image courtesy Daniel Scheibmeyer) 5
Figure 7: Forté Apartments (left) and Dockland Library (right) (images courtesy Lend Lease) 5

1. INTRODUCTION

Cross-laminated timber (CLT) was first developed in Austria in the early 1990s. By the mid-90's it had gained popularity in Western Europe and Canada. It is now well established as a building material in many countries including the United States. In New Zealand, research on CLT only started in the last decade, but since then there has been increasing interest from researchers and practitioners in the material. This report summarises recent research initiatives and describes the engineering challenges with the material. Design demands are also discussed, as well as the structural systems and concepts proposed to meet those. Completed and planned projects demonstrate the applicability of CLT. The present manufacturing capabilities and the market potential indicate a positive outlook for the product.

2. INITIAL RESEARCH, PRODUCTION AND APPLICATIONS

Fortune and Quenneville (2007) first investigated the feasibility of production of CLT with New Zealand-grown radiata pine. They had CLT panels successfully fabricated with timber sizes and species commonly available in New Zealand and in line with those commonly produced in Europe regarding both sizes and number of laminates. The study showed that it was possible to manufacture CLT panels with predictable characteristics from locally grown timber.

Further investigations on compressive and flexural characteristics of CLT produced in New Zealand were performed at the University of Canterbury (Millen and Carradine 2010, 2011). The flexural behaviour of New Zealand-grown and manufactured CLT was established with bending tests on panels representative of the New Zealand CLT industry product. These were constructed from radiata pine, Douglas fir and mountain ash timber. The experimental results also confirmed the typical average stiffness values for individual members. The heterogeneous nature of CLT did not seem to have any significant influence on the joint strength between laminates under high compression loads.

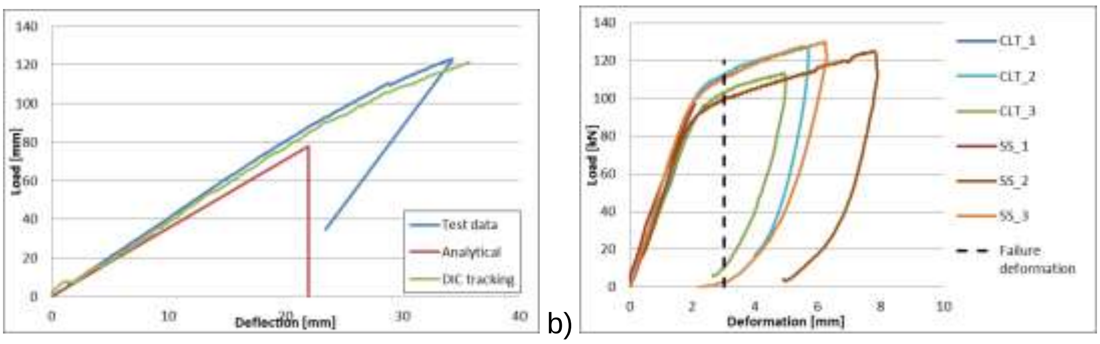
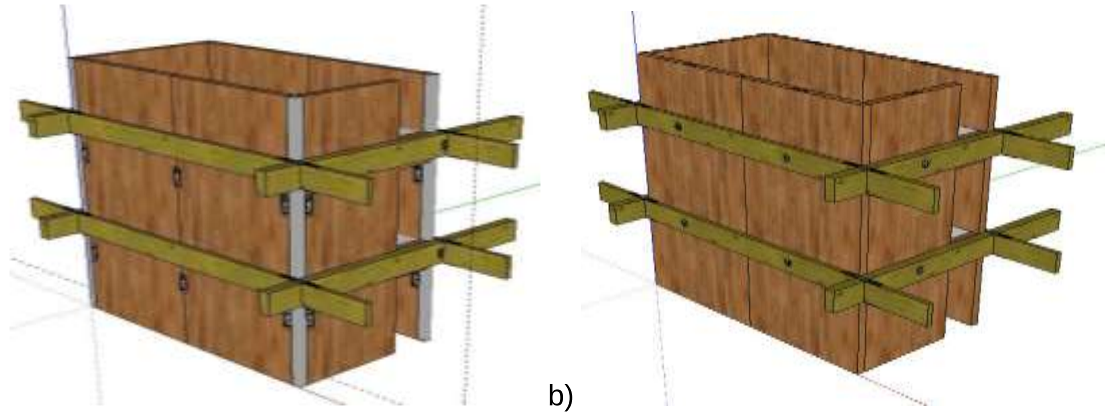
a) 

Figure 1: Load deformation of pine CLT in a) perpendicular to grain compression (Millen and Carradine 2010) and b) flexure (Millen and Carradine 2011)

In recent years, there has been significant research particularly at the University of Canterbury on structural systems with engineered wood products with self-centring and energy-dissipating capability for seismic applications. Although most of the systems use laminated veneer lumber (LVL) or glulam, focus has also been put on CLT in more recent investigations. After the initial stages with small-scale tests and subassemblies, complete structural systems and arrangements have been studied as a potentially applicable solution in practical structures.

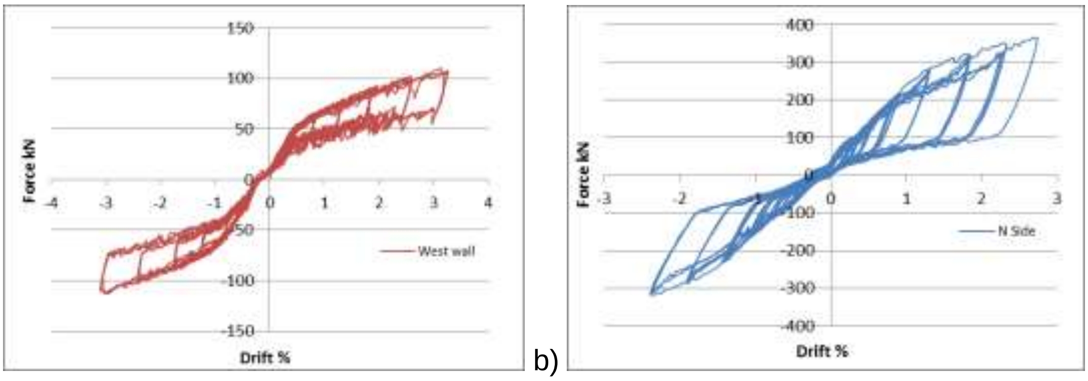
Dunbar et al. (2014) tested two half-scale two-storey post-tensioned CLT stairwells under bidirectional quasi-static seismic loading. The high seismic option consists of post-tensioned CLT walls coupled with energy-dissipating U-shaped flexural plates (UFPs) attached between wall panels and square hollow-section steel columns at the corner junctions. An alternative low seismic option uses the same post-tensioned CLT panels with no corner columns or UFPs. The panels were connected by screws to provide a semi-rigid connection, allowing relative movement between the panels and producing some small level of energy dissipation.



a) b)

Figure 2: Post-tensioned CLT rocking walls – a) high seismic option and b) low seismic option (Dunbar et al. 2013)

A desirable seismic performance was achieved using core walls made from post-tensioned CLT panels providing low damage recentring behaviour. For the low seismic option, the best behaviour was observed when a very small number of screws were used to connect the panels, as they were allowed to rock as individual panels. In the high seismic tests, the corner columns were found to work well as a shear key in addition to being a means to carry the vertical loads from the floor beams. The results of these tests provide confidence to use post-tensioned CLT core walls for lateral load resistance in open-plan multi-storey timber buildings.



a) b)

Figure 3: Hysteretic behaviour of a high seismic option stairwell – a) single wall and b) coupled walls (Dunbar et al. 2014)

The first New Zealand commercial manufacturer of CLT started production in 2012 and produces structural timber panels for use as roof and floor diaphragms and shear walls in commercial and residential buildings. Commissioning of the factory began in April 2012, and trial production started around the middle of the same year.

The manufacturer went through the process of setting up the commercial production procedure while trying to expand the local market. As part of the initial development process, it has produced a CLT design guide (XLam NZ 2013), developed in collaboration with the University of Canterbury.

The first application of CLT panels in a New Zealand structure was in a building on Waiheke Island in 2012 (Jack 2012). Because of the isolation of the location the panels had to be flown in with a helicopter, which was more expensive compared to other modes of transport. Despite that, it was a reasonable solution because of the saved time and reduced difficulties in construction. It also underlined potential levels of interest from building owners and designers which has been evident in other projects undertaken since then.

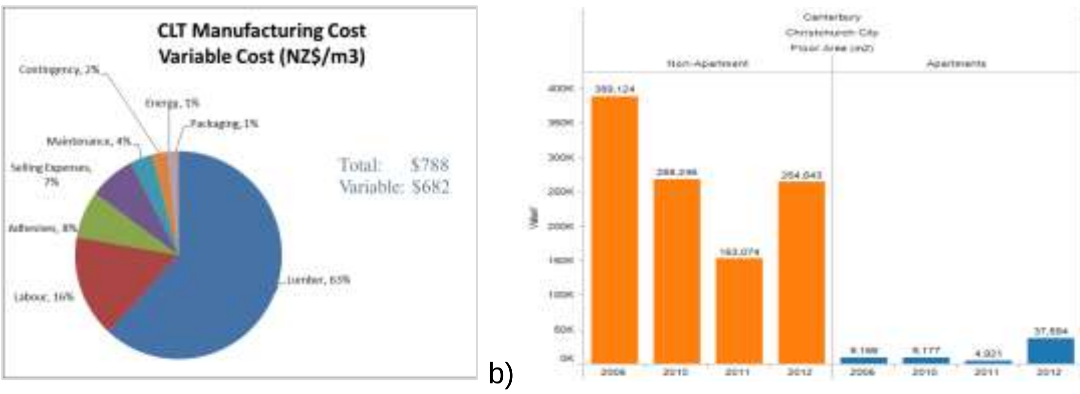
Following extensive research on post-tensioned timber structures at the University of Canterbury, the first application of the technology with CLT was the new Kaikoura District Council Building (Buchanan 2012). The building is a three-storey all-timber structure with a number of post-tensioned CLT shear walls (Figure 4). Construction of the facility is nearing completion at the time of writing.

Figure 4: Kaikoura District Council Building (images courtesy DesignBASE/Andy Buchanan)

3. CURRENT MARKET SITUATION AND PROSPECTS

A BRANZ-Scion study (Scion 2013a) for Grow Rotorua[1] estimated the demand for CLT in New Zealand. The study estimated demand to grow to 46,000 m^3 by 2018 from around 40,000 m^3 in 2012. The study calculated the manufacturing cost (Figure 5a) and found that CLT is most cost competitive for non-residential buildings – the figure is based on 10% penetration within the non-residential market. Another 1,450m ^{3} is expected in non-cost-effective solutions for non-residential buildings and an additional 750 m^3 for 1% market penetration into all new detached houses. The study indicated that cost competitiveness may be influenced by additional requirements for seismic performance in New Zealand. The competitiveness analysis can also include finishing elements beyond the structural components such as claddings. Most of the current demand is concentrated around Auckland and Christchurch (Figure 5b). The study also suggested assessment of the Australian market for additional opportunities.

a)



b)

Figure 5: CLT uptake – a) manufacturing cost components and b) demand (Scion 2013a)

[1] A council-controlled organisation of Rotorua District Council that is tasked with implementing the Rotorua Sustainable Economic Growth Strategy.

A recently completed BRANZ research study investigated advanced residential building construction techniques for New Zealand (Buckett 2013). The focus was on better building construction practices, possible opportunities for improvement in quality and productivity, opportunities for innovation with new materials and techniques as well as business strategies and industry transformation. CLT was identified as one of the materials with prospects for contributions in all of these areas. With mechanised manufacturing processes and computerised numerical control (CNC) machine-aided precision, CLT members can be produced as prefabricated building elements. These elements can be used in modular construction of multi-unit buildings in medium to high-density urban built environments.

The vision for the New Zealand Forest and Wood Products Industry Strategic Action Plan (Woodco 2012) includes delivering innovative wood-based building solutions from a sustainable resource. Investment into specific research and development is emphasised to provide growth opportunities along with development of new products and systems that:

- increase productivity
- compete with alternative products
- open opportunities for new markets for wood-based products
- support increased use of timber elements in multi-storey construction.

There are expected benefits to forest growers such as increased returns and reduced market risks. The new products and systems are also expected to make the wood processors and manufacturers more successful in competition against wood substitutes. One of the required actions identified is to develop high-value processing and manufacturing. The objective is to transform the use of wood in building systems such as prefabricated material, new wooden products, treatments, wood modifications and so on. This would be achieved through, among other things, research and development of new products, systems and processes.

The recent Scion-Wood Council of New Zealand joint study (Scion 2013b) states that supply of CLT is expected to ramp up over the coming year, and it presents a strong growth opportunity. However, developing acceptance within the New Zealand and Australian building codes will be one of the key factors in achieving greater success.

Timber buildings performed well in the recent Canterbury earthquakes (Buchanan and Newcombe 2010, Buchanan et al. 2011, Buchanan, Carradine and Jordan 2011). There is renewed public confidence and interest in timber buildings. The Christchurch rebuild presents an excellent opportunity for more timber buildings. That is particularly true for multi-storey buildings potentially using engineered wood products. In addition to the inherent properties of wood favouring good seismic performance, products like CLT can be used in prefabrication, which will be advantageous with savings in construction time and therefore cost.

Being the nearest neighbour and with closely associated markets, the prospects for CLT are also influenced to some level by acceptance of the product in Australia. CLT has already been used in two notable projects in Australia, including the tallest timber building in the world at present (see below). Although all the CLT used so far was imported from Europe, a number of big projects incorporating CLT are currently in the planning stage. This has created the opportunity for current and potential new CLT producers. There are also potential opportunities for New Zealand suppliers in growing markets in Asia.

4. APPLICATION OUTLOOK

A number of applications of CLT in New Zealand building projects are currently under construction. Several more are in different stages of planning. In these projects, CLT has been used in combination with other engineered wood products and/or other materials such as concrete and steel. A warehouse in upper Queen Street in Nelson used CLT and LVL as the shear walls and columns respectively with concrete beams and floor (Figure 6). In the Tait Communications Building in Christchurch (Figure 6), CLT is used with LVL beams and column and steel frames. These projects demonstrate the versatility of CLT applications.

Figure 6: Building in upper Queen Street in Nelson (left) (image courtesy Progressive Building) and Tait Communications Building in Christchurch (right) (image courtesy Daniel Scheibmeyer)

Figure 7: Forté Apartments (left) and Dockland Library (right) (images courtesy Lend Lease)

There have been a couple of major CLT buildings completed already in Australia. The 10-storey Forté Apartments in Melbourne (Figure 7), built by Lend Lease, is currently the tallest timber building in the world. The Dockland Community Library in Victoria Harbour in Melbourne (Figure 7) is the first CLT public building in Australia. Both of these buildings are built with CLT imported from Europe. A number of apartment projects are currently planned in Sydney, Brisbane, Adelaide and Perth. Plans are currently under way to expand the applications beyond New Zealand and Australia. The Building Control Authorities of Singapore have already issued in-principle acceptance for construction of CLT buildings in Singapore (Building and Construction Authority 2013).

5. CHALLENGES FOR APPLICATIONS

Structural systems and details have to meet the seismic requirements of the seismic design standards for New Zealand. Some of the concepts developed with other materials, such as self-centring rocking systems, can be used with modifications for the material-specific properties of CLT. More work is necessary to develop suitable panel jointing systems for the CLT elements.

Proof of acceptable fire performance is one of the greatest hurdles for acceptance into building codes and practices. This is of much greater importance for multi-storey and tall structures where CLT is better suited.

Serviceability criteria such as floor vibration, acoustic and flanking noise, deflection and sway must be satisfied to the acceptable limits in a CLT structure. Some of these issues can be addressed with help from research performed overseas, particularly in Europe and North America, with appropriate adaptation for the local timber species.

All of these areas have to be covered by standards, and sufficient information has to be provided in design guidelines and tools for practitioners to facilitate use of this product. Collaboration between researchers and practitioners is essential for the transfer of technology. Research institutions and professional organisations must work together to facilitate the transfer.

Like components of other materials used in prefabricated systems, the connection types and details are a key issue for CLT members. Standard joint details are still being developed globally, with an increasing number of products and applications. Seismic demands will often govern the design in New Zealand structures. Design of ductile connections is an added challenge for such situations. Conventional design for elastic response may be a conservative but practical alternative in some cases. In general, typical fabrication details need to be developed in sufficient detail to reduce cost through use of off-the-shelf products in regular applications.

Being a relatively new material, there are some unknowns regarding the long-term performance of CLT. The creep of the material can be an issue for loadbearing members particularly if they are part of a post-tensioned structural system. Conventional structural members can develop permanent deformations over long time periods due to creep. In post-tensioned structural systems, the structural members rely on post-tensioning for self-centring behaviour, particularly during earthquakes. If the members shrink under sustained compressive stress due to post-tensioning, the self-centring capacity of the system will be reduced. It can also be a concern in the serviceability condition for other types of systems. There has been very little opportunity to investigate the long-term behaviour of the panels manufactured here in the New Zealand climatic conditions.

Requirements for weathertightness of the structural members have direct implications on the design, details and costs of buildings. Propagation of moisture and heat through the materials directly affects shape stability and stress performance such as shrinkage and cracking. They are also related to overall building performance, energy efficiency and sustainability. To avoid future problems with built structures, the hygrothermal properties of CLT in local conditions have to be well understood before it is widely used as a building material. Knowledge gained on the subject can also be used to manufacture CLT with optimum quality in the New Zealand climate.

6. RESEARCH NEEDS AND INITIATIVES

The research needs and priorities for the Building and Construction Industry have been identified in the New Zealand Government's latest research strategy (Ministry of Business, Innovation and Employment 2013). They include "viability and applicability of new and innovative building materials" within building materials research under the Material Performance theme.

The current BRANZ research initiative to investigate the use of CLT within the New Zealand building industry was launched in 2014. The two-stage research is expected to span over 4 years. In the current stage 1, the scope and opportunities for applications are being investigated. Stage 2 of the project will focus on new developments and testing, with particular attention to connection details for seismic applications, and development of guidelines for practical applications at the end of the project.

7. CONCLUSION

CLT has gained increasing popularity in New Zealand in recent years as it is a cost-effective method of adding value to New Zealand's second-generation radiata pine timber. The current market is favourable to further applications, but the commercial competitiveness has to be explored further.

Initial research findings and case studies have indicated potential for applications of the product in New Zealand, including seismic regions. There are, however, significant technical and financial challenges for widespread acceptance of CLT as a building material. As a new material, commercial competitiveness of CLT against other building products is uncertain at the moment. Insufficient knowledge of short and long-term performance of CLT has left some uncertainty among potential users. At the same time, lack of design information and guidelines is a significant deterrent for the engineering community. Further technical details such as fabrication and connection details are not yet completely resolved.

It is expected that the cost of CLT will reduce, and it will be more competitive with an increasing number of applications. More research has been undertaken in recent times to develop connection details, including those for seismic applications. One of the latest BRANZ initiatives is planned to address some of these issues. Other uncertainties are also likely to be reduced over time through further research and experience. An overall comprehensive approach can facilitate utilisation of CLT to its full potential in New Zealand.

REFERENCES

Buchanan, A. 2012. *Building in Engineered Wood Post Christchurch*. PMA/WPA/FTMA Conference, Rotorua, October.

Buchanan, A. and Newcombe, M. 2010, The performance of residential houses in the Darfield (Canterbury) earthquake. *Bulletin of the New Zealand Society for Earthquake Engineering*, 43 (4),387–392.

Buchanan, A. Carradine, D., Beattie, G. and Morris, H. 2011. Performance of houses during the Christchurch earthquake of 22 February 2011. *Bulletin of the New Zealand Society for Earthquake Engineering*, 44 (4), 342–357.

Buchanan, A., Carradine, D. and Jordan, J. 2011, Performance of engineered timber structures in the Canterbury earthquakes. *Bulletin of the New Zealand Society for Earthquake Engineering*, 44 (4), 394–401.

Buckett, N. 2013. *Building Better: Advanced Residential Construction Techniques for New Zealand*, *Study Report SR294*. BRANZ Ltd, Judgeford, New Zealand.

Building and Construction Authority. 2013. *In-principle acceptance.* Building and Construction Authority, Singapore. http://www.bca.gov.sg/cpc/others/BIP2012-12-0003.pdf

DesignBASE. 2014. New Kaikoura District Council Building. http://www.designbase.co.nz/about-us/news/new-kaikoura-district-council-building/

Dunbar, A., Pampanin. S.. Palermo, A. and Buchanan A. 2013. *Seismic design of core-walls for multi-storey timber buildings*. Annual Conference of New Zealand Society for Earthquake Engineering, Wellington, April.

Dunbar, A. Pampanin, S. and Buchanan, A. 2014. *Seismic performance of core-walls for multi-storey timber buildings.* Annual Conference of New Zealand Society for Earthquake Engineering, Auckland, March.

Fortune, A. and Quenneville, P. 2007. Feasibility study of New Zealand radiata pine cross-laminated timber. *New Zealand Timber Design Journal*, 19 (3), 3–7.

Irving, A. and McDonnell, G. 2012. *Structural System Optimisation Report*. Irving Smith Jack Architects, Nelson.

Jack, R. 2012. *Rebuilding Canterbury with Wood: Cross Laminated Timber*. http://www.marlboroughforestry.org.nz/mfia/docs/Rebuilding_Chch_14_Nov_2012.pdf

John, S., Mulligan, K., Perez, N., Love, S. and Page, I. 2011. *Cost, Time and Environmental Impacts of the Construction of the New NMIT Arts and Media Building*. University of Canterbury, New Zealand. Research Report 2011-01 (ISSN 1172-9511).

Millen, M. and Carradine, D. 2010. *Compression Strength of Cross-Laminated Timber Joints*. Project Report. Department of Civil and Natural Resources Engineering, University of Canterbury.

Millen, M. and Carradine, D. 2011. *Flexural Behaviour of New Zealand Grown Cross-Laminated Timber Joints.* Project Report. Department of Civil and Natural Resources Engineering, University of Canterbury

Ministry of Business, Innovation and Employment. 2013. *The Research Strategy for the Building and Construction Industry*. Ministry of Business, Innovation and Employment, Wellington

Scion. 2013a. *Cross Laminated Timber Potential in New Zealand*. Scion, Rotorua. http://www.scionresearch.com/__data/assets/pdf_file/0020/42167/CLT-potential-NZ.pdf

Scion. 2013b. WoodScape Study – Technologies and Markets. Scion, Rotorua. http://woodco.org.nz/images/stories/pdfs/woodscape/woodscapetechreportfinal3_web.pdf

Standards New Zealand. 2010. AS/NZS 4063.1:2010 *Characterization of structural timber – Test methods*. Standards New Zealand, Wellington.

Woodco. 2012. *Forest and Wood Products Industry Strategic Action Plan*. Wood Council of New Zealand. http://woodco.org.nz/images/stories/pdfs/Strategic.pdf

XLam NZ. 2013. *Cross Laminated Timber Design Guide.* XLam NZ, Nelson.