

BACK TO THE FUTURE: THE NEXT 50 YEARS

The 51st International Conference of Architectural Science Association (ANZAScA)

29 November - 2 December 2017
Victoria University of Wellington, New Zealand

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51st International Conference of the Architectural Science Association (ANZAScA)

Edited by Marc Aurel Schnabel

Hosted by:

School of Architecture
Victoria University of Wellington
29 November – 2 December 2017

School of
Architecture
TE KURA WAIHANGA



Example of how to cite a paper from these proceedings:

Lastname, A. and Lastname, B. (2017) Example Title of ASA2017 Paper, in M. A. Schnabel (ed), *Back to the Future: The Next 50 Years*, (51st International Conference of the Architectural Science Association (ANZAScA)), Architectural Science Association (ANZAScA), pp. 1–10.



www.anzasca.net

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ISBN 978-0-9923835-4-1

Printed in New Zealand
Cover Design: Serdar Aydin

Less and More in Aotearoa New Zealand

More Houses and Less CO₂ Emissions

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Abstract: This paper outlines the case for further research into an expanded use of bio-based materials for housing construction in Aotearoa New Zealand. Not only are large numbers of houses required to address ongoing shortages, but there is also an urgent need to address climate change. The embodied CO₂ emissions of the materials used to construct the future housing stock are, therefore, critical and warrant further investigation. Bio-based materials have very low CO₂ emissions, and some of those grown in Aotearoa New Zealand, are currently underutilised. Over 40 percent of straw, a byproduct of grain production, is currently burned in the field but it has the potential to be used on the scale necessary to satisfy current and future housing needs. Engagement with grain growers and researchers is necessary in order to further the research, as is gaining an understanding of overseas developments in prefabricated straw construction. Public perception is also important. Seventy years ago and facing a similar housing crisis, an attempt was made to introduce an alternative construction method, soil cement, into mainstream building practice. The reasons for Terracrete's forward-thinking but ultimately unsuccessful venture are considered when speculating on a contemporary response using an uncommon material.

Keywords: Bio-based; housing; straw; embodied energy.

1. Introduction

“Housing is to-day a major issue. This is as true of New Zealand as it is of most other countries. Probably never before have so many houses been wanted so quickly. And perhaps never before has the problem been so complex.”

One could be forgiven for thinking these words were written yesterday. In fact, they were penned by architect Cedric Firth in 1949. Firth's book, *State Housing in New Zealand* (1949), is an account of the New Zealand Government's response to a chronic housing shortage in the middle of the twentieth century. Seventy years later, in 2017, housing is still a major issue in Aotearoa New Zealand. Not only is there a shortage of new houses, but also of skilled tradespeople; much of the existing housing stock is in poor condition, and housing has become unaffordable for many lower and middle-income earners. But the problem has become even more complex: there is also the urgent need to address climate change.

Thirty years ago, global attention was drawn to the serious issue of climate change by the Brundtland Report, *Our Common Future* (1987). In a July 2017 report, New Zealand's Parliamentary Commissioner for the Environment, Dr Jan Wright, describes climate change as "the ultimate intergenerational issue" and urges the government to enact climate change legislation, including the setting of greenhouse gas (GHG) emission targets, a key mechanism for mitigating global warming (Wright, 2017). For the construction industry, this means looking at ways to reduce CO₂ emissions, both in the operation of buildings and in their material make-up.

Bio-based materials, including timber, absorb CO₂ and sequester carbon as they grow, making them an important resource to consider when looking for ways to reduce the carbon footprint of an ever-expanding built environment. Timber is the predominant structural building material in Aotearoa New Zealand, particularly for housing, but there are other bio-based materials worthy of consideration by the construction industry. Hemp from the fledgling industrial hemp industry, wool from sheep farming and straw from grain growing all have the potential to be fashioned into building products and manufactured at scale, enabling further reductions to national GHG emissions. Straw is a useful place to start in considering the potential of such materials. It is already grown in large quantities as a byproduct of grain production, and currently has little value. Over the last 24 years a small number of straw bale houses have been built in Aotearoa New Zealand, predominantly by owner-builders in rural locations, but overseas advances in the use of prefabricated systems suggest that a broader uptake is viable.

2. Aim

The aim of this paper is to present the case for further research into using a broader range of bio-based materials, specifically straw, for construction in Aotearoa New Zealand. It is predominantly a literature review providing the background for more detailed research and for speculation on how a new low carbon building material, might be integrated into mainstream construction over the next 50 years. Reflection on a previous attempt to introduce an uncommon building material, soil cement, into mainstream construction 70 years ago aims to provide insight into factors beyond the scientific that could affect the success or failure of a contemporary proposition.

The proposed research would follow the lines of enquiry introduced in this paper:

- interrogation of the different methodologies involved in measuring embodied CO₂ emissions,
- engagement with researchers and farmers to gain an understanding of the grain growing methodology in Aotearoa New Zealand,
- analysis of overseas prefabricated straw construction techniques.

Engagement with the prefabrication industry in New Zealand is not covered in this paper but would be part of the proposed research.

3. Methodology

The paper begins by examining Firth's 1949 report on the New Zealand Government's response to a chronic housing shortage in the middle of last century. The short history of Terracrete Construction, provides an example of the government's willingness to consider new construction methods, but also illustrates the political and social factors that influence their success or failure. This is investigated using published books, archival journal and newspaper articles, and personal interviews.

A contemporary response to the current housing crisis requires the issue of climate change to be addressed, in particular via the control and reduction of CO₂ emissions. This is investigated via an analysis of research by Hammond and Jones (University of Bath), and Alcorn (Victoria University of Wellington) on the embodied energy and emissions of building materials. Differences in methodologies are reviewed, particularly regarding carbon sequestration, an important factor when considering the use of bio-based materials.

Focusing on straw as a case study, further interrogation of Alcorn's research follows with a view to investigating the feasibility of using straw for building large numbers of houses. To gain an understanding of the role of straw in the process of growing grains, close reading of a report prepared by the Foundation for Arable Research (FAR) for Environment Canterbury in 2013, was undertaken, revealing detailed information about current farming practices. Interviews with the CEO of FAR provided further clarification. A brief history of straw bale construction and current building practices is provided, and leads into a desktop overview of two prefabricated systems, Modcell® from the UK and Ecococon from Lithuania.

Speculation follows as to how lessons from the past, current developments in straw building technology, future government legislation on climate change, and potential changes to grain growing methods, might inform a strategy to successfully introduce a new low carbon building system.

4. Back to the Future in 1949

4.1 State housing in New Zealand

Firth's *State Housing in New Zealand* was a response to "inquiries received from overseas and local sources" about the First Labour Government's housing programme (Firth, 1949, p.2). The extract quoted in the Introduction outlines the situation the government was responding to, a situation that sounds all too familiar. In 1949, in an attempt to respond to a worsening housing crisis, exacerbated by the six years of WW2, the government ramped up the intensive house building programme which it had begun in 1936. Statistics provided by Firth show that during the first twelve years of this radical new housing initiative, the government built 20 to 40 percent of all new dwellings constructed annually (1949, p.67).

The State Advances Corporation (SAC) and the Housing Division of the Ministry of Works carried out the housing program, acting as developers, property managers, architects, planners and financiers. They were keen to encourage innovation:

"The Division is on the look-out for ideas – for new materials and systems of construction that may be useful in speeding up the supply of houses, or in reducing costs. Anyone interested is invited to submit prices for houses involving any type of construction at all" (1949, p.44).

4.2 The terracrete experiment

In 1952 an enterprising family of builders from the Wellington suburb of Wainuiomata put the Housing Division's invitation to the test. John Anker heard about engineer P.J. Alley's pioneering work in soil cement at the University of Canterbury (Alley, 1949). Anker and his brothers, Chris and Peter, saw potential for the material and sent soil samples from Wainuiomata to Alley for testing (Alley, 1952). The outcome was favourable and the brothers began by building houses for their own families. They formed a company, Terracrete Construction Limited, designed and patented machinery for wall placement, and

devised a method they believed could compete with the prevailing timber-framed construction (Evening Post, 1954). Their system was sanctioned by the SAC who approved loans for Terracrete houses (Parade of Homes, 1958).

In 1958 Terracrete won a contract with the SAC to build six state rental houses on Wainuiomata Rd, the main road into town. The Housing Division thus proved that they were open to “new materials and systems of construction,” and it seemed that the vision, shared by Alley and the Ankers, for soil cement as a material with a future, could become a reality. The houses, along with nine other Terracrete houses in Wainuiomata, have been continuously occupied for sixty years, but after 1959 no more were built.

According to Miles Allen, “Although Terracrete successfully built houses slightly cheaper than their competitors, their contract [with SAC] was not renewed” (Allen, 1997). He suggests that the government was more interested in promoting the use of timber from its own forests than supporting the commercialisation of soil cement. Maureen Anker, wife of Peter, also suggests that most people were still too conservative to consider soil cement and perceived building with earth a backward step (Anker, 2017).

5. Climate Change and the Embodied Carbon of Building Materials

Since 1987, the effects of climate change have become increasingly obvious, and it is now widely accepted that anthropogenic GHG emissions are increasing the rate of change (MFE, 2014). Globally, much attention has been focused on energy efficiency as a way of mitigating the effects. Current building regulations in Aotearoa New Zealand reflect this focus by requiring increased levels of insulation for most types of building. The GHG emissions embodied in the building fabric, however, are also significant, particularly when global demand for housing continues to grow and operational emissions are falling because of tighter building regulations (Rawlinson and Weight, 2007).

Andrew Alcorn interrogates the makeup of GHG emissions in his 2010 thesis, *Global sustainability and the New Zealand house*, and finds that if operational emissions are broken down into categories such as hot water heating, space heating, cooking, and refrigeration, then the emissions associated with building materials become second only to hot water heating. He concludes that

“The ratio of construction CO₂ emissions and absorptions to total emissions for average and currently constructed New Zealand housing is significant, at approximately 1:4” (2010, p.317)

Values for the embodied energy and CO₂ emissions are available from several sources, including the University of Bath’s *Inventory of carbon and energy* (ICE) (Hammond and Jones, 2011), *Embodied energy and CO₂ coefficients for NZ building materials* (Alcorn, 2003) and Alcorn’s PhD thesis (2010). However, differences in methodologies mean that it is difficult to compare findings, and it is the CO₂ emissions associated with the possible end-of-life scenarios that complicate matters. An important difference between the UK and New Zealand sources concerns timber, the most prevalent bio-based construction material in both countries. Hammond and Jones do not factor in the negative impact of carbon sequestration on embodied CO₂ calculations, stating that to do so “requires a fundamental understanding of the carbon cycle, which is still a developing science” (Hammond and Jones, 2008, p.11). Alcorn includes sequestered carbon in his calculations, assuming landfill as the end-of-life scenario. He maintains that the carbon locked up in buildings for decades or centuries is a crucial mechanism for mitigating global warming (2010, p.218). Despite this difference, widespread acceptance of the importance of embodied carbon of building materials is reflected by the interest shown in the ICE database (Hammond and Jones, 2008) and Alcorn’s New Zealand equivalent.

Bio-based materials like timber have low embodied CO₂, whether carbon sequestration is factored in or not. A 2008 study by John et al investigated the impact of different materials over the life cycle of four similarly designed buildings. They concluded that the timber-rich buildings “have significantly lower net emissions over the full 60-year life-cycle of the buildings,” regardless of whether the end-of-life scenario was landfill, material recycling, or the permanent storage (sequestration) of the carbon in the timber (John et al, 2008, p.128).

6. Bio-based building materials in Aotearoa, New Zealand

6.1. General

Timber is already widely used in construction; it is the predominant structural component of the national housing stock, and provides a strong starting point from which to continue exploring low or ultra-low carbon bio-based building options. Primary industry, specifically agricultural primary industry, has the potential to provide further raw materials, like hemp, wool and straw, for manufacturing building elements. Both hemp and wool are worthy of further research, but straw, the low value byproduct of grain production, has more obvious potential as a low carbon building material option for future housing needs.

6.2. Straw and grain production

6.2.1. Grain production

Grains were first grown in Aotearoa New Zealand by European missionaries (Zydenbos, 2008) and by 1855, when grain production was first recorded, there were 4,000 hectares of wheat grown nationwide (BIRT, 2017). Between 2008 and 2012 the average area under cultivation for all cereal grain production, wheat, barley and oats was 123,720Ha (FAR, 2013). New Zealanders are good grain growers; two farmers from Canterbury, where 70 percent of cereal grain is grown, currently hold world records for barley and wheat yields (Stuff 2017). The industry is well supported by research carried out at the two agricultural universities (Lincoln and Massey), Crown Research Institutes, and the Canterbury-based Foundation for Arable Research (FAR).

6.2.2. The role of straw

Along with world record grain yields, there are correspondingly high yields of straw - around 900,000 tonnes annually (FAR, 2013, p.12). It is the main component of what is termed ‘crop residue’ by the industry and the annual yields are nearly twice that for the same crops in Australia (FAR, 2013, p.16). Yet, despite the large quantities produced, straw has a low value. Between 2008 and 2012 an average of 41 percent of straw was burnt in the field; the rest was used for landscaping, horticulture, animal bedding, the occasional straw bale house, and as a supplementary food source for the dairy industry. This last use has risen since 2012, with increased dairy farming in Canterbury, but the price the straw commands is very low because of its low nutrient value (Pyke, 2017).

Every year the post-harvest burning of straw, or stubble, by grain farmers in Mid Canterbury raises concerns about air pollution and fire risk, so much so that in 2013 Environment Canterbury commissioned FAR to review the role and practices of stubble burning in New Zealand (FAR, 2013). The resulting report is comprehensive, explaining the rationale behind current farming practices and investigating the pros

and cons of other options for dealing with the residue. It considers the English precedent, where similar amounts of straw per hectare are produced but where the practice of post-harvest burning has been banned since 1992 (2013, p.13).

The FAR report argues that differences in farming practices, specifically the preferred crop rotation cycle, make it unfeasible to ban burning in New Zealand (2013, p.16). Crop rotation is a significant element of grain growing practice in New Zealand. Typically grain rotations are followed by small seeded crops like ryegrass and clover, and burning the crop residue, the straw, from the preceding crop is considered the most beneficial method of preparing for the next crop (2013, p.24). The report investigates four alternative methods of managing crop residues, including “Baling and removing straw” (2013, p.6) which rates as third best out of the five options. Consequently, it appears that unless the value of straw increases and/or a ban is placed on burning crop residues, the current practice is likely to continue.

6.2.3 A short history of straw construction in New Zealand.

New Zealand has a history of using straw in construction, albeit in a limited way. In the 1950s an imported compressed straw wall and ceiling panel, Stramit, was available in New Zealand (Home and Building, 1955), and its contemporary equivalent, Durrapanel, is still imported for specific acoustic treatments, for example in Auckland’s Vector Arena (Ortech, 2008). Towards the end of the twentieth century straw bale houses made with locally grown product began to appear.

Straw bale construction began in the late nineteenth century in Nebraska, USA (Steen, 1994) but it was not until 1995 that New Zealand’s first straw bale house was completed (Hall, 2012). The relatively simple construction method makes it attractive to owner-builders, and for the last 24 years a small number of straw bale houses have been built around the country each year. National figures are not available but in the Nelson/Tasman area there were 32 in existence by the end of 2010 (Hall, 2012). It is reasonable to speculate that there may be 300 straw bale houses nationwide. Assuming the Nelson/Tasman sample is indicative of the national position, 69 percent of the houses were built with a high degree of owner participation, and 85 percent are in rural locations. These findings support the general perception of straw bale as a material suited specifically to owner-builders on lifestyle blocks.

There is no building code for straw bale construction, and building consent applications must be made as alternative solutions. Design professionals and building practitioners with straw bale experience use documentation based on overseas codes and guidelines to support their applications, specifically King’s *Design of Straw Bale Buildings* (2006) and the more recent *Appendix S* of the *2015 International Residential Code* (ICC, 2015).

Straw bale houses have been built with a variety of timber supporting structures, straw bale infill walls with cement, lime or earth plaster coatings, and timber framed roofs. This method allows the roof to be constructed first, providing cover while the moisture-sensitive straw bale walls are built. In some cases, the infill walls have been engineered to provide lateral bracing. While the framing and straw bale raising components are relatively fast to construct, the plaster finishes are slower. To speed up the process, a Geraldine-based design build company, Sol Design, have been experimenting with prefabricated straw bale panels, a system which allows much of the time-consuming plastering process to be carried out off-site in controlled conditions (Hall et al, 2014).

7. Straw as a material for the future

7.1 Straw as a low carbon building option

Alcorn's research highlights the importance of reducing embodied carbon in building materials as a major strategy when envisioning a sustainable future. For Alcorn, "Sustainability meets the needs of the present without annual CO₂ emissions exceeding what the planet can absorb" (2010, p54). He calculated a negative value, -210Kg/m³, for the embodied CO₂ emissions of straw bale, based on a building lasting for 90 years (2010, p280, 329). His House 14, with timber and straw as major carbon sequestering building components, combined with on-site wind generation was the only house in his study that met his definition of sustainability. Bodegar et al's UK study, *The carbon reduction potential of strawbale housing* (2011, p.17), also concludes that straw has a negative value for embodied CO₂ emissions when sequestration is factored in.

7.2 Straw as an insulation material

Along with its low carbon credentials, straw is also a good insulator. Testing of full-scale straw bale walls at Oak Ridge Laboratories in the USA and at the Technical University of Nova Scotia provide conservative estimates for thermal resistance of 450mm thick straw bale walls as being in the range R 4.5-5.3 C°m²/W (King, 2006). Additionally, the use of bio-based insulation with R values greater than R 5 of itself results in an overall reduction in CO₂ emissions by way of the reduced heating requirements. This is not the case for other insulation materials, like fibreglass or polystyrene, where the extra embodied emissions present in the thicker material outweigh the savings in heating emissions (Alcorn, p.297).

7.3. Prefabricated straw panels

Sol Design's experiments aside, building with straw in Aotearoa New Zealand has not moved beyond on-site construction of one-off houses. However, off-site prefabrication has been developing in other parts of the world. The most advanced of these are Modcell® Straw Technology, based in the UK, and Ecococon, based in Lithuania. Both companies construct wall panels off-site, but their methods are different.

Modcell® has been developing its wall systems since 2002 in an on-going collaboration with the University of Bath. The Balehaus at Bath, constructed on campus in 2009, has provided the opportunity for continuous monitoring of the Modcell® system in use. Large wall panels, consisting of full-width engineered timber frames with straw bale infill, are constructed in controlled conditions off-site. Finishes vary according to panel type and range from traditional lime plasters inside and out, to breathable sheet linings both sides, and cavity battens to the exterior supporting a variety of rain screen options. The Modcell® Core+ panel meets Passivhaus standards. Built projects to date include schools, business centres and housing projects (Modcell, 2017).

Ecococon, operating since 2008, also constructs wall panels off-site, but its panels are smaller. Sawn timber is used to construct double frames spaced 400mm apart to contain the full wall thickness. Rather than using straw in bale form, loose straw is rammed tightly within the frame. As with Modcell®, a variety of interior and exterior finishes can be applied. Walls have been successfully tested for fire, structural integrity, air-tightness and thermal and moisture performance, and meet Passivhaus standards. The built examples shown on the Ecococon website indicate that the system has been used predominantly for standalone houses (Ecococon, 2017).

Both the Modcell® and Ecocon systems could be replicated or adapted for New Zealand conditions, the scale of the prefabricated panels being determined by the target market. The large Modcell® panels require heavy machinery to lift in place and are well suited to larger projects, a medium density housing project for instance. On the other hand, the smaller Ecocon panels can be manipulated by hand or small-scale lifting machinery and are therefore better suited to single house projects. The decision to use straw in bale or loose form would be affected by preferred harvesting methods, which requires engagement with the grain growers.

8. Discussion

Nearly 70 years have passed since Firth's report. During that time, the government's role as a housing provider has changed dramatically, but the dire housing situation described by Firth has not. In 1949 over 25,000 houses were needed nationally (Firth, 1949, p.48); in 2016 a report prepared by ANZ for the Treasury estimated a national shortfall of 60,000 houses (Newshub, 2017). Since 1949 successive governments have systematically altered their visions for the future, from one where the state felt a responsibility to provide houses for all citizens to one where provision of housing is largely left to the private sector. The role of government may well change again over the next 50 years, not by returning to the 1949 position but by legislating to reduce CO₂ emissions, thereby creating an environment where low carbon building technologies would become highly relevant.

Life-cycle analysis, including embodied CO₂ emission calculations, of proposed construction systems will be an important aspect of the research proposed in this paper. Experts agree that bio-based materials have relatively low CO₂ emissions, regardless of the end-of-life scenario. However the carbon sequestered in the fabric of buildings is a key factor in the case for using more bio-based materials and it is imperative that those end-of-life scenarios be included in the calculations.

The agricultural sector contributes nearly half of New Zealand's GHG emissions, mostly via methane emissions from livestock (MFE, 2016), but the sector also has the potential to mitigate the effects of climate change by growing low carbon building materials. New Zealand farmers are very good at growing grains, but current farming practices, specifically burning straw after the grain harvest, mean that the potential benefits gained by sequestering carbon while the plants grow are offset by the act of burning, where most of the carbon stored in the stalk is volatilised, releasing CO₂ back into the atmosphere (FAR, 2013, p.18). In the UK, burning straw and stubble has been banned since 1992 and if a similar ban were to be enforced in Aotearoa New Zealand, the prospect of using straw to manufacture construction materials may provide an attractive option for grain farmers. The 2013 FAR report did not consider other markets for straw when investigating alternatives to burning. The analysis and subsequent recommendations assume a low value based on straw's low nutritional value. If, however, it was highly valued as a vital raw material for an innovative prefabricated wall system, it is reasonable to speculate that farmers would be open to adapting their farming methods to suit.

It is useful to reflect on the Terracrete venture and speculate how an unconventional construction system might be successfully marketed in 2017. In the 1950s, when building with earth was considered a thing of the past, Alley called the material 'soil cement' and the Anker brothers branded it 'Terracrete', both parties making conscious decisions to present earth as a modern material for modern times, and achieving a limited degree of success. The general perception of straw building as a marginal activity practised by owner-builders presents a similar problem. As well as committed support from government and the private sector in relation to research, regulation and the development of standards, and buy-in from the construction and grain growing industries, a sophisticated programme aimed at educating the

public about the environmental benefits of straw, and dispelling negative associations, is likely to be necessary. The branding and marketing employed by Ecococon and Modcell® portray both products as being environmentally responsible and technically innovative. Both companies use the results of their scientific testing and Passivhaus ratings as marketing tools, and Modcell® uses built projects as case studies to illustrate the adaptability of their product to suit a range of building types and styles. Further interrogation of the effectiveness of both companies' marketing strategies would inform an appropriate approach to introducing straw as a future building material for Aotearoa New Zealand.

9. Conclusion

This paper set out to present a case for further research into the viability of using locally grown bio-based materials to manufacture building materials and develop associated construction systems capable of being utilised at scale. If timber, the country's predominant structural material, is combined with other bio-based materials such as straw, it is possible to significantly reduce the CO₂ emissions embodied in the fabric of the large number of new buildings required to satisfy current and future housing needs.

In order to explore this proposition, a number of factors require further investigation. Firstly, it is important to engage with growers and researchers to gain an understanding of the farming methods and economics of grain production. Currently straw is treated as a low value byproduct, 40 percent of it is burnt in the field following harvest, and unless the value of straw increases or a ban is placed on burning, current practice is likely to continue. Secondly, a thorough analysis of international straw prefabrication techniques and how these might inform a New Zealand system needs to be carried out. Proposed systems would require life-cycle analysis, including embodied emissions that are specific to the New Zealand environment. Finally, reflecting on the ultimate failure of Terracrete Construction's attempt to introduce soil cement as a building material for the future in the 1950s, it is clear that while gaining support from industry and regulatory authorities is essential, public perception is also an important factor to be considered.

The future imagined 70 years ago was quite different to one imagined today. The housing shortages in 1949 were similar to those in 2017, but any vision for 50 years ahead did not consider climate change. As public awareness grows and pressure mounts on governments to take affirmative action on reducing GHG emissions as well as addressing housing shortages, the benefits of using bio-based materials may be recognised as a way of building more houses with less CO₂ emissions in Aotearoa New Zealand.

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