M. A. Schnabel (ed.), *Back to the Future: The Next 50 Years,* (51st International Conference of the Architectural Science Association (ANZAScA)), ©2017, Architectural Science Association (ANZAScA), pp. 475–484.

Timber Frame Construction for a Circular Materials Economy

Alternative Framing Methods and Post-Use Certification

Gerard Finch[1], Nick Forbes[2] and Guy Marriage[3]
Victoria University of Wellington, Wellington, New Zealand
[1, 2] *{finch.gera, forbes.nick}@myvuw.ac.nz,* [3] *guy.marriage@vuw.ac.nz.*

Abstract: The building and construction sector in New Zealand consumes more than 50% of all raw materials while simultaneously generating more than half of all waste sent to landfill. These unprecedented levels of consumption are set to continue as demand for residential housing continues to grow rapidly. This research suggests that building construction methodologies and compliance infrastructure could be established that would enable the widespread reuse and recycling of building materials. Design experimentation shows that an efficient, flexible and affordable reusable wall system can be fabricated using a range of commonly available construction materials. Practices for the post-use certification and strength testing of materials are proposed to validate widespread adoption of material reuse in the construction industry. Visual strength grading of recycled timber is highlighted as a critical factor for enabling the widespread and affordable reuse of this material.

Keywords: Material Reuse, closed loop design, cradle to cradle, sustainability.

1. Introduction

Architects and building professionals, as key figures in the building sector, have a responsibility to implement systems that reduce the impact of our industry on the environment. This research sets out to eliminate key barriers for material reuse in New Zealand. There is inherently two dimensions to this work. Buildings must be designed to enable the reuse of material and crucially, the integrity of those second-hand materials, at the end of their first life, must be assured.

1.1. The Waste Problem

In New Zealand the building and construction industry produces more waste than every other sector combined (Inglis, 2007; Storey et al, 2005). The industry has been optimised for economic efficiencies and in doing so has adopted the widespread application of single use and composite materials (Curtis, 2014). These materials, although adaptable, durable and cost effective, have no reuse value as they are either damaged on removal or not approved by building codes for reuse. Products such as plasterboard (drywall), treated framing timber and reinforced plaster monolithic claddings are all single use materials that are found in most residential structures built in New Zealand (Curtis, 2014. Baker-Brown, 2017). These 'engineered' materials are fixed in a way that makes removal without damage an impossibility and are also difficult to recycle or reprocess in a meaningful way (Baker-Brown, 2017). Furthermore, these materials are often treated with chemical stabilizers to prevent the ingestion of water, notably copper, chrome, arsenic (CCA) treated timber. When landfilled these chemicals will delay the decomposition process, damage neighbouring ecosystems and potentially contaminate groundwater (Parisio, 2006). Based on current building trends we can expect to see the dumping of increasingly toxic building waste (Curtis, 2014; Inglis 2007; Keene and Smythe, 2009).

1.2. Eliminating the waste problem long term: Reusing Building Materials

A tightly regulated building industry makes it difficult to simply replace chemically enhanced building materials with natural alternatives. The widespread use of treated timber in New Zealand buildings today reflects the recent ‘leaky building crisis’ where water penetrated the cladding and rotted untreated structural timber framing (Ridley, 2003). Legislation was introduced in 2004 to resolve this issue that made the use of treated timber mandatory for all structural applications of the material (NZS3602:2003). This measure ensured that even if water contacted the timber frame rotting and decomposition would be significantly delayed (NZS3602:2003). Consequently, reverting to the use of untreated or partially treated timber for structural framing of building is unlikely due to the recent leaky homes issues and would face significant opposition (Harris, 2017). Modern building practices dependence on chemically enhanced materials that have the potential to cause significant harm to the environment dictates that we must develop effective methods for reusing these materials.

Fortunately, the benefits of reuse are remarkable. Reusing building materials prevents potentially hazardous substances (such as CCA) from being deposited into landfills (Chini, 2001). Reuse also helps to lock in carbon and significantly reduce the industry's demand for new ‘virgin materials’ (Storey et al, 2005). Furthermore, through the reuse of so called ‘waste’ material we have the potential to stabilize the cost of materials in the construction industry, reduce our reliance on petrochemicals, improve the air quality of internal spaces all while minimising the impact of building on the environment (Baker-Brown, 2017).

2. Redesign: Closing the Loop

2.1. Closed Loop Materials Design

Fundamental barriers to widespread material reuse in the construction industry are the result of economic imperatives. These imperatives dictate the use of low cost fixing methodologies and the uninterrupted supply of quality certified building materials. A highly regulated building industry also means demands the use of specialist, non-removable and adhesive fixings. Materials fixed using these methods are often damaged on removal, lowering both the resale value and reuse potential of that material. For this reason any product that is to be reused must be recertifiedto prove that it will retain the required integrity for the next lifespan/use.

To successfully eliminate hazardous waste products from the construction industry architects must design for a *closed material loop* (Baker-Brown, 2017). This process ensures that every material contributes positively to its surrounding environment at all stages of its life cycle - thus creating a closed loop where the devaluing *(*downcycling*)* of a material is carefully controlled and there is ‘no waste’). Ideally each stage of a materials life cycle should feed intrinsically into its next. Materials used in construction today typically fall into 3 categories of reuse ‘loop potential’ (Braungart and McDonough, 2010; Baker-Brown, 2017).

- **Technical Cycle** - refers to materials that are highly engineered and often energy intensive to fabricate. These materials are generally highly durable and resistant to damage and corrosion. Providing they are jointed in a way that enables deconstruction these materials can be used again and again without producing any waste. Materials with such properties include aluminum and steel.
- **Organic Cycle** - refers to materials that feed into a natural waste management process. Often decomposition transforms these materials, over time, back into the nutrients that the materials once grew from. Materials matching this description include untreated timber, lime based plaster renders and unbound stone.
- **Compromised** - refers to materials that are either designed poorly or compromised in some way over their lifetime. These materials cannot be naturally decomposed without causing harm, nor processed by humans without losing their integrity. CCA timber is a leading example of a material that has a compromised potential to be effectively and safety disposed of.

2.2. What redesign must achieve

The introduction of more effective mounting, jointing and wall systems will enable disassembly and reuse without causing damage to the individual components. The ideal design solution ensures that all the materials put into one building have a place in future buildings. For example, a wall designed for material reuse must fulfil all the criteria of a modern-day walling system, and also allow for ‘economical’ disassembly, relocation and re-erection (Table 1). This means that the dimensional properties of the walls components must be attractive to a broad range of design contexts. Likewise, the finished surfaces of this reusable walling system must be specified to retain a ‘new’ aesthetic right throughout their ‘endless’ lifetime. This ensures that the wall not only meets technical reuse imperatives but also meets the demands of the construction marketplace.

Table 4: Comparison of Conventional vs Closed Loop Wall Design (with reference to Chini, 2001).

Conventional walling system features:	Additional features necessary for reuse:
Provide support for overhead members	Allow for economical disassembly
Be easily transportable to site	Be easily transportable from the site
Support waterproof barriers and aesthetic claddings	Be undamaged by the process of deconstruction
Support insulation / thermal resistance	Retain an ‘as new’ external aesthetic quality
Support internal aesthetic linings	Facilitate the removal of all components
Allowing the fixing of lights and appliances	Account for all material at end-of-life
Carry electrical and wet services	

2.3. Analysis: Existing Solutions

Conventional construction methodologies are examined and categorised qualitatively based on the essential features of a closed loop wall design (outlined in Table 1) in Table 2. Factors determining the potential for reuse have been equally weighted when rating a construction method for reuse. Specific features of a system that significantly impact the reuse potential have been noted to highlight the range of factors that determine the potential reusability of the materials in each construction method.

Table 5: Common existing wall construction options in New Zealand & their potential for material reuse.

Construction System:	Specification:	Deconstruction Notes:
Light Timber Framing (LTF)	90*45 KD PG SG8 Radiata Pine Timber Studs with Nogs @ 800ctrs. Nailed.	Moderate potential for reuse. Single use/damaging structural fixings. No direct reuse potential for timber due to a lack of certification. Conventional linings (plasterboard) damaged on removal, 'downcycled', contaminated and dumped. Time consuming deconstruction.
Light Steel Framing (LSF)	90mm x 40mm galvanised 0.55mm Gauge steel, lipped 'C' section. Riveted.	Moderate potential for reuse. Riveted connections slows deconstruction and can damage the material. Frame often damaged by lining fixings and adhesives - time intensive to prepare for reuse. Plasterboard lining damaged on removal, 'downcycled', contaminated and dumped.
Structurally Insulated Panels (SIPs)	165mm polystyrene foam (XPS) with 18mm Orientated Strand Board (OSB). Screwed.	Limited potential for reuse. Large panel sizes make the deconstruction process more expensive. Edges often sealed with an adhesive based foam that is inherently single use. Custom cut panels cannot be reused readily. Expanding foams make extraction without damage challenging.
Insulated Concrete Forms (ICF)	40mm polystyrene foam (EPS) formed blocks with reinforced concrete infill.	No potential for reuse. Initially modular but compromised by reinforced monolithic concrete to create composite single use system. Expensive, messy and disruptive to remove. Requires single use fixings of linings and claddings. Waste material downcycled or landfilled.

2.4. Key Issues to Resolve

The analysis of existing wall construction methods (Table 2) illustrates key areas of concern with regards to material reuse. A critical concern is the layering and fixing of engineered materials to create monolithic finishes. This is an area of significant waste that is difficult to mitigate as the monolithic surface, generally plasterboard, is a highly desirable aesthetic that also aids in the sound and draft proofing of spaces. A similar concern is the dependence of conventional walling systems on adhesives, silicon sealants, and fragile fabrics to form the waterproof barrier of the building. Reuse of such materials is difficult and strictly prohibited as such practices are deemed a risk to the water-tightness of the building envelope. Collectively these two issues become the focus when designing a walling system that will eliminate waste.

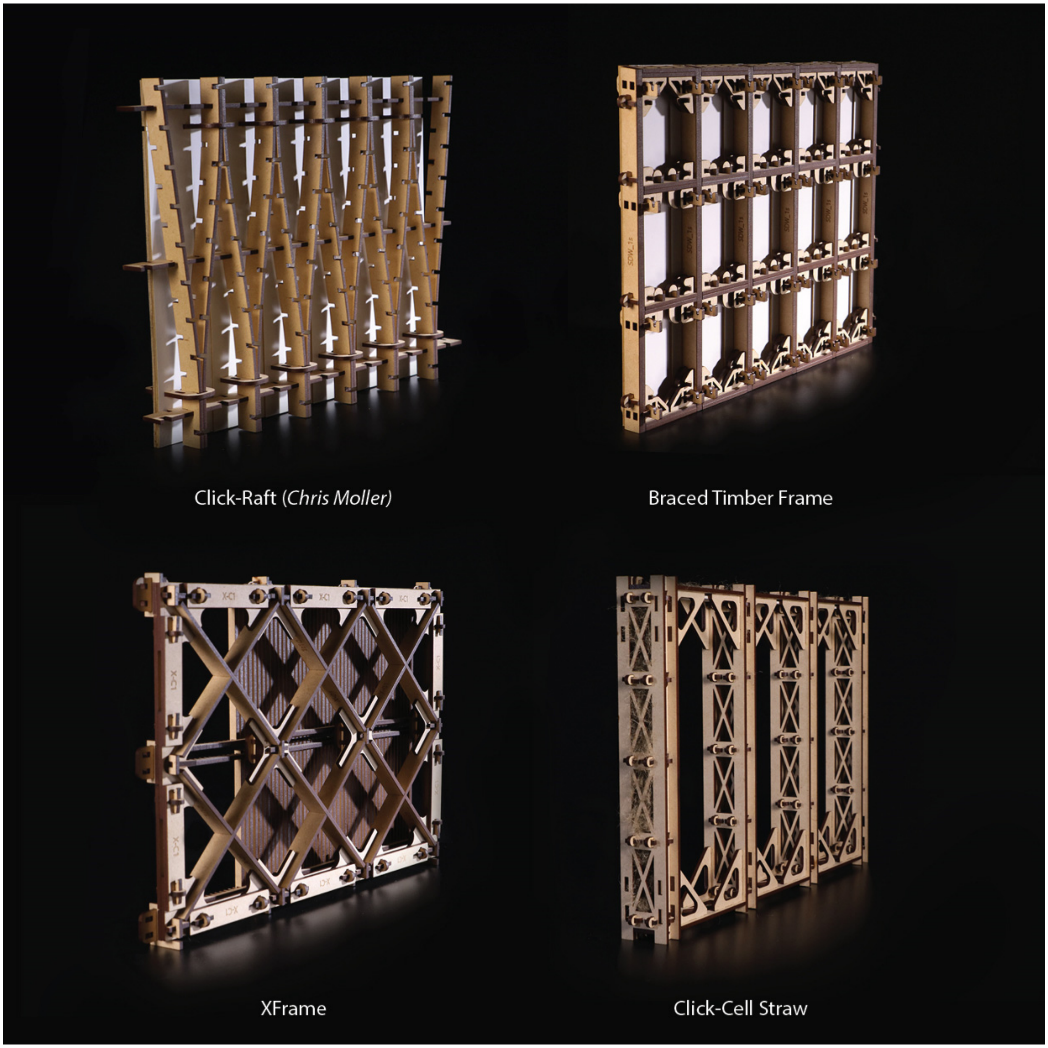
2.5. Analysis: Designed Solutions

Common wall construction techniques (Table 2) generally fall into three categories: monolithic, panel based and framed. Framed solutions, such as LTF, are listed has having the most potential for reuse due to their inherent separation of materials into discrete, removable, layers (Chini, 2001). This separation allows materials to be deconstructed into their individual components more readily and without significant damage. Panelised wall options (i.e. SIPs) have similar characteristics but are often too large to handle and transport easily without significant expense. Monolithic walling systems, such as ICF's, have no potential for reuse as they are generally composite and to large, heavy and fragile to relocate effectively. Unfortunately, framed wall designs are often clad both sides with monolithic plasterboard and reinforced cement plaster render finishes. Although these materials do not damage the structural frame upon removal they are too fragile to be removed without 'catastrophic damage' and therefore become waste. Monolithic surface finishes are also commonly found on panelised wall systems. These issues have been addressed collectively in design based experiments (Table 3 & Figure 1).

In response to these issues a range of alternative wall framing and assembly methods have been evaluated. The selected systems are a combination of existing experiential methods, not specifically intended as a cradle-to-cradle solution, as well as construction methods explicitly designed to promote material reuse. Existing experimental systems have been selected based on their perceived ability to meet the 'additional features necessary for reuse' outlined in table 1. The inclusion of these systems is intended to indicate the potential feasibility moving to reusable construction approaches. New and alterative wall assemblies have been designed in direct response to the criteria outlined in table 1.

Table 6: Summary of experimental wall designs and their deconstruction and material reuse potential:

Construction System:	**Specification:**	**Deconstruction Notes:**
Click-Raft (designed by Chris Moller Architects)	Computer numerically controlled (CNC) router cut structural square edge Plywood sheet. 2400*1200 CD Grade 12mm CCA H3.2 Treated.	Moderate potential for reuse. Multi-use structural fixings where necessary, generally minimal fixings required, no damage to structural material. Lightweight, easy to disassemble and transport. Self-bracing, allowing conventional linings to be fixed alternatively - preventing likely dumping.
Click-Cell Straw (author modified ModCell Ltd Straw Panel System)	450*350*900 Straw Bales with CNC router cut structural square edge Plywood sheet. 2400*1200 CD Grade 24mm CCA H3.2 Treated.	Good potential for reuse. Multi-use structural fixings where necessary, generally minimal fixings required, no damage to structural material. Largely organic, quickly renewable and non-contaminated material basis. Monolithic, purposely sacrificial, decomposable finishes.
'XFrame' (by author)	CNC router cut structural square edge Plywood sheet. 2400*1200 CD Grade 18mm CCA H3.2 Treated. Self-Braced.	Strong potential for reuse. Multi-use structural fixings where necessary, generally minimal fixings required, no damage to structural material. Lightweight, easy to disassemble and transport. Self-bracing, allowing conventional linings to be fixed alternatively - preventing likely dumping. Massively modular in plan and elevation. Integrated cladding and lining 'fixingless' system.
Braced Timber Frame (Authors modified conventional light timber frame).	90*45 KD PG SG8 Radiata Pine Timber Studs CCA Treated with Nogs @ 800ctrs. Bolted and Pegged.	Good potential for reuse. Multi-use structural fixings with reusable steel interlocking plates. Like current LTF system and deconstruction friendly but significantly costlier. Self-bracing, allowing conventional linings to be fixed alternatively (clipped)- preventing dumping/downcycling of materials.



Click-Raft (*Chris Moller*)

Braced Timber Frame

XFrame

Click-Cell Straw

Figure 1. Wall Iterations / Options / Design Solutions

XFrame and *Click-Cell Straw* (see figure 1) both assemble using fully reversible compression based joints and mix technical materials with 'sacrificial' natural materials to create assemblies that have significant potential to eliminate construction waste. These alternative solutions are derived from the self-braced *Click-Raft* frame developed by Chris Moller and the *ModCell* glue-laminated timber straw bale system popular in the United Kingdom. The *XFrame* system (figure 1) uses readily available and replaceable materials in a pattern that is self-bracing, requires no additional fixings and provides the foundation for fixing free waterproof cladding and internal wall lining to be added. The components of this system can be handled, assembled, and disassembled, by a single person with only the use of a simple wooden mallet and a step ladder. The wall, and its linings, can be scaled in size in 600mm intervals and facilitates the easy installation and removal of plumbing and electrical services.

3. Certifying Materials for Reuse

The proposed reusable design solutions are dependent on approval by the New Zealand Building Code (NZBC) as an *acceptable alternative solution.* To achieve this, it must be proved that reused materials, like those specified in the proposed design solution (figure X), can perform to the necessary strength requirements stipulated by the industry. In New Zealand however there is currently no legislation for the reuse of structural timber. Accreditation and formal legislation is essential to streamline the evaluation process of reused materials and assure their reuse potential. For this reason a possible process of post-use certification has been studied and associated technical challenges considered.

3.1. The need for post-use certification

Current New Zealand building standards do not require specific engineering in simple light timber frame construction. This practice dictates that the supplied material must be certified to perform to a minimum standard to ensure it is adequate for all potential use cases. This presents an issue for material reuse. Research in the field shows that the strength of a timber member will vary over its lifespan. Inconsistencies such as the duration, size and nature of an applied load can all affect *strength* over time (Crews et al, 2008). This is expressed through a common denominator, the *'K-Factor',* which explains how a constant load can degrade a timber member over a given period (Crews et al, 2008). There are other scenarios which can also affect the grade of the timber after its first life such as fixing extraction and damage incurred through transportation. Collectively these variations impose uncertainties in the structural abilities of second-hand timber, effectively requiring each member to be re-tested against established codes of compliance. This testing ensures that the material is of an adequate level of performance and will structurally bear the load which is placed upon it.

3.2. Strength Certification Methodologies

To test for structural integrity of timber the industry uses a range of grading techniques. Traditionally the building industry utilized *Visual Strength Grading* (VSG) as its primary method of quantifying the potential strength of a timber member. All material was sorted on site and timber with impurities (knots or rot) or of a low quality was removed and assigned to areas with low structural requirements such as dwangs or nogs. This system proved highly economical as it allowed the builder to recycle and reuse timber without the need for independent testing. Today however mechanical grading has been introduced throughout the industry and the grading requirements are much more stringent. Mechanical strength grading has replaced all VSG and is achieved either using a three-point bending test machine or the more sophisticated method of acoustic strength grading "that uses sound waves to measure timber stiffness" (Scion, 2008). These testing methodologies are outlined in detail below:

Three Point Bending Strength Grading

Traditional mechanical bend testing is achieved through a three-point hydraulic system which is manually controlled by an operator applying pressure through a jack handle. The applied force is represented through a pressure gauge which reads both the imposed BAR and PSI pressures acting on the timber through the hydraulic ram. This figure and the displacement distance of the timber is multiplied with the area of the ram to give force acting on the member. Testing with this machine can see varied results due to the need to accurately calibrate the pressure gauge and hydraulic ram. Consequently the accurate grading of reused timber in the field using this method may be difficult.

Acoustic Strength Grading

The New Zealand based crown owned research institute Scion developed, in association with Falcon Engineering, an automated acoustic strength grading machine in 2005 (Scion, 2008). Acoustic strength testing is achieved by “a pneumatic hammer producing a tone in the selective timber member, and a highly sensitive recording device receiving this tone” (Scion, 2008). This tone can then be translated, with all the other known factors; size, weight, density, into the respective bending strength of that timber member (Scion, 2008). This new and experimental grading technology has been installed in several different timber mills around New Zealand.

3.3. Developing a VSG Standard for Recycled Timber

The most desirable method for certifying the strength of recycled timber is visual strength grading (VSG). VSG significantly reduces the cost of grading timber for its second life as specific testing machinery is not required. Likewise, the recycled materials do not have to be transported from their original site to a testing facility and then to a new site. These economic savings can be passed directly onto the consumer and help to keep recycled timber cost competitive with virgin materials. Visual strength grading of recycled timber can also be more accurate than automated acoustic or bend testing processes. VSG calls for a detailed aesthetic inspection of the material which will help to identify common recycled timber issues quickly such as crushed or splintered sections. Mechanical strength grading processes as they are today would not identify such defects.

To achieve accurate VSG standards and guidelines for reusing timbers (such as those specified in the proposed reusable wall designs - figure 1) a series of interrelated strength tests must be carried out. Studies of reused timber with a specific set of defects and the correlation between mechanically strength graded values and visually graded values is a critical first step in this process. Testing will allow for an accurate VSG grading guide to be established for recycled timbers. This testing to establish a standard must be extensive and methodologically documented as it will dictate what damage or defect each timber member can have before it is compromised structurally and becomes unusable.

Sampling reused timber to establish a VSG standard

As part of the process towards establishing grading standards for the use of recycled timber test samples must be selected. Fortunately, 95% of all houses built in New Zealand use a timber framing system that could provide valuable samples for testing (Shelton & Beattie, 2011). However this quantity of potentially recyclable material also creates a problem. For each member extracted for testing and analysis the full history of the timber member must be understood. The timber’s geographic location, nearby environmental conditions and previously attached cladding and wall lining systems will all likely influence the strength performance of it in some way. Such a varied sample base makes defining VSG criteria difficult.

Testing recycled timber samples to establish a VSG standard

The process of testing samples to establish a standard for grading recycled timbers is proposed. The material will firstly be visually assessed as it would be in real world conditions. This will assess the recycled timbers strength based on aesthetic information. This information includes knots, fixing holes, crushed and splintered material, warping, rot and other deformations. Strength grading standards are based on established VSG literature; specifically New Zealand's 1998 NZS: 3631, visual grading schedule, and also Australia's 'Recycled Timber – Visually Stress Graded Recycled Timber for Structural Purposes' (Standards New Zealand, 1988) (Crews, Hayward, & MacKenzie, 2008). These documents include the original VSG guidelines for New Zealand prior to the widespread introduction of machine graded timber, and the recently developed interim timber recycling and reuse guidelines for Australia. International standards (ISO) for visually strength grading timber, namely 'ISO 9709:2005 Structural Timber – Visual Strength Grading – Basic Principles' will be used to ensure grading processes are in accordance with international best practice.

After the completion of initial VSG, the accuracy of this grading will be measured using a mechanical grading system. While the acoustic grading machine can conduct all necessary measurements at a high turnover rate, acquiring such a machine is both costly and difficult. It is therefore likely that the testing will revert to the traditional mechanical strength testing approach of a three-point bending test. As these tests are to be completed under laboratory conditions the accuracy of the pressure readings can be assured.

3.4. Continuations

Testing of recycled timber samples to establish a visual strength grading system for the proposed reusable wall design is in its infancy. Further research hopes to conduct a comprehensive analysis of recycled timber samples obtained from a wide variety of construction and demolition sites to eventually establish an accurate correlation between mechanical strength tested recycled timber and VSG. This correlation will be largely supported by existing VSG codes available in New Zealand for new timbers and the interim standards for the reuse of timber in Australia (Standards New Zealand, 1988) (Crews, Hayward, & MacKenzie, 2008).

This paper has dealt with two key barriers restricting widespread material reuse in the construction of light timber framed buildings; post use certification and structural assemblies. There are numerous other barriers to enabling the widespread reuse of materials; the cost of dumping vs the cost to reuse, product storage, transport issues, structural compromises, legislation, durability, dismantlability, disaggregate potential and the numerous conflicts between recyclability vs reusability, downcycling and upcycling. It is the intention of the authors to continue their research into these areas.

4. Conclusion

The building and construction industry faces major waste management challenges in the next 50 years. Current building practices that depend on single use materials and adhesive based connections must be eradicated to eliminate the production of downcycled or waste materials. This research demonstrates that waste produced from the demolition of residential structural walls can be all but eliminated with the introduction of alternative construction methods. The proposed methods integrate fully modular and reusable structures with integrated provisions for the fixing free and reversible attachment of waterproof and aesthetic linings. To ensure the feasibility of material reuse adoption by the industry post-use compliance testing processes for timber have been proposed and discussed. Economic issues associated with the process of strength grading materials for compliance at the end of their first life proves to be a significant barrier to the adoption of widespread material reuse. However, the adoption of visual strength grading (VSG) standards for recycled timber members in structural applications has potential to make certification of recycled timber economical.

Acknowledgments

The authors thank the numerous industry professionals and business who have offered material samples, advice and insight.

References

Baker-Brown, D. (2017) *The Re-Use Atlas: A Designer's Guide Towards a Circular Economy*. 1st ed. London: RIBA Publishing, 15-19.

Christchurch Case Study. *University of Canterbury, New Zealand*, 54.

Chini, A. R. (2001) Deconstruction and materials reuse: technology, economic, and policy. *Proceedings of the CIB Task Group*, *39*, Wellington, 5-12.

Crews, K., Hayward, D., & MacKenzie, C. (2008) Interim Industry Standard Recycled Timber – Visually Stress Graded Recycled Timber for Structural Purposes. Methods (Vol. 61). Sydney.

Curtis, M.D. (2014) Study Report SR309; *Physical Characteristics of new houses in 2013.* Building Research Association of New Zealand (BRANZ), Judgeford, Wellington, 15-17.

Fraser, S. (2013) Treated Timber Waste Minimisation Project Timber Identification Tool (Vol. 8).

Harris, C. (2017) Concern at untreated timber risk. *The Dominion Post*, C10.

Inglis, M. (2007) Construction and Demolition Waste–Best Practice and Cost Saving. *SB07 New Zealand*, 1.

Keene, S., Smyth, C. (2009). End-of-Life Options for Construction and Demolition of Timber Waste

Keene, S., & Smythe, C. (2009) End-of-Life Options for Construction and Demolition Timber Waste: A Christchurch Case Study.

McDonough, W., & Braungart, M. (2010) *Cradle to cradle: Remaking the way we make things*. North point press, New York, 34-35.

Moller, C (2017) *Click-Raft News and Development Blog.* Web.

Marriage, G. (2016) Experimental construction in a timber house: Proceedings of the 50th International Conference of the Architectural Science Association ASA 2014, Architectural Science Association (ASA), Adelaide, 691-692.

ModCell Ltd, (2010) *ModCell Technical Guide 2013.* ModCell Ltd. Bristol.

Naujokas, M. F., Anderson, B., Ahsan, H., Aposhian, H. V., Graziano, J. H., Thompson, C., & Suk, W. A. (2013) The broad scope of health effects from chronic arsenic exposure: update on a worldwide public health problem. *Environmental health perspectives*, *121*(3), 295.

Parisio, S. (2006) *Arsenic & Old Landfills: What we have learned from post-closure groundwater monitoring at inactive landfills in NY State*. New York State Department of Environmental Conservation. 2006 SBRP Workshop on Arsenic and Landfills: Protecting Water Quality. Boston. Slide 18.

Ridley, G. S. (2003) “Six months in a leaky boat”: The biosecurity of New Zealand forests. New Zealand Journal of Forestry Science, 33(3), 429–438.

Scion. (2008) A-Grader, A timely innovation for New Zealand’s wood processing industry. *Next Generation Biomaterials*

Shelton, R., & Beattie, G. (2011) Timber Framed Buildings and NZS 3604, (Nzs 3604), 5. Available from: <www.timberdesign.org.nz/files/00556 Roger Shelton.pdf> (accessed 2 June 2017)

Storey, J. B., Gjerde, M., Charleson, A., & Pedersen, M. (2005) The State of Deconstruction in New Zealand. Centre for Building Performance research, Victoria University, New Zealand. *7-9.*