BUILDING TODAY - SAVING TOMORROW

CONSTRUCTION AND DECONSTRUCTION

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BUILDING TODAY - SAVING TOMORROW

BY MARY PANKO AND LINDA KESTLE

The construction and demolition (C&D) industry is one of the largest waste producing industries in New Zealand. C&D waste may represent up to 50% of all waste generated, 20% of all waste going to landfill and the remaining 80% going to cleanfill. In an attempt to highlight these issues and encourage a culture of waste minimisation Unitec Institute of Technology organised a conference in Auckland in July 2015, which was supported by a grant from Auckland Council. The conference attracted delegates from New Zealand, Australia, Canada and Singapore and comprised a mix of academics and practitioners. These included industry speakers involved in both construction and deconstruction.

The major themes of this conference included 'construction for deconstruction'; reuse and recovery; C&D waste reduction, waste management on site and good practice; landfill diversion and cleanfill diversion. "Clean", in this case, means environmentally clean, i.e. free from contaminants, including corrosive, combustible, noxious, zootoxic, reactive, or radioactive materials. "Fill" is top soil, clay, sand, gravel, rubble, even brick or concrete.

The problems associated with waste minimisation are not new. Bossink and Brouers (1996) highlighted a number of lesser known sources of waste generation such as: a lack of attention paid to the sizes of the used products, lack of influence of contractors, and lack of knowledge about construction during design activities. Myers (2005) reported that although a number of initiatives had already been taken to encourage the construction industry to support the agenda of sustainable development, the fragmented and diverse nature of the industry had not encouraged companies to change their business practices. Another aspect of waste minimisation, described by Keys, Baldwin and Austin (2000) was that of 'designing out waste'. This was also considered by several presenters at this conference, highlighting the links between 'designing out waste' and the future waste management and recycling industries, indicating where opportunities may exist.

This reviewed publication comprises the papers supplied by a number of the academic presenters from both New Zealand and overseas, looking at sustainability in building design and waste management from places as far apart as The Cook Islands and Canada. The outlines provided in the latter section of this introduction are largely taken from the abstracts provided by the presenters.

KEYNOTE PRESENTATIONS

In addition to the papers published here, there were also presentations by a range of keynote speakers.

- John Cumberpatch, General Manager Operations Implementation, Canterbury Earthquake Recovery Authority (CERA)
- Alex Cutler, Chief Executive, New Zealand Green Building Council
- Michael O'Sullivan, Architect, BOS
- Dr Michele Rosano, Associate Professor, School of Civil and Mechanical Engineering and Director of Sustainable Engineering, Curtin University, Australia
- David Brown, Board of Directors, Beacon Pathway Inc.
- James Griffin, Sustainable Business Network
- Simon Gaines, Fletcher Construction and Adam Benli, Sustainability and Energy Advisor within the Chief Sustainability Office, Auckland Council
- Adam Benli, Sustainability and Energy Advisor, Chief Sustainability Office, Auckland Council

JOHN CUMBERPATCH

General Manager Operations Implementation, Canterbury Earthquake Recovery Authority (Cera)

John has been working on the Christchurch earthquake response and recovery in the operations space since the beginning. He is responsible for scoping, delivering, monitoring and reporting on appropriate strategies and programmes of work relevant, but not limited to, the delivery of full or partial demolitions of property, both commercial and residential within Christchurch as well as Selwyn and Waimakariri Districts. View John Cumberpatch's presentation.

ALEX CUTLER

Chief Executive, New Zealand Green Building Council

Alex›s career has been focused on influencing business and government to understand and adopt the strategic opportunities that sustainability represents. As CEO of NZGBC, this is focused on the building and construction sector. Previously Alex built the sustainability practice at PwC NZ, was a consultant at PwC UK and Sustain Ability Ltd. The early part of her career was working with socially responsible business pioneers such as Anita Roddick of The Body Shop, through Social Venture Network Europe, and her first role was the creation of a new venture - the New Academy of Business, a management education organisation for developing new ways of doing business. View Alex Cutler's presentation.

MICHAEL O'SULLIVAN

Architect, BOS

Michael is a draughtsman and a registered architect. He is a practical and sensible thinker that holds a position at Auckland University teaching Studio and supervising Masters Students' thesis work. He enjoys physically building and making furniture for his residential clients. His success as an architect has been well documented in the public eye. Since 2012, BOS has been working with Fletcher EQR and other Earthquake-related insurance companies in response to the two major earthquakes in Christchurch that happened in 2009 and 2010. Participating in over 130+ repairs, including chimney rebuilds, firewall rebuilds, re-clad, foundation repairs as well as new homes, BOS is one of the top architectural firms to provide services for the Canterbury Home Repair Programme (CHRP). View Michael O'Sullivan's presentation.

DR MICHELE ROSANO

Associate Professor, School of Civil and Mechanical Engineering and Director of Sustainable Engineering, Curtin University, Australia

Michele is a resource economist whose research interests include life cycle assessment, resource economic modelling and sustainability metrics. Michele has worked internationally in the mining industry in a number of senior executive positions in London, Japan and Singapore and as a lecturer and researcher in Australia. She is currently leading a number of industrial ecology research projects in industrial by-product re-use, waste management, engineering sustainability education and life cycle assessment. View Michele Rosano's presentation.

DAVID BROWN

Board of Directors, Beacon Pathway Inc.

Beacon's objective is to transform New Zealand's homes and neighbourhoods to be high performing, adaptable, resilient and affordable through facilitating and undertaking demonstration projects which show the benefits of higher performing new and existing homes; facilitating and providing robust research which builds a fact-based platform for sustainable, affordable, buildable and comfortable homes; enabling members to lead the transformation of the built environment in New Zealand; collaborating with and bringing together other stakeholders in New Zealand's residential built environment to create greater change. David Brown is also the Chairman of the Board for Certified Builders Association of New Zealand. Certified Builders represents a nationwide network of trade qualified builders who meet the highest industry standards for workmanship and business practice. They have 3,500 members who undertake over $2 billion of construction (20% of NZ total) and operate mostly in the residential and light commercial sector. View David Brown's presentation.

JAMES GRIFFIN

Sustainable Business Network

James works with the Network Team to ensure that SBN delivers relevant and valuable activity that helps members achieve sustainable success. He has extensive commercial experience having worked in large corporates and owned his own business. His business sustainability journey started many years ago via the coffee industry where he was involved in Fair Trade. James presented on the Circular Economy Model Office (CEMO). The aim of CEMO is to minimise waste created by the refurbishment and build of offices by using the principles of a 'circular economy': a system that operates in a closed loop with no waste, where the lifecycle of materials is maximised, usage optimised and at the end of life all materials are re-used. View James Griffin's presentation.

SIMON GAINES

Fletcher Construction and Adam Benli, Sustainability and Energy Advisor within the Chief Sustainability Office, Auckland Council

The Fletcher Construction Company, Building + Interiors is the leading general contractor in New Zealand and the South Pacific delivering projects for commercial , retail, health, hospitality, education and government buildings. As part of Simon's role he reviews, develops and implements Quality and Environmental management systems throughout the business, always fostering a continual improvement ideology. Leading a quality team, Simon ensures quality and environmental targets are met including the development and delivery of NZGBC and ISCA business capabilities and requirements. View Simon Gaines' and Adam Benli's presentation.

ADAM BENLI

Sustainability and Energy Advisor, Chief Sustainability Office, Auckland Council

As an accredited Green Star Professional and NABERSNZ assessor, Adam Benli is an advocate of resource efficient sustainable design on Council's new build projects. A recent example has been Wellsford Library, which has incorporated passive design principles, efficient lighting with automated daylight dimming controls and a low energy displacement ventilation system. A Solar Photovoltaic system installed on the roof caters for 70% of the building›s electricity needs. More recently his focus has been on the sustainable fit-out of one of Council›s most recent corporate property acquisitions - what was the old ASB tower on Albert Street.

REVIEWED PAPERS

Five papers from both New Zealand and overseas have been double blind reviewed. These have been authored by:

- Terri-Ann Berry and Daniel Wairepo / Asbestos remediation in the Cook Islands – A long-term solution for making schools safer / Unitec Institute of Technology
- David Turner / Whole building recycling as a waste reduction practice / Department of Architecture, Unitec Institute of Technology
- Patrick Zou (Swinburne University of Technology), Robyn Hardy (University of Canberra) and Rebecca Yang (RMIT University) / Barriers to Building and Construction Waste Reduction, Reuse and Recycling: A Case Study of the Australian Capital Region
- Tony Gillies and Bryan Poulin / The Efficient House Innovation: Healthful, efficient and sustainable housing for Northern and Southern Climates / Lakehead University, Ontario, Canada
- Nalanie Mithraratne / Building Adaption For Waste Minimisation: Impact Of Policies / Department of Architecture, School of Design and Environment, National University of Singapore

ASBESTOS REMEDIATION IN THE COOK ISLANDS – A LONG-TERM SOLUTION FOR MAKING SCHOOLS SAFER.

Terri-Ann Berry and Daniel Wairepo (Unitec Institute of Technology)

Asbestos contamination in the South Pacific originates mainly from construction products containing asbestos (SPREP, 2011). In Rarotonga, asbestos contamination in the soil surrounding two schools examined (Nikao Maori and Avatea) is believed to have originated from the super six roofing product that previously covered all existing classrooms on the site. The roofing has only recently been replaced with corrugated iron. Super six roofing becomes brittle and susceptible to increased weathering as the product ages. The weathering process from the sun, wind and rain releases the asbestos fibres into the environment (Bowler, 2014).

The aim of this research was to identify remedial solutions for the removal and disposal of contaminated soil around the schools and for the future earthworks in Rarotonga. Three potential solutions were identified including: i) capping the contaminated soil on-site, ii) removal and disposal of the contaminated soil off-site and iii) a combination of both i. and ii. Solutions considered the feasibility of each option (both in the short and long-term), minimising impact on the residents and the workers exposed, reducing environmental impact and quantifying the financial implications for each option.

WHOLE BUILDING RECYCLING AS A WASTE REDUCTION PRACTICE

David Turner (Unitec Institute of Technology)

This paper considers strategies for whole building recycling in New Zealand. Assumptions about waste and recycling potential that are made most frequently in the process of refining and improving construction systems seek to develop methods that may be generally characterised as reductive. These are often effective, and make significant contributions to the overall efficiency of the industry. However, the tradition of uplifting, removing, relocating and restoring – and in this process, recycling – a whole building is well established as a practical and economic alternative to demolition, in which process only a small proportion of all the original material is likely to be salvaged. The "relocatable", in which space as well as material is recycled, can be seen as a highly sustainable practice in social terms, and as a valuable contribution to the reduction of waste and resource depletion.

The argument for expanding the practice is developed in this paper through case study examples with a focus on three elements: material recovery, irreducible waste by-products from the usual process, and social advantages, through which, it is argued, waste is minimised by direct personal commitment commonly encountered throughout the period of the building's recovery. Case studies are supported by research that has had access to the files of some of Auckland's leading house removal companies.

BARRIERS TO BUILDING AND CONSTRUCTION WASTE REDUCTION, REUSE AND RECYCLING: A CASE STUDY OF THE AUSTRALIAN CAPITAL REGION

Patrick Zou (Swinburne University of Technology), Robyn Hardy (University of Canberra) and Rebecca Yang (RMIT University)

Building and construction waste materials continue to be a major problem that causes significant environmental impact worldwide. The broad aim of this university-industry collaborative research is to identify the barriers, opportunities and strategies for reducing, reusing and recycling building and construction waste materials. To achieve this aim, several workshops and phone interviews were undertaken in the Australian Capital Region, with different stakeholders as well as examination of case studies undertaken elsewhere. This paper presents and discusses the results in relation to the barriers. The workshop participants and interviewees were first provided a list of 12 barriers obtained from review of relevant literature. They were then asked to think 'out of the box' to identify any more barriers that were not captured in the list. Seven new barriers were identified, given a total of 19 barriers. This paper discusses each of these barriers in detail. Strategies to potentially overcome these barriers were also discussed in the workshops and the results are presented in this paper. This research contributes to the field by identifying new barriers and providing relevant strategies, which were developed together with frontline practitioners and managers. The outcomes of this research have led to the development of the second stage of this collaborative research project.

BUILDING ADAPTION FOR WASTE MINIMISATION: IMPACT OF POLICIES

Nalanie Mithraratne (National University of Singapore)

Construction and demolition waste represents a significant wastage of natural resources and energy while also contributing to air pollution. Measures to reduce construction waste include achieving flexibility in design of new buildings, and recovery of materials and components from existing buildings or adaptation of existing buildings to new uses. Although prolonging the building life through designing for adaptation can reduce the rate of demolition, the low rate of building renewal means that material recovery and whole building reuse are equally important in minimising construction waste. While the quality of recovered material/component depends on the original design and recovery process, there is a lack of measures to promote the use of recovered materials. Changes in decision-making on

how buildings are designed, demolished and reused can therefore significantly improve the resilience of building stock and reduce the adverse impacts. While theoretical underpinnings of designing for deconstruction or adaptation of existing buildings are well established, their practice depends more on location, policy issues and incentives. This paper discusses the preliminary findings from a research project which aims to develop a set of guidelines on designing buildings for flexibility, based on life-time environmental and financial performance of alternative strategies, and generate data on relative environmental performance of recovered construction materials/components compared with virgin alternatives used in Singapore.

THE EFFICIENT HOUSE INNOVATION: ADDRESSING HEALTHFUL, EFFICIENT HOUSING IN NORTHERN AND SOUTHERN CLIMATES

Bryan Poulin and Tony Gillies (Lakehead University, Ontario, Canada)

This paper tracks the 2000 to 2015 emergence of Efficient House Innovation (EHI). The idea for the innovation is based on the need for more healthful, more energy efficient, longer lasting housing. It does this by extending previous work on breathing walls that was begun in the 1970s and by revisiting fresh air and heat lass and gain in buildings and houses: convection (somewhat handled by most building codes with building envelope insulation); radiation (not addressed by most codes); and conduction (not well enough addressed by most codes). Commercialization is similarly a multi-faceted collaboration. Results of the Efficient House Innovation include two demonstration projects, the first for which the researcher-authors received their university's Innovation Award in 2009; and later a Canadian patent in 2014. It concludes with implications on the innovation process and EHI as one approach to healthy, long-lasting, efficient, sustainable housing.

Unitec Institute of Technology wishes to thank the construction and demolition practitioners, academics, government and local government leaders/change makers, apprentices and students and others who are actively working to reduce C&D waste for their valuable contributions to the Building Today – Saving Tomorrow Conference. It also recognises with gratitude the funding kick-start provided by Auckland Council, without which this hui would not have been possible.

Particular gratitude is expressed by the conference organisers to Daniel Fuemana, Head of the Department of Building Technology, and Brenda Massey, Senior Grants Advisor without whom the conference would never have taken place.

Mary Panko and Linda Kestle - Editors

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ASBESTOS REMEDIATION IN THE COOK ISLANDS A LONG-TERM SOLUTION FOR MAKING SCHOOLS SAFER

TERRI-ANN BERRY
DANIEL WAIREPO
UNITEC INSTITUTE OF TECHNOLOGY

Asbestos Remediation In The Cook Islands: A Long-Term Solution For Making Schools Safer by Terri-Ann Berry and Daniel Wairepo, is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

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ABSTRACT

Asbestos contamination in the South Pacific originates mainly from construction products containing asbestos (SPREP, 2011). In Rarotonga, asbestos contamination in the soil surrounding two schools examined (Nikao Maori and Avatea) is believed to have originated from the Super Six roofing product that previously covered all existing classrooms on the site. This type of roofing becomes brittle and susceptible to increased weathering as the product ages. The weathering process from the sun, wind and rain releases the asbestos fibres into the environment (Bowler, 2014). The roofing has only recently been replaced with corrugated iron. The aim of this research was to identify remedial solutions for the removal and disposal of contaminated soil around the schools and for the future earthworks in Rarotonga. Four potential solutions were identified including: i. Capping the contaminated material on-site; ii. Removal and disposal of the contaminated material to local landfill; iii. Removal and disposal of the contaminated material internationally; iv. Removal and disposal of the contaminated material at sea. Solutions considered the feasibility of each option (both in the short and long-term), minimising impact on the residents and the workers exposed, reducing environmental impact and assessing the financial implications for each option.

INTRODUCTION

Asbestos is a general term applied to a number of fibrous silicate-based minerals, for which there are two distinct configurations, namely serpentine and amphibole. Chrysotile (white asbestos) is derived from serpentine minerals and accounts for 95 per cent of all the asbestos used in the twentieth century and 100 per cent of the asbestos used in the world today (Virta, 2005; Natural Resources Canada, 2006). Of the amphibole minerals, the most commercially successful forms include amosite (also known as brown asbestos) and crocidolite (or blue asbestos) (LaDou et al., 2010).

The world's largest producers of asbestos include Russia, China, Brazil, Kazakhstan and Canada, and current global production is estimated at around two million tonnes per annum. (Haynes, 2010; LaDou et al., 2010). Asbestos production reached its peak in the 1970s (Radetzki, 2010) due to its valuable physico-chemical properties including resistance to heat and fire, insulation capability and strength (Godish, 1989). Asbestos-containing materials (ACM) have been used for floor and ceiling tiles, as a surfacing material, as thermal insulation around pipes and boilers and as roofing material as well as for many other uses where its inert properties are particularly valuable (Godish, 1989; New Zealand Ministry for Education, 2015).

Unfortunately, despite its value for use in building products, overwhelming proof from the scientific community has classified asbestos as a non-threshold toxicant – a substance which can cause harm at any concentration. Health risks from exposure are well-documented (WHO, 2014; Haynes, 2010; LaDou et al., 2010), there is no safe level of exposure to asbestos and no exposure to asbestos is without risk (LaDou et al., 2010; Welch, 2007). Microscopic asbestos fibres are dangerous as they can be inhaled easily. There is little research which proves that it may be harmful by other entry routes into the body although the risks of ingestion have been questioned by research but with no causal link between colon cancer and exposure (Gamble 2002). As duration and regularity of exposure to airborne fibres increases so does the risk of asbestos-related disease, such as asbestosis, lung cancer and mesothelioma (Haynes, 2010). While it has been observed that ACMs left undisturbed do not pose "any immediate significant health risks" (Fentons, 2012), those thought to be most at risk are tradespeople or contractors who are responsible for repairs and maintenance. Estimates of those affected by asbestos exposure are variable and made difficult by the long latency period of asbestos-related diseases which can take up to 50 years before symptoms develop (Fentons, 2012; Haynes, 2010).

Despite the evidence against the use of asbestos in building materials, only 55 countries have banned all forms of asbestos, with influential countries such as USA and Canada continuing its use. The majority of South Pacific Islands, including Samoa, Fiji and the Cook Islands, as well as New Zealand, have yet to join this initiative (Kazan-Allen, 2014). As more developed countries ban the use of asbestos, producer nations continue to export asbestos and ACM to developing nations, where imports are growing (Dooley, 2012). It has been observed that greater than 85 per cent of the world production of asbestos is currently used to manufacture products in Asia and Eastern Europe (Virta, 2005). Although there are a number of safe alternatives available for the building industry, asbestos continues to be popular in poorer nations due to its low cost.

ASBESTOS IN SCHOOLS

The production of inexpensive, mechanically strong and heat-resistant building materials containing asbestos has inevitably led to its use in many public buildings globally. It is therefore not surprising that, since the asbestos boom in the 1970s, some 30 years later the risks of this hidden danger have been exposed. These observations have been made due to many factors, including the latency period of the symptoms of asbestos exposure, the recent research clarifying the health risks associated with exposure and the deterioration of building materials over time. Recently, a particular concern has been the potential for asbestos exposure in school buildings. Children are more at risk from asbestos exposure than adults; the estimated lifetime risk of developing mesothelioma for a five-year-old is about five times greater than for a 30-year-old adult (Shponline, 2013). Schools may contain friable asbestos-containing materials which are particularly dangerous as the asbestos is not bound within the cement matrix (Godish, 1989). Materials in a friable form or those caused (usually by maintenance or deterioration) to release fibres into the air pose a potential risk of exposure and asbestos related disease.

Evidence from the Medical Research Council, United Kingdom (Abrams, 2015) estimates that within poorly maintained schools asbestos fibre levels are between five and five hundred times greater than those found in outdoor air within schools that are maintained to a good condition. Evidence of health risks to both teachers and students is mounting and with this, a realisation that the removal of asbestos from schools globally may be a huge financial and environmental burden (Abrams, 2015; Shponline, 2011; Cooney & Conway, 2013). In New Zealand, asbestos was used widely from the 1930s to the 1980s, in a number of building products, often mixed with cement. In 2010, a Wellington-based former teacher was diagnosed with mesothelioma thought to be caused by work-related exposure (Education Aotearoa, 2010). In 2014, the disturbance of asbestos during renovations at an Auckland primary school raised further concerns about safety (New Zealand Ministry of Health, 2014).

It is apparent that identifying asbestos in schools followed by safe removal and disposal will be a time-consuming and costly operation for the future. As poorer countries continue to use asbestos and its products, how do we prepare for the long-term disposal of these products and should a worldwide ban of their use be encouraged?

ASBESTOS USE IN THE COOK ISLANDS

The following case study examines asbestos fibre contamination of schools in the Cook Islands, specifically in Rarotonga. Of the Cook Islands, Rarotonga is the largest and most densely populated, with approximately 15,000 permanent residents, served by ten local schools. Nikao Maori and Avatea schools (situated in Northwest Rarotonga), had previously been selected for reconstruction, however the topsoil surrounding the main building was identified as containing high levels of asbestos contamination (K2 Ltd, 2014).

Asbestos contamination in the South Pacific originates mainly from construction products containing asbestos (SPREP, 2011). Asbestos contamination in the soil surrounding these two schools is believed to have originated from the Super Six roofing product that previously covered all existing classrooms on the site. The roofing has only recently been replaced with corrugated iron. Super Six roofing becomes brittle and susceptible to increased weathering as the product ages. The weathering process from the sun, wind and rain releases the asbestos fibres into the environment (Bowler, 2014). In addition to the contaminated soil, ACM was observed in the wall cladding of both schools. A recent survey of asbestos and ACM in the Pacific Islands has identified that approximately three per cent of houses and public buildings, e.g. schools, contained these materials (SPREP, 2015).

The aim of this research was to identify remedial solutions for the removal and disposal of contaminated soil around the schools and for the future earthworks in Rarotonga. Rarotonga does not currently have its own legislation or policy on asbestos, New Zealand legislation and best practice was reviewed and incorporated into the work methodology.

METHODOLOGY

School Selection

Prior to this investigation, Cook Islands Investment Corporation (CIIC) carried out asbestos air sampling of a number of government schools in Rarotonga. Initially, Avarua Primary school was identified with high levels of asbestos in the soil. The soil around the perimeter buildings was excavated and buried off-site and replaced with clean soil materials. Subsequently Nikao Maori and Avatea schools were selected for deconstruction and during this initial assessment phase, asbestos contamination was identified in the soil around the school buildings and within the buildings themselves. This research project was carried out to identify more sustainable solutions to the removal and disposal of this contaminated waste.

Assessment and viability studies

The type and quantity of asbestos contaminated waste and soil was estimated during site visits and using laboratory studies carried out previously. Both contaminated soil and building materials could be retained on site with adequate capping/encapsulation or removed for disposal elsewhere. An assumption has been made that the removal and disposal solutions for these schools could be adopted for other buildings in the Cook Islands and hopefully for the Pacific region in general.

Viability studies were conducted to determine the options available for disposal using a combination of desktops studies and site visits to potential disposal areas (e.g local landfill). This included investigations into previous disposal solutions for this hazardous waste (e.g sea disposal). Discussion with government, local companies, K2 Ltd and CIIC as well as SPREP was essential to these investigations.

Disposal Solutions

Potential solutions (Figure 1) for the contaminated soil and wall cladding were identified including:

i. Capping (sealing, enclosing or encapsulation) internally and externally
ii. Removal and disposal off-site to a local landfill
iii. Removal and disposal internationally (to landfill)
iv. Removal and disposal at sea

Evaluation of solutions considered the feasibility of each option (both in the short and long-term), minimising impact on the residents and the workers exposed, reducing environmental impact and assessing the financial implications for each option. The initial disposal options put forward are similar to those recommended globally. Reuse and recycle options were not considered in this case as they are not applicable for the contaminated soil, and for the ACM present further hazards to human health if not handled and stored properly. Options of treating asbestos waste via vitrification, high temperature transformation (Haynes et al., 2011), plasma arc technology (Deegan et al. 2007), degradation by hydrofluoric acid (Kakegawa et al., 2008) and thermochemical inactivation (Yvon & Sharrock, 2008) etcetera are not feasible based on cost, reliability of energy source and also the relatively small volume of waste produced from the Pacific Islands.

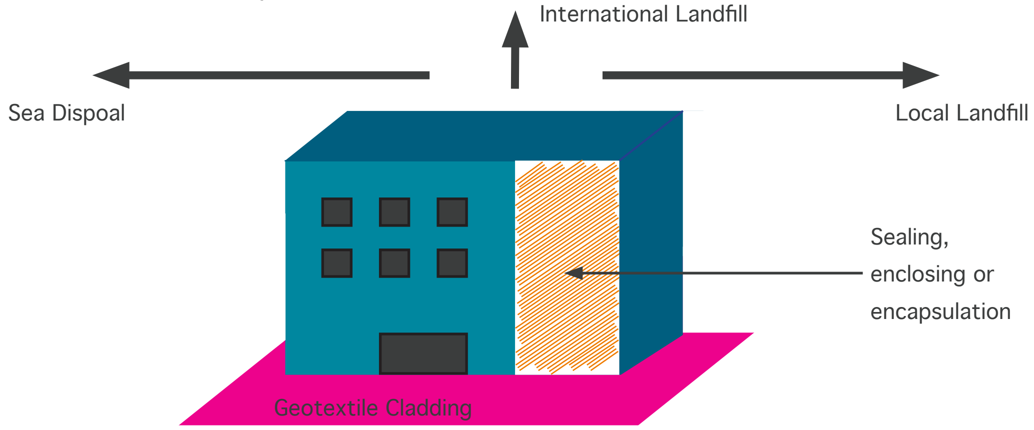

Figure 1. Options for removal and disposal of asbestos contaminated soil and ACM at Nikao Maori and Avatea schools, Cook Islands.
Source: Authors own

The evaluated disposal options were based on those recommended by the Secretariat of the Pacific Regional Environment Programme (SPREP) and The World Health Organization (WHO) in 2014. All standards used were based on a combination of current New Zealand and Australian codes of practice on how to safely remove asbestos.

The relative merits and risks associated with each of the four options are summarised in Table 1. Following evaluation of the four options, the safe removal of contaminated soil and ACM from both schools was initially found to be preferable to capping. This was based mainly on cost but also on local preference. Removal and disposal to landfill requires creation of an asbestos management plan to ensure correct procedures and control measures are used. In addition, a significant upgrade of the landfill facilities would be required, including lining and covering the waste material. Alternatively disposal to containers for later removal from Rarotonga to a specialised waste disposal unit overseas has potential for the future, however strict quarantine regulations (in New Zealand and Australia) combined with high costs may make this option prohibitive.

Soil Removal and Transportation Procedure

The removal of the contaminated soil from the site should involve excavation of the existing soil and disposal off-site to the landfill facility at Arorangi. The asbestos plan should contain all the procedures and control measures needed for this part of the operation. Removal of contaminated soil and disposal off-site, would involve removing the top 200-500mm of soil from the site and transporting it to a disposal facility on the island, then replacement with clean soil. Previously at Avarua school, Rarotonga, removal of contaminated soil reduced the level of asbestos dust in the air to <0.01/ml. This is the recognised safe limit according to the Health and Safety in Employment (Asbestos) Regulations 1998.

Option	Advantages	Disadvantages
Capping Including sealing, enclosing or encapsulation within building and multi-layer capping externally	- Very little disturbance to the area - Least potential to cause harm to human health - Successful model observed (multi-layer capping) (Tomasicchio, 2010)	- Requires careful labelling - Public opposition - Additional weight (additional long-term hazardous waste) - High level of skill and knowledge and expertise required - Expensive (multi-layer capping) - Requires on-going maintenance
Removal and disposal at local landfill	- Removes any future risk to human health once removed - No on-going maintenance required	- Landfill close to capacity - No current specialist hazardous waste disposal - Requires strict removal procedure to ensure public health - Labour–intensive
Removal and disposal internationally	- Reduces human health risk - No on-going maintenance required - Provides a longer-term disposal solution - Specialised hazardous waste treatment - Overall reduction in number of disposal sites	- Requires strict removal procedure to ensure public health - Labour-intensive - High cost for transportation - Potential quarantine issues - Temporary storage required prior to shipping - Reliance on external party(ies)
Removal and disposal at sea	- Reduces human health risk - No on-going maintenance required - Reduces pressure on landfill - Long-term storage solution.	- Establishing suitable area with the Exclusive Economic Zone (EEZ) - Dependent on permit - Questionable permanency of location - Public opposition

Table 1. Summary of disposal options: Advantages vs Disadvantages
Source: Authors own

The area around each of the school buildings to be excavated would require a trench 2m (w) x 200mm (d). The trench should start at the dripline of the roof, to ensure all contaminated material will be removed.

All trucks involved in the removal operation would need to be covered, and all soil loaded would need to be dampened down during the excavation process to reduce the amount of dust created. Once contaminated soil is unloaded and before uncontaminated soil is loaded the truck bed would need to be cleaned. All trucks should follow the route designated and all drivers should have a copy of the designated route.

Wall Cladding Management and Removal

As samples of wall cladding panels tested positive for asbestos, an assumption was made that the majority of the panels would contain asbestos fibres. The cladding can be left on the building when it is demolished. While there is a risk of contaminating the area with dust, risk mitigation via water soaking is an option. Despite the legality of this option (there is no current asbestos legislation in the Cook Islands) and the low cost, this proved to be unpopular with the local community.

The cladding may be removed safely by following recommended guidelines (Safe Work Australia, 2011). Once removed, these panels can be stored off-site in a sealed shipping container, until a disposal option can be established. Shipping containers are used to seal the ACM from external weathering elements and any other disruptions. These containers may also be transported off-site easily without exposing the public to any dust or debris. Once panels have been removed, it would be necessary to swab test the framing to confirm no further asbestos contamination is present.

Cost Summary

Total costs for the safe removal and temporary disposal of ACM and contaminated soil for both schools were estimated. All soil volumes are estimated from the plans provided by CIIC. A depth of 200mm was selected based on evidence from sampling and analysis. A total of 588 cubic metres of soil was estimated to need to be removed. Costs were based on estimates provided by CIIC for removal and disposal of the contaminated soil (at NZD 330 per m^3). The storage of the wall cladding would require three standard shipping containers. The total cost was estimated to be NZD 340 000.

DISCUSSION

The prolific use of asbestos containing materials in the Pacific Islands is an issue of global concern for many reasons. In terms of cost, the removal and disposal of asbestos at the two schools was estimated at NZD 340 000. These schools represent a small fraction of the buildings believed to contain ACM. The predicted cost of the removal of all the ACM in the Pacific Islands is NZD 150 million (S.Williams, personal communication, June 24, 2015). This value does not cover disposal costs, only removal, and it appears that the long-term disposal solution for these hazardous materials has no strategy on a regional, national or global level,

Although legal (with a permit), under the London Convention (Coenen, 2011) and the Noumea convention in the case of the Cook Islands (SPREP, 1986), disposal at sea is not generally a publically acceptable option. This was clearly demonstrated by the public debate which followed the deliberate sinking of the vessel, *Miss Mataroa*, which contained ACM from the Cook Islands (Asbestos.net., 2014). Whilst more careful selection of disposal area at sea may increase the potential of this disposal route, is it a viable long-term solution?

Disposal to landfill requires strict adherence to control factors such as soil depth, planned segregation of asbestos waste and careful labelling (UK Landfill Directive, 2010; Worksafe New Zealand, 2015). These measures ensure that there is no risk to human health by preventing airborne particles. The practicalities of this approach are tested by the increasing pressures on landfill operations due to increasing waste volumes and land area limitations. In this case, the landfill in Rarotonga is close to capacity and unable to deal with large volumes of ACM. To meet recommended guidelines, this contaminated waste requires a lined excavation, covered with the same polythene liner and covered, with at least 1m of fill and compacted soil.

An alternative disposal route via international destinations (Australia and New Zealand) is controlled by the Basel and Waigani Conventions (Basel Convention, 1992; SPREP, 2001). Once again, it is a viable option, already demonstrated in New Zealand but not Australia. Only, recently the New Zealand Government approved and financed 20 shipping containers containing asbestos waste to be shipped from Nuie and disposed of to a New Zealand landfill (PacificGuardians.org, 2014). This precedent underpinned the recommendation of storing wall cladding materials in shipping containers, as outlined in this report. However, as ACM continues to enter the Pacific Islands, there is doubt that this is a long-term solution. It is also cost-prohibitive and is often complicated by quarantine restrictions.

As well as careful selection of a suitable long-term disposal route, the technical expertise and knowledge for the safe handling and disposal of these materials must be passed on to these and many other small communities. This is especially important given the generally lack of painting and maintenance for these buildings (which prevents damage of the ACM) and the high occurrence of extreme weather events which may expose asbestos from its binding material. Experience from

Figure 2. Factors affecting the choice of disposal route for asbestos contaminated soil and building materials
Source: Authors own

the devastating effects of the 2015 Cyclone Pam in Vanautu has demonstrated that despite the development of an inventory for ACMs in the area, the clean-up procedure did not use this data to ensure public health and safety (S.Williams, personal communication, June 24, 2015). Further evidence from events such as the collapse of the World Trade Centre, USA in 2001, the 2011 earthquake and tsunami in Japan, and the tropical cyclone Yasi which hit Queensland, Australia in 2011, has demonstrated that asbestos contamination following these events should be considered from both a human health perspective as well as an ecological perspective. At Ground Zero, improper clean-up and communication compromised the health of people living and working there (Sheer, 2011). After natural disasters, the disposal options appear to be limited to on-site storage or landfill (Ryan et al., 2014; Asari et al., 2013).

Factors affecting the best disposal option include (placed in order of importance): public health, cost, public opinion, longevity (how long will the materials be safely retained?) and sustainability (the long-term capacity of the disposal option) (Figure 2). Using the example as provided by the remediation at these schools, it could be possible to list the preferable disposal options with respect to each factor (Figure 3) and then further use this data to determine numerically which of the options is most suitable (determined by the lowest value) (Table 2).

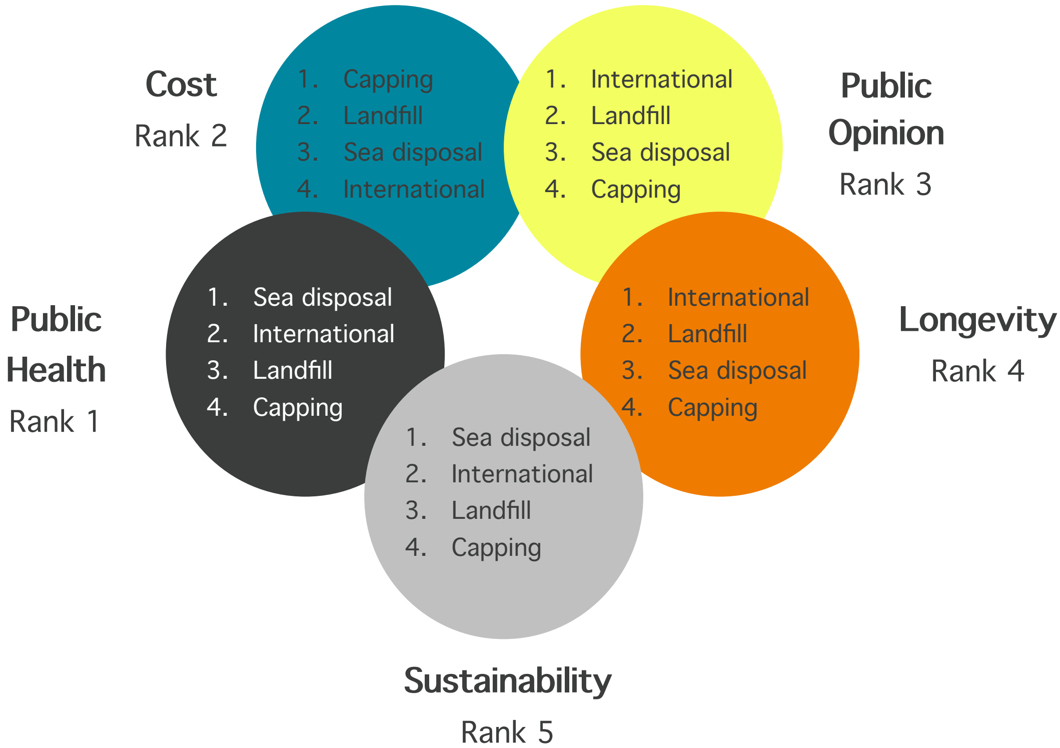

Figure 3. Preferred disposal options for ACM for each of the factors affecting the disposal decision (where option 1 is most preferred and option 4 is least preferred)
Source: Authors own

Although public health is unarguably the most important single factor affecting disposal choice, the rank of the other factors may be debated. It is interesting to note that by changing either the rank of the factor affecting the decision (Figure 2) or the impact of the disposal option on that factor (Figure 3); the choice of disposal option may change. The factors and weightings will be specific for any given scenario.

Option	Public Health (5)	Cost (4)	Public Opinion (3)	Longevity (2)	Sustainability (1)	Total
Capping	20	4	12	8	4	48
Landfill	15	8	6	4	3	36
International	10	16	3	2	2	33
Sea Disposal	5	12	9	6	1	33

Table 2. Selection of the preferred disposal route for ACM for Nikao Maori and Avatea schools (value = rank in brackets x preference of option, lowest value indicates preferred option). Source: Authors own

CONCLUSIONS

There are a number of options available for the safe removal and disposal of asbestos from buildings in the Cook Islands. In Rarotonga, as funding to upgrade the island's other schools is extremely limited, interim measures to protect those schools on the 'waiting list' from the health and environmental impacts of asbestos contamination could include sealing wall panels with paints and covering existing play areas with an extra layer of soil. Air monitoring tests at each school would indicate the priority needed for asbestos mitigation measures.

Despite public opposition, the eventual solution at the two schools in this case study was on-site burial (which involved three-metre deep burial with 200μm polythene covering), which was mainly based on cost. Although the overall aim of this research was to identify more sustainable solutions, low cost appears to have outranked these alternative options. This highlights the requirement for a unified approach to a global problem which is dealt with only in the short-term and without considering the legacy of multiple sites of marked (or unmarked) contaminated land. In addition, the lack of available land for safe disposal of hazardous chemicals in these islands highlights the requirement for larger countries with a greater capacity for both treatment and disposal to consider aid on a case–by-case basis.

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WHOLE BUILDING RECYCLING AS A WASTE REDUCTION PRACTICE

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ABSTRACT

This paper considers strategies for whole building recycling in New Zealand. Assumptions about waste and recycling potential that are made in the process of improving construction systems usually relate to the development of new practices that may be generally characterised as reductive. These are often effective, and make significant contributions to the overall efficiency of the wider building industry. However, the tradition of uplifting, removing, relocating and restoring – and in this process, recycling – a whole building is well established as a practical and economic alternative to demolition and salvage, in which only a small proportion of all the original material is likely to be recovered. The “relocatable”, in which space and volume as well as material is recycled, can be seen as a sustainable practice for reduction of waste and resource depletion, and also sustainable for its social function. The argument for expanding the practice is developed in this paper through case study examples with a focus on three elements: material recovery (including energy), irreducible waste by-products from the usual recovery process, and identifiable social advantages. It is argued here that waste is minimised through the element of direct personal commitment commonly encountered during the period of the building’s recovery. Case studies are supported by research that has had access to the files of some of Auckland’s leading house removal companies.

INTRODUCTION

This paper has its origins in a relatively disparate collection of intersecting research interests, all of which have roots in housing research. Auckland is an increasingly complex city where perceptions of sustainable urban paradigms are shifting. Our perceptions now bear on concepts of heritage, density, social norms and habits, transport and non-transport energy efficiency; from these new positions innovative ways of thinking about traditional practices in the house building industry are being generated. Many of Auckland’s recent residential typologies, such as medium and high-rise apartments, which were once reserved for the least wealthy (Schrader, 2005), are now embraced with enthusiasm by their occupiers in all age and income sectors of the market. For the City, the advantages of higher densities are recognised by a majority; the need to limit sprawl and make more effective use of urban land is no longer a battle for the advocates of the compact city, but reflects a shared understanding of a legitimate strategy for the city’s continuing rapid growth (ARC, 2000; Syme, McGregor and Mead, 2005).

However, intensification of the city is now obstructed by our history of suburban housing development. To intensify the urban mass, after all vacant land has been developed it becomes necessary to liberate suburban space that, in the new perceptions of density, is perceived by market forces to be under-capitalised.

Moving buildings from place to place has been an accepted custom in the New Zealand housing culture from the earliest period of European settlement, and is a distinguishing characteristic of our housing system (McLaughlin, 2002; Isaacs, 2009). The standard building method associated with housing is based on single storey, lightweight timber construction, on timber pile and bearer beam foundations; almost 90% of houses in New Zealand are built in this form (DTZ, 2009). It has never been difficult to relocate these buildings (Belich, 2001), and we have a general agreement that this practical and technically feasible system of building redistribution is unaffected by other, possibly conflicting notions of ‘place’, ‘permanence’, or the desirability of spatial continuity. We endorse a rationale that supports the practice, and in doing so tacitly accept other consequences, in order to subscribe to a particular collective logic: the ‘relocatables’ satisfy an instinct to waste nothing; to retrieve, to build on previous invested effort, to apply ingenuity, and to preserve and retain memory. None of these motivations are unfamiliar in the housing culture of the tangata whenua, where essentially similar practices are commonplace. This practice may be attributed to a residual pioneering culture applicable to both Māori and the nineteenth century settlers from Europe (Fairburn, 1989; Bassett, 1990).

RELOCATIONS AND SUSTAINABLE BUILDING PRACTICE

The relocating of houses might also be considered an ultimate form of recycling, and thus have implications for the general narrative of sustainability. In pursuit of sustainable outcomes, recycling whole buildings is a process that achieves low waste of resources, minimal waste to landfill, minimal resource depletion, and has, in the common course of the process, the potential social benefit of high levels of user participation. Significant personal satisfactions are derived from house relocations: recycled buildings are less expensive, can be occupied more quickly, and anecdotally, deliver a sense of personal investment from participation in the process, which then contributes to a powerful perception of ownership (C. Walker, personal communication, August 22, 2008). The alternative, of demolition and limited component recycling, with additional costs of handling and further loss by attrition – including damage to materials, and unusable off-cuts – acts against economic material recovery, and reinforces the argument for relocating the entire building.

Houses that have been ‘relocated’ are not generally stigmatised by market prejudices, despite their exclusion from most new sub-divisions. Rather than penalise relocated houses, market perceptions appear to extend approval, particularly for the rimu heartwood framing (which is no longer obtainable), the recovery of hardwood flooring and fireplaces, and original doors and windows; their occupants are even tolerant of out-dated room layouts. The primary structure and spatial organisation of the house is retained: only components of the building that need attention in the short term, or those that would have to be renewed with or without relocation are affected. Thus, a common and an arguably vernacular understanding is evident, resulting in a residential ‘relocations’ building sector that manages between 2,600 and 3,200 house removals each year, and an industry that accounts for up to 12% of New Zealand’s annual housing supply measured by total numbers of consents granted (Turner, 2010).

RESEARCH APPROACHES: LITERATURE AND EXAMPLES

If the principle of the relocation of houses is broadly accepted, it is useful to examine the practice in detail, to consider its contribution to reduction of waste in the building industry and to quantify where possible the primary costs and benefits of the process.

The subject has attracted remarkably little attention in academic literature, and only occasional reference in popular works and in the general media. Brief references occur in studies of architectural conservation (Salmond, 1986). Where settlements were often expected to be temporary, the practice of moving buildings was considered to be part of a historic residential system of supply (Arden and Bowman, 2004). Others in the field of building history make passing references to relocations as an aberrant part of the New Zealand story: no writers have paused to reflect on the environmental or economic issues that frame the practice (Dunstall, 1992; Salmond, 1986). Particular (and spectacular) examples of buildings shifted and relocated, such as St Mary’s Cathedral in Auckland in 1982, and the Museum Hotel in Wellington (1993) are celebrated in the media as engineering proof of our natural native skills; and a widely shared interest in motor vehicles, in this case the trucks that provide the moving power is more the centre of attention in two recent books on the ‘relocatables’ industry than the buildings in transit (Carter, 2010; Dawson, 2012).

In this study I focus on the ‘first order’ issues of material recovery, waste avoidance, and recycling. However, it is recognised that a full analysis needs to extend into parallel factors, as suggested by Mitharatne et al (2004) to acknowledge the variables that make up a complete study of life-cycle costs, and thus justify or otherwise the initial proposition of a building relocation. Research by the Department of Architecture with Genesis Energy in 2012-13 for the Tomorrow Street project identified and recorded some of these variables, or second order factors in household (operational) energy use. In addition, third order items (including banking, interest charges, and insurances) are seen as expenses that in some cases tip the commercial decision one way or the other: there are fewer certainties, and therefore greater risks in any dealings with old buildings than there are in developing a new housing subdivision. Here, factors that affect construction and demolition, and by extension sustainability are examined through two case studies of buildings recovered through relocation.

Case Study A: No 62 Walters Road, Kingsland, moved to Waitoki in 2011

The Waitoki house is a typical example of a late Victorian single bay villa that had occupied the site of 62 Walters Road, in Kingsland for about 100 years. The house was in the path of plans to enlarge the public concourse in front of the adjacent Eden Park stadium for the Rugby World Cup in 2011, and was removed along with six neighbouring houses. The building was sold at auction, cut into two pieces, loaded and transported 45 kilometres by road to Waitoki, where it now occupies a large semi-rural site. Its modest architectural qualities are intact and it functions in Waitoki as a house for a young family. The owners, a plumber and his partner, were also the developers, and have invested the re-sited villa with energy and time, but minimal capital expenditure.

Figure 1. The Kingsland-Waitoki villa re-sited
Source: Authors own

The technology involved in the relocation process is not sophisticated. The principal tools used are chain saws, wrecking bars, sledgehammers, and manually operated jacks. Up-lifting and relocating a house is only possible at all in the context of New Zealand’s light-weight timber-framed building tradition, in which most houses are attached to the ground by wire dogs and galvanized perforated straps onto short timber piles. In the course of all relocations, new foundations are designed to current standards and constructed on site prior to the move. Structural framing can tolerate a small degree of distortion in the course of the move, usually without causing irreparable damage to the more fragile components of the building (fibrous plasterwork, glass, etc.) or to the integrity of the building’s primary structure (C. Walker, personal communication, August 22, 2008).

Concurrent repairs on the Waitoki villa included replacement of iron roofing, guttering and roof flashings, and small sections of external cladding, as well as repainting of the exterior, a level of renovation that usually applies to pre-1940 houses. Re-fitting of service elements (bathrooms, kitchens, laundries, and re-wiring in older houses) has been carried out, and as is often necessary with pre-1920s houses, most internal wall linings have been replaced. The on-site operations included new electrical circuits, telephone and television connections and insulation to current standards.

Energy costs of removal and relocation vary widely in this industry. For the Waitoki case study these can be estimated fairly accurately. Distance of travel is a relatively small factor, and is estimated for this energy audit as an averaged consumption of fuel based on two 400Kw diesel engines running for 22 hours at 90% capacity, representing the energy used in a 50km transit and including the engine in operation while stationary for rams and hydraulic positioning manoeuvres. Other energy is consumed during site works by diggers, piling rigs, small electrical equipment, and by temporary lighting since much of the relocation activity is conducted at night.

Standards of repair work generally have to meet the durability requirements of the New Zealand Building Code, thus upgrading the building to current standards, but these are subject to unpredictable interpretations by local councils. At Waitoki the re-fitting programme was measured to include the complete renovation of one bathroom, one large kitchen and utility, 66% re-wiring, 100% relining of internal walls, and 20% of windows and external doors replaced with new single glazed timber frames and sashes. Most of the original ornate ceilings are repaired, and insulation has been installed to the roof space, external walls, and below the floor. The brick chimney has not been rebuilt.

The majority of relocations are not early twentieth century villas such as that relocated to Waitoki; most are single-storey suburban houses in serviceable condition produced in the post-1945 building boom by companies such as Keith Hay Homes. Houses originally built for the Housing Corporation or for other government departments are now frequent, and often preferred candidates for relocation. The second Case Study illustrates this preference.

Case Study B: 379 West Coast Road, Glen Eden

The development by Land Development and Civil (LDC) is an example of an enterprising start-up company taking advantage of a strong housing market in Auckland, but motivated by a conviction that the quality of houses built between 1945 and 1960 was superior to present-day standards and that their recovery is worth the effort involved in comprehensive reinvestment. The company has previously carried out a similar development, also on West Coast Road, for 11 relocated units.

Figure 2. 379 West Coast Road: aerial image prior to development (far left, Source: Authors own) and the project site plan (left, Source: Daniel Thomas at Land Development & Civil)

LDC's policy is to avoid classic villas, but sources older houses in low-density suburbs where redevelopment programmes, including in this case the Hobsonville Point project, are demanding large cleared sites. The West Coast Road project consists of a 2,314m^2 site which was zoned for industry and bought with one existing but dilapidated house. LDC's application for resource consent for residential use was not resisted by Council, or by the neighbouring residents. Figure 2. illustrates the site before development, and the site plan, which is now approximately 70% completed. The site has been rearranged to provide 5 units including the existing house in a new position. Three of the units, ex-NZRAF staff houses, were relocated from Hobsonville, and the fourth came from Point Chevalier. All five houses are well-designed, in generally good original condition, and represent a period of house building in New Zealand when high quality materials and workmanship were taken for granted.

LDC's philosophy is based on maximising recovery of the fabric, which in all these houses includes the repair of windows and doors, rimu weatherboard cladding and internal secondary elements – the doors, cupboards, second-fix skirtings and architraves. The houses comply with current Code standards for drainage and foundations up to the new bearers; for the superstructure, further upgrading to meet Code standards becomes expensive if the developer makes any significant changes to internal layouts because additional bracing is a likely requirement. For this reason gib board internal wall linings are retained, with external walls insulated with a wool-mix insulant blown into wall cavities. All floors are either tongue and groove rimu or matai, and are to be sanded down for varnishing.

Figure 3: Case Study B: a work in progress: one of the re-sited houses
Source: Authors own

The houses will be sold under separate titles, with the access road owned jointly in a separate lot. In their finished condition LDC can claim that these houses are more substantial than other market products, with a prospect of life-cycle durability exceeding that of new houses. They can also claim these to be houses in which both the structural and finishing materials used are superior to those available to the current building industry. The company, with the statement "Engineered solutions for people & environments" in its title, supplies renovated housing that emerges from a building process designed and managed to generate less waste, and that contributes significantly to reduced resource depletion, including, particularly, energy resources.

COSTS AND BENEFITS: THE CASE STUDIES

Relocations involve small building companies, self-employed tradesmen, and often, as in Waitoki, the owners themselves, all of whom have a greater propensity to recycle materials, and are considered more likely to embrace a culture of waste minimisation. This serves, simultaneously, to reduce costs and waste and to meet unquantifiable social objectives of sustainable building.

The current estimate of on-site and embodied energy in new houses is between 3,500 and 4,000 kWhrs per square metre (Vale, 2008). For an average relocatable house of 100m^2 with five main spaces, 250-300m^2 of new 10mm plasterboard is required, and approximately 220m^2 of insulation will be used in external walls and roof spaces. A further 100m2 of under-floor insulation is recommended but is not usually required for a building consent. Including on-site energy consumption, transportation, embodied energy in replacement materials and re-wiring, a fully insulated relocatable of this size with new services and internal finishes can be supplied for an estimated total of re-invested energy of 55-65,000 kWhrs, or approximately 600 kWhrs per square metre. Calculations are based on tables of energy coefficients produced by the Victoria University of Wellington's Centre for Building Performance Research.

Details of ground and site works on the West Coast Road site (excavation, levelling works, drainage, timber and concrete retaining walls, fencing – some of it 2.0m 'acoustic' close-boarded – and access road construction) are more difficult to estimate at this stage of completion, suggesting that an updated assessment of the project will be necessary at a later date. The Kingsland-Waitoki house is also unfinished, but site works including fencing and access paving will add, eventually, to the total material investment.

These estimates of the energy required for a renovated relocatable house show substantial savings over that typically invested in new houses of a similar size, where the first order total of energy invested and embodied would be approximately 400,000 kWhrs. If, however, new house sizes are represented by those being built at Hobsonville or Flat Bush at approximately 240m^2, the total energy investment per unit is nearly one million kWhrs, or about 15 times the new energy used to re-supply one of LDC's houses in Glen Eden.

CONCLUSIONS

A report in the Sydney Morning Herald's Weekend magazine investigated the phenomenon of demolition and waste in Sydney's northern suburbs (Hawley, 2003). When bathrooms, kitchens and electrical installations became out-dated, the entire house, often less than thirty years old is demolished with little or no attempt to salvage materials. The market rationale is simple: the building is not worth re-investing in – tastes and styles change, and property values are maintained only if wholesale re-development is undertaken. Apart from metal roofing the building materials are not of high enough quality to be recycled. Private freehold property ownership is by far the largest capital asset for most householders, and maintaining the value of the asset is a high priority. Housing supply in Auckland does not need to follow this pattern; however, although we follow Australia in many building practices, we should be clear about the fundamentally unsustainable nature of this new suburban paradigm. I have argued here that much of our older existing stock is recyclable, and our housing traditions are open to the idea of renovating and relocating on a large scale.

To summarise this analysis, it is suggested, firstly, that technical objectives of sustainability are satisfied by the low-tech process of shifting and relocating whole houses, with an estimated investment of new energy a small fraction of that required in standard new house-building, and significant reductions of new materials necessary for the process. For the 'big picture', and in the context of Auckland's severe housing shortage, these houses present a supply-side alternative that prevents the net loss of existing housing in the course of urban consolidation, where sites are being developed over earlier low density footprints. Relocated houses can also mitigate some of the problems of affordability, particularly if supply and ownership systems are modified by, for instance, not-for-profit housing providers such as the Housing Associations used in the UK.

Without developing this area of the argument in detail, there are many legislative settings that could be adjusted to encourage more relocations and fewer demolitions. Some of the practical options are:

- Requiring demolition consents to be justified on more demanding terms
- Relaxing some consent procedures for relocated houses
- Applying preferential rates of goods and services taxes (gst) for industries that contribute most effectively to sustainable development
- Removing covenants that block or obstruct relocatables in some new developments
- Underwriting the practice through the planned recycling of government housing stock at low prices

In addition, by raising construction standards to enable whole building renovation in the future, we would 'future-proof' the houses we are building now. A more detailed audit of energy, material and labour resources used in LDC's Glen Eden project is programmed for next year when accounts for the development are complete.

GLOSSARY OF TERMS

Tangata whenua: Refers to the original Māori settlers of New Zealand, meaning people (*tangata*, a group of people) and land (*whenua*, incorporating the concept of land as the mother to the people). 'Land' in this culture is treated as a communally-owned resource for food gathering and includes forests, rivers and sea beds. See: Williams' definitive *Dictionary of the Māori Language*.

Rimu, Matai: Māori names for common New Zealand coniferous tree species ***Dacrydium cupressinum***, known as **rimu**, and ***Prumnopitys taxifolia*** (**Matai** or **Black pine**) which were widely used in the first half of the twentieth century for housing construction: rimu for weatherboard claddings, floors, facings, doors and secondary fittings, and matai, particularly for flooring.

Keith Hay: Keith Hay Homes were popular in the period 1950-1975 in Auckland, for being affordable, well built, and offering rapid supply to site, usually as a prefabricated standardised unit. Hay himself was the first volume house builder to see the economies possible with ***pinus radiata*** (an imported softwood conifer, fast-growing and produced from local plantations) in preference to rimu, and other native coniferous species. Because it is a true softwood, pinus radiata can be nailed more quickly. In 1949 the principle of off-site construction, and a 'relocatable' process, pioneered by Hay, contributed to meeting the high demand for new housing in Auckland in the post-1945 period. He was also a prominent local politician and a leader of the Auckland Christian community. See: Margaret McClure, the Dictionary of New Zealand Biography Volume 5, 2000.

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BARRIERS TO BUILDING AND CONSTRUCTION WASTE REDUCTION, REUSE AND RECYCLING

A CASE STUDY OF THE AUSTRALIAN CAPITAL REGION

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ABSTRACT

Building and construction waste materials continue to be a major problem causing significant environmental impact worldwide. Broad university-industry collaborative research was undertaken in 2014 to identify the barriers, opportunities and strategies for reducing, reusing and recycling building and construction waste materials in the Australian Capital Region (located in the south-eastern corner of Australia and includes the Australian Capital Territory). This paper presents and discusses the results in relation to the barriers and possible strategies to overcome these barriers. To identify the barriers several workshops and interviews were undertaken. The workshop participants and interviewees were first provided a list of 12 barriers derived from review of relevant literature. They were then asked to think 'outside of the box' to identify any more barriers that were not captured in the list. Seven new barriers were identified, resulting in a total of 19 barriers. This research contributes to the field by identifying new barriers and providing corresponding strategies, which were developed together with frontline practitioners and managers. The overall outcomes have led to the development of the second stage of this collaborative research project.

INTRODUCTION

The Capital region consists of 13 local government areas of the South East Region of New South Wales (NSW) and the Australian Capital Territory (ACT) (refer to Figure 1. and 2.). The region is highly interrelated in terms of industry. The construction industry is important; comprising around 14 per cent of the regions output value. Builders work across the state and local government borders of NSW and the ACT, using all waste facilities where it is convenient to do so, regardless of jurisdiction. In 2013 a group of organisations from the Australian Capital Region – broadly representing the building and construction industry and government – came together over a mutual concern that the residential component of construction and demolition waste (C&D) was largely being disposed to landfill, and economic benefit that could be generated from waste and recycling was being lost.

RESEARCH AIMS

The broader aims of the full research project were to:

1. Identify the types and scale of recyclable materials generated in residential construction, renovation and demolition;
2. Identify possible reuse and recycling methods;
3. Identify barriers, risks and opportunities in the reuse/recycling process; and
4. Investigate strategies that may facilitate material reduction, reuse and recycling.

This paper concentrates on the outcomes of the broader C&D waste research in terms of the identification of the barriers to recycling and reuse and potential strategies and responses to those barriers. It excludes types and scale of recyclable materials generated, potential reuse and recycling methods, and other factors which were examined in the full research project.

LITERATURE ON CONSTRUCTION AND DEMOLITION WASTE

The definition of construction waste adopted in this study is: *Any material from the construction process which is used onsite as landfill or is transported offsite for reuse, recycling, or landfill elsewhere.*

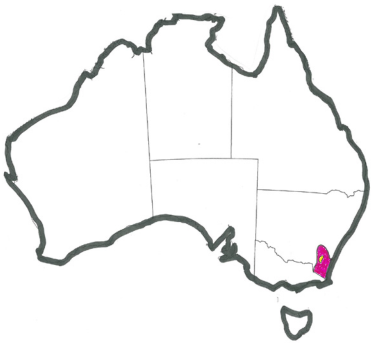

Figure 1. (left) Map of Australian Capital South East Region
Source: Courtesy of Canberra Region Joint Organisation (formerly known as the South East Regional Organisation of Councils)

Figure 2. (above) Map of Australia highlighting South East Region
Source: Authors own

The existing literature has examined waste, including construction and demolition (C&D) waste and its causes, from a number of different perspectives: an efficiency of manufacturing perspective (Ohno, 1978); a value or loss of value point of view (Formoso et al., 2002); a value and efficiency perspective (Skoyles, 1976); and a sources viewpoint (Gavilan & Bernold, 1994; Bossink & Brouwers, 1996). Others have considered C&D waste as a result of design and/or procurement/project management and materials handling inefficiency (Keys et al., 2000; Ekanayake & Ofori, 2000; Gamage, Osmani & Glass, 2009). Pinto (1989) and others (Soibelman et al., 1994; Pinto & Agopayan, 1994) have looked at waste by materials type, and Osmani (2006, 2007) has examined C&D waste through the prism of its lifecycle and origins.

The literature on barriers (CIB, 2014; WALGA, 2013; Boser, Bierma & El-Gafy, 2010; DSEWPC, 2012) indicates that they are numerous. They include:

1. Lack of knowledge about what can be recycled, or about recycling opportunities;
2. Contamination of recyclables due to lack of separation or lack of space for separation;
3. Lack of markets for the recycled materials;
4. Technological barriers in terms of conversion of waste materials to useful ends;
5. Cost of recycling processes making products more expensive than that from virgin materials;
6. Design for deconstruction has not yet been incorporated into the building process;
7. Alternatives to recycling are less costly – landfill gate prices are too low;
8. Government policy is not driving recycling;
9. Lack of confidence in recycled materials;
10. Lack of communication and industry infrastructure;
11. Lack of knowledge across industry; and
12. Low value/low volume products being landfilled rather than stored for recycling because it is uneconomic to stockpile.

RESEARCH METHOD AND PROCESS

To achieve the broad research aims of the full study, the following methods were utilised:

1. Desktop study to identify the types of waste material generated from residential building
2. Focus group workshops with invited participants from the building and construction industry and government;
3. Interviews with waste management facility operators; and
4. Surveys of residential builders.

Five workshops were scheduled throughout the Capital Region to ensure a range of views were captured from the whole geo-political area: four were held in small rural and regional locations and one in the capital, Canberra. The workshops were held in Queanbeyan, Moruya, Yass, Young and Canberra on the 5th, 7th, 12th, 14th, 19th August 2014 respectively.

Attendees were openly invited from a range of building-related occupations via email, telephone and through the local government networks. A facilitated workshop was conducted with the same material and research questions for each group. This involved a short presentation by the researchers of the research background and the causes and barriers identified by the literature. The discussion was then opened up to the Participants. Thirty-seven people representing the full range of the building and construction industry, waste management and recycling attended the five workshops. With the majority of builders concentrated in the Canberra-Queanbeyan city areas, attendances at the workshops, while small, were considered very representative particularly of the broad spectrum of stakeholders interested in building and construction, waste and waste governance. Pre-interview electronic questionnaires were sent to relevant waste and recycling managers of six local government areas (the Shires of Young, Goulburn Mulwaree, Yass, Snowy River, Cooma, and Eurobodalla) and the ACT, one construction products manufacturer/producer, one private sector waste manager and one building products recycler allowing them to prepare for follow up telephone and personal interviews. Interviews were conducted with seven respondents, one of whom is responsible for managing waste in seven of the local government areas.

RESULTS AND DISCUSSION

The desktop study yielded an initial list of 12 barriers to reuse and recycling.

In this research, the workshops and interviews confirmed the barriers identified in the literature. However, the workshops identified seven additional barriers to recycling in the Australian Capital Region:

1. Most people in the industry do not consider C&D material as a potential resource (except metal) and that this mindset drives some of the behaviour to landfill all C&D material
2. Australian State Government environmental regulations are seen as working against recycling. Environment Protection Authorities do not allow stockpiling of uneconomic quantities of product due to potential contamination issues. This works to discourage recycling
3. Many workshop participants raised the issue of the lack of facilities for recycling. There are very few facilities for the recycling of C&D waste across the region and these are not conveniently located
4. Inconvenience of location of recycling facilities increases haulage costs and recycling facilities tend to 'cherry pick' the valuable C&D materials and reject others
5. The requirement for materials to meet certain specifications and standards makes it easier to select new product than go through the process of having recycled product certified for use
6. The lack of facilities to store soil particularly virgin excavated natural materials (VENM) for reuse later was considered a major issue across the region.
7. Different pricing structures between the jurisdictions constituting the Capital Region are encouraging builders to 'shop around' for the cheapest landfill sites, particularly as there appears to be little restriction on entry

The combined list of barriers is shown in Table 1. The major areas of commonality of barriers identified by the previous research (literature), the workshops and interviews were analysed. The shaded and checked boxes indicate the barriers identified by each.

The top six barriers identified by all sources were categorised as:

- **Policy and governance**: Government policy is not driving recycling;
- **Quality**: Contamination of recyclables due to lack of separation or lack of space for separation;
- **Cost**: Alternatives to recycling are cheaper – landfill gate prices are too low;
- **Information**: Lack of information re industry infrastructure;
- **Knowledge and education**: Lack of knowledge across industry and requirement for training; and
- **Perception and culture**: C&D material is not considered as a potential resource (except metal).

	Barriers identified by the literature	Barriers confirmed by Local Stakeholders					
		Interviews	Workshop 1	Workshop 2	Workshop 3	Workshop 4	Workshop 5
1	Lack of knowledge about what can be recycled or recycling opportunities		√	√	√	√	√
2	Contamination of recyclables due to lack of separation or lack of space for separation	√	√	√	√	√	√
3	Lack of markets/lack of demand for the recycled materials	√					
4	Technological barriers in terms of conversion of waste materials to useful ends						√
5	Cost of recycling processes making products more expensive than that from virgin materials	√		√			√
6	Design for deconstruction has not yet been incorporated into the building process		√				
7	Alternatives to recycling are less costly – landfill gate prices are too low	√	√	√	√	√	√
8	Government policy is not driving recycling	√	√	√	√	√	√
9	Lack of confidence in recycled materials		√				
10	Lack of information re industry infrastructure	√	√	√	√	√	√
11	Lack of knowledge across industry and requirement for training	√	√	√	√	√	√
12	Low value/low volume products being landfilled rather than stored for recycling because it is uneconomic to stockpile	√	√	√	√	√	

	Additional Barriers identified in the Workshops/Interviews	Barriers identified by Local Stakeholders					
		Interviews	Workshop 1	Workshop 2	Workshop 3	Workshop 4	Workshop 5
13	C&D material is not considered as a potential resource (except metal)	√	√	√	√	√	√
14	Environmental regulations are working against recycling	√	√	√	√	√	√
15	Lack of facilities for recycling		√	√	√	√	
16	Inconvenience of location of recycling facilities or need to take materials to many different places		√	√	√	√	
17	Material specification in buildings not encouraging recycling		√	√	√	√	
18	Lack of facilities to store soil particularly VENM for reuse later		√	√	√	√	√
19	Different pricing structures between jurisdictions encouraging landfilling		√	√	√	√	

Table 1. Barriers to Building and Construction Waste Reuse and Recycling
Soucre: Authors own

Strategies to encourage reuse and recycling of C&D Waste

The workshops resulted in discussions about potential solutions some of which were put to the participants by the researchers and others which were nominated by the participants themselves. The proposed strategies and solutions included:

Policy and Governance, Quality and Cost related

1. Regulation by government to require manufacturers to take back product and packaging and to rate product recyclability.
2. Regulation to force builders to separate and recycle C&D materials.
3. Enforce Waste Management Plans or scrap them.
4. Use Government Procurement incentives to drive behaviour, e.g. 10% price allowance on recycled materials.
5. Establish a 'star rating' for new home construction that rewards resource saving and recycling.
6. Government allocation of temporary parcels of land for waste material storage.
7. Implement differential landfill fees to encourage recycling and discourage landfilling.
8. Examine specifications for building to ensure allowance for recycled materials use.
9. Provide support for new businesses for recycling and reusing.
10. Make recycling easier with one stop shops and prevent 'cherry picking' by recyclers.
11. Encourage onsite sorting services provided to create business opportunities.
12. Ensure that all landfill sites are professionally manned and operated.
13. Encourage waste broker businesses to source materials and potential buyers.

Information related

14. Develop an information App and map to enable ease of identification of waste and recycling facilities.
15. The App solution should provide the most cost efficient route to a recycling facility.
16. Encourage or develop an information App which brings together buyers/builders who need/have soil.

Knowledge and Education, Perception and Culture related

17. Develop a footprint of deconstruction to provide an indicator to home owner consumers of C&D projects.
18. Targeted media for the public to stimulate demand and community thinking.
19. Education and training of builders and designers, waste management facility operators and government procurement staff to raise awareness and change the mindset of waste to one of potential resource.
20. More scientific research into C&D materials in the Australian context.

CONCLUSION AND FUTURE RESEARCH

Overall, the study revealed that there are significant barriers to recycling and reuse of C&D waste in the Australian Capital Region as other research has discovered worldwide. Limitations of this study include that the further barriers which were identified, may or may not be specific to the Australian Capital Region. Among the 20 proposed strategies, many are related to government policy and information sharing, while there is also need for knowledge and perception development through better education and more research. The efficacy of these measures to reduce waste and increase the level of reuse and recycling would need to be tested. The outcomes of this research have led to the development of the second stage which will focus on these research needs.

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BUILDING ADAPTION FOR WASTE MINIMISATION IMPACT OF POLICIES

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ABSTRACT

Construction and demolition waste represents a significant wastage of natural resources and energy while also contributing to air pollution. Measures to reduce construction waste include achieving flexibility in design of new buildings, and recovery of materials and components from existing buildings or adaptation of existing buildings to new uses. Although prolonging the building life through designing for adaptation can reduce the rate of demolition, the low rate of building renewal means that material recovery and whole building reuse are equally important in minimising construction waste. While the quality of recovered material/component depends on the original design and recovery process, there is a lack of measures to promote the use of recovered materials. Changes in decision-making on how buildings are designed, demolished and reused can therefore significantly improve the resilience of building stock and reduce the adverse impacts. While theoretical underpinnings of designing for deconstruction or adaptation of existing buildings are well established, their practice depends more on location, policy issues and incentives. This paper discusses the preliminary findings from a research project which aims to develop a set of guidelines on designing buildings for flexibility, based on life-time environmental and financial performance of alternative strategies, and generate data on relative environmental performance of recovered construction materials/components compared with virgin alternatives used in Singapore.

BACKGROUND

Buildings are central to the fabric of everyday life, embedded in the spatial form, character and skyline of a location. However in some extreme cases, buildings are being replaced only 10–15 years after construction (Building Construction Authority, 2010). This not only removes any traces of heritage, it is also wasteful in terms of large volumes of resources embodied in buildings and construction waste that ends up in landfills. Construction waste is generated by activities such as clearing building sites and construction of buildings and infrastructure. Apart from conserving limited landfill space, construction waste minimisation is also helpful in safe-guarding limited natural resources, reducing energy use for manufacture of building materials and products, and reducing hazardous emissions released as a result of product manufacturing and building demolition processes.

The quality and the quantity of construction materials recoverable at the end of the useful life of a building however, depend on two factors; the original design of the building and the demolition process employed. While the demolition waste recovery rates vary depending on the construction material, and may even be more energy-intensive compared with the use of new materials (Brown & Buranakarn, 2003), the general perception of designer/public/developer that ‘new is better’ together with uncertainty on the suitability of the recovered material for the intended purpose are barriers to wider uptake of recovered materials. This suggests that decisions on sustainability of the building sector should extend beyond design, construction and operation phases and selection of low impact materials and systems to include designing for deconstruction and adaptive reuse, and strategies to recover and manage demolition waste.

While using a life cycle perspective can promote waste minimisation through matching construction material properties with intended building use and useful life, designing for deconstruction or adaptation can reduce demolition waste by enhancing the potential for reuse of buildings or building components. Although the concept of deconstruction and design principles to facilitate it are well-documented (Chini, 2001; Crowther, 2002; Douglas, 2006; Kibert, 2003), these are currently neither considered nor practiced in the design process unless there is a specific requirement in the design brief to do so, generally for economic reasons. With the rate of renewal of buildings reported to be as low as around 2% (Holness, 2008; Ravetz, 2008; Wilkinson et al., 2014), continued use of existing building stock by maintaining, refurbishing, and adapting to new uses could be far more effective in reducing construction waste than any measures to reduce waste from new buildings. Adaptation of buildings should also receive focus in attempts to achieve a more sustainable building stock, as the reuse of buildings could save as much as 95% of the energy embodied in the existing building stock as reported by an Australian study (Australian Government, 2004), in addition to social and environmental benefits. Studies in the UK have also shown that regenerating areas by converting disused buildings to be multi-functional activity centres can improve sustainability through increased activity levels during day and night times and use of sustainable modes of mobility to support local economy (Bromley et al., 2005).

With this background, this paper focuses on building adaptation as a measure to minimise construction waste in land and resource-scarce Singapore. The paper presents preliminary findings from research investigating the current building adaptation practices in Singapore using two case studies to determine factors influencing the adaptation strategy employed. The paper is organised as follows: First, the current knowledge in building adaptation is discussed and then the study location Singapore is introduced along with unique characteristics of the location and relevant development policies. Then the selected case studies are presented, along with the drivers applicable to each case and the adaptation strategy employed. Results on waste minimisation and sustainability achieved by the projects are then presented and conclusions are drawn.

BUILDING ADAPTATION – CURRENT STATE OF KNOWLEDGE

The term ‘adaptation’ describes any work other than general building maintenance, which can change performance, capacity and function of a building (Wilkinson et al., 2014). While adaptation can facilitate reuse of a building either for same (in-use adaptation) or a different (across use adaptation) use, it can also delay demolition of buildings due to obsolescence. However, age and condition are important determinants of suitability for reuse, while flexibility of design, location characteristics, local policy and market forces play an important part in reuse of buildings (Ball, 2002). The level of adaptation necessary prior to reuse depends on the in-built adaptability of existing buildings (Kincaid, 2000). A Norwegian study (Arge, 2005) investigating in-built adaptability of buildings found that level of in-built adaptability depended on the time frame of interest in the building, i.e., whether the building is for sale or own use. This could be expected as a high degree of adaptability was reported to add 20-25% to the total cost of an office building and without a long-term interest in the building, developers would be unwilling to bear the additional expenditure. The most commonly used adaptive measure according to this study was elasticity, the least expensive, which allows the building to be divided to parts which could be rented or sold separately.

In developed countries where the majority of the future building stock is already in existence, due to low renewal rates, the expenditure on building adaptation as a percentage of the total spent on construction is high at 42% in the UK and close to 18% in Australia (Goodier & Gibb, 2007; Wilkinson et al., 2014). Where there are low-grade buildings that do not meet the current regulatory environment or modern performance expectations, adaptations can be an alternative to new constructions. The drivers for building adaptation could be as diverse as, conservation of historic buildings or retrofit of disused buildings for regeneration of derelict areas, and horizontal or vertical expansion of existing buildings to maximise the allowable floor space while accommodating contemporary building demands. Reuse of derelict buildings in a precinct augmented by some new buildings can provide variety and character, which is not feasible in an entirely new development, and thereby attract people and businesses to an otherwise abandoned area. Nonetheless, anecdotal evidence suggests that adaptation of contemporary buildings for same or different uses is uncommon in Singapore.

SINGAPORE CONTEXT

Singapore is a highly urbanised thriving city state with an affluent population, a very high per capita GDP (SGD 71,000 in 2014) but with no natural resources and limited land mass to accommodate her 5.5million population (Department of Statistics Singapore, 2015). Although Singapore has increased its land area by almost 25% over the years through land reclamation, the population has also steadily increased, while the demand for floor space continues to grow due to economic growth. As such, urban planning and land use policies of the government are critical to the liveability and sustainability of the built environment of Singapore. Due to the land scarcity the government of Singapore takes a long-term approach to optimise the use of land, thereby determining the land requirements for various development needs along with the pace of development.

The main policies governing land use and development controls in Singapore are, Concept Plan and Master Plan. While the Concept Plan guides long-term (over 40 to 50 years) broad development objectives, the five-year Master Plan provides detailed strategies for implementation (i.e., land use zoning, intensity for each land parcel, etc.) over short-term (over 5 to 10 years). In order to address the increasing demand for land for development activities, the government releases new and reclaimed land through government land sales (Urban Redevelopment Authority Singapore, 2015). To ease the pressure on the old Central Business District (CBD), government released the land reclaimed in 1970s to construct the Marina Bay Financial Centre which was completed in 2013. The high cost of land reclamation and land scarcity means that development controls such as building heights and Gross Plot Ratio (GPR) are continually revised to meet the market trends and demand for floor space through intensification. As a result, existing buildings may not be utilising the maximum allowable gross floor area due to changes introduced by Master Plan since the time of their construction.

Even with the heightened pressure for intensification the average annual building renewal rate in Singapore is only marginally higher at 5% (Building Construction Authority, 2010), compared with 2 to3% of other developed countries such as UK, USA and Australia. As such, while the perception is that Singapore buildings are renewed at a higher rate, the majority of the building floor space at any given time comes from existing constructions. A study (Hwang & Yeo, 2011) considering perceived benefits of construction waste reduction in Singapore, revealed that waste management is perceived to be beneficial for large projects and those using steel construction but not for smaller maintenance and renovation projects, or for concrete constructions. In 2014, construction and demolition waste contributed 17% to the total solid waste generated in Singapore (National Environment Agency, 2013). Although the rate of construction waste recycling in Singapore is reported to be 99%, recycling process also uses limited natural resources while anecdotal evidence suggests that currently reuse of recycled materials in building or other projects is relatively low. Therefore, continued use of existing building stock by adapting to new uses should receive focus in attempts to minimise construction waste and to achieve a more sustainable building stock.

POLICY MEASURES GOVERNING BUILDING ADAPTATION IN SINGAPORE

Despite an initial lack of emphasis, employing mass demolition to facilitate urban redevelopment (Jones & Shaw, 2006; Loh, 2009), since late 1980s, conservation has been an integral aspect of Singapore's urban planning. While conservation is recognised as important to retain the inherent values that the heritage buildings possess, the process of conservation involves some degree of intervention which results in changes to the historic fabric. Given the land scarcity, conservation guidelines allow modifications including reconfiguration of interior spaces and intensifications to accommodate modern uses so that the conserved building remains relevant in present times. The focus of conservation policies has been that all buildings remain in use and those which are not religious buildings remain economically sustainable as well. According to the latest policy document, the level of modifications allowed depends on historical significance, context of the surroundings and long-term development goals for the area (Urban Redevelopment Authority Singapore, 2011).

However, the studies suggest that there is wide disparity between the intentions of the conservation guidelines and adaptations that have been already completed, (Belle et al., 2012; Yeoh & Kong, 2012) as evident from Boat Quay area in the 'Historic District' where buildings are to be retained and restored.

The focus of guidelines on adapting contemporary buildings for modern use published by the Building Construction Authority (Building Construction Authority, 2010) remains on energy and water efficiency, with volume of general waste and Indoor Environment Quality being the other considerations. While the Building Retrofit guide touches on the reasons, benefits and even necessity of retrofitting an old building with green systems, it primarily deals with how the shell of the building is kept intact while its old systems are replaced with new, greener systems. However, careful examination of Urban Redevelopment Authority (URA) procedures (URA, 2013a) reveals that measures to facilitate changes to the shell are incorporated into the implementation measures. This indicates that the need for buildings to remain economically sustainable by facilitating new uses takes precedence over preservation of original structure.

Two case studies of building adaptations – a shop house and a contemporary office – in the CBD of Singapore, that come under the above adaptation guidelines are presented to discuss the sustainability implications of the building adaptations practised in the Singapore context. The main methodology used in this research is deductive reasoning based on published information on the two buildings selected.

BUILDING ADAPTATION AS A MEASURE TO MINIMISE CONSTRUCTION WASTE – CASE STUDIES

Traditional Shophouses in Singapore are a building typology that is subjected to conservation guidelines. The selected case study, the former Lucky Book Store, now a private residence (in Joo Chiat Place in the east of Singapore), is a conversion project that won URA Architectural Heritage Award in 2013 (Urban Redevelopment Authority Singapore, 2013). The current owners, having grown up in the area, have an affinity to the location. This is evident in the result, which is more sympathetic to the original design. The façade which was covered in several layers of paint has been exposed and preserved with clear sealant, unlike the joyful colours of certain other adaptations, such as Boat Quay. Although the interior is modern it retains its original character and details of the building. However, some internal partition walls and service area of the original building have been demolished to accommodate modern living requirements along with connectivity with a new section constructed at the rear of the property. Being located in an area classified as 'secondary settlement zone' by the conservation guidelines (Urban Redevelopment Authority Singapore, 2011), the focus is on preserving the streetscape and new rear extensions with a maximum four-storey height are permitted. However, the rear section, in this case is single-storey so that the spirit of shophouse living – which is urban liveability at low-resource cost involving natural ventilation and lighting achieved through the use of courtyards or air-wells – is preserved.

The contemporary adaptation case study selected is the former East Asia Bank building also known as 137 Market Street (137MS). Originally constructed with pre-stressed RCC in 1970s style with a masonry façade, the 14-storey building was destined for demolition as 25% of the floor space was vacant while the M&E system and the façade were also outdated (Ho, 2014). While enlarging the lift core to accommodate modern office demands was considered impractical, the existing foundations were not sufficient to support the additional floor space that was allowed by the Master Plan revisions since the initial construction. Located in the CBD with the building occupying the whole site, demolition and reconstruction was considered to be not only disruptive to neighbouring premises but also lengthy due to the need to schedule construction work during off-peak times.

Adaptation used a load-balancing strategy of replacing four levels of the heavy concrete structure with six levels of lighter steel structure. The use of steel in the expansion also enabled off-site fabrication of entire sections of the building which were hoisted into place overnight. This was valuable as space for storage of construction materials was very limited on site. The new façade uses staggering high performance bay windows with low-e double glazing, which can remain open even during rainy weather. The adapted building which used 50% of the existing structural elements, high use of green concrete, recycled materials and a pre-engineered building system in addition to 25% lower than the target energy use achieved only Green Mark GoldPlus rating rather than Green Mark Platinum rating.

DISCUSSION AND CONCLUSIONS

Currently efforts to minimise construction waste in Singapore seem to focus on the management of end-of-life waste from buildings. With building renewal rate being as low as 5%, measures to adapt and reuse existing buildings can be much more effective in reducing construction waste, while eliminating the need to recover and recycle construction waste, and can therefore be more sustainable.

While motivation for adaptation is generally the desire to reuse buildings with historical significance, in the Singapore context, where land and resource scarcity drives the policy decisions, this is driven mainly by the desire to maximise the allowable floor space. As guidelines are focused on heritage buildings being relevant to current times and also economical, if in prime locations, historic buildings are often treated primarily as shells with façades preserved while the interiors almost completely gutted and re-constructed while intensification of use is achieved by vertical and horizontal additions. As seen from previous adaptations, the desire to achieve economic sustainability can at times conflict with conservation guidelines unless there is personal attachment to the place as seen from the shophouse case study presented here. Evidence suggests that this is generally the exception rather than the norm.

Although adapting existing buildings to modern requirements could be more sustainable than reconstruction, current development policies and building rating scheme in Singapore do not appear to promote adaptive reuse. Currently, the focus of Singapore building rating system Green Mark is on energy efficiency with sustainable material use being limited to around 10% of the total score for any variation of the Green Mark scheme. As evident from the contemporary case study of 137MS, which achieved only Green Mark Gold Plus rather than Green Mark Platinum, measures to adapt and reuse buildings are currently not rewarded by the rating scheme.

The main findings of this investigation are:

- Waste minimisation needs to cover all life stages of a building and different measures such as management, avoidance, recovery and reuse;
- Adapting existing building stock for modern uses is more important compared with strategies to reduce construction waste from new buildings;
- Context-specific drivers determine the level of success of measures; and
- Building rating tools and incentives can promote more sustainable practices.

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THE EFFICIENT HOUSE INNOVATION
HEALTHFUL, EFFICIENT AND SUSTAINABLE HOUSING FOR NORTHERN AND SOUTHERN CLIMATES

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ABSTRACT

This paper tracks the Efficient House Innovation (EHI) from 2000 to 2015. The main idea of ‘Dynamic Air’ behind EHI is associated with John Timusk (1987) who recognised existing housing solutions were not sufficiently healthful, efficient or robust. His solution was to bring relatively cool, dry air dynamically through the walls instead of the usual air-tight, static construction. However some problems remained. Starting in 2000, the authors of this paper extended and added features to Timusk’s solution to arrive at the EHI. Initial tests of EHI prototypes indicate the reliable fresh air, robustness of structure and energy efficiency that Timusk envisioned. This paper focuses on EHI prototype testing from 2008 to 2015, with implications for housing in cold, temperate and sub-tropical climates.

INTRODUCTION

It has been reported that buildings in general use about 40% of total energy and more than 50% of all energy worldwide, if embodied energy during construction and deconstruction of failed solutions are taken into account (Cigler, Tomosko & Siroky, 2013; Todorovic & Kim, 2012). Housing consumes more than half of buildings and about 30% of worldwide energy, much of this inefficiently.

Inefficient energy use is one issue. Another is that air quality and durability of housing are too often compromised within the first few years of construction. This leads to the conclusion that improving air quality and structural robustness is as important as energy use (U.S. EIA, 2012, 2014; and Ontario Clean Air Alliance, 2011). This is particularly true in far Northern and far Southern climates where people face extreme winters in houses offering insufficient efficiency, poor air quality and compromised durability. The Efficient House Innovation (EHI) is one promising solution.

For centuries traditional houses may have had their faults in terms of energy efficiency but these did not rot or introduce mould like houses in much of the world today. Out of this realisation the “dynamic air” concept was born (Timusk, 1987). As with earlier variations of the idea, the EHI draws outside air through the exterior of a house, to supply fresh air, and improve energy efficiency and longevity of the structure of houses (Chow et al. 2010; Rosart et al. 2014). A major aspect of the EHI is conceptually shown in Figure 1.

Figure 1 illustrates how conductive heat loss can be recovered; this aspect is ignored by building codes that only handle convective, not other heat losses or gains with mostly fibre insulation. The other two mechanisms of heat transfer, conduction and radiation, are either addressed partially or not at all. Similarly, air quality and structural robustness are either ignored or inadequately handled by building practices and codes. For example codes and standard building practices ignore drying of interstitial, within-wall, moisture that can lead to mould and rot in wood structures.

The EHI is a science and engineering-based concept designed to improve all aspects of performance of houses, for all climates except tropical: health, efficiency and structure. It is based on the realisation that current building codes and practices of sealing up our houses need to be re-examined; the starting point is to look to the early dynamic air approach of scientist John Timusk (1987).

Note: An early and partial version of the research reported here was presented to a management and technology conference in 2012, Ryerson University, Canada. This paper reports on both this previous and also on new research and development work in 2014 and 2015. As an aside, the authors also regularly visit Australasia and particularly New Zealand, both professionally and personally to visit colleagues, families and friends.

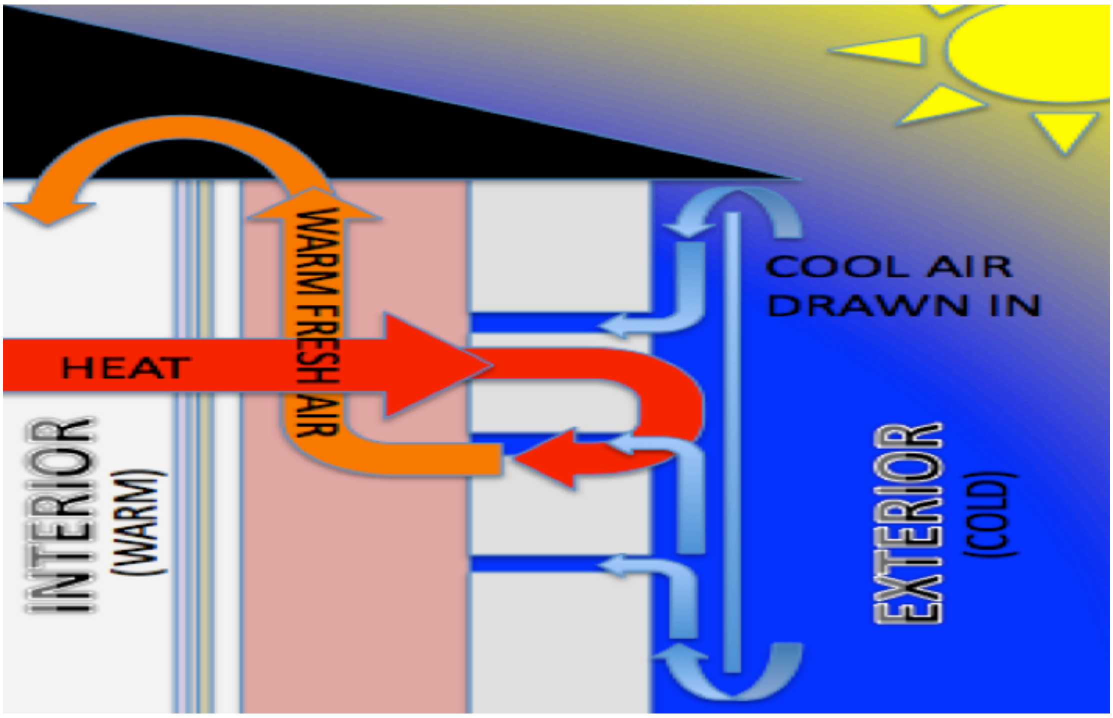

Figure 1: Dynamic Heat Transfer in exterior walls
Source: Authors own and as adapted from ideas contained in Timusk (1987).

Timusk's Dynamic Wall Approach: Forerunner to EHI

The Dynamic (or breathing) Wall (DW) approach to housing in Canada is associated with John Timusk (1987), formerly head of the Centre for Building Science at the University of Toronto, Canada. In late 1970 Timusk recognised the need to improve energy efficiency, durability and fresh air supply in housing. He and a colleague in Sweden were concerned about the plastic bubble method being used to save energy in housing (Timusk 1987). This involved stuffing ever-more insulation between the framing of exterior-facing walls and ceilings, together with sealing up the envelope in ways that could trap moisture; the latter causing extensive problems, including mouldy exterior walls and unlivable conditions: sometimes referred to as sick house syndrome

Going back to basic physics, Timusk came up with a new approach for housing that turned the plastic bubble approach on its head by addressing both convection and conduction in a way so as to provide fresh air to occupants while also keeping the structure dry. His concept showed promise, though early application was flawed. For example, when the houses were depressurised to bring in the fresh air, unanticipated air was drawn through gaps around exterior doors and windows. Timusk's dynamic wall approach needed improvement.

UNDERSTANDING, IMPROVING AND EXTENDING THE DYNAMIC WALL APPROACH

As indicated, the idea of Timusk's dynamic wall approach was to slowly draw relatively cooler and drier fresh air through the exterior walls from the outside to recover conductive heat, dry exterior-facing walls, and supply fresh air to occupants. Calculations made on the basis of standard heat flow science and air permeability characteristics of common building materials suggested that both fresh air supply and heat recovery in winter conditions were possible. The following are equations for calculating heat loss or gains, by conduction, radiation and convection (for example, Timusk, 1987, p.63).

Conductive heat loss rate – in the direction of decreasing temperature:

Where:

$$Q = \frac{A\ \Delta T}{RSI} \qquad Equation\ 2.1$$

Q	Heat transfer per unit time (Watts)
A	Surface area (m^2)
ΔT	Temperature difference across the material (°C or K)
RSI	Thermal resistance of the material (m^2 C/W)

The principle step in conductive heat loss reduction is to specify materials with adequate thermal resistance across the envelope.

Radiant heat loss rate – transfer of heat through electromagnetic radiation:

Where:

$$Q = \varepsilon\sigma A(T_s^4 - T_a^4) \qquad Equation\ 2.2$$

Q	Heat transfer per unit time (Watts)
$\mathcal{E}\delta$	Thermal emittance, emissivity as a fraction of a perfect black body (1) versus perfectly reflective surface (0). Many natural building materials have an emissivity of about 0.9
T_s	Surface temperature (°C or K)
T_a	Outdoor surface temperature (°C or K), usually taken as the ambient air temperature

Radiant heat loss can be reduced by incorporating a reflective barrier and adjacent air space in the envelope, but this is not common practice. Also the importance of maintaining the air space is not recognised in many installations.

Convective heat loss – energy transfer between a solid surface at one temperature and an adjacent moving gas (air) at another temperature – can be modelled as follows:

Where:

$$Q = h_c A(T_s - T_\infty) \qquad Equation\ 2.3$$

Q	Heat transfer per unit time (Watts)
h_c	Convective heat transfer coefficient (W/m^2 K). Values range from 5-25 for naturally convecting air to 25-250 for forced air convection.
A	Surface area (m^2)
T_s	Temperature of the surface (°C or K)
$T\infty$	Temperature of the air at a distance far enough not to be affected by the surface temperature

Convective heat loss is lessened by filling stud cavities with a material of low thermal conductivity but sufficient mass to limit natural convective air current loops (e.g. fiberglass batts). Convective heat loss also occurs through envelope leakage paths.

The concept of the Dynamic Wall Approach was to address convective and conductive heat loss and gain and, at the same time provide a means for supplying fresh air to occupants while controlling for mould and structural robustness. All this is theoretically possible by simply drawing relatively dry air through the exterior envelope. The optimum flow rate of the air flowing through a dynamic wall or roof system is that at which all the conductive heat within the insulation layer is transferred to the incoming ventilation air. By equating the conductive heat loss rate through the still air in the insulation layer (Equation 2.4) to the rate that air is able to absorb heat (equation 2.5), the optimum rate of air flow, q, through the dynamic envelope component (wall, ceiling or floor), can be determined (Equation 2.6) (Timusk, 1987, p.63).

Where
$$Q = \left(\frac{k}{t}\right) A\,\Delta T \qquad \textit{Equation } 2.4$$

Q	Conductive heat loss through the air in the insulation (W)
k	Coefficient of thermal conductivity of air (0.025 W/m K)
t	Thickness of insulation layer (m)
ΔT	Difference in temperature across the insulation layer (°C or K)

And

Where
$$Q = q\,\rho\,c_p\,\Delta T \qquad \textit{Equation } 2.5$$

Q	Rate of heat absorption by the incoming air (W)
q	Rate of air flow through the envelope component, m^3/s
p	Specific density of air (kg/m^3)
C_p	Specific Heat of Air, (J/kg)
ΔT	Temperature difference across the layer (°C or K)

Resulting in the optimum airflow, q (m/s):

$$q = \left(\frac{k}{\rho\,c_p}\right)\left(\frac{A}{t}\right) \qquad \textit{Equation } 2.6$$

Dynamic Wall Performance and Potential

The early dynamic air houses constructed under Timusk's direction in Alberta did result in good air quality but fell short of predicted heat recovery gains, at about half that predicted. The disappointing heat recovery result was due to unanticipated and uncontrolled air infiltration (Mayhew, 1987; Nakatsui, 1996). As Timusk (1987) reported, the Swedish Building Council also found its similarly dynamic Swedish houses enjoyed mixed results: reasonably good indoor air quality but energy goals not met.

Despite these limitations, the concept of dynamic air showed promise. With new and complementary ideas, the potential may have been possible in the 1990s. However, it would be another decade before a complete system using dynamic air was invented. This lack of interest in further development was partly due to low energy prices at the time and the missing elements to the innovation and the process (DeProphetis, 2006).

RESEARCH METHODS

Timusk (personal conversation, 1999) later recognised his failure in two modes: not sufficiently improving on his idea; and not setting in place sufficient social and commercialisation opportunities. The authors of this paper, one an engineering professor and the other a business professor with an engineering background, set out to avoid the failure modes while building on Timusk's early concept of dynamic air. The enhanced innovation involved three main steps:

1. Technology extension by improved design (e.g. drawing fresh air from exterior walls and ceiling areas, and adding a radiant material in the walls);
2. Prototype testing; and
3. Management of the innovation process.

Re-examination of heat loss and the innovation process itself were first steps, since these were likely where more attention was needed. Under guided supervision, two graduate students set about initial re-examinations, with the following general results.

1. It is established that innovation can lead to creative destruction as the old is replaced by the new, sometimes a very difficult process (Schumpeter, 1942, pp. 82–83).
2. Innovation is a combination of science and engineering insight and advances as well as management of the innovation process from idea to feasibility to commercial reality (Burgleman, 1984; Poulin, 1987).
3. Although innovation tends to destroy inferior systems, the journey can be fraught with difficulty as existing industry and culture resist change.

In this case, overlooked aspects of the science, constraining building codes, entrenched industry practices and weaknesses in the innovation process would all have to be identified and overcome.

The Innovation Process

Burgleman (1984) classified the innovation process in terms of three levels or stages, where decision-makers need to be successful at each level. Table 1. summarises the innovation and new venture process at each of three stages and levels.

Stage	Key Decision Makers	Process & Outcomes	Strategy, Resources & Structure
Stage 1: **Idea/ Concept**	Project managers selected for ability to act as innovation champions	Engineering and management are integrated	Strategy outlined, resources given, flexible structure established
Stage 2: **Feasibility/Prototype testing**	Mid-level corporate managers chosen for their engineering and management knowledge and experience	Scarce resources secured as warranted to develop and test prototypes for feasibility	Substantial collaboration between engineers, mid-level managers and senior-level managers
Stage 3: **Commercialization**	Very senior level corporate managers enlisted to both fairly evaluate and support the new venture	Innovation and venture are fairly evaluated (all this assumes competent senior managers)	Corporate support for new venture with continuous learning among mid-level and top level managers

Table 1. Process of Innovation and New Venture
Source: adapted from Burgelman (1984) and Poulin (1987)

From examination of the innovation process, it is apparent that by the end of the 1980s the Dynamic Wall Approach was failing in some of the key elements required for success. For example, the idea was stuck between Stage 1 and Stage 2, due to limitations in resources that might have led to further refinement of the idea. It was no surprise, looking back, that the project managers would go on to other things.

Resetting the stage for the dynamic wall to become a successful innovation required a combination of better science and engineering design, prototype development and management of the innovation process. Two of the first steps were to examine limitations of building codes and practices, and to look closely to see if Timusk had missed something important with his Dynamic Wall Approach.

Failure of Building Practices and Codes to Account for Science

The three mechanisms of heat loss and gain are not sufficiency dealt with in typical building codes. Convection (e.g. air currents that transfer heat from warm to cold) is controlled by code regulation and this is accomplished by builders installing fibre insulation between studs of the exterior walls and ceiling joists/trusses. Conduction is inadequately handled by building practices by installing rigid insulation to slowing down conductive heat transfer. Radiation is ignored by building codes and practices.

Extending the Dynamic Wall Approach of 1980s in the 2000s

In 1998, one of the early advocates of Timusk's technology returned from 10 years of academic service in New Zealand, accepting a faculty position at Lakehead University in Canada. In 1999 he contacted Dr. John Timusk and found nothing had been done on the Dynamic Air Approach since the Edmonton houses of the 1980s (Timusk, personal conversation, 1999).

Timusk made a suggestion for improving the system (contained in a letter dated February 2, 1999) where he recommends depressurising the exterior walls rather than the entire house. This is to overcome the problem of unanticipated infiltration air, a partial explanation for the heat recovery being less than predicted by his design calculations. Later it became apparent that Timusk omitted to address radiant heat losses in his theory and the building of early houses he demonstrated in Ontario and Alberta. This provided added reason for the lower than expected heating efficacy.

Based on the above, including the results of the student studies, the two professors at Lakehead University (both civil engineers, one teaching engineering and the other teaching business) agreed to work at extending Timusk's previous work. The one focused on engineering with his engineering students while the other focused on innovation with business students, each suggesting ideas to improve the others' work.

Also by the 2000s, oil prices had risen. This caught the attention of funding agencies, helping the research team obtain seed funding for research and prototype development and testing. A parallel effort existed in Europe.

The two centres were University of Aberdeen, Scotland and Lakehead University, Canada. The approach by both Aberdeen and Lakehead was to depressurise the exterior walls, as distinguished from Timusk's earlier Dynamic Air Approach where he depressurised the entire house.

While outwardly similar, the two University-based initiatives differed considerably. For example the Aberdeen group focused on inventing proprietary and prefabricated exterior wall panels that would allow air to pass through the exterior walls, while the Lakehead group focused on understanding the physics and mechanisms of heat gain and loss, and optimising the entire system using existing building materials and construction methods.

Research Aims of the Efficient House Innovation

The research aims came about from initial studies conducted from 1999 to 2004 by the two authors of this paper and groups of business and engineering students at Lakehead University, Canada. The initial studies first established market needs, and later the engineering and business feasibility of meeting the requirements for more robust, more energy efficient, more healthful housing, assuming the technical and innovation challenges would be overcome.

By early 2004, the two main researcher-inventors had committed to satisfying the need for better housing by building on the dynamic air approach. The research-inventors and collaborators agreed on these five research aims:

1. Understand and apply the physics of heat loss and gain;
2. Overcome technical and commercial approaches of the past;
3. Improve design in terms of fresh air, energy efficiency and durability;
4. Address funding for design, demonstration, and testing of prototypes; and
5. Imbed a continuous improvement approach with the system (Goldratt & Cox, 2008).

Also in 2004, about the same time as the initial review of the literature on Timusk's work was completed, it became known by the authors that Lakehead University Student Union (LUSU) was planning to construct a new, energy efficient building to store and service bicycles. The servicing was to be in a heated portion that would house a club that would advocate the benefits of cycling, and teaching others how to repair and service their bicycles.

Subsequently, funding of $10,000 (CAD) was arranged. This helped the students afford the incremental cost of introducing the new EHI technology in their new building as well as installation instrumentation for testing of the EHI technology. The students agreed to accept the new EHI technology in the heated portion of their facility shown as Figure 2, an elevation view of this first demonstration of EHI.

Figure 2: Elevation View EHI Demonstration, Lakehead University 2004-2006
Source: Chow K., Cotton C. and Deemter, M. (2010)

Construction of the heated portion of the bicycle building was with standard 2x4 (or 4x2) wood framing, clad with R10 rigid insulation and R14 rock wool-fibre insulation between the studs, giving an overall insulation value of R24 in 'static' mode, that is when the fan is off and not in dynamic mode

Although insulation was nominally rated at approximately R24 in 'static' mode, the dynamic mode makes for much higher thermal resistance because conductive heat is recovered by the air brought 'dynamically' through the exterior envelope.

UNDERSTANDING DYNAMIC AIR FAILURES OF THE 1990S

Understanding past failure and success of both engineering and management was critical to moving from overall failure to successful innovation that has resulted in the Efficient House Innovation. One reason for the disappointing energy efficiency results in Timusk's Ontario house of the early 1980s was that important technical aspects had not been taken into account or had been only partially taken into account.

For example, not enough thought was given to depressurisation, and no attention was given to both radiation of heat or drawing in fresh air and recovering heat from the largest uninterrupted area of houses: the exterior facing ceiling (and potentially the floor) areas. Such critique applied to Timusk's two experimental houses in Edmonton (Lstiburek, 2002) and also likely applied to the Swedish houses of the 1980s.

All was not lost in past failure to improve and commercialise the Dynamic Air Approach for the Edmonton Alberta demonstration project in the mid to late 1980s. It was this early work that inspired the Lakehead University research team to revive the "dynamic air" idea by extending and adding new features, and improving performance and practicality.

The Efficient House Invention (EHI)

As mentioned, in 2004, the architect and the authors worked together with Lakehead University Student Union (LUSU) to have the improved innovation demonstrated and tested in the 72.5 S.M. or approximately 780 sq. ft. structure shown as Figure 1, constructed by a local contractor and supervised by the co-author of this paper, also head of civil engineering at Lakehead University.

The demonstration was completed in 2006 with modest financial support from Lakehead University and Federal agencies, assisted by LU's Innovation Management office and the students. The basic principles of the dynamic wall or more generally dynamic envelope technology were illustrated by the formulas on pages three and four and demonstrated in the structure shown as Figure 2 on page 51.

Typical test results in the following Figure 3 indicate performance of the EHI system in each of the North, South, East and West facing walls, and exterior facing ceiling.

In winter, the relatively drier cool air is drawn though the envelope in a controlled way, though perforations in the rigid insulation and then through the fibre insulation where the air is collected and returned to the 'house', in this case the heated portion of the bicycle building. This has three major effects: fresh air is supplied, conductive heat is recovered; and the structure is keep dry and robust. When the flow of air is reversed the house can be kept cool in summer season (exactly the reverse).

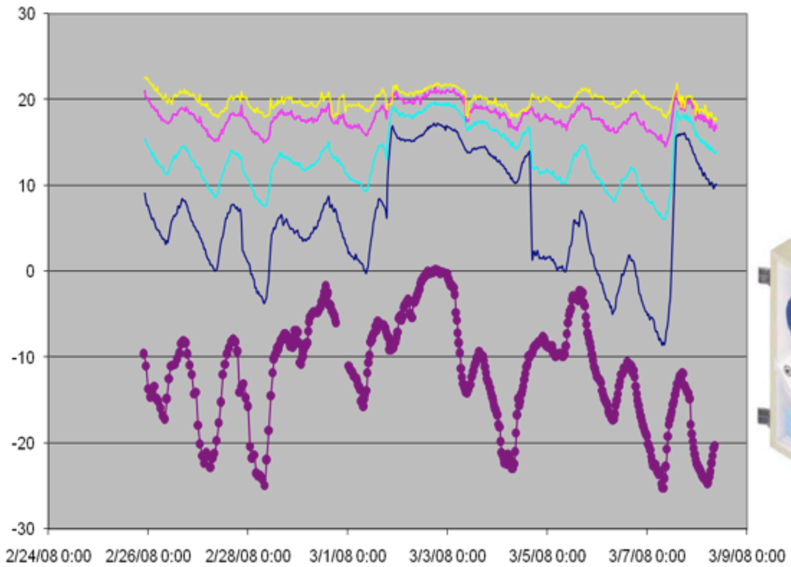

Figure 3: EHI Results Lakehead University Bicycle Building 2008 Winter Season Source: Tracz, Kapush and Mcquaker (2008),), unpublished report, Lakehead University

Adding the reflective material to the normal within-wall insulation reflect heat back (in winter) or out (summer) and boosts both the effectiveness and the efficiency of the EHI system. Initial test results over winter 2007/2008 indicated that the EHI in active mode (e.g., air drawn through the walls) was 25% to 30% more efficient than when inactive (e.g. air not drawn through the walls). However, as will be seen, these results did not answer how much more efficient is the EHI than conventional construction.

The question is, how does the Efficient House compare with buildings and houses built to the current Building Code of Canada? This critical observation and question sent the authors back to designing and testing baseline structures to building code requirements and other experimental structures, using aspects of Efficient House technology to test these against the same performance-based criteria. From 2010 to date, design and construction of two test hut prototypes was to answer the question and ready the innovation for patent applications. Figure 4 below shows an image of the two test huts each 8 ft. x 8 ft. (64 sq. ft.), one hut to Canadian Building Code and the other with EHI breathing envelope technology.

Figure 4: Comparison Test Huts – Standard Code on Left, Dynamic on Right
Source: Authors own

Progress from 2010 to 2015

It took two years from 2010 to 2012 to apply and receive the $10,000 funding, assemble materials and organise engineering students to build and monitor the test huts under supervision. Part of the delay was the engineering professor in charge of construction and monitoring going on a year of Sabbatical leave. Figure 5 shows charted results from a report on the test huts by the engineering students (Roshart et al., 2015) supervised by one author in consultation with the other author of this paper.

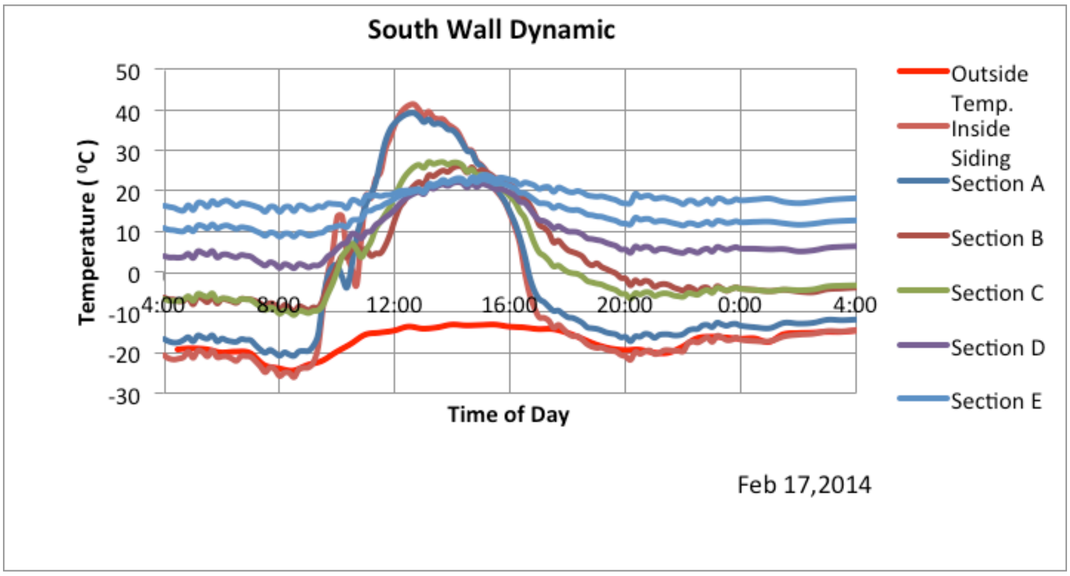

Figure 5: Daily EHI Temperatures: South Wall, Winter 2014
Source: Rosart, C., Couwenberg, P., Gilbride, C. and Jessome, J. (2015)

Daily EHI Temperatures: South Wall, Winter 2014

As the reader will see from Figure 5, temperatures in the afternoon are elevated to over 40 degrees Celsius (˚C) behind the siding on the south-facing side of the hut, when the outside air temperature is -12˚C, a difference of 52˚C. This is a source of free heat since the dynamic envelope design can draw it through the structure, collect this dry warm air and redistribute it throughout the house. Figure 6 below indicates typical winter profile temperatures through the South facing wall in Canada.

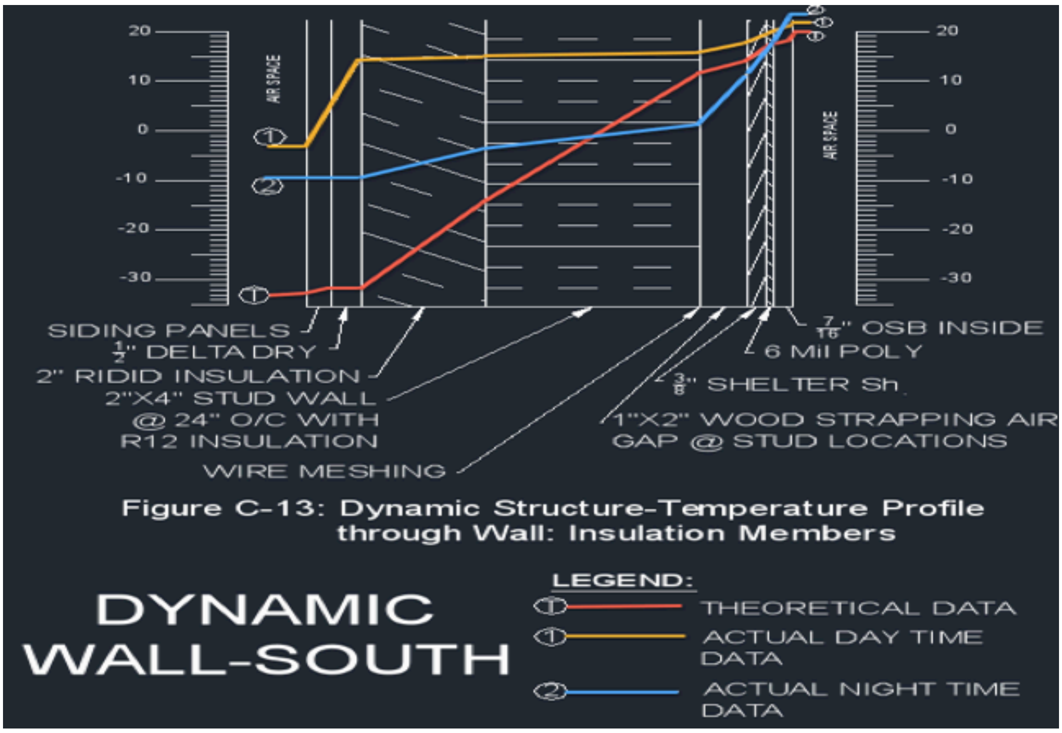

Figure 6: Temperature Profiles through the South Wall of Dynamic Structure
Source: Rosart, C., Couwenberg, P., Gilbride, C. and Jessome, J. (2015)

Line T is Thunder Bay winter design condition, inside 20˚C and outside -33˚C (note that this line would move upwards to match actual, not design temperatures). Line 1 is a sample measured daytime profile when the outside temperature was -4˚C and the inside heated space was maintained at 22˚C. The radiant heat gain behind the siding is apparent and the heat is pulled through the insulation by the dynamic air flow as evidenced by the raised profile slope. Line 2 is a sample nighttime profile. There is no longer any radiant heat increment behind the siding and the colder air is pulled through the wall causing the 'sag' in the through section temperature profile. The pattern clearly demonstrates that a dynamic flow exists. A study of these measured profiles with varying fan speeds will enable the optimum air flow to be determined.

In short, the first prototype and test huts together establish Proof of Concept, and a Canadian Patent for the EHI was granted in February 2014. This achievement has been with support and effort by the authors and students and many others. Today, the control is manual. In the future the system needs to be automatically controlled to optimise internal conditions such as faced by buildings in the North, likely including all of Canada, and in the South, for example in at least some parts of New Zealand.

Subsequent testing, conducted between after 2010, indicated efficiency gain between conventional construction and EHI is approximately 30% to 50%, and air quality can be achieved without a separate air-to-air heat exchanger. In other words, the heat required to heat an EHI building could be about 40% that of a building built to current Canadian Building Code with nominal R24 insulation (note the EHI challenges these nominal ratings). Modest extra incremental cost of the EHI would be due to the control system and some extra level of care in the design and construction of the building, not in the amount of materials which actually is less.

In summary, efficiency increases are important and so too are extra durability of structure and health considerations as the EHI delivers fresh air in just the right amount without the necessity of failure-prone air-to-air heat exchangers. All this, and the EHI is a low energy building technique that can be complemented by efficient technologies, such as efficient furnaces, and solar, wind and geotechnical power.

ACCOMPLISHMENT OF RESEARCH AND DEVELOPMENT AIMS

The EHI did accomplish the research aims in general terms as it promises to revolutionise housing in the North and in the South, single and two-level houses or light frame buildings. It is a total system that conserves more energy, provides healthful fresh air to occupants more reliably and provides superior durability of the exterior shell. This system approach is first to take into account and optimally reverse and/or mitigate all three major mechanisms of heat loss and gain through the exterior shell or envelope of the building.

Implications for the EHI, Going Forward

Implications relate to the insights that have been gained by attempting to innovate in a tertiary education setting that is open to industry without being controlled by industry. These implications are expressed in terms of general responses to the five research questions posed. Both engineering technology and management of the innovation process must be jointly considered with innovation, and this applies to the EHI. Feasibility of the Efficient House is nearing completion. It needs more work and resources to be fully developed and commercialised.

From the beginning the idea was to establish a Centre for research, education and training for Housing in the North at Lakehead University, to permanently secure resources to further develop and eventually commercialise the EHI, and to continually improve and develop Efficient House technology more optimally.

CONCLUSIONS

The Efficient House Innovation (EHI) illustrates how important it is for the right people to work together with the right supports, and at the right time. Also Centres for Housing Innovation need be established in both the North and South to attract the right resources and the right people and keep them together on a long term basis. Here housing innovation would be a need-based process of adaptation and improvement for the particular circumstances of regions both North and South.

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