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AUCKLAND, 3–5 SEPTEMBER 2014

Ministry of Business, Innovation & Employment

CONSTRUCTION INDUSTRY COUNCIL CIC

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CSG CONSTRUCTION STRATEGY GROUP BUILDING INDUSTRY VALUE

ISBN: 978-1-927258-42-2

Published: March 2015

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WATER VIEWS: THE IMPORTANCE OF WATER ON URBAN LANDSCAPE PREFERENCE

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ABSTRACT

Auckland possesses the privileged conditions for a strong character as a water city. However, the increase in population and the on-going densification of the city can negatively influence the intrinsic landscape value of the city. In the context of this issue, this study sought to uncover the role of visual access to water on urban landscape preferences.

An innovative method was developed and applied to explore the visual quality of Auckland's windowscape. 158 postgraduate students of two Auckland universities were requested to draw from memory the most significant features of their home and office window-views. Participants were also asked to assign scores according to how much they liked each feature within their views and their windowscapes in general. Participants' sketches were then compared against photos taken from their views.

This paper presents and discusses preliminary findings of the research. The results of this study revealed that the water is an important factor of urban landscape appreciation. Preference was significantly higher for windowscapes with water bodies. Furthermore, the majority of those participants who had visual access to both greenery and water omitted to draw the former in their sketches and exaggerated the size of water, highlighting the significance of this feature. Buildings, which (partially or completely) prevented visual access, were the least preferred features of windowscapes. However, preferences for obscuring buildings were significantly lower where visual access to large bodies of was not completely obscured.

The findings contribute to the landscape preferences studies and provide some information about the visual quality of the existing urban areas in New Zealand. The study may help to formulate some guideline for the future management of Auckland's built environment to develop positively perceived landscapes. In particular, urban planners and policy makers should take into account the view or waterscape preferences in allocating land to residential and business uses.

KEYWORDS:

Water; Landscape preferences; Urban areas; Auckland; Windowscape

INTRODUCTION AND BACKGROUND

Researchers interested in environmental psychology have consistently reported the positive effect of water on landscape preferences (Kaplan and Kaplan, 1989; Ulrich, 1983, 1993; Nasar, 2000). Furthermore, a strong tend was found in preference of natural scenes over urban views, especially when the latter lack natural content such as vegetation and water (See, for example, Kaplan et al., 1972; Wohlwill, 1976; Zube et al., 1975; Bruce Hull IV and Revell, 1989).

The preference for water as a visible feature is referred to as hydrophilia (Herzog 1985) and has been explained from the point of evolutionary-based theories by the fact that water plays an essential part in human survival (Appleton, 1975; Kaplan and Kaplan, 1989; Ulrich, 1993). Evolutionary-based theories of landscape preferences argue that natural features – especially water, green vegetation, and flowers – should be visually preferred over human-made features such as glass and concrete (Ulrich, 1983; Kaplan and Kaplan, 1989). These natural features should tend to elicit liking and attention as during the course of human evolution they signalled a nourishing food source.

Presence of water in views found to have economic and physiological values. For instance, Samarasinghe and Sharp (2008) reported the positive impact of water views on Auckland properties. The findings in Jim and Chen, (2009) calculated that a broad harbour view in Hong Kong could increase the value of an apartment by 2.97%. Window views of green vegetation or water, rather than of other buildings or a brick wall are found to be associated with improved attention capacity in adults (Tennessen and Cimprich, 1995). Moreover, urban environments with water could have the same stress-reducing and mood-enhancing power as a natural environment (Karmanov and Hamel, 2008).

There is relatively little research into urban landscape preference (White et al., 2010; Kaymaz, 2012; Thompson, 2013). The aim of this paper is to address this gap and identify the subjective value of large bodies of water as an urban feature on landscape preferences in Auckland. Auckland possesses the privileged conditions for a strong character as a water city. However, rapid urban intensification in the city can limit visual access to this natural feature and, therefore, affect the intrinsic landscape value of the area.

The question is how to measure urban landscape preferences from point of view of daily observers? Kaymaz (2012) suggests that limited research on urban areas is due to their highly complex structure, which makes assessing preference determents rather difficult. There are also significant shortcomings with the methods that have been used. For example, the method of asking people to rate photographs of the scenes cannot capture the subjective value of urban environments as experienced on a daily basis.

Most research into landscape preference proceeded by asking people to rate photographic images of scenes instead of holistic and haptic experiences of the landscape itself. This undermines justification to use the findings to influence public landscape policy (Porteous, 1996, p. 143). The validity of using photographs in landscape preference studies is well-documented; however, it does not change the fact that “a photograph is totally unable to convey the life of the scene; unable to discriminate; it merely records everything at one instant” (Pocock, 1982a, pp. 360–361). As Wohlwill (1978) rightly points out, a photograph cannot capture the ambience of an urban environment, which is composed of visual, as well as sonic and dynamic components. Another issue of the photographic method is related to the question of how to frame the scenes. As Johnson (1979) states, "a landscape requires selective viewing and a frame". However, the selection of the frame or landscape features may differ between the photographer of the scenes and the people directly experiencing the environment. Other shortcomings of the photographic method are outlined by Bruce Hull IV and Revell (1989). The traditional photographic method neglects the meanings associated with landscape features and overlooks the impact of attention-attracting features and the temporal dimension of landscape preferences (ibid).

This study develops a novel method to investigate preferences for everyday urban scenes. The novelty of this method lies in the usage of drawn responses in addition to photographic evidence. In this method, instead of sitting in a darkened room and passively looking at photographs of the scenes,

participants are actively engaged by drawing them. The method is called, therefore, *Active Perception Technique* (APT).

A driving philosophy behind APT method is the notion of active perception, which states that one actively probes the environment in order to extract behaviourally relevant information (Gibson, 1986). Active perception, as Bell (2000, p. 129) explained, “acts as a filter to determine what is worth seeing and comprehending in an otherwise confusing scene”.

Windowscape is used in APT as a convenient, useful tool. Windowscape can be of highly complex structured with too many kinds of natural and human-made features and APT can help to determine which of these features more significantly contributed to overall preferences of the views. APT is devised to externalize mental picture of a windowscape held by observers and is only interested on those features of windowscapes that outstand from views and stick in ones’ mind. These features are assumed to be determinants of windowscape preferences.

The use of APT can overcome some of the limitations of the previous research. The drawing component of the method allows participants to select features, they find salient within the landscape. Since window-views are changing during the day (or year), the temporal or dynamic dimension of landscape is more likely to play a role, if any, in their preferences. Although the preference for visual aspects of the landscape is the focus, the auditory aspects can also affect preferences.

METHOD

RESEARCH DESIGN

Active Perception Technique (APT) for measuring windowscape preferences stems from Kevin Lynch’s (1960) seminal work, *Image of the City*, and Nasar’s (1990) study, *The Evaluative Image of the City*. Interested in how people make sense of the vast amount of visual information in a city, Lynch (1960) asked research participants to draw a quick sketch of their city as if they were making a rapid description of the city to the stranger. Lynch's analysis predominantly deals with the effects of physically perceptible objects and the relation between image and physical form. He proposed the concept of environmental image, a generalized mental picture of the exterior physical world (1960, p.6):

> *Environmental images are the result of a two-way process between the observer and his environment. The environment suggests the distinctions and relations, and the observer…selects, organizes, and endows with meaning what he sees. The image so developed now limits and emphasis what is seen, while the image itself is being test against the filtered perceptual input in a constant interacting process. Thus, the image of a given reality may vary significantly between different observers.*

Nasar (1990, 42) argued “evaluation is central to our perception of and reaction to the environment” and Lynch's theory of the city image must be strengthened by attempting to measure the emotional meaning that an individual brings to the image. Nasar (1990) asked residents of two cities to identify areas that they visually liked and areas they disliked, and to describe the physical features accounting for their evaluation.

Nasar’s concept of likability was used to develop Active Perception Technique. The term likability refers to “the probability that an environment will evoke a strong and favorable evaluative response

among the groups or the public experiencing it" (Nasar, 1998, p.3). Likability derived from what Gibson (1977) has labelled *affordance*— the reciprocal relation between environmental properties of things and the active perceiver. For instance, a road affords (supports) walking or driving. According to Nasar (1990), likability has two components imageability and affect. In other words, a feature must stands out as memorable and evoke feelings (like or dislike). APT, accordingly, composed of two parts:

- Capture the imageable features of urban windowscape,
- Determine preferences for those features and their influence on overall windowscape preferences.

Research participants were asked to draw from memory what they see from their window-views. They were then required to number each feature of the view in the order that they have been drawn, and to express their feelings towards them on the Likert scale by notating the letter (A) for Strongly like, (B) for Like, (C) Not Sure, (D) for Dislike, and (E) for Strongly Dislike for each feature) and labelled these features. They were also asked to evaluate the windowscape as a whole based on the same Likert-scale. These sketches were compared against photos taken from the views. Home and office windowscapes are chosen as two case studies to examine if contexts of the views have any impact on preferences on windowscapes. Therefore, each participant is asked to provide two sketches. Figure 1 presents a sketch of a water view from home. This view was rated as *strongly like*.

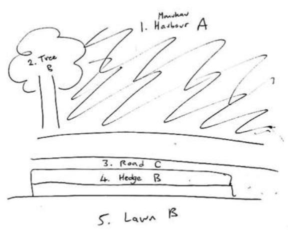

Figure 1- An example of the data obtained from the sketching exercise

PARTICIPANTS

The study was conducted in two Auckland-based universities. A target population was identified as postgraduate research students, who had assigned university workplaces with outdoor views. Using students as respondents are efficient in terms of time and money. It was decided to use postgraduate students because they are the only students who are usually assigned workplaces at universities and spend most of their times within their workplaces.

158 postgraduate research students were interviewed. The distribution of participants across gender was well balanced with 51% female and 49% male. Most of the participants were in the age group of 26-35 (93 students, 59%); followed by the group <26 (48 students, 30%) and only 11% were above the age 35. The study participants were ethnically diverse (32% Far East, 24% Pakeha, 19% European, 13% Middle East, 12% other).

PROCEDURE

Face-to-face questionnaire-based interview sessions were used as a tool for data collection. The participants were self-selected, voluntarily approaching after advertising the aims and objectives of the project. Recruitment of participants was by an invitation circulated via fliers, emails, Facebook, and universities newsletters, or a group presentation in one of the postgraduate student meetings. All who responded to advertisements or submitted their email addresses were contacted to schedule a date and time for an interview.

All the participants were initially met at participants' workplaces or occasionally in their departmental common rooms. Most interviews were conducted with a single participant, but a few involved more people when officemates wanted to be interviewed at the same time. Interview followed a standardised pattern. The questionnaire was designed to be self-guided, and participants had an unlimited amount of time to complete it. During the interview, they were encouraged to ask questions if they found any part of the questionnaire to be unclear.

Participants were presented with a regular lead pencil, eraser, and a set of colour pens for sketches exercises. No rules or guidance on how to draw mental images were given to the participants. The only restriction was that the image should not be copied from the outdoor view but drawn from memory. This was clearly explained to the participant during the interview. Participants were also supervised to ensure, they would not look out of their office window while drawing. If a lack of confidence with drawing skills were observed by the researcher or expressed by participants themselves, writing down the name of features instead of drawing them was suggested. Only one participant, whose drawing skill was reasonably good, wrote some of the features name under her sketch without drawing them.

For the office-view sketches, participants were advised to draw the view they could see when they were sitting behind their desks. For the house views, however, the choice of view was more complicated. Some of the participants were living in university halls of residence, with the others living at home, or in private accommodation. Hence, several had access to more than one window in their homes. In these cases, participants were advised to choose from their room and living room view, the one that they spend most of their time in. Participants were encouraged to talk freely during sketching. The interview took about 20 to 30 minutes to complete. Photos were taken of their office window views. To make it more comfortable for participants, they were requested to email photos of their outdoor view through their living room/room window. The majority of interviews were conducted between July and August 2012; only 19% were held between November and December 2012.

ANALYSIS

Following the data collection, all sketches were scanned. A digital library was built by placing sketches and the corresponding photographs next to each other in one page using Adobe Photoshop CS6. To avoid identification, all respondents are referred to by code numbers. The montage collection of sketches and photographs together with participants' socio-demographic data-sheet was then uploaded into NVivo 10 for content analysis. Content analysis is an empirically grounded method, which has been widely used in the studies involving with visual data (Bell, 2001; Maggi and Scholz, 2008). The purpose of using content analysis was to identify the most common features within the views (e.g. trees, street, buildings). Frequency data generated by content analysis was analysed using SPSS. Statistical comparison was done by non-parametric methods (Mann Whitney U-test). For the statistical data analysis, responses were recorded as A = 5, B = 4, C = 3, D = 2, and E = 1. A p-value less than 0.05 was considered significant for all tests.

RESULTS

The dataset comprises 158 respondents, 153 office-view sketches and 157 home-view ones, and 304 corresponding photos of the views. Missing data is because either participants did not have access to windows from their workplaces (n=5) or their places of residence (n=1), or they did not email their home-view photographs (n=6). On average four features were drawn in each sketch, and the results presented here are obtained from the analysis of more than 1240 drawn features. The majority (86%) of the participants' offices were in city campus buildings, whereas 64% were living in Auckland suburbs. The collected data covers a variety of Auckland windowscapes. Figure 3 presents the word cloud of common features within the views in which font size is associated with relative frequency. As it can be seen, buildings, roads, and trees were the most frequent feature within the view, and the harbour (large body of water) was only found in twenty office-view and eighteen home-view sketches. Based on this analysis, the frequently drawn features were divided into seven main classes, and preference scores for each are shown in Figure 2. A straightforward result of this analysis reveals that urban natural features were preferred over urban built ones. Large bodies of water and the sky were the two most preferred,

Figure 3- Word cloud of drawn/labelled features

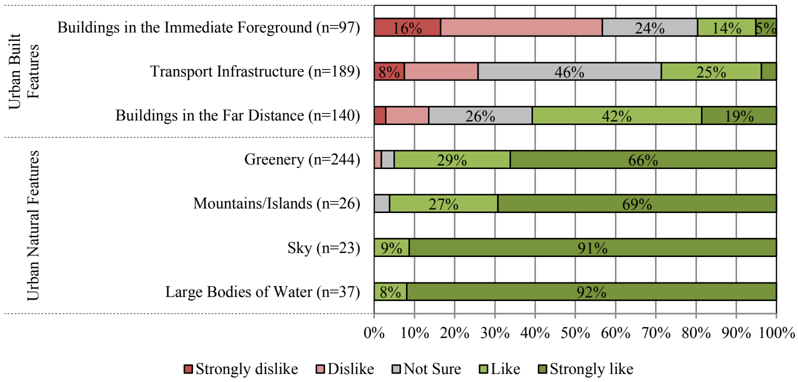

Figure 2- Feelings attached to the most common features of the view

- Buildings in the immediate foreground that blocked (or partially blocked) the views,
- Transport Infrastructure (e.g. motorways, streets, driveways, parking lots),
- Human-made features that can be viewed from distance (e.g. distant buildings, sky tower, bridge etc.)
- Greenery (e.g. gardens, trees, and parks),
- Mountains/Islands,
- Sky,
- Large bodies of water (e.g. Waitemata Harbour)

and buildings that blocked the views were the least preferred features of urban windowscapes. Views to large bodies of water were positively preferred by 92% (n=24) of the observers (see Figure 4). Two participants were *not sure* about their preferences for their water views, which were partially blocked by a building in the foreground.

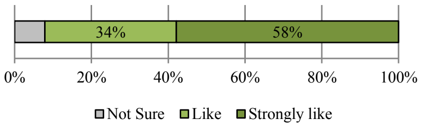

Figure 4- Preferences for water views

To measure whether the presence of water can influence preferences for windowscape, views without water were compared against those with water views. Waterscape views in this research were all high in complexity (i.e., the total number of landscape features in a scene) and literature shows that the complexity of urban landscapes has a positive impact on preference (Han, 2007; Heath, Smith, & Lim, 2000). Therefore, for this analysis only views without water that contained at least four drawn features within their sketches were included. This approach was appropriate to ensure that the result was not confounded by the complexity of the views. The Mann-Whitney test revealed a significant effect of water on preferences of the views, (U-test = 1654, $z = -3.01$, $p < .005$, $r = -.23$), with waterscapes rating significantly higher in preference (Mdn= strongly like) than complex views without water (Mdn= like). No significant difference was found in preferences of waterscape view between home and office context (U-test = 177.5, $z = -.68$, ns). All office windowscapes offering views to large bodies of water, and 94% of home ones were rated as *Strongly Like* or *Like*.

Sketches and their corresponding photographs were compared with each other to identify the most and least memorable features of windowscapes. The expectation was that large bodies of water, which created strong positive preferences, would be included in all the corresponding sketches. Not only was this prediction confirmed, but surprisingly, three participants found that they anticipated seeing a sea out of his window while such views could be seen only if they were in upper levels of their buildings. Anticipation of seeing large bodies of water indicates the desire of these participants to have this feature in their views. It is also interesting to note that the presence of large bodies of water was recalled and drawn with exaggeration even in the cases where the water was hardly visible in the horizon. A few water views were found in which boats were drawn and positively preferred; a participant explained "The boats are interesting because they're always moving and always different. You can look at them and wonder what they're doing, where they're going." Although the sky was assigned the same preference score as the large bodies of water, 88% (n=161) of the participants omitted it from their sketches.

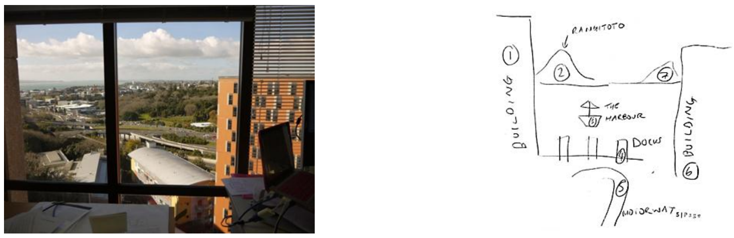

Figure 5- A participant omitted the greenery (Domain Park) from her drawing while, on the other hand, exaggerated the size of the harbour and the islands.

Greenery was noted in 89% (n=34) of the photographs of waterscapes. This provides an opportunity for a comparison of preferences between these two natural features. Intriguingly, the presence of water bodies captured the eye of 41% (n=14) of these participants in the way that they omitted greenery from their drawings and exaggerated the size of the ocean/sea (e.g. Figure 5). In ten out of twenty sketches with both greenery and water bodies, preferences for water bodies were more positive than greenery, while the remaining features created the same preference.

Preference scores for buildings in blocked views were compared with preference for blocking buildings in long views with large bodies of water. Mann-Whitney U-test shows that blocking buildings within waterscape views (Mdn = dislike) were rated significantly lower in preferences compared to ones in blocked views (Mdn = not sure), U-test = 128.5, $z = -3.1$, $p<.005$, $r = -.43$. Contrastingly, waterscape views with blocking buildings were positively preferred by 88% (n=13); whereas blocked views were rated as *like* or *strongly like* by 35% (n=13). Figure 6 presents examples of a blocked view and a water view. While the foreground building in the blocked view is rated as *note sure;* in the water view, the building was *disliked*.

Figure 6- Examples of blocked view and water view

DISCUSSION AND CONCLUSION

The main aim of this research was to determine how large bodies of water affect visual preferences of urban windowscapes in Auckland. Investigating this question can be used to positively influence the health of urban dwellers; research has shown that there is a strong relationship between landscape preferences and human well-being (Hartig and Staats, 2006; Karmanov and Hamel, 2008; van den Berg et al., 2003; Van den Berg et al., 2007). In this study, research participants were asked to rate how much they liked not only the views from their windows as a whole scene, but also the features within it. In line with previous research, almost all the urban natural features were given strong preference ratings; they were rated considerably higher in preference rankings as compared to urban built features. It should be noted that some of the natural features received more positive ratings than others. For example, 'large bodies of water' and 'the sky' were rated as *strongly liked* by more than 90% of participants, whereas 'greenery' was rated as *strongly liked* by 66%. The omission of the sky from 88% of the sketches led the author to agree with Lothian's (2000, p. 246) assertion that for the

majority of participants in this study “the sky plays literally a backdrop role in landscape and appears to be generally disassociated from the landscape itself."

‘Large bodies of water’ were the most preferred and ‘buildings in the foreground of the views’ were the least preferred features of urban windowscapes. Moreover, the difference between preferences for urban windowscapes with water versus complex views without water was highly significant at the $p < .005$ level. These results can be explained by evolutionary-based theories. Preferences for water are believed to be related to survival value in our evolutionary history (Kaplan and Kaplan, 1989; Ulrich, 1983).

‘Blocked views and obscuring features’ are one element of Appleton’s prospect/refuge theory, an evolutionary theory of landscape preferences (Appleton, 1975, 1984, 1996). The theory posits that preferences for environments are strongly related to the extent to which such environments provide places for prospect (the ability to see), and refuge (to remain without being seen). The negative preferences for ‘obscuring buildings’ support Appleton’s theory. Furthermore, there was evidence that preferences towards buildings in the immediate foreground were more negative for waterscape views than blocked views. This result may be because the presence of an obscuring building not only limits an individual’s visual access to water views, but it also deprives the viewer from enjoying a wide view of this preferred feature of urban windowscape.

Participants recalled even very limited visual access to large bodies of water, and the mere presence of this feature within the view was associated with positive preferences. This finding echoes results by White et al. (2010) who found that although built scenes containing water were rated more positively than those without, an increase in the proportion of water has minimal impact on preferences. Therefore, the presence of water in urban views is more important than its extent. The exaggeration in the size of the water features found in the majority of water-view sketches also stresses the value of this feature to the observers.

Greenery was omitted from 41% of water-view sketches; this supports our earlier findings that large bodies of water are superior to greenery in creating positive preferences. In line with this finding, White et al. (2010) demonstrated that responses to built environments where water was present were just as positive as those to entirely natural green space without built form or water. Earlier, Karmanov and Hamel (2008) showed that urban environments with water could have the same healing power as a natural environment, despite a limited amount of greenery.

Photographs still play a role as a research instrument in this study; though the use differs from photograph study protocols. Traditional protocols see photographs as a reasonable surrogate of the physical environment. In this research, photographs are considered to be tools, as an objective record of the view outside. Photographs capture exactly what is there to be seen, and the comparison between photographs and sketches indicates how a person perceives the view, which can contrast greatly with the reality documented in the photograph.

Participants in this study had visual contact with a view on daily basis, therefore, the results reveal the reaction of participants to a three-dimensional, ever-changing environment. However, it should be mentioned that the results present postgraduate students’ preferences and may not be transferred to the general public. The current work would benefit by being repeated in different population groups.

The importance of this research rests on the fact that preferences reflect how well the given environments support well-being (e.g. Hartig and Staats (2006); van den Berg et al. (2003)). Identifying environmental characteristics, which can contribute to the enhancement of the visual quality of urban areas, may potentially be useful to policy makers, architects, urban planners, and environmental experts (Jackson, 2003). So far, the provision of green spaces within the city is considered to be the primary means of enhancing urban dwellers' wellbeing. Given Auckland's privileged location, laying out parks and gardens is not the only way, and providing a view to large bodies of water can provide the same or superior benefits. Urban planners and policy makers can consider the value of visual access to large bodies of water on landscape preferences when allocating land to residential and business uses and when preserving existing view shafts to water as the city intensifies.

ACKNOWLEDGEMENTS

I gratefully acknowledge and thank my supervisor, Dr Michael Linzey, for his invaluable and constant support, subtle guidance, and encouragement to keep me motivated and on track.

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COMPARISON OF NZ'S ENERGY EFFICIENCY REGULATION AND VERIFICATION ASSUMPTIONS TO REAL BUILDING LOADS AND OPERATION

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ABSTRACT

The New Zealand building design industry assumes various building model inputs for the consumption of energy through lighting and appliances. It also makes assumptions regarding when these energy consumers are considered to be 'turned on'. This paper aims to better inform industry energy modellers about the real load and operation of real commercial buildings in New Zealand when compared to New Zealand Standard energy efficiency requirements and assumptions. The paper presents a set of New Zealand relevant commercial building operation information. Typical operation information is provided for three commercial building types: 1) Office, 2) Retail, and 3) Mixed/Other. The information provides low, typical, and high installed building load and operation pattern scenarios for the three building types. The typical data presented in this paper is significantly different to the load requirement and operation modelling assumptions presented in the New Zealand Building code (Standards New Zealand, 2007a, 2007b).

The results established in this paper are informed by data gathered in the Building Research Association of New Zealand (BRANZ) Building Energy End-use Study (BEES) (BRANZ Ltd, 2013a). The purpose of BEES is to increase knowledge on energy use patterns for the entire New Zealand building stock (Isaacs et al., 2009). The intention of this paper is to disseminate the established knowledge that will eventually update the assumptions used in New Zealand commercial energy models. As part of the BEES modelling research, a set of EnergyPlus Template models was developed. The template models aimed to reduce the difficulties associated with energy modelling, with a particular focus on improving the ease and speed of creating a model to produce reliable results (Cory et al., 2009).

Initially, it was proposed that the New Zealand relevant template models would be developed as adaptations of the US Department of Energy (DOE) benchmark/ reference models (Deru et al., 2011; Torcellini et al., 2008). However, there are a number of limitations associated with the BEES template models, the largest of which relates to the installed building loads and their operation patterns. The building load and operation patterns presented in this paper aim to provide real information that can be used to update and improve the BEES template models for the New Zealand industry.

KEYWORDS:

Building Energy Modelling; Building Load; Operation Patterns, BEES; Monitored data.

INTRODUCTION

This paper presents typical, high and low building load densities and patterns of use for commercial buildings in New Zealand. Patterns of use refers to the daily use profiles of the load presented as the percentage of load 'on' at different time intervals throughout the day. The goal is to better inform building energy modellers about typical lighting and equipment end uses. In the process, this work highlights the differences between the assumptions made when using the modelling verification method to meet the New Zealand Building Code (NZBC) and what is occurring in real buildings (Department of Building and Housing, 2011).

The research is a part of the Building Research Association of New Zealand (BRANZ) Building Energy End-use Study (BEES). The purpose of BEES is to monitor and analyse the energy and water consumed by non-residential buildings around New Zealand. The project has been running for 6 years. **(**BRANZ Ltd, 2013a). BEES aims to provide more insightful knowledge of energy use patterns for

the entire New Zealand commercial building stock (Isaacs et al., 2009). Real data is collected within selected premises through the BEES programme from the monitoring of temperature, humidity, light levels, $C0_2$ levels, occupant and equipment schedules, internal loads and fuel consumption.

BACKGROUND

Currently, when analysing building energy performance, the New Zealand building design industry must make assumptions about various building model inputs based on New Zealand Standard (NZS) verification method for displaying compliance with NZBC. Inputs to their performance calculation models rely on assumptions about the energy consumed by lights and appliances. Energy modellers assessing energy may use the NZS 4243 Lighting Power Density (LPD) value as a base scenario for what is currently installed in commercial buildings. NZS values are used because there is no other reliable information on the typical building load power densities found in real commercial buildings.

Half of the commercial buildings in New Zealand were built before 2000. This pre-dates the NZBC and NZS 4243 clause regulating the LPD. This can cause modellers to enter into their performance calculation of an existing building retrofit analysis assumed values that may not be typical. Additionally, there is no such NZBC regulated density value for other building loads, such as office equipment and hot water. This results in modellers inputting a value for an Equipment Power Density (EPD) and Hot Water Power Density (HWPD) that is a best guess or an assumption based on what is included in the NZS 4243 modelling method to prove a building design meets the NZBC. Table 1 displays the power density 'assumptions' found in the NZS4243.

Table 1 – NZS 4243 Power densities. Table created using (Standards New Zealand, 2007a, 2007b)

Building Type	Power Densities (W/m^2)		
	Regulated LPD	Assumed EPD	Assumed HWPD
Office	12 W/m^2	8.1 W/m^2	Not required
Retail	8-16 W/m^2 depending on retail type	1.1-2.7 W/m^2 depending on retail type	Not required
Mixed/Other	8-18 W/m^2 depending on use type	1.1-8.1 W/m^2 depending on use type	Not required

Note: the Retail and Mixed/other power densities have a range due to the different building types.

The same problem occurs for the operation patterns of building loads. No measured information for the patterns of use of building loads in real buildings is currently published. As a result, an energy modeller is left with little option but to assume when equipment is turned 'on' and when it is turned 'off' based on the modelling assumptions set in the NZS 4243 energy modelling method. Table 2 presents the operation pattern assumptions found in the NZS 4243 energy modelling method for different building types. There is no evidence that these assumptions will be relevant to how real commercial buildings in New Zealand consume energy.

Table 2 – NZS 4243 Lighting and Plug Load patterns of use. Table adapted from (Standards New Zealand 2007a, pp.30-31)

Building type	Day type	Patterns of use (% of load 'On')				
		12am-8am	8am-11am	11am-6pm	6pm-10pm	10pm-12am
Office	Week	5%	90%	90%	30%	5%
	Saturday	5%	30%	15%	5%	5%
	Sunday	5%	5%	5%	5%	5%
Retail (Restaurant)	Week	5% (15%)	90% (40%)	90% (90%)	50% (90%)	5% (50%)
	Saturday	5% (15%)	90% (30%)	90% (80%)	30% (90%)	5% (50%)
	Sunday	5% (15%)	40% (30%)	40% (70%)	5% (60%)	5% (50%)
Mixed/Other	Week	5%	90%	90%	5%	5%
	Saturday	5%	24%	5%	5%	5%
	Sunday	5%	5%	5%	5%	5%

Note: Retail has two patterns of use presented as restaurants a different to general retail. Also, Mixed/Other are the assumptions for a warehouse, but it could be a mixture of all three use types.

New Zealand is not alone with regard to these assumptions and lack of information. The current state of the art in prototypical building models can be found in a US set of prototypical building models (Torcellini et al., 2008). These are based on informed engineering judgements about 'typical' or 'design' values for building loads and their operation. As part of the BEES modelling research, a set of EnergyPlus Template models (BRANZ Ltd, 2013b) were developed which followed the same format as the US prototypical models. The aim of the template models was to reduce the difficulties associated with energy modelling, particularly relating to the ease and speed of creating a model to produce reliable results (Cory et al., 2009). The BEES models have the same short comings in that they are built on assumptions about the building loads and their operation. If the BEES models were updated using the measured data presented in this report, they would be more advanced than any prototypical models currently found. The biggest single advantage of updating the models with measured building load and operation patterns is that they offer the potential for building design teams to examine the risk that a predicted building performance is dependent on the assumptions made about people, lighting and equipment used in the design modelling. There have been criticisms of high performance designs due to the fact that they only perform well in the particularly narrow focused situation 'assumed' during the performance modelling (Bordass et al., 2006). The low and high building loads data from BEES allows designers to quickly test realistic design scenarios and establish how robust their design concept is.

METHODOLOGY

This study uses the measured data for lighting, equipment and hot water energy use from the BEES survey of commercial premises. The BEES team collected data over a four year period from 2008 to 2012. Energy was measured at one minute intervals for a 2-3 week period in a representative sample of New Zealand commercial building premises. The weekly periods were spread throughout the year for different buildings. This means that the energy results could be from a two week period in summer or a two week period in the winter. Because this report only deals with lighting, equipment and hot water the outdoor conditions will have a minimal impact on energy use. This was the case for lighting also as there were no daylight induced electric lighting dimming in any of the premises.

This report presents the power density and patterns of use for lighting, equipment, and hot water. The lighting used is strictly indoor lighting to provide task lighting to the occupants. Equipment is made up of a number of appliances that are used by occupants to undertake day to day tasks and enable businesses to provide a service. Appliances include computers, printers, servers, refrigerators, chillers, water coolers, water boilers, phone systems, security systems, ovens, stove tops, deep fryers, and other appliances used in the day to day use of commercial buildings. Hot water energy use covers the energy used to provide hot water for domestic use, such as hand washing and showers, and commercial use, such as dishwashing.

All results were calculated using the measured average weekday and weekend 10 minute interval load. Each 10 minute interval measured was averaged against other weekday and weekend 10 minute intervals. The power densities were calculated by dividing the maximum measured load (for lighting, equipment, and hot water), by the monitored floor area. The operation patterns were calculated by dividing the measured load by the maximum measured load to establish the percentage of load 'on' during that 10 minute interval.

A typical, a low and a high energy load scenario is presented in this report. The typical scenario is the Median (50^{th} percentile**)** load and pattern of use found across the sample of building premises. Because the sample has outliers which can differ greatly from other values, the median provides a good indicator of the most typical value in the sample. (Urdan, 2010). The Low scenario is the 10^{th} percentile of measured load and pattern of use across the sample of premises. The High scenario is the 90^{th} percentile of measured load and pattern of use across the sample of premises. The sample sizes vary between the lighting, equipment and hot water assessments and are displayed in Table 3.

Table 3 – Sample sizes used to calculate typical, low and high values

End-use	All buildings	Office	Retail	Mixed/Other
Lighting	101	35	29	37
Equipment	83	28	22	33
Hot Water	30	9	7	14

The time intervals used in the patterns of use analysis were decided by assessing natural breaks across the whole data set in the amount of load 'on' during each hour. For example, 12am to 5am is used as there was less than 10 precent difference in load across these hours. The hours were then averaged to get a percentage value of load 'on' across these 5 hours. These data are presented for 3 different building types. The load was split by building use type because NZS 4243 regulates load for different building types, and the use of different commercial buildings results in very different building load attributes. Table 4 displays the three building types assessed (Office, Retail, and Mixed/Other) and the detailed uses found within each of the three building types.

Table 4 – Building type categories

Building type	Office	Retail	Mixed/Other
Specific building use types found in each building type	Office-type use	Retailing use, Motor vehicle sales and services, Liquor outlets including taverns, Service stations, Tourist-type attractions	A mixture of office and retail use types. As well as, warehouses, and service buildings.

A further breakdown was made when assessing the lighting, equipment and hot water power densities. The breakdown assessed the impact of building floor area size. Building floor area size was assessed because NZS 4243 regulates building loads for only 'large buildings' which it deems are 300m^2 or greater. The assessment of size indicates whether building size has a significant impact on the building loads. Table 5 displays the breakdown of the different building floor area sizes assessed (small, medium and large), and the percentage of the total commercial building floor area each building size makes up.

Table 5 - Building size groupings

Building Size	Small	Medium	Large
Building floor area range	5 to 649m^2	650 to 3,499m^2	Over 3,500m^2
Percentage of all commercial floor area	20%	40%	40%

RESULTS

All results displayed in the graphs below are documented on the Victoria University of Wellington Centre for Building Performance Research (CBPR) website in a tabular form. The tabular results enable energy modellers to enter the values into energy models more precisely and easily when compared to the graphs presented in this report.

Lighting Power Density (LPD)

Figure 1 displays the typical, high and low LPDs' for an average commercial building (White), Offices (light grey), Retail (dark grey), and Mixed/Other commercial use types (black). As can be seen, Retail use types have the highest installed LPD's. This is followed by Offices, and Mixed/Other commercial use types. This trend mimics the trend of the maximum allowable LPD set by the NZS 4243 verification method (Standards New Zealand, 2007b). It is worth noting that the typical LPDs found in Offices are slightly lower (11W/m^2) than the value set by NZS 4243 of 12W/m^2 (Standards New Zealand, 2007b). By comparison, the LPDs found in Retail premises are similar to the minimum set out in NZS 4243. For Retail NZS 4243 requirement is 8-16W/m^2 depending on retail use type, and the typical measured LPD across all retail use types is 14W/m^2 (Standards New Zealand, 2007b). The typical LPD measured in Mixed/Other commercial use type premises is much lower than the NZS 4243 requirement. NZS 4243 allows for a maximum of 8-18W/m^2 depending on use type, and the

typical measured LPD was 6W/m². Mixed/Other commercial LPDs are below the sample average. Also, the high scenario (20W/m²) for Mixed/Other commercial LPD's is not significantly different to the Retail (26W/m²) and Office (21W/m²) high values as the low and typical scenarios.

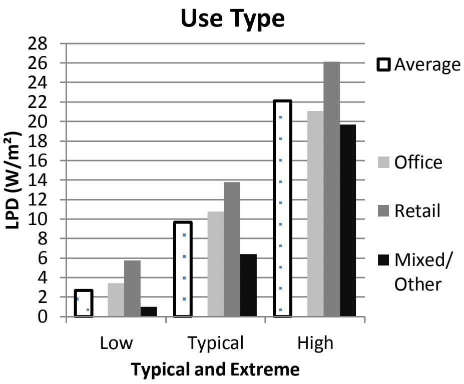

Figure 1 – Typical, High and Low LPDs' for different commercial building types

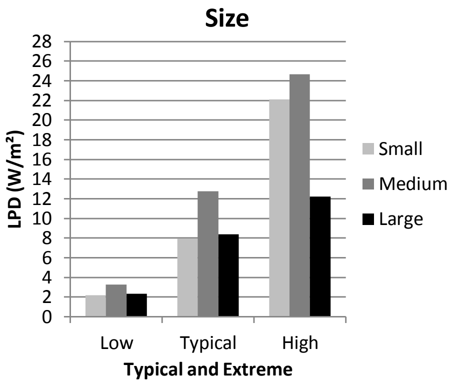

Figure 2 – Typical, High and Low LPDs' for different sized commercial buildings

Figure 2 presents the typical, high and low LPDs' for Small buildings (light grey), Medium sized buildings (dark grey), and Large buildings (black) to assess if size has an impact on the installed LPD. As can be seen, Medium sized buildings have the highest measured LPDs with a typical value of approximately 13W/m². The LPDs found in Small and Large buildings were the same with 8W/m². The high scenario results suggest that lighting was most dense in Medium and Small sized buildings due to the Large building high LPD value being half the Small and Medium sized buildings LPDs.

Lighting Operation Patterns

Figure 3 displays the typical (green), high (orange), low (blue) and NZS 4243 (Black) patterns of lighting use for Offices, Retail and Mixed/Other commercial use types. As can be seen, Offices have the largest difference in usage patterns between weekdays and weekends. The typical lighting usage of an Office was higher (80-90 percent turned 'on') than Retail and Mixed/Other commercial uses during the weekdays (70-80 percent turned 'on'). Retail and Mixed/Other commercial uses have less difference in usage patterns between weekdays and weekends (20-40 percent difference) when compared to Offices (60-70 percent difference). This fits with expectations that Retail and Mixed/Other commercial use buildings have more intense and longer weekend hours compared to Office buildings. Interestingly, the high use Retail and Mixed/Other use types have almost as intense weekends as weekdays compared to the lighting in high use Offices.

The typical lighting use pattern for Offices was similar to the NZS 4243 assumed pattern of use. However, the Retail and Mixed/Other patterns sit between the typical and high scenario patterns of use. If the NZS 4243 assumptions were used in an energy model, then the model would slightly overestimate the amount of lighting turned 'on' in a typical building.

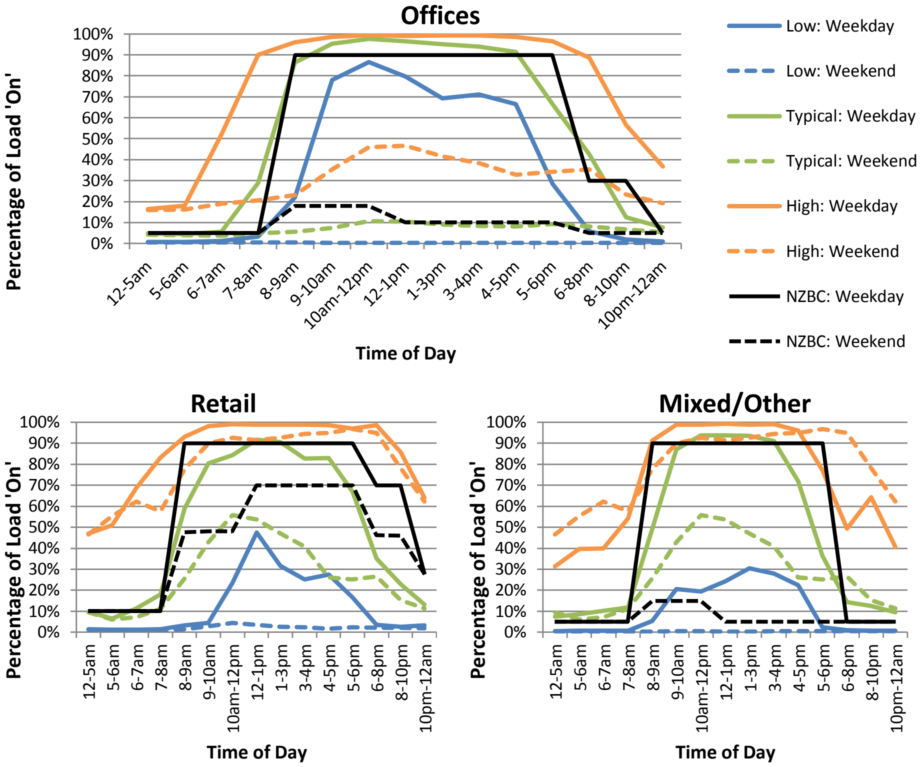

Figure 3 - Typical and Extreme Lighting Patterns' of use for different commercial building types

Note: The Retail pattern of use was an average between the NZS 4243 retail and restaurant patterns. The weekend patterns were an average of the NZS 4243 Saturday and Sunday patterns of use.

Equipment Power Density (EPD)

Figure 4 displays the typical, high and low EPDs' for the average commercial building (White), Offices (light grey), Retail (dark grey), and Mixed/Other commercial use types (black). Mixed/Other commercial use types have the lowest typical EPD with 5W/m^2. Offices were the second lowest equipment focused use type with a typical EPD of 8W/m^2. Retail has the highest typical EPD of 15W/m^2. This suggests that Retail buildings are the highest equipment energy intensive building type. This finding makes sense as Retail buildings contain premises which are often used for food sales that include refrigeration and cooking. Retail also has a significantly larger high scenario EPD than the other building types, with an EPD of 58W/m^2. The typical EPD of Offices was similar to the NZS 4243 assumption of 8W/m^2. However, the other two building types typical EPD's were well above the NZS 4243 assumed EPDs (refer to Table 1 for NZS 4243 assumptions). This highlights the difference between the theoretical EPD and the real buildings EPD. The impact this would have on energy models would be large considering the amount of internal heat gains that would not be modeled using the NZS 4243 assumptions

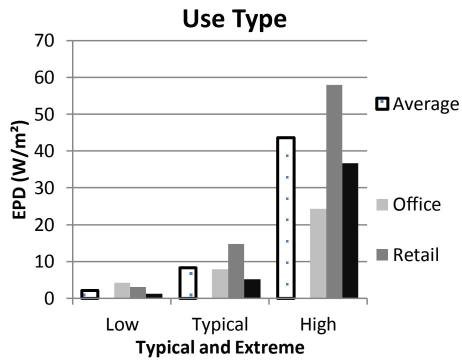

Figure 4 – Typical, High and Low EPDs' for different commercial building types

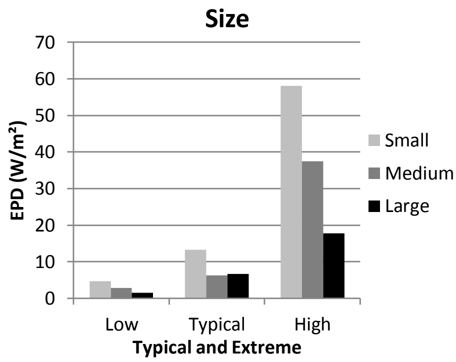

Figure 5 – Typical, High and Low EPDs' for different sized commercial buildings

Figure 5 presents the typical, high and low EPDs' for Small buildings (light grey), Medium sized buildings (dark grey), and Large buildings (black) to assess the impact of building size on the installed EPD. Small sized buildings were the most equipment focused with a typical EPD of 13W/m^2. Medium and Large buildings have a substantially lower density of equipment installed with a typical EPD of 6W/m^2 and 7W/m^2 respectively. This trend follows in the high EPD scenario. However, small buildings have a much larger EPD (59W/m^2) when compared to both Medium and Large sized buildings, which have high EPDs of 38W/m^2, and 18W/m^2 respectively. This suggests that Small and Medium sized buildings are dominated by Retail loads while larger buildings are dominated by Office loads.

Equipment operation patterns

Figure 6 displays the typical (green), high (orange), low (blue) and NZS 4243 (Black) patterns of equipment use for Offices, Retail and Mixed/Other commercial use types. Offices have the least energy intensive patterns of use as seen by the amount of load that was left 'on' during unoccupied periods. This was shown by the weekend and night load percentages. Also, Offices have the biggest difference between night and daytime load patterns. This was highlighted by the larger peaks in equipment energy use of approximately 30-50 percent during daytime hours. Office weekday patterns of use have a consistent peak of use whereas their weekend schedules were more or less consistently flat throughout the weekend. This was shown by the weekend day loads not being significantly different to the overnight use. Retail buildings have the most energy intensive patterns of use. This was highlighted by the larger percentage of equipment 'on' and for longer periods of time. This was further reinforced by the fact that Retail buildings have higher EPD's (refer to section 4.3). Furthermore, the greater the energy intensity of a Retail premise, the closer the weekend pattern of use was to the weekday pattern. The daytime pattern of use peak in Retail premises (20-30 percent more equipment 'on') was not as large when compared to Offices (30-50 precent more equipment 'On'). This could be due to the large refrigeration loads running consistently throughout the whole day, while only a small number of appliances were turned 'on' during occupied hours. Unlike Office and Retail, the weekend patterns of use were higher than the weekday patterns of use in Mixed/Other commercial use buildings. The weekday and weekend on Mixed/Other use buildings also have a definite daytime peak of equipment use. Consistent with Retail, the daytime peaks were not as large as for Offices; however, there was a bigger daytime peak during weekdays when compared to the weekends. Also, the weekend loads were more consistently 'on' and the weekend night loads were greater than the weekday night loads. This could be due to premises with restaurant and other food type having longer weekend hours.

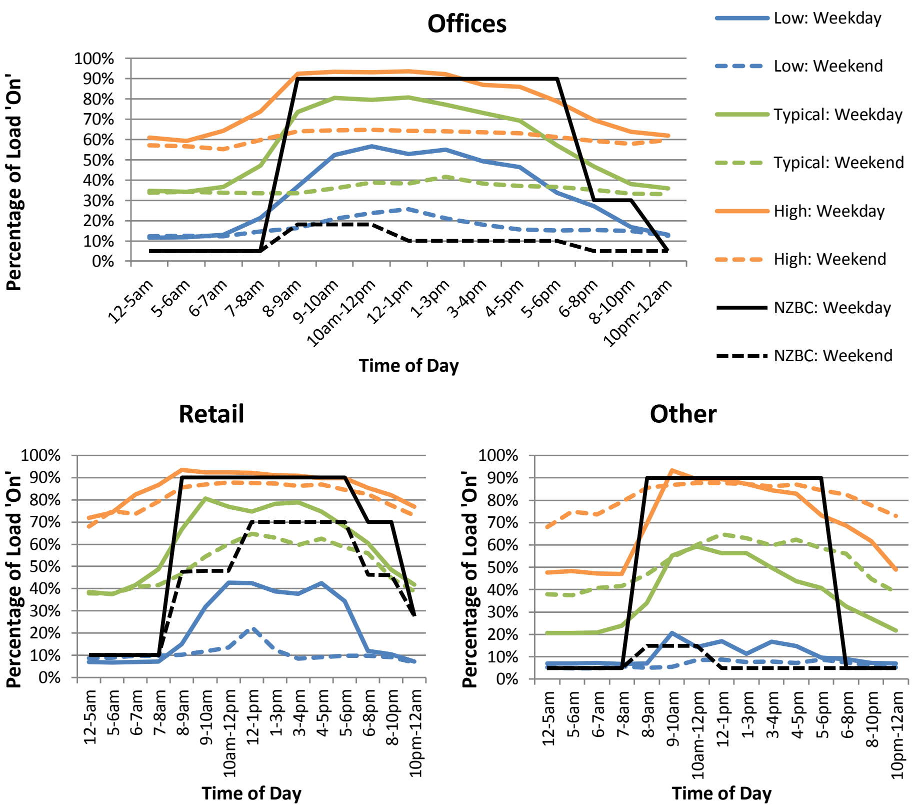

Figure 6 - Typical and extreme equipment patterns' of use for different commercial building types

Note: The Retail pattern of use was an average between the NZS 4243 retail and restaurant patterns. The weekend patterns were an average of the NZS 4243 Saturday and Sunday patterns of use.

The results indicate that the common perception of equipment being left 'on' during unoccupied hours is true. Half of the installed equipment load in Offices was left on overnight. Over a yearly period this equates to a large sum of energy that is essentially wasted. Coupled with this being typical across the commercial building stock, it would seem there is large potential for energy savings if equipment is turned off over night.

The NZS 4243 patterns of use assume that 10-20 percent more equipment is turned 'on' during daytime hours in Office and Retail buildings, and 10-30 percent more in Mixed/Other buildings. The NZS 4243 patterns of use sit between the Typical and High scenarios for all three building types during daytime hours and around the Low scenario during night hours. Therefore, if the NZS 4243 assumptions are used in the model, they would overestimate the amount of equipment turned 'on' during daytime and underestimate equipment turned 'on' during night hours in a typical building.

Hot Water Power Density (HWPD)

Figure 7 displays the typical, high and low HWPDs' for average commercial buildings (White), Offices (light grey), Retail (dark grey), and Mixed/Other commercial use types (black). Retail buildings have the largest HWPD with 7W/m^2 for a typical building and 24W/m^2 for high use buildings. This was most likely due to the food use types associated with Retail using larger amounts

of hot water compared to Offices and Mixed/Other commercial use types. Office and Mixed/Other use type HWPD's were below the average for commercial buildings with $3W/m^2$ and $2W/m^2$ respectively. The high scenario HWPDs for Office and Mixed/Other building types were significantly lower than the Retail HWPD.

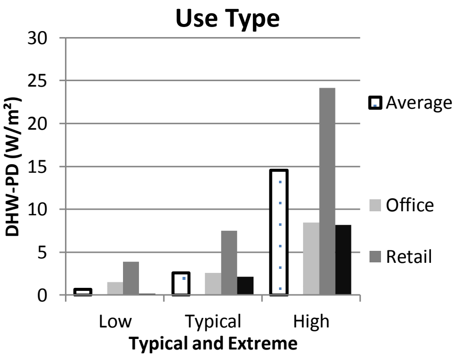

Figure 7 – Typical, High and Low HW-PDs' for different commercial building types

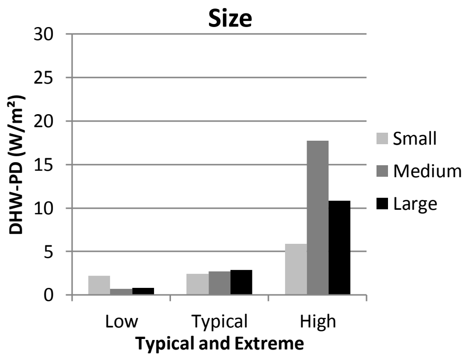

Figure 8 – Typical, High and Low HWPDs' for different sized commercial buildings

Figure 8 presents the typical, high and low HWPDs' for Small buildings (light grey), Medium sized buildings (dark grey), and Large buildings (black) to assess if size has an impact on the installed HW-PD. The typical HWPD was relatively similar for each of the three building size groups. However, the 'high' scenario indicates that Medium–to-Large sized buildings were more hot water orientated, which could be attributed to larger buildings having more occupants to service.

4.6 Hot Water operation patterns

Figure 9 displays the typical (green), high (orange) and low (blue) patterns of hot water use for Offices, Retail and Mixed/Other commercial use types. Office hot water energy use was very different between weekday and weekend, but also from nighttime to daytime use. Office hot water use was much lower overnight, by approximately 30-40 percent, as well as during the weekend with a 20-40 percent smaller daytime peak of hot water energy usage. Retail hot water energy use patterns have consistent trends across both weekdays and weekends. The intensity of use between weekdays and weekends also does not change considerably (less than 10-20 percent). Mixed/Other commercial use types consume more hot water energy in the weekends than during weekdays. This was consistent with the equipment patterns of use for Mixed/Other use building types.

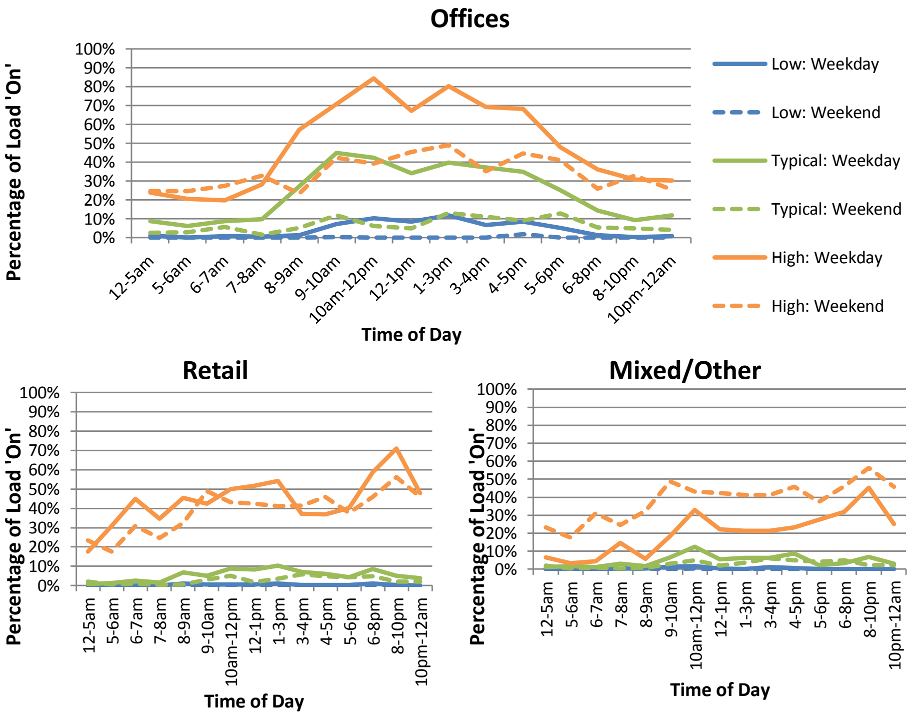

Figure 9 - Typical and extreme DHW patterns' of use for different commercial building types

CONCLUSION

This paper presents the typical, high and low building load densities and their operation patterns for commercial buildings in New Zealand. It fills the gap for the shortfall in information available for commercial building designers and environmental engineers. The shortfall relates to the lack of information regarding building loads found in real commercial buildings. Additionally, this paper compares the building loads found in real commercial buildings to the loads regulated in the NZS 4243 and the assumptions used in the modelling method for comparing energy use to prove the building code has been met.

The results established in this paper indicate that the current NZS 4243 values for power densities and associated schedules are not representative of existing building design in New Zealand. It has been found that the NZS 4243 values for the LPD are indicative of the typical LPDs found in existing buildings. It suggests that typical commercial buildings are designed to just meet the code and not to be any more energy efficient than they need to be. The Retail and Mixed/Other lighting patterns of use overestimate the amount of weekday lighting turned ‘on’. The EPDs found in real buildings were significantly higher for Retail and Mixed/Other commercial use type buildings than the assumptions made in the NZS 4243 modelling method. This results in an underestimation of equipment energy use and internal heat gains if the NZS 4243 values were used. If concerned about assumptions affecting the performance of the building design, an energy modeller could double the power densities or reduce them by a third. By doing so, it roughly estimates the extreme lighting and equipment scenarios which occur across the commercial building stock.

Additionally, the common perception that equipment is left 'on' during unoccupied hours is true. Half of the installed equipment load in Offices was left 'on' overnight. Over a yearly period this equates to a large sum of energy that is essentially wasted. This combined with the typical values across the commercial building stock indicates that there is large potential for energy savings if equipment is turned off overnight in Offices.

FUTURE WORK

This paper was originally intended to present prototypical model details which were founded on the real building performance established by the BEES studies. Therefore, future work is required to update the BEES template models (BRANZ Ltd, 2013b) to include typical building load information. In addition, a more detailed breakdown into end-uses such as refrigeration and cooking could be undertaken as well as a breakdown of what typical individual appliances consume such as computers, laptops and printers.

ACKNOWLEDGMENTS

The authors would like to acknowledge the BEES team members and BEES project funders who enabled the analysis of the load and patterns of use data.

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ENERGY - PLUS DOWNTOWN

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ABSTRACT

The climate crisis will be the main driver of social pressure in the next twenty years, and the production of food is the biggest single component of CO_2 emissions (today already one billion of seven billion people are malnourished).
In New Zealand the climatic condition, food production and the residential density are extremely favourable which will therefore represent a perfect case study in which to test new sustainable urban strategies.
In view of increasing population to at-least two billion by 2050, it is essential to safeguard the availability of soil for sustainable food production.
Increasing the housing density in already urbanized areas and making them energy self-sufficient is an absolute need in this hour.
One of the strategies that can guarantee results, in short term, is retrofitting of the downtown buildings' fabric through "Energy-Plus" interventions, thus transforming urban districts into power generators.
The present study provides possible solutions and applications of this approach in Auckland City Central through sampling of some districts, in order to analyse results for power generation (energy- plus), and overall benefits of comfort, reduction of Heat Island Effect and seismic response of buildings.

KEYWORDS AND KEY-TERMS:

Energy-Plus; Building Fabric; Integrated Double Envelope; Solar Gallery; Hydroponic Plant cultivation Media

INTRODUCTION: REASON FOR TRANSFORMING DOWNTOWN BUILDINGS' FABRICS

Professionals and scientists around the world are increasingly apprehensive since the 1970's when it was established that the consistently increasing concentration of green house gases would lead to climatic change destabilising the planet's natural conditions as we know them. Global warming is the effect caused due to continuous warming of the Earth's atmosphere causing a consistent rise of average temperature resulting in grave changes in the climate system (Refer Weart, 2008). Data from U.S. Energy Information Administration (Refer www.eia.gov) and other climate observatories around the world have revealed that burning of fossil fuel at the current rate which is right now plentiful and supposedly cheap, is enough to push the planet to 450 ppm (parts per million) of CO_2 in the atmosphere.[1] Attaining this limit would trigger a chain of potentially irreversible events of climate change, glacial melting and rise in sea level (Refer Inter- governmental Panel on Climate Change- I.P.C.C by U.N.).
Since the 1990's the Earth's atmosphere has experienced an increase of average global temperature by 0.7°C. By 2050 a further rise of 1°C and an increase of 2°C by 2100 (from 1990) is expected (refer- mfe.gov.nz). In another record by Al Gore (2013, pg 294) in his book 'The Future', it is mentioned, "*In 2012, new World Bank President Jim Yong Kim released a study showing temperatures will likely rise by 4 degrees C (7.2 degrees F), without bolder steps to reduce CO_2 and that there is no certainty that adaptation to a 4degree world is possible*." As is obvious, the future awaits us with warmer and more uncomfortable conditions for life habitation.
Higher temperatures and a warmer atmosphere would lead to melting ice caps and increase of average sea levels resulting in two other disruptive phenomena, natural stringency and reduction of soil area to build on. Future predictions by experts reveal a global sea level rise from 18 to 59 cm (Refer National Geographic) which would lead to chaos and destruction, besides putting out a then estimated population of nine billion

[1] Scientists are forewarning that at approx. 450 ppm CO_2 in the atmosphere, will trigger potentially irreversible glacial melt and sea level rise "out of humanity's control". We are currently at 398 ppm (february, 2013- refer www.co2now.org), and are increasing atmospheric concentrations of CO_2 at an unexpected rate.

people to run into acute shortage of habitable land (Foley, Ramankutty et al, 2011). Also, the extent and extremity of catastrophic natural events would be a devastating state of affairs (www.unfccc.int).
Clearly as discussed, at this rate we today stand in grave danger to prevent an observable fact which is a threat to the existence of life and Earth. Before looking at the solutions that can impede further deterioration of the situation, it is important to speculate on what has caused global warming.
The primary reason for global warming is release of high concentrations of Green House Gases namely Carbon dioxide (besides Nitrous oxide, Chloro Fluoro Carbons, etc) resulting in heat being trapped which roots the occurrence of the Green House Effect (Refer I.PC.C.). Further on, there are three crucial causes of increase of Carbon dioxide levels:

- Deforestation: cutting down of dense forest areas for using timber as fuel, in construction or in industries (such as paper manufacturing) or for continuing them as plantations that release lower oxygen levels compared to forest cover.
- Food Production: Foley and his co-authors (2011) while writing 'Solutions for a Cultivated Planet' have highlighted that high levels of emissions are also due to an elongated chain of post harvest processing and transportation of food resources.
- Burning of Non- renewable fuel: releasing harmful, toxic and green house gases by burning coal and petroleum to generate electricity or as transport fuel. In New Zealand, it has been documented that of the 67000 BTU energy generated per annum, 35- 40% is utilised by buildings (refer- mfe.gov.nz).

  Elaborating that, commercial buildings spend up to 60% energy in trying to maintain optimum indoor habitable temperatures (refer- mfe.gov.nz). In a publication by the International Energy Agency (I.E.A., 2013, pg. 117), the writers mention that "*Building envelopes comprise of a range of (read: envelope) elements, with roofs, walls, windows, foundations and air leakage being the primary elements that affect building heating, cooling and ventilation loads. With over a third of global energy used to make buildings comfortable for occupants, advanced building envelopes will be essential to reduce energy consumption*".

It is thus evident that the Urban building sector in New Zealand and elsewhere, is consuming high levels of energy, that eventually results in Carbon emissions and Global Warming, by mechanically trying to heat or cool the building.
The solution is straightforward; to have better designed building fabrics, that are able to generate energy as well as allow the building to consume lesser electrical energy and limit the CO_2 emissions by exhausting lesser non-renewable and polluting resources.
This research aims to identify the energy generation potential of the Auckland CBD. The strategies examined mainly concern retrofitting of the existing high- rises and the open parking lots within the highest dense district of the city. High-rise buildings, on average characterized by low performing envelopes, and heat islands like the frequent large parking areas, can instead contribute to a better New Zealand through a new strategic design for energy generation, improving outdoor and indoor comfort and by introducing to cultivate local food produce on current urban unproductive surfaces. Giving the buildings a second skin would enable them to perform consistently both as a passive and an active device. Where appropriate, the external skin can contribute agriculturally. Power plants and green houses can be located in the open parking spaces. This would considerably reduce dioxide emissions by lowering consumption of non-renewable, polluting natural resources, increasing local food production, and the energy generation from renewable sources. At the same time the strategy ensures high standards of comfort both inside and outside the buildings. The preceding discussion demonstrates the strong and influential relation between designing an energy- plus building fabric and the global warming phenomenon.

General Review of Green Building Rating systems on Energy performance of the Building Fabric

In the last 2 decades various agencies and councils have emerged to legitimise and audit- evaluate building designs to categorise them as 'Green or Sustainable' designs. Author Lemieux in 2004 publication states that "*the building envelope accounts for up to 80% of litigation in the construction process, it is therefore, necessary in the present times for Green Building Councils to develop guidelines that shall help the building industry design innovative and sustainable exterior envelopes*". It is hence necessary to review the significance allotted to energy efficient design of the building fabric by various green building rating systems.
Following is a review of a research conducted on this topic by a research student at the University of Auckland (Khanna, 2014, pg 47-50):

- LEED allots up to 39% of its credits' weightage towards designing a sustainable building envelope. Also, almost 8% of the total credits are dedicated towards an energy-plus building fabric design.
- BREEAM allows 55% of total credits to impact a sustainable fabric design. On the other hand, allows 14% of total credits to direct the design of the building fabric to be energy efficient.
- NZGBC the local New Zealand green rating system allows 48% of total credits to influence the design of building fabric as sustainable and 14.5% credits to direct the design to be energy efficient.
- The Living Building Challenge or LBC does not have a credit or point rating system. However, 2 of its 20 petals' intents strictly impose the building fabric to contribute to 'net- zero' energy objective of the site. This can involve the building fabric to generate electricity for site use. This is the only system that directly emphasises the need for urban agriculture, that in an urban context like the Auckland downtown can only be practiced on building envelope due to shortage of ground soil area.

These percentages highlight the significance devoted by some of the popular green building rating systems and that they can without doubt assist the architects and designers to accomplish a building fabric design that is energy efficient and contributes to the 'plus' factor.

ENERGY-PLUS SOLUTION 1: INTEGRATED DOUBLE ENVELOPE SYSTEM

Authors Harrison and Boake (2003) in their book Techtonics of the Environmental Skin define a double Envelope as *“essentially a pair of glass “skins” separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound. Sun-shading devices are often located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes”.* Hence, the following definite characteristics of a Double Envelope System are gathered: an interior skin layer, an exterior skin layer (in this case an energy generating and conserving facade system), a cavity of appropriate dimensions between the two skins, openable panels strategically placed on both skins to allow appropriate ventilation as per requirement and climate, detailed integrated ventilation system to naturally or mechanically control pressure zones and induce wind currents.

As per current requirements, it is evident that the exterior skin of the integrated envelope must be highly efficient in character. To result in an energy- plus solution, it is necessary for the exterior skin to be equipped with energy generating elements like photovoltaic panels and comprehensive equipment like sensors and automatic control systems that operate the sustainable and an almost intelligent facade system in an efficient manner.

Classification of Double Envelope Systems

Double envelopes are classified under many criteria. The differences between each type under every criteria is significant to understand in order to implement at the design level.

Criteria A: On the basis of type of ventilation method:

1. Natural Ventilation: this relies on stack effect and pressure differences for air movement. E.g. The Building Research Establishment Building in Garston, U.K which has smaller shaded fenestrations creating pressure differences and wind movements. Internal vertical tunnels open on the top of the envelope as visible functional elements.
2. Mechanical Ventilation: implementing mechanical systems to enable exchange of air. E.g. The G.S.W. Office block by Sauerbruch Hutton Architects, in Berlin.
3. Hybrid Ventilation: or mixed-mode is a combination of natural and mechanical ventilation methods. This type requires a complex, centralized environmental management system that switches the façade’s components from natural mode to mechanical mode depending on climate and user need.. E.g. Minerva Tower Building, London.

Criteria B: On the basis of mode of ventilation (Refer Barkumme, 2007):

1. Outdoor Air Curtain
2. Indoor Air Curtain
3. Air supply
4. Air exhaust
5. Buffer zone

Energy Generating- Examples of Advanced Integrated Double Building Envelopes

- Photovoltaic cell exterior: to harvest Solar energy
  Panels can be used on roofs and or mounted as curtain glass walls. e.g. GENyO, Center for Genomic and Oncology Research, Granada, Spain has a Photovoltaic second skin. The facade is responsible for generating 31,837 KWh/ yr of energy. This prevents 21.33 ton of CO_2 from being emitted into the atmosphere (Refer: www.onyxsolar.com).
- Wind energy exterior
  Wind turbines are used to harvest wind energy. High rise buildings in coastal areas are appropriate for placing wind turbines that can catch wind at the correct speed. A famous example of such a building is the Bahrain World Trade Centre by Atkins Architects which is able to generate 11% to 15% of its total energy requirement. However, the current technology has been able to provide for a finer solution. The designers are attempting to integrate smaller wind turbines with the exterior of an aero- dynamically shaped building. The shape and turns of the exterior skin channel and amplify the flow of the winds towards the turbines. The Taiwan Tower by Decode Urbanism Architects is one of the first projects to be designed on this concept, however, it is yet to see the light of day.
- Combined Systems
  Multiple combinations of two or more systems can be implemented so as to create a system that suits the building design as per location and climate. The possibilities and types of these combinations are many, although this paper shall limit to describing only the following:

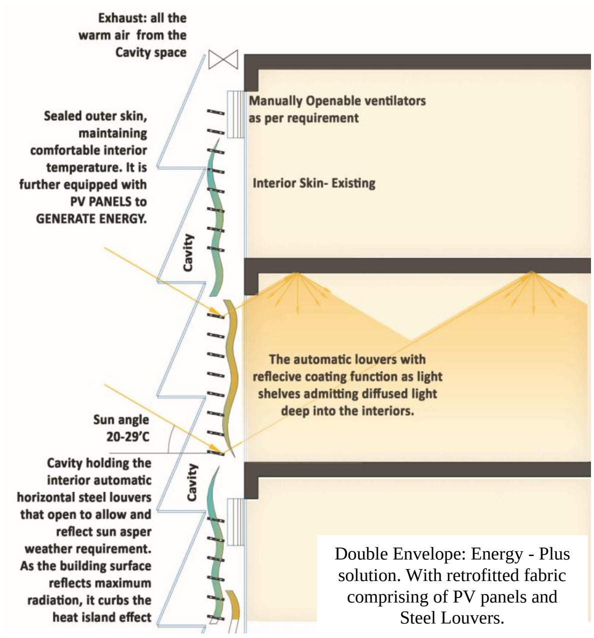
a) Bio- mimetic and Dynamic skin system: the skin structure is mostly dependant on intelligence based dynamic systems that responds to climatic variations. Example is the Abu Dhabi Investment Council Headquarters Tower.

b) Bio- mimetic and Phase changing materials: in a recent advent labelled 'Metal that Breathes', biologist turned architect Doris Kim Sung unveiled her research on thermobimetals, a smart material made of thin metals that change their shape with change in temperature.

Retrofitting and Designing Double Layered Building Fabrics for Energy-Plus Solutions

For testing purposes, models were generated similar to the building fabric of popular downtown building, Fay Richwhite, on Queens Street in Auckland, that has a typical glazed facade. The fully glazed building was implemented with a possible retrofitting strategy by adding an exterior layer to the existing envelope skin. The result of implementing the strategy can be noted by the phenomenal display of energy efficiency of the buildings. The double layered fabric demonstrates the following positive results:

- The basic requirement of energy is substantially decreased due to the implementation of an integrated double skin system. The intermediate buffer works as an effective insulation in winters and a pressurized air channel allowing air to flow at high speeds due to strategic location of fenestrations in summers.
- On implementing energy generating PV panels on the sun facing building facades, the building is able to produce sufficient energy to support its own, now decreased, requirement, and in some cases, be able to feed back surplus to the city lines. Strategically oriented PV panels in

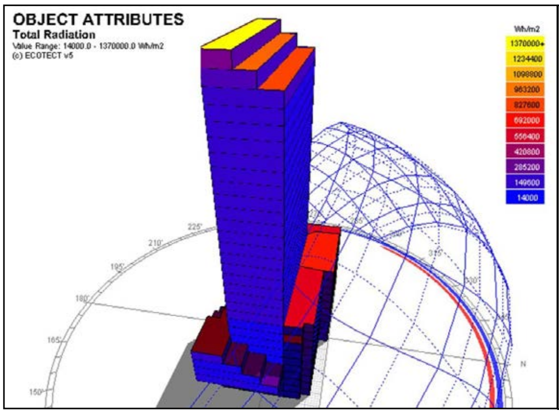


Double Envelope: Energy - Plus solution. With retrofitted fabric comprising of PV panels and Steel Louvers.

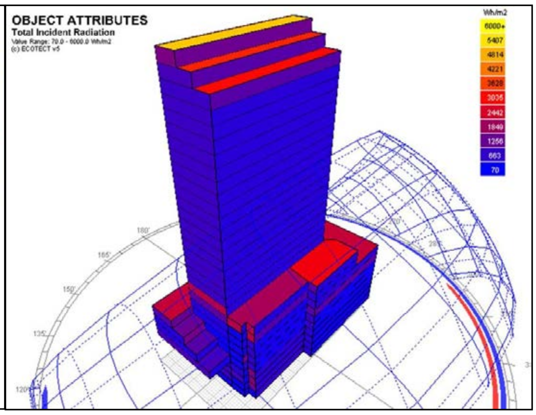
Auckland climate can generate energy of up-to 100-125 kwh/ m^2 per annum (Byrd, 2013, pg 92). A conventional 30 floor building in Auckland downtown, if equipped with appropriately oriented PV systems, can generate an average of 600Mwh/ per annum of electricity over the effective surface area of 5840 sq.m.(as tested on the simulated model's south and part east- west facades only). This is more than the general energy requirements of a commercial building of this scale when retrofitted with a double fabric. Thus, the retrofitted downtown building holds the potential to generate sur-PLUS ENERGY for the city.

- Lastly, around the world, no city of any country is equipped with buildings that will survive through the expected climate change due to global warming. Keeping in mind the future, it is possible for Auckland to integrate its buildings with systems that can counteract the effect of soaring temperatures that would lead to a surge in energy demand throughout urban metropolitan centres across the globe. An integrated double envelope is a solution, as it is observed that with rise in temperatures due to climate change, the retrofitted building would perform even better and more efficiently. Adding a second energy generating skin to existing building facades is not only beneficial for reducing carbon emissions at present, but is a long term effective solution with due course of time and climate change.

The proposed model was tested on Autodesk Ecotect software to achieve the energy requirements of the building before and after the implementation of the double envelope strategy. A third model was also tested under presumed weather conditions that would prevail in Auckland 100 years from now as per the predicted climate change due to global warming. Following are the results of the simulations:



Total radiation absorption by EXISTING BUILDING FABRIC. note the range is between 14 to 1370 kwh/m^2. Derived from: Autodesk Ecotect Analysis Software

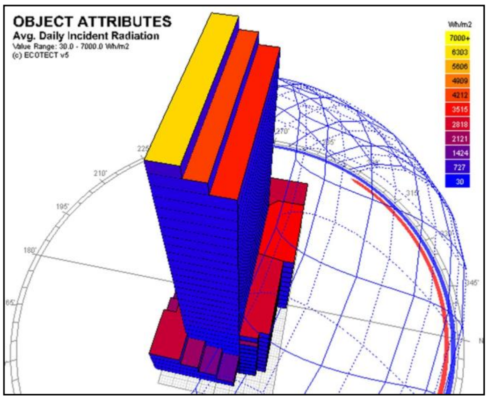


Total radiation absorption by the NEW DOUBLE ENVELOPE OF THE BUILDING (2114). note the range is between 0.03 to 7 kwh/m^2. Derived from: Autodesk Ecotect

Note that with the implementation of this strategy the radiation absorption of the building fabric is significantly decreased. Based on this, the software also calculated the figures for energy required to maintain the internal temperature equilibrium. This also is significantly decreased as the energy required to cool or heat the building mechanically is very low.

Also, as was discussed, introduction of an integrated PV system on the exterior skin of the double envelope would lead to an Energy-plus solution, as enough energy would be generated in order to suffice the retrofitted building's requirement and return the surplus to city lines.

Surface area of PV paneled facade (of 30 floor test model) = 5840 sq.m.
Electricity generated by 1sq.m. of PV panel= 100-125kwh/annum
Total Energy/ annum=
5840x(100 or 125)= 60,000kwh or 600Mwh/annum



Total radiation absorption by the NEW DOUBLE ENVELOPE OF THE BUILDING (2014). note the range is between 0.07 to 6 kwh/m^2. Derived from: Autodesk Ecotect

	Total radiation absorption through the facades (kwh/m²)	Heat gain and loss percentage due to composition of the envelope	Annual consumption of energy (kwh)	Annual consumption of energy per unit area (kwh/m²)
Existing single glazed model	14-1370	84.3%	110434.6	498.6
Integrated second skin 2014	0.07-6	68.3%	630848.7	284.8
Integrated second skin 2114	0.03-7	59.9%	600881.3	271.2

(all data and calculated values have been tabulated as per the analysis of the model building carried out on Autodesk Ecotect Software)

ENERGY-PLUS SOLUTION 2: INTEGRATED PHOTOVOLTAIC SOLAR GALLERIES

Power plant green-houses

The energetic green house is a sustainable and temporary architecture solution for open spaces e.g. surface parking lots in Auckland CBD for areas in the range of 750 sq.m. (e.g. 50x15 sq.m. open spaces). It combines the advantages gained from the power generation through systems based on renewable energy such as solar installations with the liabilities of the construction, creating a system that interacts with the surrounding responding to specific site characteristics such as the direction and intensity of sun exposure and wind velocities.
The idea of the project is based on the significant relationship between architectural form and energy efficiency, the two aspects complement each other and define the essential combination for buildings of the future. The intriguing geometry and specific technological choices that characterize the design are derived from an intense evaluation process following a precise hierarchical analyzing method:

- The reduction of energy consumption through modeling
- The optimization of energy generation and plating system
- The production of energy from renewable sources

The goal of the research is to create an installation that generates an optimal microclimate for performance of various activities, including that of food production. The system works within the buffer space in relationship with climatic context and is controlled by the shape and planting components. The materials used for construction are 100% recyclable.
The project also aims to ensure social sustainability, setting up the structure as a multi-functional element. The particular form of the glazed skin is derived from studying the site and environmental features (sun orientation and prevailing winds) for which the form acquires a sculptural value. As each site is different, so is every proposed form, individualizing each building from another and adding sculptural aesthetics to the overall district.
The project looks to contribute towards economic sustainability, beside the energy generation. The standardization of the elements that make up the glass structure allows ease of production and speed in the implementation. This construction system can be designed to be "scalable", thus as per requirements, it is possible to increase or reduce the extent of the structure. The remarkable performance and the ability to fully recycle the materials make the investment considerably profitable and sustainable overtime.

Energy analysis

The Energy analysis has been conducted on the basis of climate data (Auckland microclimate) i.e. the average solar radiation per annum, wind velocity, temperatures and air humidity. The technology is designed to wrap focuses on the realization of a skin that works as passive cooling machine whose special structure allows an aerodynamic shape. The complex form is obtained by successive refinements through software simulations taking climatic data for a specific geographic area as input that are returned with parametric-geometric responses. Hence it is possible to provide a specific form to the varying architectural and site contexts as per location. The particular climate data (Solar radiation mesh and wind flow diagrams) and analyzing parameters dictate the software simulation. Upon assessment, the resultant polygonal faceted form is obtained giving respect to each position and orientation. The result is able to maximize solar gains on the PV surface.

Optimization of the shape - Fluid dynamics analysis

The form is modeled as per the numerical simulations carried out by parametric softwares. The result is an aerodynamic structure that is able to accommodate the cold, and the prevailing winds by sliding them onto the outer surface, avoiding frontal impacts that would cause excessive cooling of the gallery. The pavilion is shaped and oriented to take advantage of the winds sliding above the glass skin so as to trigger a "natural draft" by creating pressure channels, when the covering panels, located in the right positions, are open.
A similar pressure difference draws exhaust air to the interiors, through special nozzles, thus ensuring flow of natural air into the interiors. The quality of comfort is particularly effective for the central areas of the tunnel, especially if it is made with a number of modules equal to or greater than 3, as in these areas there will be more static air, compared to the exterior 'open' head zones.
The fluid dynamic analysis of the shape (Computational Fluid Dynamic Analysis) takes place through the mesh settings of the analysis surfaces which are returned as vector values and chromatic behavior of the wind, with a precision of 0.001m, which is representative of the glass envelope.
The model is represented in uniform configuration, free of junctions or elements between panels that make up the surface as each junction would be appropriately sealed.
The analysis tests have been made through a horizontal plane (located at a height of 1.50 m from the floor) and a vertical plane (all sections have been verified at each vertical interval of 1.00 m). The wind was calculated with a speed of 10m/ second.
On conducting Vector analysis of multiple positions on planes, the output demonstrates how the various sections representing the fluid do not cause any turbulence or downdraft in correspondence to vertical surfaces. This demonstrates the effectiveness of the form in assisting movement of winds in the area of analysis, as they are designed as obstructive vertical surfaces but are inclined to behave aerodynamically effective.

Energy generation

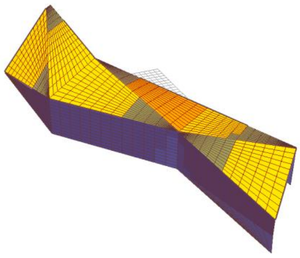
The structure of the gallery is made of glass portals created by the TVT building system (based on Glass Tensegrity Beams conceived and licensed by Prof. M. Froli, University of Pisa and Ing. G. Masiello). The building envelope is a power generator and is equipped with integrated photovoltaic cells on the exterior, containing a buffer space within, for the realization of passive environments. The geometric shape is designed to not just improve, but to maximize both energy generation and indoor comfort. The inclinations of the faces allow larger surfaces of PV elements to be oriented towards the sun-path, regardless of the climatic context and location of the gallery.
This enables the structure to obtain maximum yield for the duration of sun exposure on at least one portion of the PV surfaces, while the remaining part will integrate the generation with lesser yield. This results in total generation in each case, to be sufficient for the energy requirements of the gallery and also feeding the excess into the city grid.
The project includes the use of thin-film photovoltaics, the sticker type that will be placed in between glass panels. In the resultant tests, yellow areas indicate better PV performance, the orange shows the areas with openable glass modules for natural ventilation, and the grey facades, are areas with lower generation power (these lower generating areas have not been taken in to consideration in the test model calculation). The arrangement of photovoltaic cells is studied to develop an adequate solar shield, ensuring shading during the hottest hours of the summer season. Stratified glass is also included, partly alongside the cells obtaining opaque panels and in part by creating a sunscreen system by placing cells like a "chessboard" on panels, obtaining shading of 50% of the concerned areas. The "thin film" PV is monolithic, and does not require the assembly of multiple cells as in the case of crystalline silicon panels. The material appears to have a lower yield than the equivalent monocrystalline but, having considerably lower amount of semiconductor compared to standard cells, the generation cost will be lower as well.

Calculation

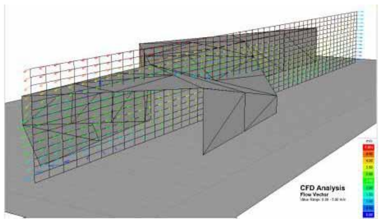
The parameters taken into consideration for the 750 sq.m. open site (dimensions 50x15 sq.m.) are:
- thin-film panels: Power between 77.5 and 87.5 Wp, generic shape of size=120x60cm, thickness=0.6cm;
- Of the total facade surface, area appropriately oriented for maximum solar gains: 50 % of 835sqm=415sqm;
- estimated power: (1,2x0,6) = 0.72 sqm generating 77.5 Wp;

(415x77,5) / 0.72 = 44'670, 14 Wp => <u>44.67 kWp (49.14 kWh / year);</u>

Net energy consumption for eventual use of the gallery (greenhouse) is lesser than the energy generated. Hence, the building will be able to provide to the surrounding buildings and infrastructure. The selected photovoltaic technology, with integration of the cells in the glass layer, will contribute to the reduction of maintenance costs, as the PV would remain protected by the outermost layer of glass. Maintenance will also be facilitated by the modular nature of the paneled construction system, which is possible to be dismantled and reassembled.



Perspective Artist Impression of the software simulated model



The model undergoing software simulations and extensive evaluation for energy generation performance

ENERGY-PLUS SOLUTION 3: INTEGRATING STRUCTURAL STABILISING STRATEGIES WITH URBAN AGRICULTURE AND SOLAR ENERGY GENERATION STRATEGIES

Egbelakin and colleagues (2011) found that the investment on traditional seismic retrofitting of the Earthquake Prone Buildings could not make contributions to promote the buildings' ability of competition in marketing because the investment could hardly be paid back. Seismic retrofitting is the protection of structure from an unpredictable earthquake in the uncertain future; as a result, the added retrofitting may reduce the existing building's ability to resist or reduce the damage due to seismic disasters, the system however, does not bring about benefits until buildings are under threat. In other words, the investment can be effective only when the seismic structure works against natural possibly destructive forces. This makes it seem like a dead investment for building owners as there is no surety of returns or benefits of this expense. To a large extent, building owners and investors consider seismic retrofitting of buildings economically and financially unviable. In the absence of a sound structural design, the threat of earthquake disasters continues to loom over majority of the high-rise structures in metropolitan downtown areas where urban density is high and impacts can be extreme. Approximately 92% of the Earthquake Prone Buildings’ owners never get any financial payback from their investment on seismic retro-fittings (Egbelakin et al., 2011).

In this scenario, a solution proposal can be made to externally retrofit building fabrics. By adding a second stronger exoskeleton over the existing fragile envelope, the building can be made structurally sound and safe. The system can also be experimented with to implemented as a Design- Plus solution.

Seismic strengthening by Fabric Retrofitting

Building fabric retrofitting for seismic strengthening optimizes the building's ventilation and heat distribution efficiency without reducing the quality of natural light in the interior spaces. It is a type of integrated double envelope system and hence acquires all characters that make the building fabric lessen the energy requirement of the building. Moreover, the seismic retrofitting envelope can be experimented with to achieve advanced innovative solutions, like developing hydroponic urban agriculture and food producing systems which can reach out to diminish the ever-growing carbon footprint of modern city settlements and reinstate the use of urban land for food production. The addition of a hydroponic food production system on seismic retrofitting envelops makes the resolution more comprehensive and meaningful as it is economically viable to invest on a structure that has the ability to gather returns overtime. This solution not only targets the issue of seismic stability but also eliminates the burden on infrastructure due to constantly increasing population, food shortage, CO_2 emissions, deteriorating urban environment and quality of life. It brings about a ballance between economic and environmental sustainability.

Design Proposal: Geometric cells

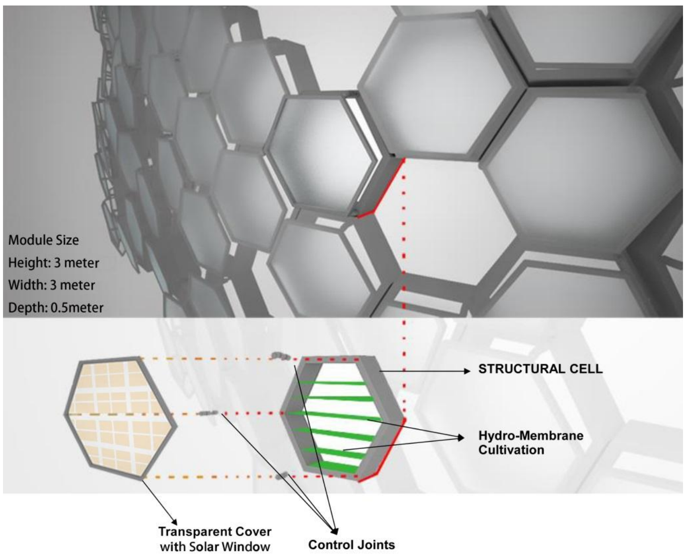
The selection of a seismic retrofitting design system must be decided after contemplation and analysis of structural soundness, stability, performance and cost. One such study has analysed a hexagonal grid exoskeleton to be rigid for the purpose of structural stability and cost effective at the same time. The study compared the hexagonal grid structure to regular triangles, squares and pentagonal grid structures to arrive at this result.

The retrospective seismic envelope structure that allows food cultivation, hence constitutes of numerous hexagonal cells. Each of the cells is a food production unit equipped with a Hydro-Membrane system as plant cultivating media. Every cell has a Transparent Cover that prevents growing plants from the impact of natural forces, such as storms and winds. Structural cell and Transparent Covers are connected by three Control Joints which achieve flexibility by adjusting both the size and direction of opening, and optimizing local ventilation.

Every hexagonal element works as an independent semi-open laboratory producing food. This not only means that there is no interruptions between cells, but also reflects on its feasibility. Structural frames separate cells by their varying cultivation purpose or species, which prevents unexpected disease to spread from plant to plant. The varying space requirements of different plants can be easily fulfilled by individual density setting, more importantly; the flexibility of plants' growth pattern and settlement dictates the best efficiency of space use. Scientific and reasonable use of spaces can always save resources. Vertical layout of cultivation system makes it possible that more food production can be achieved per unit of ground area.

Hydro-Membrane Cultivation Media

A new hydroponic system known as IMEC has been invented by Japanese scientist Dr. Yuichi Mori from Tokyo-based scientific firm Mebiol (PRLOG, 2011). The system uses 'Hydromembranes' as the primary medium to grow plants. 'Hydromembranes' are constituted by hydrogel-filled substances, which have high absorbing quality, and this material is generally used in diapers; further on, Hydrogel contains water and mineral solutions providing adequate nutrition for the proper growth of plants (Mebiol, 2013). This self-sufficient supplementary growth technique can be used on different surfaces, even concrete and ice, which is surprising. This is to say, the types of foundations that support this hydroponic system is not defined, and in turn, hydromembrane cultivation system will not affect foundations that it attaches on. Further, this technology makes it possible to grow food in extreme arid climates like the deserts where natural ground is not an appropriate plant growing media (Kraemer, S., 2012). Even though the sizes of the plants cultivated by IMEC is slightly smaller, their quality is significantly much higher than the traditional food produce, because the duration of plant growth is slow and elongated due to slow rate of nutrient absorption. The growing crop in turn synthesises higher levels of sugars and amino acids within, making IMEC tomatoes and cucumbers sweeter and more nutritious than the conventional produce (PRLOG, 2011).



Hydromembrane technique makes the advantages prominent in seismic retrofitting envelopes. They are extremely thin and light, IMEC technology minimizes the volume of soilless food cultivation equipment. The conventional hydroponics and aeroponics are usually functioning on a relatively big foundation which needs to provide space for plants' root system and nutrition flow that is delivered by a nutrition nozzle or contained by rooting mediums. It seems that this relatively large demand of space has become one of the higher reasons for drawbacks that hinder designers

to propose large-scale vertical food production building fabrics. The large volume limits the crop yield within the designed height of grid- cell structure and increases the cost of per unit crop yield. Also, the weight of plant growing systems and equipment usually challenge the designed structure and increasing structural complications. However, the Hydro-Membrane can be easily attached on almost all kinds of modern construction materials, which in turn, do not influence the structural system and building fabric during or after the cultivation process. As a consequence, the light, thin and harmless characteristics of IMEC make the system qualify as flexible and feasible.

Resultant Effect of Design Implementation

Take the tomato producing process as an example, the producing area in each cell of this envelope will be six times more than traditional soil-based food cultivation systems. In addition, if certain plants do not need much vertical space, such as lettuce (leafy plants), the cultivation area is almost ten times more than that of soil-based farming. It is important to note that this significant improvement is just achieved by a single structural cell of the entire building exoskeleton fabric. In the context of urban scale implementation, the structure comprises of a multiple grid forming the protective envelope along the downtown high-rise buildings or skyscrapers, the food produce shall be multiplied with every successive floor. For example, if a 30-meter-long, 30-meter-wide and 100-meter-high building is protected by a seismic retrofitting envelope which is 0.5 meters thick and has cells that are 3-meter-high, it can provide approximately 17820m^2 ([30/3x4x100/3]x13.5m^2) of cultivatable area by increasing only 60m^2 (0.5m^{2}x30x4) to the existing footprint area around the building. Simply put, higher the building is, more the food production will be.
The orientations and sizes of individual Transparent Covers' opening can be easily adjusted by regulating the positional relationships between Transparent Covers and Control Joints. This will not only protect both the cultivating plants in between external and internal envelopes and the buildings from the unexpected damage caused by extreme weather conditions, but also create a possibility to optimize buildings' ventilation system. Gales and rainstorms may negatively influence the growth of plants or damage the surfaces of buildings. In general, growing plants in envelopes functioning like green facades are capable of adjusting the building's temperature as per prevailing climate. This system has all the advantages of an integrated double envelope system, as it is one of the types, i.e. the energy requirements of the building are sufficiently reduced due to the climate responsive- sustainable design of the building fabric.
To enhance the efficiency of the building envelope, the exterior most surface of Transparent Covers can be equipped with Solar Windows---which are a new innovation of electricity-generating solar coating technology. The see-through-able material is made from natural polymers and constituted by ultra-small solar cells, which achieves its abilities to be dissolvable in liquid and sprayed on to glass, plastic and even paper (New Energy Technologies, 2014). Compared with traditional silicon wafers, it is more tensile and stronger and also much cheaper; compared with other solar coating technologies, it does not demand high-temperature or high-vacuum techniques during the process of production (New Energy Technologies, 2014). Additionally, it is highlighted by New Energy Technologies (2014) that ultra-small solar cells can generate electricity energy under not only natural lighting condition, but also artificial lighting condition, and its thickness is one tenth of the contemporary thin-film technologies, but the electricity generation efficiency under artificial lighting conditions is surprisingly ten times more than them. It seems that this extremely thin material makes its transparency considerably high. It is significantly notable that this system can generate electricity efficiently without sacrificing the volume of light on the other side of the material. As a consequence, the growth of plants in Structural Cells will be contained. Besides, the controllable angles of Transparent Covers will maximize the capacity and potential of Solar Window's energy generation by changing its orientation with the changing sun-path in the day. This provides for the ultimate energy efficient solution of implementing this design. The strategy targets five important sustainable issues:

- Makes the building structurally sound from prospective earthquake threats
- Increases healthy and fresh food produce for an urban setting
- Reduces overall carbon footprint of the urban settlement
- It aims to reduce carbon emissions due to a long chain of processing and transportation of food resources from rural to urban areas.
- Like a typical double skin envelope, manages to significantly reduce energy requirements of the building
- Lastly, implementing energy generating strategies on the outermost skin of the system would make the building design Energy-plus

CONCLUSION

The paper has been able to propose strategies that:

- reduce the net energy requirement of a high-rise building.
- help contain the carbon footprint of the ever- evolving dynamic downtown.
- provide agricultural aspects with-in the urban set up, decreasing carbon emissions that result from far-off rural agricultural set- ups.
- curb heat island phenomenon in developed urban zones with large coal tarred spaces and absorbing building surfaces, by designing green or energy generating surfaces and galleries around town.
- help the building attain structural efficiency in a high seismic zone
- effectively allow the building fabric to generate energy to suit its own requirement and at a scale that it is possible to feed back the city lines.

It is obvious from the calculative analysis of the three proposed strategies, that implementing them on the city district scale in Auckland would lead to an ENERGY-PLUS DOWNTOWN.

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INTEGRATING GREEN INFRASTRUCTURE INTO THE BUILT ENVIRONMENT

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ABSTRACT

While there is widespread recognition of the value of green infrastructure in providing recreational and attractive spaces and managing stormwater, the potential multiple and measured benefits of green infrastructure are less recognized. Findings from recent research into green infrastructure from around the world which identify the various quantifiable and non-quantifiable benefits from green infrastructure to both protect the environment and to improve and enhance human health will be presented. Quantifiable benefits include management of air pollution particularly in urban canyons, treatment of stormwater pollutants including sediment, VOCs and heavy metals, treatment of industrial and domestic waste water, carbon sequestration, temperature moderation, increased biodiversity, provision of food, soil stabilization and increased property value. Non-quantifiable benefits include benefits to human mental health and increased community values and cohesion. The applicability of those findings to Auckland will be discussed. The extent to which green infrastructure could be incorporated into existing or new buildings and infrastructure will also be addressed. Finally a framework for integrating and optimizing green infrastructure within a city will be presented, recognizing the need to address current barriers and incorporate green infrastructure into building and infrastructure stock.

KEYWORDS: Green infrastructure,

INTRODUCTION

Green infrastructure is becoming more integrated into urban and infrastructure planning. Past definitions have focused on integrated networks which conserve natural ecosystem values and functions, sustain air and water quality and contribute towards sustainable resource management (Benedict and McMahon, 2002, Williamson, 2003, Davies et al., 2006). Davies et al. (2006) identifies the five functional contexts for GI as sustainable resource management, biodiversity, recreation, landscape and regional development and promotion. The European Environment Agency (EEA) (2011) categorised green infrastructure according to the ecosystem services (clean air, water, food, energy, biodiversity, etc.) that are sought:

1. Habitat services (protection/restoration of biodiversity);
2. Regulating services, such as climate change mitigation and adaptation (lower impacts and costs due to impacts of climate change such as extreme weather events);
3. Provisioning services (including mitigation of human induced impacts of the built environment, such as water and waste water management); and
4. Cultural services (health and wellbeing, recreation, protection of landmarks, tourism, etc.).

The EEA vision of green infrastructure broadens its definition beyond that of integrated networks to 'natural and engineered ecological systems that integrate with the built environment to provide the widest possible range of ecological, community, and infrastructure services'. It is therefore critical to understand the quantifiable and non-quantifiable benefits that can be provided by various green infrastructure systems if they are to be integrated successfully into the built environment and perform the expected service function.

From a functional perspective, a green infrastructure structure must be designed for a specific, primary service – for example, a green roof is often designed to mitigate stormwater runoff. Such a structure may also improve building heat efficiency, biodiversity and air quality but multiple goals for a specific structure may compromise the efficiency in achieving the primary goal. Green infrastructure systems may contain multiple small systems (Table 1), each designed for a primary goal – mitigating stormwater, managing roadside runoff pollution, improving air quality, biodiversity or carbon capture or providing recreation or sporting facilities.

The objective of this paper is to present findings from recent research into green infrastructure from around the world which identify the various quantifiable and non-quantifiable benefits from green infrastructure to both protect the environment and to improve and enhance human health. In this global context, the definition of green infrastructure in the UK was found to be limited to the traditional concept of networked ecosystems, primarily an urban planning perspective. Research North America, however, has embraced the broader definition of green infrastructure which was used in this study. Thus much of the cost and quantifiable data comes from US research while the UK research focus lies much more in non-quantifiable benefits.

TYPES OF GREEN INFRASTRUCTURE

Green infrastructure includes medium and large scale systems which may incorporate multiple smaller systems to manage localised problems such as polluted runoff from roads. Small structures are best designed to perform specific functions. Almost all green infrastructure will offer additional benefits but such secondary functions may not be as optimal as a system designed specifically to meet that function.

Table 1 Major types of green infrastructure

Type	**Scale**	**Common main function(s)**
Reserves, protected areas	Large	Ecosystem, biodiversity protection Flood management Water reservoir/catchment Outdoor recreation Education/ scientific research Tourism Mitigation of climate change impacts Heritage protection
Waterbodies, wetlands, rivers, streams	Medium to large	Ecosystem, biodiversity protection Flood management Outdoor recreation Education/community cohesion
Urban forests, community parks, botanical parks	Medium to large	Ecosystem, biodiversity protection Outdoor recreation Outdoor sports Education/community cohesion Improve air quality Mitigate stormwater runoff quality and quantity Reduce noise
Conservation corridors	Medium to large	Improve ecosystems, biodiversity
Transportation corridors/ green alleys (porous pavement, street/ corridor plantings, bioswales,	Medium to large; multiple small systems	Improve air quality Mitigate stormwater runoff quality /quantity Reduce noise Improve biodiversity

rain gardens, green walls, community gardens)		Moderate traffic speed/ reduce accidents Moderate temperatures Improve outdoor spaces
Constructed wetlands	Small to medium	Reduce stormwater runoff Improve runoff water quality Removal of pollutants/ pathogens from industrial/domestic wastewater Flood control Erosion control Recreation Ecosystem biodiversity
Community gardens	Small	Manage stormwater runoff Provision of food Education/community cohesion
Green roofs	Small	Manage stormwater runoff Manage energy demand
Green walls	Small	Improve air quality Reduce stormwater runoff Reduce noise Reduce energy demand
Bioretention/rain gardens/ swales	Small	Reduce stormwater runoff Reduce pollution of waterways and groundwater
Dry/wet ponds	Small	Reduce stormwater runoff Improve runoff water quality
Building scale engineered aquatic system/Living machine	Small	Removal of pollutants/ pathogens from industrial/domestic wastewater Reduce stormwater runoff Improve runoff water quality

QUANTIFIABLE BENEFITS OF GREEN INFRASTRUCTURE

As with any infrastructure system, the efficiency and quantifiable benefits of a specific green infrastructure system depend on design, local context and conditions (climate, soil, rainfall etc.), vegetation and system maturity, construction and maintenance. Design and construction for local conditions are probably the major factors in achieving the performance goal of the system. Much of the research provides quantifiable benefits in terms of percent removal which provides little guidance as to the actual expected performance of a system. In addition, there has been little research on long term performance of green infrastructure systems so it is not clear if their function will deteriorate over time if they are properly maintained. For large scale green infrastructure systems, however, it may take time for the system to mature and therefore the system function may improve as plants mature and new species inhabit the site due to the increased system complexity.

Regardless, it is valuable to have some understanding of the potential performance of various green infrastructure systems. Table 2 provides details of the reported quantifiable benefits from various systems, primarily small scale. For transportation corridors, permeable pavement has been detailed; other small systems such as swales, tree and vegetation planting and even community gardens (particularly along railway right of ways) are common components of these systems.

Table 2. Reported quantified benefits from various systems.

System type/references	**Removal/reductions/ comments**	
Transportation Corridors		
Permeable pavement Boving et al. 2008	>90% metals (Cu, Pb, Zn, Cd) >27% nutrients (N,P)	*Percolation results* No bacteria/BOD Minimal detection of PAHs
Constructed Wetlands		
Mungasavalli and Viraraghavan 2006	*urban stormwater runoff* 80% faecal coliform 80% organic material/ suspended solids	50% heavy metals 60% nutrients
Haarstad et al. 2012	*wastewater* 30% -60% max. efficiency of 90% heavy metal removal aerobic conditions yielded effective hydrocarbon removal 50%-100% hydrophobic organic compounds	40%-99% of pesticides Removal of explosives, pharmaceuticals and personal care products comparable to conventional activated sludge wastewater treatment plants.
Reed beds Masi, 2005; Fontoulakis, 2009; Agudelo et al. 2010; Töre et al., 2012	effective for phthalates, alkylphenol ethoxylates, oestrogens, polycyclic aromatic hydrocarbons (PAHs), several types of pesticides	
Scholz and Lee 2005	review of various wetland systems and treating capabilities	
Community gardens	75% runoff	
Green roofs Köhler 1989	75% runoff	
Fassman-Beck et al. 2012	56% runoff	
Getter et al. 2009	C sequestration 73 - 276 g C/m^2 above ground Total 375 g C/m^2 168 g C/m^2 above ground plant biomass, 107 g C/m^2 below ground plant biomass, 100 g C/m^2 substrate carbon.	
Green walls/street trees Pugh et al. 2012	40% NO_2	60% PM_{10}
Street trees McPherson et al. 2006	*Per tree* 1100-8200 L rainwater 130-400kg C sequestered 0.18-0.5kg NO_x	0.1 – 0.3 kg SO_2 0.07-0.13 kg O_3 0.08-.016 kg PM10
Green walls Dinsdale et al. 2006	25% heating demand, Kingston, Canada	
Wong et al. 2003	74% cooling energy Singapore	
Schumann 2007	73% cooling energy; cooled building by 11.3°C Maryland, USA	

Table 2 (cont.). Reported quantified benefits from various systems.

Bioretention		
Vegetated swales EPA 1999	81% total suspended solids; 67% oxygen demanding substances 38% nitrate 9% total phosphorus	62% hydrocarbons 42% cadmium 51% copper 67% lead 71% zinc
Rain gardens Davies et al. 2006	95% copper 98% phosphorous	20% nitrate 50% total Kjeldhal nitrogen
US EPA 2012c Maryland	43%-97% copper 70%-95% lead 64%-95% zinc 65%-87% phosphorus 27% calcium	52-67% total Kjeldahl nitrogen (TKN) 92% ammonium (NH_4^+) 15%-16% nitrate (NO_3^-) 49% total nitrogen (TN)
grassed channels Schueler 1997	81% total suspended solids 29% total phosphorous 38% nitrate nitrogen	14% - 55% metals 50% bacteria
Herrera Environmental Consultants, 2006	64% total suspended sediment 18% total phosphorus 47% total zinc	poor bacteria (8%) poor hydrocarbons (10%)
Wet/dry ponds US EPA 2012a, b	limited protection	limited ecosystem services
Internal engineered aquatic systems/Living Machine US EPA 2001	*Effluent results* BOD5 <10mg/L TSS, total nitrogen	<5mg/L nitrate <1mg/L ammonium

Cost benefits

It is difficult to obtain accurate cost data for green infrastructure due to the complexities of such systems. Most data are cost estimates. Implementation of green infrastructure still entails policy, political, design and construction problems, in some cases resulting in costs significantly above the initial estimate. Bureaucratic issues such as a lack of understanding of green infrastructure benefits can result in significant delays in consents, required duplication of systems to avoid perceived risks and refusal to accept green infrastructure treated water as of good quality simply due to legal labelling. All such issues result in higher costs for construction and implementation of green infrastructure systems, particularly when such systems are being designed and constructed for the first time within a municipality.

Odefey et al. (2012) provided a good overview of the cost savings potentially associated with green infrastructure while the Center for Neighborhood Technology (2010) provides a guideline for calculating rainwater retention, pollution reduction, energy savings and carbon sequestration from various green infrastructure systems using US data and averages. Case studies cited by the latter study include

4 million m^3 stormwater runoff diverted from sewers, reductions of 1.37 million KWh in energy, 990 tonnes CO_2 and savings of US$108,000 per annum from installations of green infrastructure in Aurora, Illinois;
Savings of US$2.846.4 million for Philadelphia, Pennsylvania from implementation of a city wide 50% LID green infrastructure system;
Savings of US$100,000 per city block from installation of green infrastructure in Seattle, Washington.

This study also refers to research on the influence of green infrastructure on property values. Wachter (2004) and Wachter and Wong (2008) found an increase of 2-10% in value with street plantings. In King County, Washington, Ward et al. (2008) estimated that, for properties adjacent to LID green infrastructure, values were 3.5-5% higher. Stratus Consulting Inc. (2009) found values increased by 0-7% with an average of 3.5% but recognised that it was difficult to isolate the values provided by green infrastructure proximity.

NON-QUANTIFIABLE BENEFITS

There is wide-spread recognition of the non-quantifiable benefits (Table 3) of green infrastructure but showing how such benefits directly impact on communities is more difficult. While some of these benefits could be measured in economic terms, as with property values, it is difficult to isolate the value provided solely by green infrastructure.

Table 3 Non-quantifiable benefits of green infrastructure (modified from TCPA, 2008)

Economic value	Social value	Environmental value
High-quality environment to attract and retain a quality workforce. Boosts to the local economy. Links between town and country Increased resilience to natural disasters	Recreation, enjoyment and health benefits Community development and cohesion Provision of space for public art, concerts, etc. Non-motorised transport systems Exposure to nature and increased awareness of environmental issues. Education and training Visual screening of unsightly buildings or infrastructure Heritage preservation and cultural expression	Biodiversity protection/restoration Enhancement of habitat and species – preserving ecosystems Landscape restoration and the regeneration of degraded sites Protection of significant geological sites

There has been considerable work on health benefits of green infrastructure (Takano et al., 2002; de Vries et al. 2003; van Kemp et al., 2003; Nielsen and Hansen, 2007; Yang et al., 2008), particularly the removal of air pollutants. A recent study by White et al. (2013) found that ‘individuals have both lower mental distress and higher well-being when living in urban areas with more green space’. Many of the non-quantifiable benefits such as recreational activities, biodiversity protection, high quality environment and community development and cohesion are better offered with medium to large scale green infrastructure systems (reserves, wetlands, urban forests). However, as green infrastructure systems, both large and small, increase across a city, the city overall shifts to becoming a green space, thus the benefits spread across the city.

GREEN INFRASTRUCTURE IN AUCKLAND

Auckland already has a significant green infrastructure framework. The Auckland Plan (Auckland Council, 2012) points out that over 40,000 ha of Regional Parks lie within its boundaries, protecting biodiversity, natural and historic sites, providing recreational and tourism opportunities and delivering many of the benefits of green infrastructure in pollution prevention, resource management and improvement in human wellbeing. Regardless, the Plan reports that:

- air pollution from home heating and transportation contributes to approximately 730 premature deaths per year and 1.6 million lost working days;
- stormwater management has 'lowered water quality and ecological function within catchments and degraded coastal receiving environments';
- significant areas of Auckland are subject to soil erosion and degradation;
- flooding, storm surge and landslips are significant natural hazards for Auckland.

Of the five goals set out in the Plan, two directly relate to green infrastructure:

'Goal 2 Strongly commit to environment al action and green growth;

Goal 4 Radically improve the quality of urban living.'

Significant developments from the Auckland Plan include the Waterfront Plan, the City Centre Master Plan, the Unitary Plan and the Energy Resilience and Low Carbon Action Plan. The Waterfront Plan (Waterfront Auckland, 2012) particularly focuses on environmental and sustainability initiatives with the following objectives:

1. "Reduce greenhouse gas (GHG) emissions and develop a low carbon precinct;
2. Increase resiliency of the built and natural environment and of the community;
3. Design and develop the waterfront public land according to sustainable design principles;
4. Identify opportunities to restore and enhance environmental quality;
5. Develop a diverse business and residential community;
6. Manage travel demand and prioritise and promote sustainable transport; and
7. Create an authentic waterfront experience respecting cultural and heritage values."

The City Centre Master Plan also identifies three outcomes directly related to green infrastructure:

"Outcome 5: An exemplar of urban living - with a wide choice of high-quality residential options.

Outcome 7: A walkable and pedestrian-friendly city centre - well connected to its urban villages.

Outcome 8: An exceptional natural environment and leading environmental performer."

The recently approved Energy Resilience and Low Carbon Action Plan includes development of a green infrastructure plan for Auckland, the promotion of the benefits of sustainable design and best practice and integration of the principles of sustainable design into planning (Auckland Council, 2014).

Green Infrastructure within Auckland

There have been excellent moves to incorporate green infrastructure within Auckland – Auckland Waterfront incorporates rain gardens, green walls and is planning a local school garden; green walls have been incorporated into new building designs and into one of the largest systems in New Zealand along Federal St., the Twin Streams project has revitalised streams in Waitakere and reduced flooding and La Rosa stream daylighting has resulted in a wetland reserve available for education and recreation while increasing biodiversity. However, to achieve the goals of the Auckland Plan, a more robust approach is required, to clearly support the installation of green infrastructure and recognise the benefits to both the City and its taxpayers.

Auckland Council needs to better examine how they will manage infrastructure for the future, particularly new developments for both housing and infrastructure. A stormwater recycling system will result in significant savings for taxpayers if allowed to be properly developed without onerous restrictions and that has been clearly demonstrated by many such systems in the US. Setting a policy

on green infrastructure implementation will not only support the various plans but will also clearly define how CCOs and developers should integrate green infrastructure into planning.

New infrastructure, particularly along transportation corridors, already often includes swales and plantings. Including permeable pavement where practical (footpaths, parking lots). Allowing community gardens to be established along railway verges and unused Council areas will support and bring together local communities.

There are significant opportunities for stormwater management, rainwater capture and reuse and air quality improvement through incorporating green infrastructure into building design and construction. Green roofs can manage stormwater but capturing and recycling rainwater can enable roof gardens to produce food, improve air quality, reduce heat islanding, lower energy costs or provide a pleasant place for building inhabitants to relax. Green walls will require careful planning and management but can also reduce stormwater and improve air quality and reduce energy costs. An internal engineered aquatic system can be used to treat waste from one or more buildings, delivering water of high quality and reducing pressure on existing sewerage systems.

A Green Infrastructure Plan for Auckland

Developing a Green Infrastructure Plan for Auckland will require not only a strong commitment from the Council but also from council employees and support from industry, developers, architects, engineers, planners and local communities. To that end, any Plan will require specific objectives and outcomes aimed at the various audiences. Demonstration projects should also be developed and monitored, with the results available on line for education purposes. Collaborations with the business and local communities will be essential in the success of any such plan so it will be important to engage with both with the drafting of the plan.

Policy

The policy must be sufficiently robust to clearly establish the priority for developing green infrastructure across Auckland and ensure that it overcomes the current policy and procedural barriers that are inhibiting greater implementation of green infrastructure. It should also set out priority areas for action, identifying priority areas for developing green infrastructure systems including:

key stream/wetland/coastal areas,
poor income and degraded neighbourhoods,
areas at high risk of flooding or storm surge,
areas of poor air, surface and ground water quality,
transportation corridors,
new developments.

The policy should also require collaboration among and engagement with Council, businesses and local communities in identify and deciding priority areas. The policy should also include the development of a robust life cycle cost benefit assessment tool for green infrastructure specific to Auckland.

Local Area Plans

Once the priority areas are established, local area plans can be developed in collaboration with local communities and businesses. Such plans will provide the details of the various green infrastructure systems which will address local issues (as identified through the collaboration) and the timeframes for implementation of the various systems.

Incentives

Since incorporation of green infrastructure into buildings (both new build and renovations) and infrastructure will provide benefits to Auckland as a whole, it would be worthwhile to develop an incentive mechanism into the consent process which will encourage green infrastructure development.

Such incentives may include reduced consent costs, lower rates, fast-tracking of consents and even Council support with labour or materials (for example in constructing a community garden).

Education

Providing workshops and educational material which outlines good practice in designing, constructing and maintaining green infrastructure will be crucial in ensuring that any system installations are successful. Council guidelines have been developed for green infrastructure systems such as green roofs (Fassman-Beck and Simcock 2013). Such guidelines need to be expanded to better encompass the broad types of green infrastructure systems. In conjunction with the guidelines, resource consent and other barriers to developing and implementing green infrastructure should be reconsidered to ensure that Council processes do not cause unnecessary delays in planning permission or increases in cost.

Guidelines also need to be developed for homeowners and businesses which they can use to understand the best practices required for green infrastructure. Many of the current guidelines are difficult for the layman to understand and even calculating stormwater runoff frequently requires advice from an engineer. Council should provide support services to advise on good practice and commit to encouraging green infrastructure development.

CONCLUSION

There are significant social, environmental and economic benefits to incorporating green infrastructure into urban environments. The initial concept of green infrastructure as green networked ecosystems has now expanded to include all types of ecosystems within an urban environment. The large to medium scale green infrastructure systems still function most effectively when linked via green corridors but small systems can be incorporated within larger systems to perform specific functions. The quantifiable and non-quantifiable benefits of green infrastructure as shown through research and case studies clearly demonstrate the potential value of such infrastructure systems to city dwellers. While Auckland already has significant green infrastructure, developing and implementing a green infrastructure plan for the city would enable it to meet the goals of the Auckland Plan, the City Centre Master Plan, the Waterfront Plan and the Energy Resilience and Low Carbon Action Plan. Such a plan will require a robust policy outlining a strong commitment to green infrastructure, should target priority areas and ensure that Council, businesses and local communities are fully engaged in developing and implementing the Plan.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Transforming Cities TRI at the University of Auckland for providing funding to undertake the primary work in this paper.

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WASTE NOT, WANT NOT: EDUCATION FOR SUSTAINABILITY IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

Not teaching but transforming – an educational process which is easy to espouse but frequently hard to achieve in practice. This case study, set in the building technology environment of a tertiary institution, shows that by immersing students in the practicalities of construction waste management, they can cross a threshold of understanding of the wider principles of sustainability (Timmermans, 2009). By persuading degree students to climb into construction waste bins, analyse the contents and investigate re- or up-cycling for all of the products, they became able to appreciate the role that waste reduction can play at each stage of a product's life cycle, from sensitive design to careful deconstruction. Using the guidelines provided by Jaques (2013) teams of students are subsequently required to search for examples of recycling and debate the relative advantages and disadvantages critically in an online forum as part of their degree course. This process in turn encouraged transformational thinking, clearly evident in students' critical analysis and implied that all trades and disciplines, including the construction and infrastructure industry, can transform their perspectives on sustainability. The Construction and Infrastructure industry is New Zealand's fastest growing sector with employment currently forecast to grow at 2.6% (Daly, 2014). With this growth in the building and construction industry, it is clear that many more students will be entering this trade in the near future. Therefore, this research indicates that educating these future builders on wider principles of sustainability will be a determining factor in the sustainable development of New Zealand. It is imperative that the systemic approach of sustainability is embedded into their curriculum to ensure that there is transformation in values and attitudes of the future New Zealand workforce.

Keywords: Waste management; Product life-cycles; Transformational learning

INTRODUCTION

The United Nations (2002) defines education for sustainability as learning processes that encourage decision making in favour of the long-term future of the environment, economy and equity for all global communities. To achieve this goal of educating global communities, 2005 to 2015 was declared as the Decade of Education for Sustainable Development (Parliamentary Commissioner for the Environment, 2004). During this decade the UN expects countries to embed education for sustainability in all educational levels thus hopefully attaining a sustainable future and therefore providing corresponding opportunities for the present and future generations.

To achieve global sustainability that the UN envisages, it is essential that educators move away from transmissive forms of learning to transformative learning. In the current education system "students are asked to absorb pre-packaged information presented by their teachers, even though research indicates that didactic, teacher-centred education results in reduced cognitive and behavioural outcomes" (Redmen, 2013, p. 1). According to Segalàs, Ferrer-Balas and Mulder (2010) a mixture of different methods in sustainability teaching and learning has a more significant chance of improving students' eco-literacy. A re-orientation in education is needed that requires a greater focus on experiential learning, active learning and critical thinking. Moore (2005) and Alvarez and Rogers (2006) suggests that pedagogies centred on enquiry based learning, experience and reflection being effective in initiating transformation in students. This is also emphasised by Mezirow (2000), who stated that when learners go through a process of critical reflection, they gain better awareness and understanding on the issues surrounding them. Therefore, educators should endeavour to engage their

students in learning styles that encourage greater collaboration and activities involving problem based or enquiry based learning.

Pike, Shannon, Lawrimore, McGee, Taylor and Lamoreaux (2003) explain that campus greening projects promote greater consciousness and awareness in students on sustainability. When working on real projects focused on topics of sustainability, students learn the science behind environmental responsibility. Students in their research were amazed at their ability to reduce the waste stream in actual campus projects that they undertook. Hence, active group projects allows students to see the realities of the current society which translates into a thought provoking exercise which motivates them to think much more about initiatives that can contribute to global sustainability. Evidently, engaging students in group projects, where they can see the harsh realities of everyday activities is the key first step in transforming their values and attitudes towards sustainability.

Exploring these diverse forms of learning is the key to achieving sustainable development in all trades including the construction and infrastructure industry. The Construction and Infrastructure industry has been identified as New Zealand’s most rapidly developing sector as a result of the Christchurch rebuild, Auckland house shortage and leaky buildings. The shortage of skilled workers in the New Zealand construction and infrastructure industry has been challenging for the rebuild. The Building Research Association of New Zealand (BRANZ) also estimates that Auckland’s exponential growth will continue to place pressure on the construction industry. As a result, the construction sector has been identified as the one of the most popular career pathways for 2014 (Daly, 2014). And it is likely that significant changes in the construction and infrastructure industry will entice more students towards this trade in the near future. It is therefore essential that the future students join the profession with a deep awareness of the importance of sustainability already embedded as part of their psyche.

This research, set in the building technology environment of a tertiary institution, shows that by immersing students in the practicalities of construction waste management, they can cross a threshold of understanding of the wider principles of sustainability (Timmermans, 2009).

The guidelines provided by Jaques (2013) emphasises the 5 Rs and also provides examples of the way in which these can be achieved:

- Reduce
- Reuse
- Recycle
- Recover and
- Residual disposal

METHODOLOGY OF THE CASE

The case involved students studying an Applied Technology degree at an Auckland based tertiary institute. The degree is a three year programme where students undertake a range of technical and generic courses. As part of the programme second year students take part in a compulsory paper that focuses on global sustainability. The course aims to enable the student to investigate global and local aspects of sustainable technology practices and integrate this knowledge within a local setting. As part of one of their assessments in Semester 1, 2014 students were required to participate in a waste management project. Using the guidelines provided by Jaques (2013) teams of students examined the construction waste bins on site and created an inventory of all the waste they identified. Sixty students participated in the project. After the exercise, the students were then asked to investigate the various categories of waste they identified and investigate options available to re- or up-cycling for all of the products, at each stage of a product’s life cycle, from sensitive design to careful deconstruction.

As the majority of the participants were not building students (and much of the waste was from house building projects) they were additionally asked to consider similar issues related to their own industries. These options then were critically debated amongst previously established teams on an online forum.

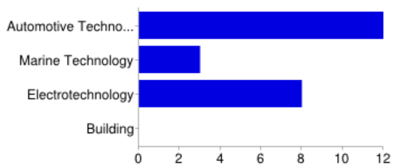
At the end of the project students were requested to participate in a questionnaire that was designed to discover to what, if any, extent their understanding of waste management had been transformed by this process.

It was envisaged that this process in turn would encourage transformational thinking. Their critical analysis via the online forum, in conjunction with the results of the questionnaire, is presented below.

DATA ANALYSIS & DISCUSSION

Twenty three students out of the sixty eight enrolled participated in the survey generating a 34% response rate. All students were studying in the Bachelor of Applied Technology (BAT) programme with 52% coming from the Automotive Technology discipline, 35% from Electrotechnology and 3% specializing in Marine Technology. The two Building students taking this course did not respond to the questionnaire but did contribute to the discussion forum.

Table 1: Disciplines of those responding to questionnaire

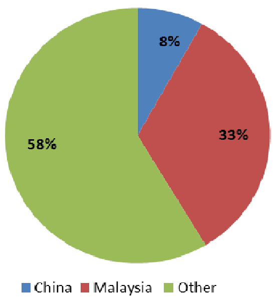


Automotive Technology	12	52%
Marine Technology	3	13%
Electrotechnology	8	35%
Building	0	0%

The depth of reflection and critique varied amongst the different groups, and this seemed to depend on the lead set by the early contributors. This meant that while some groups considered a combination of factors including ways to limit the waste being produced initially, as well as researching recycling options for the different materials, other groups took a more superficial approach. Unfortunately, this is one of the disadvantages that working in small online groups is known to create (Panko, 2002).

Out of the students who responded to the questionnaire, approximately half were international, the majority of whom were due to return to their home countries when qualified.

Table 2: Home countries of international participants



Four main themes emerged from the questionnaire evaluation and their responses were examined in parallel with the forum responses made by the different groups after their exposure to the waste. These were:

- Real World Waste
- Waste management in industry
- Money matters
- Students' perceptions of the activity's value

Real World Waste

A majority of the participants appreciated the waste management project as it gave them an insight into the 'real waste' that is generated by most businesses. One student commented that "*it helped me see what sort of waste is created in the area we are in and if we don't see it than we can't imagine it*". Another student elaborated *"it is good to get out of the classroom and see and touch what we are learning about*". Some students were very enthusiastic about this small scale project and suggested visiting waste management sites "*that would be more effective with each group looking at the waste material generated from their industry*". Project work of this scale gives student an opportunity to experience first-hand the waste accumulated by society. As suggested by Pike et al. (2003) this experience for students is the first point for transformation of values and attitudes. The realisation that waste is detrimental to the entire triple bottom line became evident when students commented on environmental issues (land-fill and toxins) social aspects (employment and potential health problems) and economic concerns (ineffective use of resources).

One of the international students photographed the waste shown in Image 1, and commented:

> *"students are mixing all the waste together which is very hazards'[sic] because most of the waste are flammable and easy to catch the fire. Moreover the containers are uncovered and not made for collect most of the waste. In addition the safety topics are not covered in this area."*

Sustainable practices featured highly with students in this project. Within their groups students were able to identify issues of waste management that were very simple to handle but easily ignored by industry. Students elaborated on the disappointment they experienced seeing the waste not properly grouped or sorted before they were discarded. Comments such as "*waste material sorting method wasn't appropriate or correctly sorted*" and "*people did not classify waste material very well"* indicates that students started to critically evaluate the waste and their understanding of the. ….

Image 1: Construction waste on campus

Additionally, proper planning was considered very important to some students in reducing waste as some identified quantities of waste materials found in the bins that could have been avoided. One student stated that "*planning ahead of project saves material wastage*" and another commented that "*the waste in the bin was still useful*". One student suggested "*educating people*" as a key to reducing waste.

When asked to reflect on their future employment and their inclination to practice sustainability in industry students gave a number of positive responses. The majority of them were enthusiastic to participate in proper waste management activities given the opportunity, "*I will try to plan out what is required initially before I do something that cuases [sic]me to make mistakes and create waste*" and another student said, "Yes, if I work for a company that doesn't recycle properly I will bring this issue up with my boss to plan ways to recycle properly".

Waste Management in Industry

All the participants considered waste to be an extremely important issue for their respected industry and were able to relate waste with their own disciplines. One Automotive student stated "*we need waste management information for e.g. oil can't be recycled and can't throw away in public places*". An Electrotechnology student commented that "*as there are many electrical wastes getting into the environment everyday making technology more sustainable is crucial in today's world.*"

The student who took the picture shown in Image 2 noted that:

"We came across a large amount of metal 'off cuts' which seems to have come from pipe welding (as per picture) the reduction of this metal waste could have easily been overcome by simply measuring the exact material that is needed and make use of the entire pipe opposed to cutting at random lengths which left us with the 'off cuts'.

This seemingly simple observation indicates that students are now thinking about the full life-cycle picture of Sustainability and not solely focussing on waste recycling. However, it is not possible to know from our study at this stage whether they had realised this earlier, or not.

Image 2: Metal waste

Nevertheless, the groups varied greatly in their critical analysis of the waste they identified when they discussed issues online. Some groups, as represented by the quote provided above, did consider product life cycles as well as attempting to identify in some detail what could happen to the discarded material. However, others merely listed what was found and talked generally about ‘recycling’.

Money Matters

Interestingly, a lot of students were able to associate waste with financial loss. Many suggested that if businesses reduced their waste they could also save financially. One student stated that, “*waste management could save some money*” and another stated that, “*when I am qualified I will set up waste management so I can save more money in my business.”*

Comments of this nature demonstrated that many students had realised that waste management was not an overall expense to industry but was an area where significant financial savings could be returned to companies involved with many different disciplines.

Students’ perceptions of the activities value

Overall students confirmed that the activity had heightened their awareness of waste management although one student made the following insightful comment:

> *I do not think that the practical exercise was as effective as it could have been. It would have been more effective if each group went to a waste field which their industry and look at the waste material there so [when] we are qualified we will know how to recycle what material concerns our industry.*

For the remainder it is clear (see Figure 1) that the activity had value and could have produced a transformation in their attitude.

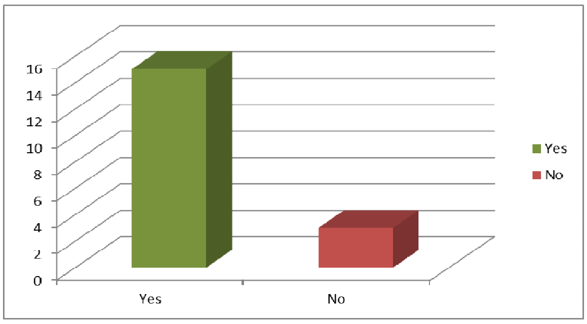


Figure 1: Value of the exercise to students

CONCLUSION

By persuading our degree students to climb into construction waste bins, analyse the contents and investigate re- or up-cycling for all of the products, they become able to appreciate the role that waste reduction can play at each stage of a product’s life cycle, from sensitive design to careful deconstruction.

The questions posed at the start of this study were: was the waste investigation project worth doing and would it allow transformational learning to occur? While the students’ responses to the first is an unequivocal ‘Yes’, it is more difficult to guarantee the latter. However, it does appear that it has

allowed students to move towards a greater awareness of their engagement with the issue. It is proposed that the exercise be repeated but linked to external visits to recycling plants.

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Weathertight performance of flashings for taller buildings

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ABSTRACT

Residential buildings are now better engineered to manage rainwater following the leaking building problem in New Zealand. The next challenge is to improve the weathertightness of medium-rise buildings which often use joint details from E2/AS1 but are subject to higher wind pressures and surface runoff rates. This study begins to address this challenge by measuring the water performance limits of the following E2/AS1 flashings with static and dynamic rain and wind loads to see how their performance might be improved:

- Horizontal H and Z jointers between direct fixed sheet claddings
- The window head flashing in a cavity wall
- A horizontal apron flashing at the junction between a roof and wall.

All of these joints were found to resist water leakage to pressures equivalent to the hydrostatic head of the upstand, so long as there were no air leakage paths through the joint. When vents were added, or openings were present that might arise due to construction tolerances, then the onset pressure for leakage was found to fall by as much as 50%. Vents, of course, are essential for ventilation drying in rainscreen walls and even with vents present, the onset of leakage was at generally at least twice the 50 Pa wet wall pressure required by E2/VM1. Opportunities were found to improve the way vented joints deal with runoff by enlarging the gap between the cladding and flashing. This prevented the outer joint volume from filling with water and occluding the vents. The apron flashing was found to cope better than a window head joint with runoff, because of the larger 35 mm vertical gap between the cladding and apron.

KEYWORDS:

Weathertight joints; flashings; upstands

INTRODUCTION

Most water leaks in residential buildings occur at joints between claddings and components such as windows etc. This is illustrated in Figure 1 using data from a survey of leaking buildings in New Zealand by Bassett et al 2003. Over 60% of leakage sites were at junctions between claddings and other components and less than 40% were associated with roof and wall claddings. Contributing causes were found to include the omission of traditional metal flashings at junctions between components along with limited protection from eaves in newer building designs. A similar fraction “26%” of water entry points around window and door junctions with claddings were identified by Morrison Hershfield Limited (1996) in a survey of leaking buildings in British Columbia, Canada. In that survey, 90% of water leakage sites were found to be at junctions between materials and components or at penetrations through the cladding.

The then Department of Building and Housing (now part of the Ministry of Business, Innovation and Employment) responded to the leaking building problem by modifying the compliance document, E2/AS1 External Moisture, of the New Zealand Building Code (NZBC) to improve the standard of water management in wall and roof designs (Department of Building and Housing 2005a). Most of the changes

were based on the 4Ds (deflection, drainage, drying and durability) approach developed in Canada by Hazleden and Morris (1999) and incorporated a water-managed cavity behind the cladding. Additional important changes include flashings around the perimeter of windows and doors.

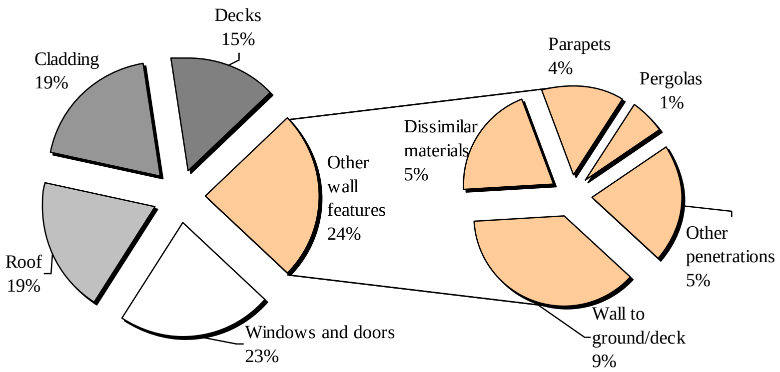

Figure 1. Water entry sites in New Zealand leaking buildings.

A new test procedure E2/VM1 ‘Verification Method’ (Department of Building and Housing 2005b) was also developed with tests to ensure that water does not systematically reach the dry side of the cavity, or above the upstand on horizontal flashings. There are, however, many questions about the performance of flashings that are not answered by this procedure and which this research is starting to address:

- How far should the flashing upstand extend upwards behind the cladding to deal with wind driven rain?
- Do the upstand heights of flashings need to be adjusted to cope with rain bouncing of a roof – particularly important for apron flashings between roof and wall?
- Do cavity closers have a role in managing air and water entry through the joint
- How should cladding to flashing clearances be sized to control runoff?
- Do hems folded into metal flashings improve the weathertight performance of flashings?

Perhaps the most pressing need for research on the leakage performance of joints is in support of timber framed walls above the height limit for E2/AS1 (three stories maximum but nominally 10 m above ground). Many of these buildings adapt E2/AS1 claddings and flashings to timber framed infill panels that are exposed to higher wind pressures and surface runoff rates than low rise residential buildings.

There are few scientific investigations of the water leakage performance of joints and how their design might be improved to cope with extreme exposure. One of the earliest investigations (Ishikawa 1974) measured the leakage characteristics of joints in a metal curtain wall and concluded that the key elements were a large external opening to prevent a water film from bridging the gap, and an airtight internal joint to support wind pressures. A more recent study (Lacasse at al. 2003) measured leakage rates through specific defects in walls such as missing lengths of sealant, and used the leakage function of wind pressure and rain load to estimate the moisture loads that have to be managed by vapour diffusion and ventilation drying within the wall. Water leakage rates were measured as a function of runoff rates and static wind pressure and fitted to an empirical relationship that was then used to estimate moisture entry loads in a range of North American climates. A similar approach to developing water leakage functions for joints is followed in this study but the next step of comparing leakage rates with the capacity of joints to control leakage with drainage and ventilation drying is outside the current scope.

MEASURED RAIN LEAKAGE CHARACTERISTICS

Equipment illustrated in Figure 2 was used to measure the water leakage characteristics of joints between building components. It consists of a pressure chamber connected to a fan and a fluctuating piston that together apply a steady pressure and a superimposed fluctuating pressure across the specimen. The pressure amplitude can be changed by adjusted the piston stroke although below 0.2 Hz there was simply not enough travel to reach large pressure amplitudes. The wall specimen measured 0.7 by 0.7 m (area 0.49 m^2) and the length of joint under investigation was 0.53 m.

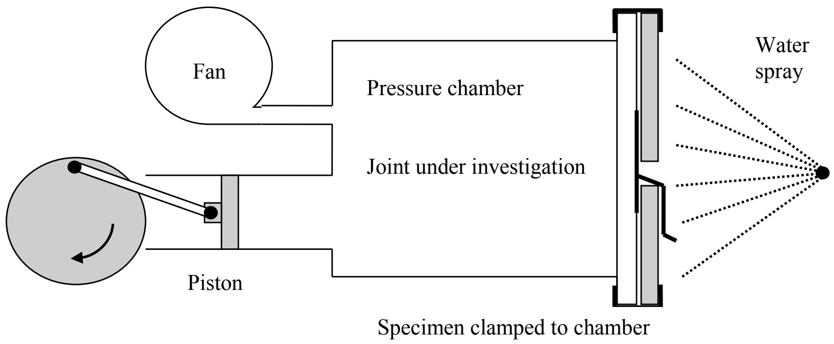

Figure 2. Equipment for measuring the weathertightness characteristics of joints.

A range of water spray nozzles were used to wet the sample area with between 3.4 l/m^2.min (corresponding to the minimum rain load called for in E2/VM1 2005) and 0.08 l/m^2.min. This is similar to the rain loads applied to large wall assemblies (0.02 – 3 l/m^2.min) by Bassett et al 2012 and provides a wide enough range of rain intensity to develop rain leakage functions that include most rain events. In these measurements the runoff rate was found to be a more useful measure of water delivered to the joint

TYPICAL FLASHED JOINTS SEEN IN RESIDENTIAL BUILDINGS

There are a large number of joints described in E2/AS1 but the three junctions illustrated in Figure 3 capture most of the essential features of flashings and their application in walls with cavities or direct fixed claddings. The three joints chosen for what is a preliminary study are:

- A Z jointer between direct fixed plywoodwall panels
- A window head flashing in a cavity wall
- An apron flashing between a roof and a higher section of cavity wall

Upstand heights in these joints have evolved from field experience although recent changes to extend the applicability of E2/AS1 to an‘extra high’ wind zone was responsible for precautionary increases to upstand heights in walls with cavities and direct fized claddings – 35 to 60 mm for window head flashings and 75 to 90 mm for roof to wall apron flashings. Another recent change required mandatory hems to the top of flashing upstands used in extra high wind zones. In lesser wind zones the hem can be traded for an additional 25 mm of upstand height. These were largely precautionary changes ahead of applicable field experience or laboratory results of the type that this study aims to provide. Another significant change that came with more widely adopting cavity construction was the provision for vents in a cavity closer. Vents are potential air leakage paths and an entry point for air carried spray. This project set out to link cladding overhang and clearances in joints with the effectiveness with which the joint rainscreens against water entry.

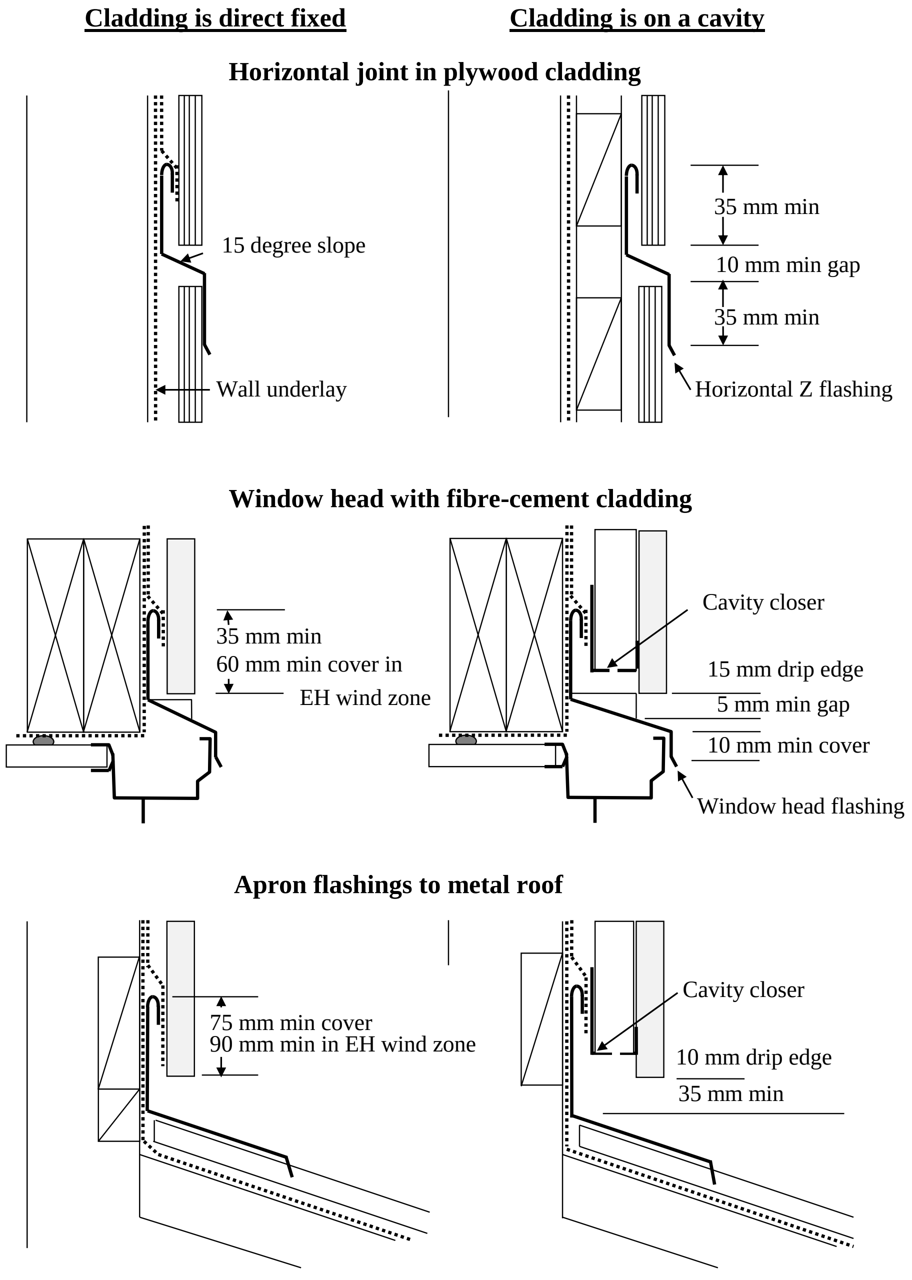

Figure 3. A selection of flashings used in NZ buildings and taken from E2/AS1

LEAKAGE CHARACTERISTICS OF A HORIZONTAL CLADDING JOINTER

The leakage characteristics of a propriatary PVC H jointer were measured between two cladding panels fixed to cavity battens as illustrated in Figure 5. This is similar to the Z flashing illustrated in Figure 3 between plywood panels on a cavity wall except that it does not include a hem now required in E2/AS1 in the extra high wind zone. There are two main leakage paths in the H jointer as follows:

- Leakage between the up-turned leg of the jointer and the cladding. In particular the significance of the offset space width (w), the height of the upstand and the presence or absence of a hem folded into the upstanding leg.
- Leakage over the top of the lower cladding past the lower legs of the H jointer - not investigated here.

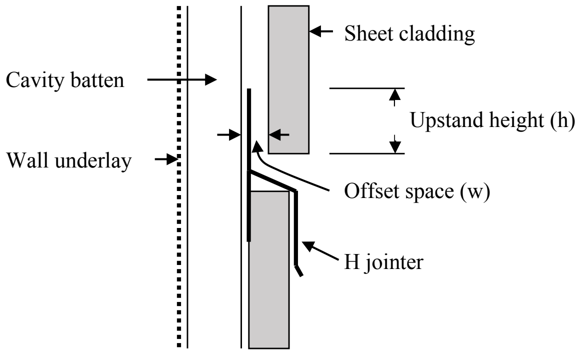

Figure 4. Sectional view through an H jointer between two sheets of wall cladding.

Significance of offset (air gaps) between the jointer and the cladding

The air pressure difference corresponding to the onset of leakage through the H jointer was measured for a range of upstand heights by cutting down the upper leg of the jointer to 15, 35 and 60 mm. A 530 mm wide section of jointer (spanning between cavity battens fixed to framing) was sprayed with water at 3.4 l/m^2 and the air pressure difference adjusted over the range 0 – 500 Pa until leakage was detected above the jointer. The pressure at which water reached the top of the upstand are shown in Figure 5 as 140, 294 and 500 Pa for the three upstand heights 15, 35 and 60 mm. The pressures needed to spill water over the upstand were a little higher than this (147, 300 and 588 Pa) because of the additional pressure needed to overcome surface tension. When the offset gap w was increased beyond 2-3 mm, air carried water leakage was observed bubbling above the upstand. Figure 5 shows air carried water leaks occurring at lower pressures as the offset gap is increased for all three upstand heights

Significance of a hem on the upstand of the jointer

The PVC H jointer was replaced with folded aluminium flashings having upstand heights of 35 and 60 mm and with and without a hem formed as shown in Figure 3. In this case water leakage rates were measured gravimetrically over a period of one minute by weighing an absorbent strip placed just above the flashing. In all cases the cladding was held against the flashing upstand (w = 0) although the flashings with a hem will have formed a 3 mm gap between and most of the flashing upstand and the back of the cladding. With a 1.3 g/m.s runoff rate over the joint, static pressure leakage characteristics for the 35 and 60 mm high flashings were as shown in Figure 6 to be similar to those measured earlier for the PVC H jointer with the onset of leakage at 300 and 500 Pa. The onset of leakage was found to be independent of the hem, but once again, it was possible to reach onset leakage pressures as high as 370 and 580 Pa

by carefully spring loading the hem of the 35 and 60mm high flashings against the cladding. Although these measurements were conducted using standard construction materials, it is likely that the tolerances achieved in the laboratory were tighter than would be seen in buildings, and that onset leakage pressures in the 100 – 300 Pa range indicated in Figure 5 for offset gap widths above 2 mm are more likely where no special care is taken to hold the flashing against the cladding. Higher upstand dimensions do bring weathertight performance advantages but only where air carried water leakage can be eliminated with a tighter fit between flashing and cladding. Onset leakage pressures of 100 – 300 Pa are higher than the 50 Pa "wet wall" test pressure applied in E2/VM1 to the field of the cladding and on this basis there is little argument for increasing upstand heights.

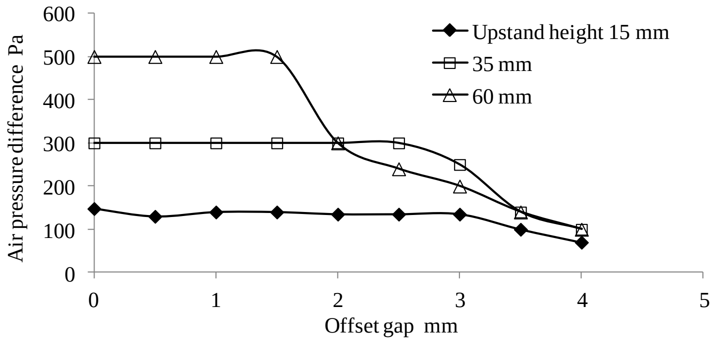

Figure 5. Air pressures at which water leakage occurrs through the H jointer as a function of upstand height and the offset gap width.

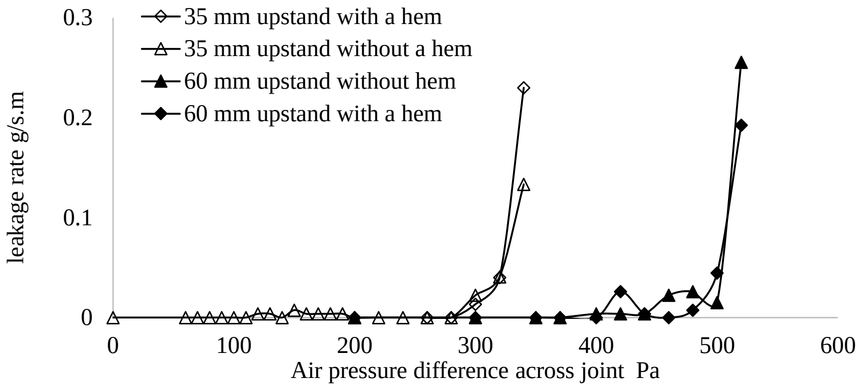

Figure 6. Steady pressure leakage characteristics of flashings with 35 and 60 mm upstands with and without hems

A more detailed study of the 35 mm high flashings applying static and fluctuating pressures was carried out and will be reported in due course. The early indications are that for frequencies less than 0.7 Hz, the water leakage rate was in phase with the pressure difference across the joint. This indicates that the inertia of water in the joint would be unimportant in a leakage function that might be used to calculate leakage rates using climate data.

LEAKAGE CHARACTERISTICS OF CAVITY CLOSER IN A WINDOW HEAD JOINT

A window head joint was assembled as in Figure 7 but with the capacity to adjust the position of the upper cladding in relation to the window head flashing. This allowed for some variations in joint dimemsions, in particular, the gap between cladding and flashing (g).

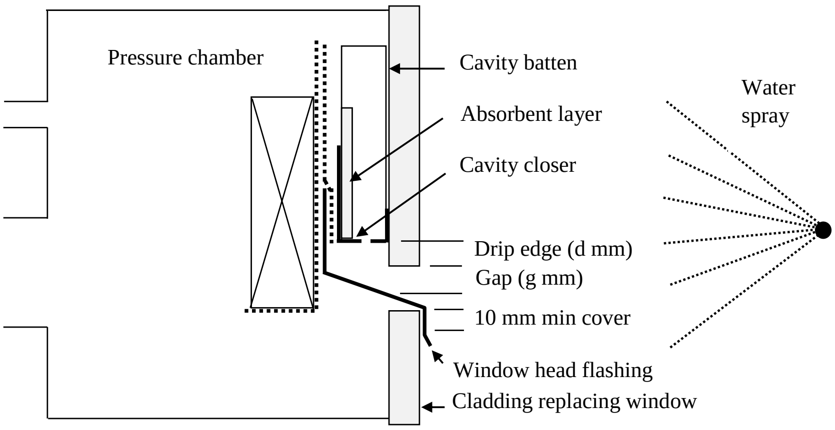

Figure 7. Experimental window head joint with cavity closer and variable joint dimensions.

There are four potential water leakage paths above the window flashing in Figure 7 as follows:

- Between the head flashing upstand and the cavity closer which is similar to the leakage path examined earlier.
- Up through vent openings in the cavity closer as examined here.
- Past the stop ends on the head flashing – not dealt with here.
- Under the flashing over the lower cladding (or window head) – not dealt with here

The upstand height of the head flashing above the base of the cavity closer is shown in Figure 4 to be 20 mm (45 mm in an extra high wind zone) but in practice, the upstand on commercially available cavity closers is around 75 mm, significantly increasing the effective upstand against water leaking through vent openings in the cavity closer. The 1500 mm^2/m vent area at the base of the cavity closer was made up of a series of slots 3 mm wide by 13 mm long and exceeded the minimum vent area of 1000 mm^2/m required by E2/AS1. Water leakage rates through the cavity closer were measured as a function of the steady air pressure across the joint and plotted against the distance travelled up the upstand. This was achieved by segmenting the absorbent layer into 9 parallel strips that could be individually weighed and assigned to a height above the cavity closer. The water spray rate was 3 l/minute.m^2 as required by E2/VM1 and Figure 8 plots deposition rates against height above the cavity closer.

It is clear that pressures above the 50 Pa wet wall test pressure were needed to drive water through the cavity closer and onto the dry side of the cavity although the leakage onset pressures are considerably lower than for the H jointers discussed earlier. In fact the onset leakage pressures for leakage above 35mm and 60 mm are in the range 100 – 125 Pa compared with 300 and 500 Pa for the H jointer, indicating that the airtightness of the joint and other aspects of joint configuration are important.

In practice, a significant proportion of wind pressure on a wall will lie across other components such as the internal lining and underlay, especially above a window which effectively partitions the wall cavity for pressure moderation across wet joints in the cladding. Secondly, it is important to acknowledge the

value of ventiltion drying in both cavitywalls and with direct fixed weatherboard claddings. While the vents associated with window head flashings might reduce onset pressures for water leakage, the pressures are still well abovethe "wet wall" test pressure of 50 Pa in E2/VM1. The potential for ventilation drying in cavity walls and behind direct fixed weatherboard walls is shown in WALLDRY-NZ (Bassett et al. 2012) to provide the secondry water management needed to cope with even quite leaky claddings and to offset some loss in onset leakage pressures across window head flashings. For joints such as the window head flashing studied here, the water leakage measured and plotted in Figure 8 have yet to be compared with the capacity for ventilation drying and drainage from the joint.

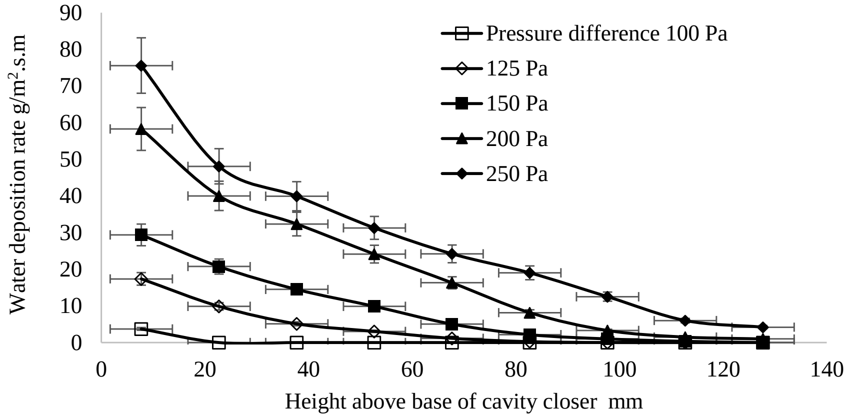

Figure 8. Deposition rate of water as a function of height above the cavity closer

It was observed that water leakage past the cavity closer depended on the runoff rate past the window head. High runoff rates tended to fill the joint, restricting the air flow into the cavity and allowing for wind pressures to carry water through vents in the cavity closer. This suggesting that the water leakage rate may depend on dimensional factors that might be optomised to improve the water leakage characteristics of the head joint. The following factors that have been investigated in sequence:

- Dependency on runoff rate over the joint achieved with a range of water spray nozzles
- The gap between cladding and flashing (g)
- Whether the pressure was applied statically or dynamically.

Dependency of onset leakage pressures on runoff rate

The net water leakage rate into the cavity closer was measured at runoff rates 0.6 – 12 g/m.s over the window head joint (equivalent to surface flow rates of 0.08 to 1.7 l/m^2.min on the limited wall area above the head joint). Figure 9 plots the steady pressure difference at which water first penetrated the cavity closer against the runoff rate over the window head joint. During these measurements the joint dimensions were fixed at those shown in Figure 7 with a 5 mm gap between cladding and the head flashing. Two water leakage regimes were observed. Above a runoff rate of 2 g/m.s, water tended to bridge across the joint, partially filling the space below the cavity closer and allowing water to be carried past the cavity closer at relatively low pressure differences. At runoff rates below 2 g/m.s the joint drained out, leaving an unobstructed air path to the cavity closer. With the vent unobstructed there was some water leakage above the cavity closer at higher pressures due to air carried spray, but the leakage rates were much smaller than those that were measured when the runoff rate exceeded 2 g/m.s.

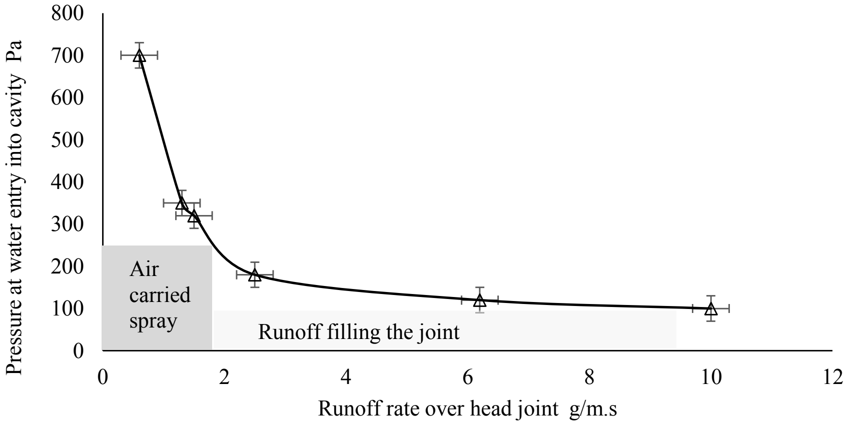

Figure 9. Pressure difference at the onset of leakage through a window head joint as a function of runoff rate over the joint

Dependency of onset leakage pressures on gap between cladding and head flashing

The dependency on runoff rate in Figure 9 suggests that the cladding to head flashing dimension might be an important factor in the weathertight performance of this joint and a separate sequence of leakage measurements were carried out to investigate this possibility with the gap width g ranging from 1 – 9.6 mm. Figure 10 shows how the onset leakage pressure increased with larger gap (g) dimensions leading to the joint draining out more effectively. This could be worth exploring more in the context of taller buildings exposed to higher wind pressures and surface runoff rates. Below a gap width of 5 mm the leakage performance of the joint appears to improve marginally, but it has to be remembered, this is at the expense of free drainage from the joint.

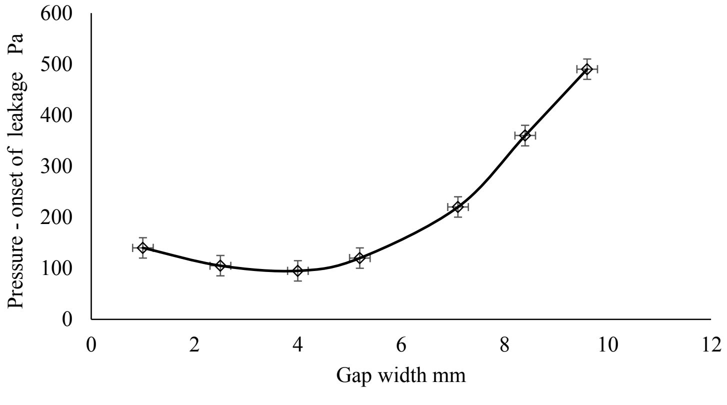

Figure 10. Pressure at which water first appeared in the cavity closer as a function of runoff rate over the window head joint.

LEAKAGE CHARACTERISTICS OF AN APRON FLASHING TO ROOF JOINT

An apron flashing was assembled as shown in Figure 16 with the cavity wall details given in Figure 4. The apron flashing was simplified to a single piece in folded aluminium with an upstand height (distance from base of cladding to top of hemed upstand) of 75 mm. The complete wall specimen measured 2.4 m by 2.4 m and a portion of the wall cladding was made removable to retreve and weigh the absorbent layer. The leakage characteristics of the joint were measured statically as a function of runoff rate following the methods used for the window head flashing. Then the static spray bar was replaced with a 1 m diameter fan capable of driving water spray at the joint with air velocities up to 17 m/s. This allowed the leakage due to wind carried rain to be compared from that due to runoff.

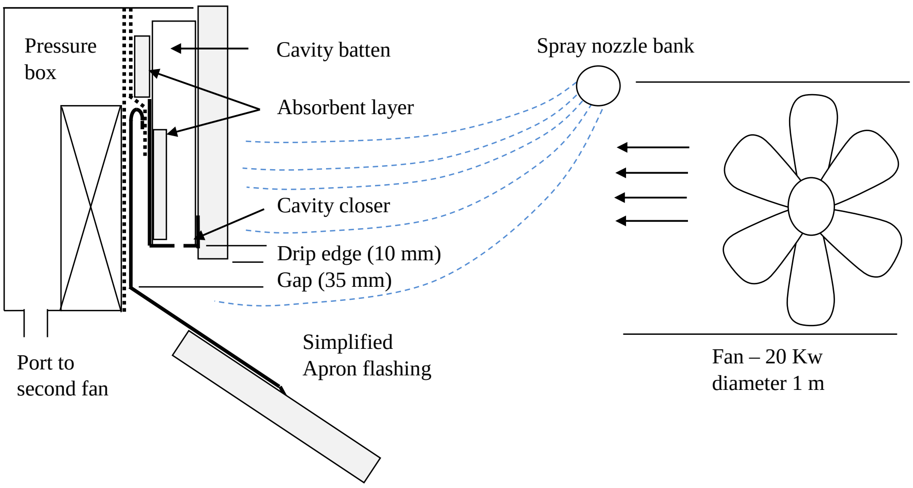

Figure 11. Experimental apron flashing joint between roof

Four potentially significant water leakage paths past the apron flashing in Figure 16 are as follows:

- Between the flashing upstand and the cavity closer.
- Up through vent openings in the cavity closer.
- Past the ends of the apron flashing – not dealt with here.
- Under the flashing over the roof deck – not dealt with here

Leakage characteristics of a 1.2 m section of joint were measured with a 75 mm flashing upstand, a cavity closer upstand of 75 mm against the flashing and a smaller 18 mm upstand against the back of the cladding. The vent area in the cavity closer was 1500 mm^2/m made up of a series of slots 3 mm wide by 13 mm long. It was the same cavity closer present in the window head joint studied earlier. Runoff rates over the joint were in the range 3 – 60 g/m.s.

Water leakage rates were measured inside the cavity closer against the taller leg at the back of the cavity, and directly above the flashing. No water entry was detected above the 75 mm flashing upstand, due to the hem fitting tightly against the cavity closer and effectively closing off air leakage paths in this area. As with the window head flashing, water entered through ventilation holes in the cavity closer and leakage rates were measured at four runoff rates and air pressure differences in the range 0 – 1300 Pa

and plotted in Figure 17. The joint behaved like a window head joint with a large gap between cladding and flashing that prevented the joint from filling up with water at even the highest runoff. The measured leakage rates were small compared to those measured into the window cavity closer and were entirely due to small droplets of spray carried by air flows through ventilation holes in the cavity closer.

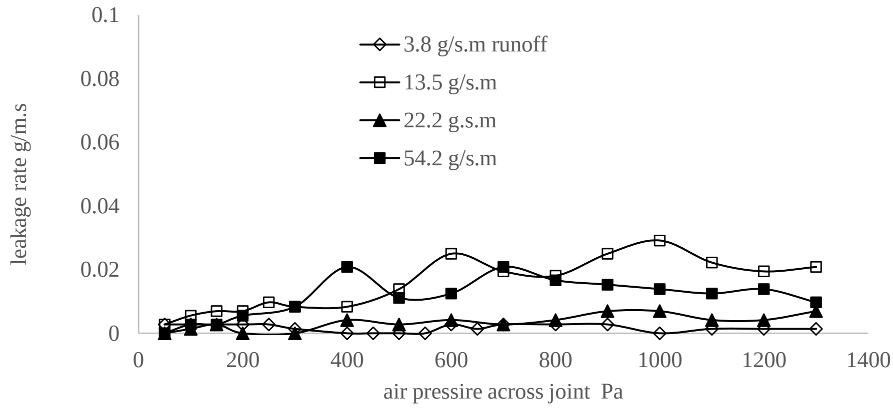

Figure 12. Water leakage rates through the cavity closer above a saddle flashing.

Wind driven water leakage past the apron flashing

The specimen was positioned in front of the large fan and the static air pressure measured at the joint. At maximum fan speed this was 168 Pa (equivalent to an air speed of 16.7 m/s and well short of the pressures applied in E2/VM1 for buildings located in very high and extra high wind zones). The E2/VM1 test sequence does not simulate wind carried driving rain and so the measurements described here are at best exploratory.

There were two processes at work carrying water into this joint. The first, involved rain drops bouncing off the apron flashing and carried by momentum into the base of the cavity closer. From here they travelled no further unless an air pressure differences greater than 100 Pa were present to drive water further into the joint. The second process involved smaller droplets entrained in air flows and these reaching higher into the joint. The first process delivered large quantities of water and the second delivered much smaller water flows that were similar to those measured earlier with static sprays. It is clear that wind driven rain is a significant issue with apron flashings that will require further investigation in the context of tall buildings.

CONCLUSIONS

Preliminary weathertight performance measurements were carried out on three flashed joints from the New Zealand Building Code approved document E2/AS1. The following conclusions were reached:

- **H jointers between sheets of cladding**. With the flashing close fitting, the joint remained weathertight up to pressures close to the head of water equivalent of the up-stand height. In more realistic building applications where the gap between flashing and cladding might exceed 2-3 mm, air carried water leaks were seen at lower leakage onset pressures (100 – 300 Pa) with little dependency on up-stand height and the presence of a hem.

- **Window head flashing in a cavity wall**. The onset of water leakage through this joint occurred at 100 Pa as a result of air carried leakage through vents in the cavity closer. Leakage past the flashing upstand was much less significant when tightly fitted against the cavity closer. Both onset leakage pressures were much higher than the 50 Pa "Wet Wall" test pressure adopted in E2/VM1. The leakage onset pressure was also found to depend on the runoff rate over the joint and on the gap between the cladding and head flashing, in fact this gap might need to be increased to cope with runoff rates on tall facades.
- **Apron flashing between wall and roof**. The 35 mm gap between the base of the wall cladding and the apron flashing prevented high runoff rates from accumulating water in the space below the cavity closer. As a consequence, only very small air carried water leaks through the cavity closer were detected up to very high air static pressure differences. Leakage rates a hundred times greater were measured with rain driven at the joint by 17 m/s wind speeds. The new water entry process involved large droplets bounced off the apron and entered the base of the cavity closer where it could be carried deeper into the joint by air flows. No leakage was detected between the apron flashing upstand (75 mm above the base of the cladding) while it fitted tightly against the cavity closer upstand.

This study identified opportunities to improve the leakage characteristics of joints to handle runoff and higher wind pressures for buildings outside the scope of E2/AS1. This is, however, only a start for more comprehensive studies that will be needed to include fluctuating wind pressures and wind driven rain into the water leakage functions for joints. These studies will also have to compare measured leakage rates with the capacity for drainage and ventilation drying.

ACKNOWLEDGEMENTS

This work was funded by the Building Research Levy. The assistance of Mark Hearfield, and Roger Stanford is gratefully acknowledged.

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BUILDING RESILIENCE

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ABSTRACT

Although considerable research has been carried out into the resilience of buildings, materials and components, there are still substantial gaps in knowledge and the information available. Such areas include how these factors are influenced by extreme events, how buildings can be made more resilient and how maintenance can extend the service life of materials and buildings.

Over recent years, New Zealand has experienced a number of extreme events, which have led to increasing costs to the building industry, homeowners, councils, government and the insurance industry. Despite being built in areas of risk, New Zealand's housing stock has limited resilience, which is further compromised by poor maintenance and repair of our existing buildings. This puts the existing stock even further at risk and there is a strong need for our buildings to be made more resilient to such events.

Building on the development of the BRANZ Durability Verification and Residual Service Life tools, current research is delivering risk profiles and developing guidelines on materials and design that can inform stakeholders about actions that can be taken to improve the resilience of both new and existing dwellings. The research involves robust investigations into the resilience of buildings and structures, taking into consideration the material and building characteristics, property characteristics, external elements, geographical location and combinations of hazards. More robust information on the effect of maintenance on service life of materials is also being developed to allow more quantitative service life assessments to be made.

KEYWORDS:

Building resilience; flood; natural hazards

INTRODUCTION

New Zealand is an island nation on the boundary of the Pacific and Indo-Australian tectonic plates, straddling a mid-latitude zone of strong westerly winds, and as a result is susceptible to a wide range of natural hazards and extreme natural events. Over recent years the country has experienced a number of these extreme events, which have led to increasing costs to the building industry, homeowners, councils, government and the insurance industry. Earthquakes account for the most significant losses, which is not surprising, given the Canterbury earthquakes in 2010 and 2011 were amongst the most significant natural disaster events in the world at that time. The insurance losses for these events alone are estimated at tens of billions of dollars. We are only just beginning to see some of the secondary effects of the earthquakes in, for example, the repeated flooding in areas such as the Flockton Basin.

Prior to the Canterbury earthquakes in 2010-2011, approximately 94% of adverse event insurance claims in New Zealand were for storms, severe floods, snow and landslides. Storm and flooding damage alone is estimated to have cost the country hundreds of millions of dollars over recent years. To provide a representative history of losses, figure 1 provides a breakdown of natural hazard losses with the recent Canterbury earthquakes removed.

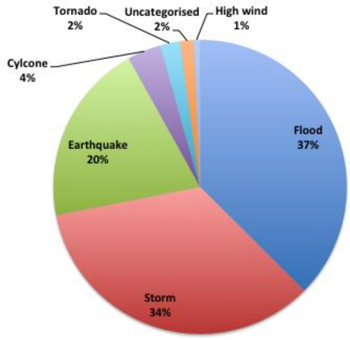

Figure 1. Insurance losses from natural hazards in NZ from 1968 – 2012 [Edge, 2013].

It is a similar situation in Australia, where cyclone, storm and flood damage have had a devastating effect on the country. Figure 2 shows the insurance losses for natural disasters in Australia from 1967 to 2013, based on 2011 normalised dollars (ICA, 2013). In 2011, extreme natural events, including Cyclone Yasi and the Queensland floods, caused damage to over 4000 homes and 3000 commercial properties, estimated at over $5 billion.

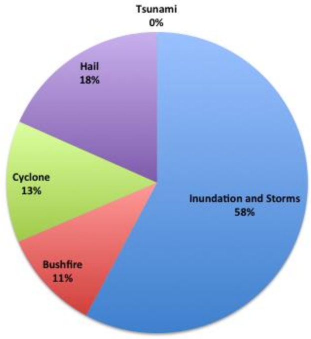

Figure 2. Insurance losses for natural disasters in Australia from 1967 - 2013 (ICA, 2013)

Throughout the world, the insured losses from climate-related disasters have increased substantially. Estimates demonstrate an increase from approximately US$5 billion to US$27 billion in annual insured losses over the last 40 years (Swiss Re, 2011). Furthermore, it is estimated that only 25 per cent of the total losses from a natural disaster are borne by the insurance industry with the remainder being absorbed by individuals and governments (Carter, 2011). Data from the International Disaster Database shows that although earthquakes are low frequency events, they have the highest economic loss. However, taking into consideration the number of occurrences of different types of natural hazard events per year, flood and storm events clearly outweigh other events and this may be an important consideration when focusing on the wider community impacts, rather than economic losses.

Valued at over $600 billion, New Zealand's housing stock is valuable both socially and economically. The building and housing sector is a key component of the New Zealand economy and is central to New Zealand's continued growth. Construction activity contributes four to five per cent of gross domestic product (GDP) and the sector employs eight per cent of New Zealand's workforce (DBH, 2010). However, despite being built in areas of risk, New Zealand's housing stock has limited resilience, which is further compromised by poor maintenance and repair of our existing buildings, as shown within the BRANZ House Condition Surveys (Buckett *et al*, 2011, 2012). This puts the existing stock even further at risk and there is a strong need for our buildings to be made more resilient to such events.

BUILDING RESILIENCE RESEARCH

Resilience Assessment Tools and Methodologies

There are a number of assessment tools and methodologies in use, or under development in different countries across the world but most research and information has been in the form of guidelines or standards, rather than tools (ABCB, 2012; IBHS; Unanwa & McDonald, 2000). These have generally adopted a systems approach to specifying construction details and types that offer more resilience, usually focusing on only one particular natural hazard such as flood, storm or bushfire. A number of other organisations have funded research investigating resilience and climate change adaptation (Hall, 2009-2012; Cox *et al*, 2012). There are few resilience tools that consider the materials that the building components are manufactured from and attempt to take account of a range of natural hazards.

In Australia, the increased frequency and the destructive effects of natural events has led to the Insurance Council of Australia (ICA) identifying the need to improve the resilience of Australian residential properties against natural hazards. The ICA, with the Australian Resilience Taskforce (ART) are developing the Building Resilience Rating Tool (BRRT). The BRRT is intended to inform homeowners, local authorities, planners, building professionals and insurers of the resilience of homes to a broad range of hazards, as well as being designed to encourage homeowners, homebuyers, homebuilders and property professionals to adopt improved material selection and design. The BRRT tool aims to measure the resilience of an individual building to a range of natural hazards. The BRRT calculates the resilience taking in to account the hazard profile, location of the house, section details, house type and the individual building materials used in construction.

BRANZ Resilience Research

BRANZ has recently been working with the Centre for Research Evaluation and Social Assessment (CRESA), to assess resilience of buildings and communities in order to understand the impact of incorporating resilient materials and design on New Zealand's dwellings. Better understanding of the effects of extreme natural events on materials and buildings, and of building design and materials selection provides the following benefits:

- Information on better design for durability and robustness;
- Better options for mitigation strategies on existing houses;
- Easier and cheaper repair of buildings after an extreme natural event;
- Ability to inform stakeholders of the risks of extreme natural events;
- Understanding of the benefits of maintenance of houses; and
- Understanding of the cost-benefit of different infrastructure and materials choices.

All of these considerations are important to a range of stakeholders including home-owners, designers, insurance industry and regulatory authorities. Assessing and understanding resilience has the potential to improve individual and community outcomes after an extreme natural event.

From the review of the material databases currently available, it is evident that data regarding the durability, environmental performance and safety of materials is very fragmented and there is no one-stop-shop for information on materials resilience. This highlights the need for a robust and transparent database, like the ART Building Resilience Knowledge Database (BRKD), which would provide consistent information on materials durability, its resilience against natural hazards and its environmental performance.

BRANZ has previously developed a Durability Assessment and Verification Database to provide a more robust durability assessment framework for the New Zealand building industry (Jones *et al*, 2013, Lee *et al*, 2008). The database aggregates existing durability knowledge and verification methods, identifying critical knowledge gaps to guide future research, and provides useful durability information in a convenient manner. This Durability Verification framework has subsequently been extended to

include a Residual Service Life Assessment Tool for New Zealand, a broadly-applicable tool designed to guide the day-to-day decisions of building industry practitioners as to when maintenance is required on buildings and building elements.

As part of the project, BRANZ has been developing a hazard risk rating for the most common building materials and building elements found in New Zealand houses. This is based on testing the performance of materials when exposed to the effects of extreme natural events. As flooding and storms were the most frequently occurring natural events in New Zealand (figure 3), responsible for the largest proportion on insurance losses, it was decided to focus initially on the effects of water damage.

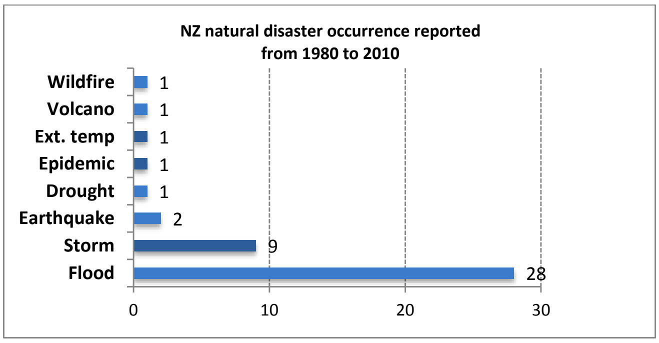

Figure 3. NZ Natural disaster occurrence reported from 1980 to 2010 (Preventionweb, 2013)

The resilience of materials and assemblies are being assessed by testing the effects on relevant properties to different hazard exposures under standardised conditions. The results of these tests are used to provide a qualitative assessment of the resistance of different materials to a particular hazard exposure. Initially the performance of individual materials is studied. Once this behaviour is understood, materials are tested in combination, such as those typically found in a building element. For example, the performance of wall insulation and plasterboard will be assessed individually and also when assembled to simulate a wall element. The materials are given relative ratings, as a 1-5 score, where a higher rating indicates a higher resilience to the specific hazard. This approach mirrors that of FEMA's Technical Bulletin on Flood Damage-Resistant Materials (FEMA, 2008) and the assessments of the ART BRKD.

Initial testing was carried out to assess the effects of fresh water flooding, starting with flooring materials and wall materials, particularly wall insulation. A variety of typical wood-based flooring materials (table 1) were selected and immersed in water for different times at ambient water temperature (12-13°C). Materials were tested in accordance with the methodology specified in AS/NZS 4266.5. Results showed there was no significant difference between samples cut in the machine direction (MD) and those cut in the cross direction. For clarity, results shown here are for MD cut samples only. Parameters measured were dimensions (thickness and width), weight, modulus of rupture (MOR) and modulus of elasticity (MOE).

Table 1. Flooring materials tested

Material	Identifier	Nominal Thickness (mm)
Tongue & Groove (T&G)	T	20
MDF	M	18
Plywood	P	20
Particleboard	A	18
Strand board	S	18

Most loss of strength (decrease in MOR/MOE) had occurred after 3 hours of immersion and then levelled off up to 7 days of immersion (figure 4). After 3 hours immersion, only T&G and plywood still met the specification for flooring (chosen from NZS1860.1:2002, for Class 2 particleboard flooring, indicated by the red dotted line in the figures).

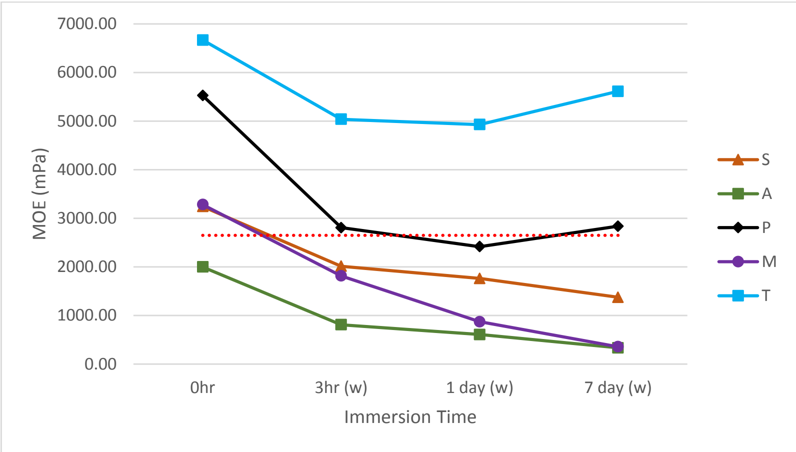

Figure 4. MOE for wood-based flooring materials after immersion in water for specified times.

There was good recovery of strength upon re-drying after immersion. Generally, if the material met the particleboard flooring specification before immersion, after 3 hours immersion it would recover strength on drying to still meet the specification. The only exception was MDF (figure 5). Particleboard recovered some strength upon re-drying, but as the specific particleboard product tested did not meet the specification before immersion it still did not meet the specification after drying.

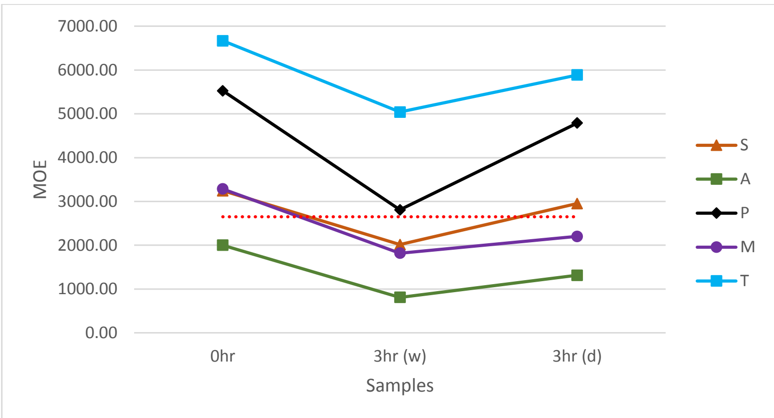

Figure 5. Recovery of strength (MOE) after immersion and re-drying.

Even after immersion for 7 days most materials, except particleboard and MDF, recovered MOE to better than 50% (an arbitrary choice) of the original value. After immersions of 1 day or 7 days, then drying, only T&G and plywood continued to meet the particleboard flooring specification for MOR and MOE.

All samples increased in thickness after immersion in water, some by up to 20%. All samples, regardless of immersion time, returned to their original thickness once dried.

These flooring materials were given relative ratings based on their performance in these tests, as shown in table 2.

Table 2. Resilience Ratings for Wood-Based Flooring Materials

Material	Indicative BRANZ Rating
Particleboard	1
Strand board	2
Plywood	3
MDF	1
T&G	4

A selection of wall insulation materials (table 3) were tested. Samples were installed in an acrylic frame to support them in a vertical orientation and immersed in fresh water, up to a depth of 200 mm, for 1 hour at ambient water temperature. The amount of water absorbed by the insulation and the length of time it took to dry out, while contained in the frame, were recorded. The insulation was dried at ambient temperature, held in the test frame in order to simulate being left to dry out in a wall cavity after a flood.

Table 3. Wall Insulation Immersion Tests

Material	Water Uptake (kg)	Drying Time – to lose half water taken up (days)	Indicative BRANZ Rating
Polyester	0.63	10	3
Formaldehyde free glass wool	3.60	35*	1
Phenolic resin bonded glass wool	6.24	240*	1
Polyester/Wool	4.71	<1	3

*extrapolated

The degree of shrinkage and slumping was also considered in the assessment of the insulation performance. This was most significant in the glass wool materials. In all cases the insulation was only wet up to the immersion depth, i.e. there was no wicking of water up any of the insulation materials tested. The ratings given in table 3 are based on the material performance alone, and may be modified after systems testing.

Materials and Systems Approaches

In the next phase, work will begin on testing systems. For example, plasterboard wall linings will be assessed in isolation and then assembled in contact with insulation materials, as would be found in a wall cavity.

A materials approach to resilience considers the durability and performance of individual materials in isolation, usually based on testing and evaluation of small samples. A systems approach considers all the materials present, their interactions, and how they are used in the building. In reality, a successful and useful resilience rating tool will draw on aspects of both approaches. Any resilience tool will always

need to consider the relative performance of materials. Some materials will perform better than others when faced with certain events and any tool will need to guide users towards favouring these materials, particularly at the early design stage.

However, an examination of the international literature has shown in some cases that assessing single building materials does not give a systems perspective, i.e. the use of several building elements together, and how compatibility and performance may change if just one of these elements is substituted or replaced. Taking a materials approach has the potential to overlook the use of several building elements together. To explore this, it is useful to consider how building elements fail during extreme events. For example, a roof is likely to fail catastrophically through the detachment of the cladding or through the detachment of the roof substructure. These failure mechanisms are mostly independent of the material from which the roof cladding is made. That said, under the first failure mechanism it may be argued that the material from which the roof cladding is made exerts some influence over the failure. If the roof structure fails, then the roof cladding material has had little bearing on the performance of the roof. Therefore, it is unlikely that a reliable assessment of the likely performance of a roof will be made by looking at the roof cladding material in isolation. The cladding fasteners, roof substructure material and roof attachments must be taken into consideration. Ultimately, the design of the whole roof system is likely to be the key determinant of the overall performance.

Further, the design and complexity of the roof, and the roof geometry, will have a significant bearing on the consequences of failures. For a simple hip roof, any blocking of the gutters could resulting in wetting of the cladding. It is not likely to lead to extensive water penetration into the roof space or to water entering the living space. In contrast, a roof with blocked, near horizontal, valley gutters could more easily have water penetrating the roof space or even the living space.

This leads to the conclusion that a resilience tool driven by collecting information on the individual materials used would still need to be consider system factors. This is because all consequential impacts would need to be accounted for. This dependency, of the exposure of one material upon the performance of another, involves three sequential phases:

- Firstly, what is the probability of the exposed material failing due to a hazard (e.g. wind lifting the roof cladding, hail breaking tiles, hail clogging gutters).
- Secondly, which of the underlying materials will be exposed to (the same or) any additional hazard(s) (e.g. rain entering a roof space or through a clogged gutter will affect other internal components).
- Thirdly, what is the extent of failure of the underlying material to (the same or) the additional hazard(s) (e.g. once exposed to rain, different components will prove more or less resilient to rainwater).

To implement this in a tool, it would then become necessary to attempt to incorporate the influence of the risk of failure of a given material on all the other materials that are protected by it. This is further complicated by the risk of failure of a given material being the product of the probability of different hazards attaining different levels of severity and the probability of failure of the actual material when exposed to that severity of hazard. Simply, using a materials based approach to resilience assessment is extremely complex and the likelihood of a key consequential impact on the performance of the building being omitted is high.

Therefore, solely adopting a materials based approach to resilience tool implementation is believed to make the tool construction extremely complex. As already discussed, this is because the tool designer has to predict and account for all consequential impacts of one material upon another. The end user is also impacted as they will be required to determine and input details of the materials used for each part of their property.

Examples of some the difficulties associated with a materials approach for resilience assessment include:

- Materials are often difficult to tell apart once incorporated into a building – hard to tell if what was specified or reported was actually used,
- Performance of a specific material relies on consistency of manufacture and supply
- Performance of a material often depends on installation
- Ignores quality of construction
- Ignores maintenance

CONCLUSION

An assessment of the frequency of natural hazards and losses in New Zealand, confirms the common beliefs on key natural hazard risks in New Zealand. Key findings from analysis and tool development include:

1. Earthquakes exceed all other hazards in New Zealand in terms of financial loss, having the potential to cause catastrophic and costly damage, but are reasonably well dealt with through building regulations.
2. Flooding is New Zealand's most frequent hazard, followed by storm.

From the current study, it is concluded that a holistic assessment methodology and assessment tool are needed to assess the resilience of typical building elements and construction materials. This approach is also most likely to allow translation of short term tests to the behaviour of a real building. Ultimately, a more robust assessment methodology will be created that evaluate the resilience and cost benefit of different infrastructure, building and material choices that can drive an increase in resilience and protection. Further development of assessment methodologies, tools and solutions to evaluate the impact of adverse events on the durability and resilience of materials and buildings will better inform key stakeholders.

ACKNOWLEDGEMENTS

This study was funded by the Building Research Levy of New Zealand. BRANZ would also like to acknowledge further contributions and funding from the Ministry for Business, Innovation and Employment (MBIE) and the Centre for Research Evaluation and Social Assessment (CRESA).

Edge Environment and the Insurance Council of Australia (ICA) are also acknowledged for discussions and sharing of information.

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5D BIM IN A CONSULTING QUANTITY SURVEYING ENVIRONMENT

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ABSTRACT

BIM is triggering a revolution in the construction industry, and the concept known as 5D BIM, which ultimately is concerned with a cost dimension being added to objects contained within the BIM model, has the potential to be used by consultant quantity surveyors (QSs) to streamline their workflows and increase the quality of the services they provide.
Questionnaires were emailed to participants, and followed up by semi-structured interviews with consultant QSs from one large global practice, experienced with the use of 5D BIM, on their perceptions of the benefits of, and barriers to, 5D BIM implementation. The sample was limited to New Zealand and Australian offices of the practice.
The findings suggest that 5D BIM provides numerous benefits to QSs over traditional methods, mainly through increased efficiency and visualization. Furthermore, other benefits could be achieved such as improved value management services to the client and rapid identification of design changes. However, as currently practised, these perceived benefits were only being achieved to a modest extent, due to a number of barriers limiting 5D BIM implementation. These barriers were mainly associated with incomplete design in the BIM model, lack of standards to facilitate electronic measurement, legal issues, lack of data within BIM model objects required for 5D BIM, and a lack of government support. As a consequence, the use of 5D BIM appears to be limited, and professional quantity surveyors are still heavily reliant on using traditional methods. Despite this, there was a strong indication that 5D BIM implementation will achieve these benefits to a greater extent in the future.
Further research should be carried out to identify the BIM skills which QSs will need in the future to reach the full potential of 5D BIM as described in the literature, and in this research.

KEYWORDS:

Building Information Modelling; 5D BIM; quantity surveying.

INTRODUCTION

Building Information Modelling [or Management] (BIM) provides an innovative, collaborative environment, offering many opportunities to various disciplines within the construction industry, through the utilisation of BIM models throughout the design, construction, and facility management of a building. BIM is a digital representation of a building’s geometric and non-geometric data, and is used as a reliable, shared knowledge resource to make decisions on a facility throughout its lifecycle (NBIMS, 2010). Various users can extract and use the invaluable data contained in the data-rich and intelligent 3D model objects. Parametric modelling facilitates the creation of a relationship between elements, and includes the specification and properties of individual elements and objects, [potentially] enabling the extraction of comprehensive and accurate information from the model which can be directly used for costing (Eastman et al., 2011). 5D BIM then, specifically concerns the extraction and modification of such cost-related data, becoming the primary source of information for quantity surveying (QS) services.

However, before the potential of 5D BIM can be truly realised, the barriers limiting its implementation must be fully understood (Mitchell, 2012). The main objective of this research then,

is to determine the perceived benefits and barriers of 5D BIM implementation within a single, large multi-national consulting quantity surveying practice in New Zealand. The results are hoped to inform and facilitate the next step in the process, which is to develop solutions for overcoming the barriers, in order to obtain the benefits of 5D BIM within that practice.

5D BIM IN NEW ZEALAND

Use of a single BIM model that contains all design documentation is not apparent within the New Zealand market; instead, projects often utilise up to three different (and separate) models, which can encompass architectural, structural and services design documentation (Boon & Prigg, 2012). A very few large projects have recently used a single integrated BIM model which can be shared with other project participants.

Literature on QS's use of 5D BIM within a New Zealand context is limited mainly due to the small market and reluctance to adopt its use (Tran, Tookey & Roberti, 2012). Boon & Prigg (2012) suggested that 5D BIM is rarely being implemented in New Zealand; however, Stanley and Thurnell (2013) suggest that New Zealand's use of 5D BIM technologies is limited but developing. Despite the purported benefits of BIM, the adoption of 5D BIM in New Zealand and Australia is significantly slow-moving due to a number of barriers limiting its implementation within industry, which are ultimately centred around the fragmented nature of the construction industry, suggesting a shift in current workflows is required (Masterspec, 2012).

RESEARCH METHODS

A qualitative survey approach was adopted, with data collected using an emailed closed ended questionnaire with follow up semi-structured interviews used to discuss the main themes that surfaced from the questionnaire responses. Purposive, non-probabilistic sampling ensured that only those people that had some 5D BIM experience were selected, and as 5D BIM is leading edge QS practice, there is a dearth of experts in 5D BIM, and so a sample of five professional quantity surveyors from New Zealand and Australian franchises of the large global consulting quantity surveying practice was obtained. The format allowed participants to elaborate when needed, though also answer questions that were more targeted and closed, by using a semantic rating scale to assess their attitudes towards the benefits of, and barriers to, implementation of 5D BIM in their organization. The interviews were recorded which enabled post-hoc analysis of qualitative responses, in order to reduce bias. Due to the limited sample size, no generalisations can be made across the entire population of consulting quantity surveyors.

FINDINGS

The first section of the questionnaire covered information on the participants experience as a quantity surveyor, and with 5D BIM. All participants were qualified quantity surveyors, with experience ranging between 5 and 20 years. One of the participants was a director, 3 were senior quantity surveyors, and one was an intermediate quantity surveyor.

All 5 participants had used 5-D BIM in the past 3 years to generate cost plans and/or schedules (bills) of quantities, on between 1 and 9 projects, in New Zealand, Australia and the USA.

Benefits of 5D BIM

The questionnaire asked participants to indicate their level of agreement with statements derived from the literature that related to the benefits of using 5D BIM in a professional quantity surveying environment. The participants' overall ratings are identified in Table 1 below.

Table 1: Benefits of 5D BIM (n=5)

[NB: 1=Strongly Disagree, 5=Strongly Agree]	**1**	**2**	**3**	**4**	**5**
3-D function improves decision making, reduces inaccurate drawing interpretation and reduces the assumptions the QS needs to make.			2	3	
Enables more efficient early stage preliminary estimates ($/GFA) (by auto-generation of quantities from BIM model objects).	1	1	2		1
Enables more efficient detailed elemental cost plans (by auto-generation of quantities from BIM model objects).			2	2	1
Enables more efficient production of schedules of quantities (by auto-generation of quantities from BIM model objects.)			1	3	1
Automatic quantities generation allows more time to be spent on other QS services for the client (e.g. cost advice on more design alternatives)		1	2	2	
Design changes can be more easily and rapidly identified by overlaying previous BIM models with revised BIM models.			1	2	2
Automatic quantities generation provides less room for human error.		2	1	2	
Improves the accuracy of estimates when there is insufficient time for detailed measures.		1		4	
Improves communication and access to information in the project team.			1	4	
Provides early construction schedule details which more accurately reflect the scope of work involved.			4	1	
Provides a commercial advantage over competitors.				4	1
Increases coordination through integration of specifications and clash detection				4	1

Enhanced visualization

No participants disagreed with the notion that BIM's 3D function improves decision making, reduces inaccurate drawing interpretation, and reduces the assumptions the QS needs to make. This aligns with Sabol (2008), who suggested 5D BIM provides a clearer understanding of construction components which in turn reduces the chance of missing or misinterpreting vital building items. However, 2 participants felt neutral, believing that the QS could still misinterpret the 3D model if they were unfamiliar with how BIM operates and where common design errors were found in the models. *"If you are not familiar where the inaccuracies lie in the model, and you just trust that the quantities that you extract are correct, often you will not get accurate data"*. This suggests the QS requires a thorough understanding of the underlying process of data embedment and also must be able to identify inaccuracies within the models. Monteiro & Martins (2013) suggest quantity extraction is "a tricky feature and tends to be only used by an expert" (p. 239); similarly, Boon & Prigg (2012) emphasise "the importance of the QS being able to identify items that were not in the model at the time of quantity extraction" (p. 94).

Efficient data extraction for early stage (preliminary) estimating

Somewhat surprisingly, only 1 participant agreed that 5D BIM enables efficient data extraction for early stage preliminary estimates, which is contrary to the findings from the literature (e.g. Matipa et al., 2008; Sabol, 2008, and Thuraiarajah & Goucher, 2013).

One participant explained: *"not at the moment, it is an experience thing, what you get out of the model is only as good as what the designer has put in, and at an early stage, the design is too inaccurate and insufficient"*. However, this will improve: *"as we get better at using the tool, and the tools become more available, we will be able to use it a lot more for that type of estimating"*. Another participant reported that it's hugely dangerous to use BIM models for early stage estimating due to the concept model containing little or incomplete information: *"the art and magic of concept estimating is estimating what's not there, you need to figure out all the things that will be included in the design*

phase like acoustics, fire, solar shades that no one has talked about but you know through experience that they will be required".

However, participants did suggest that concept models are used as a bulk-checking tool of manual measurement, and anticipated that preliminary estimating will become more efficient through 5D BIM automatic generation of quantities in the future through increasing experience and awareness.

Efficient data extraction for detailed estimating

Participants tended to agree that 5D BIM enabled efficient detailed elemental cost plans, but only for certain building items; extensive bulk checking and identification of missing items is imperative to ensure quantities are correct, and often manual adjustments are needed. Similarly, Stanley and Thurnell's (2013) New Zealand study indicated that 5D BIM is currently used to support cost planning at a detailed design stage. Some participants suggested that in order to facilitate the measurement of more building items, it is imperative that the QS works closely with the designer from the outset of the project to align data embedment with QS requirements. Roberts (2012) asserts that the QS and design consultants need to work collaboratively from project inception to enhance communication on design input.

Efficient data extraction for producing Schedules (Bills) of Quantities

No participants disagreed that the ability of 5D BIM to automatically generate quantities speeds up the process of producing schedules of quantities, but (as for detailed cost planning, above) only certain building items could be measured, and only a small efficiency is gained due to the bulk checking that is required to ensure quantities are correct, and to identify incomplete design. Boon and Prigg (2012) found similarly, describing quantities that could be extracted for items such as doors, windows, reinforcing, concrete and structural steel. However, this contradicts much of the international literature; Quek (2012) reports that 5D BIM did not facilitate this type of measurement due to the many problems associated to the way the design is embedded into the model, suggesting quantities did not conform to standard methods of measurement. Participants, however, suggested that the more industry uses the tool, and resolve the challenges associated with design embedment, producing schedules of quantities will become increasingly efficient.

Rapid identification of design changes

Participants agreed that design changes can be rapidly identified and updated for estimating through 5D BIM, which aligns with Stanley and Thurnell (2014), who assert "The ability to update and change quantities quickly can be a major benefit for QSs in terms of cost modelling" (p.110).

Improved accuracy, communication and access to information in the project team

Participants were optimistic for the future in terms of increased accuracy from using 5D BIM automatic generation of quantities: *"as designers get better coding, there will be less incorrect information in the model, and inherently that will increase the accuracy of our estimates when we use the information"*. No participants disagreed that 5D BIM improves communication and access to information in the project team, one relating how on a recent project, due to the quantity surveyor being integrated with the designer early on, access to design information was improved and communication was significantly enhanced. As a result, the two consultants were able to work together in order to embed the data to conform with the company's standard rules of measurement, something that couldn't have been achieved if they worked in isolation. The use of a single model increases communication and improves information accessibility (Thurairajah & Goucher, 2013).

Commercial advantage

Most participants agreed that 5D BIM gives a commercial advantage over competitors, which is supported by Thurairajah & Goucher (2013). One participant said: "*I think we are one of the few QS practices that are getting into it at this stage, therefore if we can get good at this quickly, it will provide a short term commercial advantage until our competitors get on board, however by that time, we would have still gone through everything so hopefully we would still be ahead of the them*".

Improved coordination and clash detection

All participants agreed that 5D BIM increases coordination through integration of specifications and clash detection, as centralised BIM models have the ability to automatically update changes and rapidly disperse this information to stakeholders. This is in contrast to traditional methodologies, where the QS had to scan through revised documentation in order to identify changes.

Barriers to Achieving 5D BIM

The questionnaire asked participants to indicate their level of agreement with statements derived from the literature that related to the barriers to using 5D BIM in a professional quantity surveying environment. The participants' overall ratings are identified in Table 2 below.

Table 2 - Barriers to achieving 5D BIM (n=5)

[NB: 1=Strongly Disagree, 5=Strongly Agree]	**1**	**2**	**3**	**4**	**5**
BIM model is not compatible with take off/estimating software tools.		5			
A high level of design detail at the early stages of a project can confuse decision-making.		2	1	2	
Data embedded into the BIM model objects by design consultants is not compatible with elemental estimating formats.			1	4	
Data embedded into the BIM model objects by design consultants is not compatible with schedules of quantities formats.			1	4	
Lack of industry standards/protocols that would facilitate the embedment of design data in BIM model objects that relate to estimating formats.				4	1
Use of BIM for quantity surveying services is too risky as there is no contractual framework governing its use.		2	1	2	
Time taken reviewing/checking extracted quantities means that 5D BIM is not significantly faster than doing manual take offs.		1	1	3	
Lack of direct government intervention to set up BIM standards/protocols reduces the likelihood of a common, agreed upon framework that is required to facilitate the process of 5D BIM (e.g. standardisation of use of IFCs, etc.).				5	
Allowances for wastes, jointing and lapping (for example) are not made as BIM superficially presents auto quantities, reducing the accuracy of estimates.				5	
The high cost and time associated with training staff in 5D BIM is too great for owners/directors.	1	3	1		
There is a cultural resistance to change from traditional QS approaches.		1		4	
Software and hardware upgrades associated with 5D BIM are too expensive for owners/directors.	1	4			

Software interoperability issues

All participants disagreed that BIM models are not compatible with estimating software tools, on the basis that their company's in-house software tool was compatible with various BIM model formats. This differs from the literature, which often suggests a major hindrance to 5D BIM implementation is due to BIM software companies using non-proprietary file types which cannot be exchanged with estimating software. For example, Olatunji et al (2010) explain how the data needed for cost planning

sits in isolation between different software vendors and applications. Nevertheless, some participants have encountered problems associated with data exchange, e.g. the inaccurate transferring of data from Revit files to IFC (Industry Foundation Class) file types. Although IFCs are compatible with the company's estimating software, the company abandoned the use of IFCs, due to the loss of data and inaccurate exchange of information from Revit files: *"an IFC basically takes the data from a Revit file and transfers the information into an IFC file, and then when you upload the file into our IDX software (the design component of Qubit), it takes that data, messes it around, and information can be messed up"*. Also, one participant suggested that designers were beginning to now not use IFCs because the risk of losing critical information was too great. The company mainly uses DWFX file types *"which are similar to a read-only type file and are fully compatible with the software"*. This view is echoed by Quek (2012) who reports that a single "merged" IFC-based model "creates a layer of complexity, with the risk of redundancies because of its large file size and compromised data transfer rates and perceived lack of incremental benefit" (p. 3405).

Excessive design detail at early stages can confuse decision making

Participants were equivocal on whether a high level of design detail can confuse decision making, one commenting "*the structure can often be far ahead of the rest*" of the models; when a detailed model is provided at an early stage, it won't be coordinated with the other models (e.g. architectural and services), and also its detailed nature can complicate the thinking of the QS when deciding which design alternative is more economical. For example, instead of having the footprint of the building, the gross floor area, some elevations and maybe a construction methodology that is commonly available at early design stages, the QS would have a detailed structure that identifies steel columns, rafters, and purlins, including their size, their connections, and their finish. This level of detail can cause confusion, as such information is neither required nor necessary at this early project stage. It is important to identify what level of detail is required at each design stage, such as at the concept stage, in order to eliminate unnecessary detail, reduce complexity and confusion, which should in turn facilitate the smooth encapsulation of required data at each design stage (Sabol, 2008).

Incompatibility with QS formats

Participants agreed that the design embedded into the BIM model is not compatible with QS formats for estimating (i.e. elemental format), nor for schedules of quantities. One said *"if you have had no input in the model, you wouldn't be able to get it at 100% complete and therefore it won't be in line with the way we produce our estimates."* Quek (2012) contends that the risks associated with design clashes with implications such as redesign, re-work and variations are ameliorated by the more collaborative approach that BIM encourages. As one participant said *"as we go through, we will learn to use it more and more and better and better, and we will also have a lot of input to the designers so that they provide what we need as part of the model for detailed estimating"*.

A technical sub-committee of the New Zealand Institute of Quantity Surveyors (NZIQS) is attempting to revise New Zealand's standard method of measurement by proposing the use of the Association of Coordinated Building Information in New Zealand's (ACBINZ) Coordinated Building Information (CBI) classification system. The CBI classification system was created to coordinate information sources such as drawings, specifications, quantities, technical and research information and publications (Masterspec, 2012). The NZIQS sub-committee came to their conclusion on the basis that it was a similar coding system to the one used in Singapore, the Construction Electronic Measurement Standard (CEMS), a classification system established for BIM measurement that is globally recognised as being successful (Boon & Prigg, 2012).

Lack of industry standards/protocols to facilitate design embedment

All participants agreed that there is a lack of industry standards and protocols to support 5D BIM implementation, which Boon & Prigg (2012) also allude to. A New Zealand BIM Schedule (BRANZ,

2014) and New Zealand BIM Handbook (Building & Construction Productivity Partnership, 2014) have been developed, and are currently out for industry consultation, which may help improve matters somewhat if they are adopted.

One participant raised an interesting point regarding early collaboration between designers and QSs: "*we need to be careful of how much we impose on designers, because they won't want to work with us, that's why standard coding is required*". So, if QSs keep telling designers what to include in their BIM models, they could potentially discourage designers from working with them, hence standard coding is required to provide consistency and to sufficiently manage the process.

Legal and liability issues

Opinion was divided on the use of BIM for quantity surveying being too risky due to a lack of a contractual framework governing its use. Foster (2008) believes that the lack of contractual framework to support this collaborative procurement method significantly hinders BIMs use, due to the current legal system supporting stakeholders in isolation, and that reform needs to occur in order to recognise shared responsibility for the BIM model. However, one participant felt that the QS's role and responsibilities are no different to the traditional approach: "*as per manual take off, the quantity surveyor has the role and duty to clarify what the correct information is if there are coordination or clash issues, however if the designer has got it wrong in the BIM model, it's still up to them to make sure that information is correct*". Some participants also mentioned the confusion as to whether or not the BIM model is a contract document, and believed that current contract documentation needs to be revised to help resolve this complication, particularly as sub-contractors are now beginning to price directly from BIM models.

Necessity of manually reviewing/checking extracted quantities

Participants tended to agree that the time required to check automatically generated/extracted quantities from the BIM model meant that 5D BIM was not significantly faster than manual take offs. Stanley and Thurnell (2013) also found that a lot of bulk checking still needs to be done, but that in the future, the efficiencies of 5D BIM would improve; this is echoed in the literature: Bylund and Magnusson (2011) suggest that through BIM it is possible to gain accuracy and speed up the process of take-offs, and Shen and Issa (2010) found that gains in speed and accuracy are achievable when using 3D models when compared to traditional 2D.

Lack of government intervention

All participants agreed that there was a lack of government intervention to set up the required protocols to facilitate 5-D BIM (e.g. standardization of use of IFC's, etc.). They also felt that there was a lack of drive, and support, from the New Zealand government for BIM development and use. Masterspec (2012) also report that a lack of government intervention was currently limiting BIMs implementation in New Zealand. However, since this survey was carried out (in mid-2013), as already mentioned, the drafts of the New Zealand BIM Schedule and the New Zealand BIM Handbook are currently out with industry for comment, and so it seems that the NZ government (through the auspices of the Building Research Association of NZ, and the Building and Construction Productivity Partnership respectively) is (somewhat belatedly) starting to move towards supporting the use of BIM in the NZ construction industry.

Lack of context for construction methods

All participants agreed that 5D BIM lacks 'intelligence' of construction methods such as wastes, jointing and lapping. One participant opined that wastes and lapping were not as much of an issue, as they can easily be built into the rates used, but items associated with joints were more problematic, as

they are not physical objects incorporated within BIM models: "…*so if you have a beam that butts into a column, that's not actually an object within the model, it's a ghost if you like, but there is definite cost to that junction"*. Shen and Issa (2010) support this view, contending that BIM models do not contain 'Process Construction Quantities', for items which are dependent on construction processes, as opposed to 'Product Procurement Quantities', which are design components which are present in the BIM model, and thus can easily be quantified, e.g. volumes of concrete, or mass of steel.

Training issues

No participants agreed that cost and time implications associated with training staff in 5D BIM are a disincentive for owners/directors to invest in 5D BIM. However, a common theme was that in order to operate in the BIM environment, experts in 5D BIM are essential, and such expertise is scarce at present. Investment in 5D BIM was thought to be worthwhile and advantageous for QS consultancies, due to the commercial benefit which BIM provides, and thus owners were willing to pay for training in 5D BIM. However, it should be noted that the participants all work for a large, global QS practice; smaller, more localized QS consultancies may find that training costs for 5D BIM are a significant challenge to overcome.

Cultural Resistance

Most participants agreed that there is a cultural resistance to change to 5D BIM from traditional quantity surveying techniques. This is also mentioned by Stanley and Thurnell (2014), who contend that the industry's adversarial culture poses another barrier to successful BIM adoption and use for 5D BIM by QSs, and that cultural transformation is a much greater challenge than any technological challenge arising from BIM.

Prohibitive software/hardware upgrade costs

All participants disagreed that software and hardware upgrades associated with 5D BIM were too expensive for directors; it was felt that a large global practice should have the resources available to upgrade software/hardware necessitated by the switch to 5D BIM; however, smaller QS practices may not. Appleby (2012) contends that companies must have the capacity to run varied formats and large volumes of intelligent BIM data, and smaller companies may have difficulty achieving this. All participants indicated the company's hardware systems had no problem running BIM files however for larger projects, due to the large files, its use was slow.

Interview open ended responses

Participants were asked elaborate on the reasons behind the semantic scale ratings they gave to the benefits of, and barriers to, 5D implementation in their large, global consulting QS practice. The main themes identified were:

-BIM models are insufficiently detailed to use for preliminary estimating, but can be used as a bulk-checking tool.
-BIM models are best used for estimating from a developed (approximately 80%) design stage, due to incompleteness at early design stages.
-Bulk checking of extracted quantities is imperative at all stages of design.
-2D drawings are needed for details, contractors and subcontractors, and may always be required.
-The absence of standards/protocols is a major hindrance to implementation of 5D BIM.
-Significant confusion exists around the term 5D BIM, and the difference between 3D and BIM.
-BIM models contain numerous errors and are often incomplete.

-Early QS involvement is extremely important, particularly without the use of BIM standards or protocols.
-An increase in accuracy for estimates and schedules of quantities by using 5D BIM is anticipated in the future.
-The lack of government intervention to drive BIM is a major limitation
-5D BIM increases costs to clients, which is unattractive, and thus is a significant barrier to its use.

Overall, the findings suggested that the benefits of 5D BIM were currently only being achieved to a limited extent, due to a number of barriers inhibiting its full potential; as a consequence, QSs still relied heavily on using traditional methods. Despite this, the perceived future outlook for 5D BIM was exceptionally positive.

CONCLUSION

This research has identified the perceived benefits of, and barriers to, 5D BIM implementation within a large, multi-national consulting QS practice. In addition, it has established that usage of 5D BIM is increasing, and its adoption has the potential to impact the QS profession in every area, and that 5D BIM is anticipated to be where the future direction of quantity surveying lies.

The main perceived benefits of 5D BIM were found to be: increased visualization of the building; a bulk checking device for manual measurement; efficient data extraction for estimating at developed design stages, as well as for producing schedules of quantities; rapid identification and costing of design changes, and provision of a commercial advantage over competitors. However, numerous barriers hindering 5D BIM's implementation were found, the main ones being: design errors and incompleteness in the BIM model; incompatibility with QS standard methods of measurement (e.g. NZS 4202:1995); a lack of industry standards and protocols to facilitate design embedment within BIM models; a lack of context for construction methodologies; the need for extensive manual bulk checking to ensure the correctness of extracted quantities; a lack of government intervention to support BIM, and additional costs to the client.

The benefits of 5D BIM implementation for quantity surveyors and their clients have been established; however, its use in New Zealand remains modest, due to the numerous barriers to its successful adoption. Participants asserted that the greatest benefits to date have been achieved when undertaking BIM in a collaborative environment, in particular, when the QS is involved early on in the design process. Participants felt that some of these barriers will be resolved in the near future, mainly through gaining experience with 5D BIM taking place outside the core BIM model, by live linking it to third party estimating software. Participants had doubts for the feasibility of Level 3 full collaborative BIM, that contains integrated cost data within a single integrated BIM model, and suggested that the ultimate goal of BIM may never eventuate. However, there was a strong indication that 2D drawings would eventually succumb to BIM in the future. Government support driving the development of BIM was thought to be essential, but has been sadly lacking in the past. Hopefully, recent developments on this front will provide forward momentum for the development of BIM in New Zealand, with the drafts of the NZ BIM Handbook (Building & Construction Productivity Partnership, 2014) and NZ BIM Schedule (BRANZ, 2014) out for industry consultation.

Due to the small sample surveyed, the findings of this research are not generalizable to the wider population of consulting quantity surveyors in New Zealand, and aimed only to provide a 'snap shot' of the current opinion on the benefits and barriers of 5D BIM implementation within a single, large global consulting QS practice.

Further research could identify the BIM skills which QSs will need in the future to reach the full potential of 5D BIM, and also investigate specific areas where the development of BIM (including 4D

and 5D BIM) can be supported, for instance by developing methods to improve inter-operability and collaborative working in the BIM environment.

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BIM-BASED ENERGY MANAGEMENT FOR SMART BUILT ENVIRONMENTS

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ABSTRACT

Building Information Modelling (BIM) provides architectural 3D visualisation and a standardised way to share and exchange information about building data. Recently, there is an increasing interest in using BIM, not only during the construction phase, but also the post-construction phase for day-to-day management of the built facility.

Meanwhile, in order to lower the carbon foot print, building energy management is crucial in today's building maintenance. With the emergence of Smart Built Environment technology which embeds most spaces and objects with sensors and actuators, building managers can be provided with the added capability of real-time monitoring and control of their building's energy loads as well as energy resources with the goal of maintaining reliable electricity supply and safe operation.

Although there have been research on various aspects of Smart Environments, very little attention has been focused on the role and application of BIM tools and techniques in Smart Built Environments. This motivates us to explore the use of BIM for day-to-day energy management of future smart buildings where real-time information objects (sensors, smart meters, etc.) and distributed energy resources (DERs) are deployed.

Since BIM is designed to host information of the building throughout its life cycle, the scope of this research has covered from architecture design to facility management phases: first BIM has been extended in the building design phase to provide Material/Device profiling and information exchange interface for sensors, smart meters and DERs; Next, a facility management tool has been designed and implemented to provide advanced energy management functions based on the BIM produced in previous phase. Through a basic but functional prototype of a smart house energy management system using Revit and xBIM toolkit, we have successfully demonstrated that BIM can be utilised for the design and smart energy management of future Smart Built Environments.

KEYWORDS:

Building Information Modelling; Energy Management; Smart Built Environments.

INTRODUCTION

Computer Aided Design (CAD) techniques have been in use by the construction industry since early 1980s. The next paradigm shift was the introduction of Building Information Modelling (BIM) in the field of Architecture, Engineering, and Construction (AEC) in the mid-1990s (Sabol, 2008).

BIM is a methodology enabled by a set of software tools and processes for facilitating the creation and use of a digital representation of the physical and functional characteristics of a facility (Teicholz, 2013). Thus, research on BIM as a methodology has been focused in the following two areas: i) Development of software tools and techniques for creating and evaluating new BIM artefacts that arise as building designs and technologies evolve; and ii) Application and usage of BIM processes across the life-cycle of a building from pre-construction design to post-construction facility management.

Recent rapid advances in Information and Communication Technologies (ICT) have led to their pervasive use across industry sectors, including the building construction. An upcoming and important aspect of ICT use which we anticipate to take a central stage is the construction and management of emerging *Smart Built Environments*. Here, 'smart built environment' refers to a built environment which has

been embedded with smart objects such as sensors and actuators with computing and communication capabilities, making the environment sufficiently 'smart' to interact intelligently with and support their human occupants in their daily activities (Nakashima et al., 2010).

In addition, as buildings are a major source of energy consumption – accounting for 40% of primary energy consumption in most countries (IEA, 2014), a Smart Built Environment will be expected to harness its new technological capabilities to achieve an unprecedented level of energy efficiency.

Therefore, constructing Smart Built Environments can have a set of requirements and procedures not defined or considered in traditional construction settings. Although there have been research conducted on various aspects of Smart Built Environments, very little attention has been focused on the role and application of BIM in pre- and post-construction processes of Smart Built Environments.

The scope of this research covers both the building design and management phases. In this paper, BIM is first extended in the building design phase to provide Material/Device profiling and information exchange interface for sensors, smart meters and DERs; next, a facility management tool is developed to provide advanced energy management functions based on BIM produced in the previous phase.

ROLE OF BIM IN SMART BUILT ENVIRONMENTS

As aforementioned, a variety of smart objects will be ubiquitously and transparently installed in a Smart Built Environment. These smart objects disseminate information and interact with each other. The communication among the smart objects and the servers can be carried by either wireless or wired information networks.

General challenges

A number of questions arise when considering the building life-cycle of a Smart Built Environment. First is how the smart objects are embedded into the environment. From the aspect of sensors, the physical location and the surrounding settings can significantly affect their ability to carry out specific tasks, e.g. ambient light or occupancy sensing. From the aspect of information network, whether a wireless sensor network (WSN) or wired Ethernet is deployed, it should be designed to offer the smart objects an excellent level of communication service.

Second is how the smart objects interact with the environment. The smart objects are situated in a specific surrounding to carry out their tasks and often require the input of space data such as building floor plans. When conducting an analysis, e.g. energy analysis, of the Smart Built Environment, not only the information from sensors/meters is vital, but the building architectural/geometry data are also indispensable.

Third is the maintenance of such smart objects in a building's post-construction phase. It is common for facility managers to complain about incomplete or excessive documentation. To maintain a Smart Built Environment, the building design and construction have to be documented and conveyed to the facility managers. Even if the company that designed and constructed the building is no longer in business, building management can continue to function properly provided that the documented information is both comprehensive and reliable.

Introducing BIM in Smart Built Environments

BIM hosts the collaborative architectural information and provides the semantic knowledge of the building. Therefore, BIM is capable of profiling smart objects in Smart Built Environments and feeding them with relevant building-related information.

Designing Smart Built Environment with BIM is both advantageous and convenient. Firstly, BIM can serve as a data repository for the physical information of smart objects. For maintenance and asset tracking in building post-construction phase, the hardware information of smart objects can be recorded, and their installation locations can be documented and visualised in 3D. Secondly, designers of the Smart Built Environment can utilise the building knowledge of BIM for planning the layouts of sensors, tags, and meters. A methodology to design WSN with BIM is presented by (Guinard et al., 2009) and BIM is shown to

be a powerful tool in such a process. Considering the BIM designed WSN as the communication backhaul, the problem of optimising the layout design of smart objects for their best possible functional performance, e.g. sensing and communication performance, can be more effectively addressed.

On the other hand, BIM provides a perfect ontology database for Smart Built Environments. Smart objects may be designed by different vendors. The data they provide may vary in structure, and they may communicate using different protocols. Middleware is a popular approach to address such issues with heterogeneous smart objects. With the introduction of BIM, each smart object can be profiled through their information exchange interface. Because BIM is standard-compliant, the middleware can extract data formats of smart objects and other building information for viewing as an ontology database.

Energy Management in Smart Built Environments

In Smart Built Environments, energy management can be enhanced through smart objects such as temperature, occupancy, and ambient light sensors that provide data for estimating the building's energy requirements, understanding the building's energy usage patterns, and decision-making by building control systems to achieve a balance between a building's energy efficiency and comfort level of its occupants.

The trend of deploying sensors in office building will only become more and more common in energy management practice. Furthermore, with the introduction of Smart Grid, buildings have an active role in the power system, as they exchange electrical power information with the power grid via their smart meters. Sub-metering systems are also important to achieving energy awareness for building management as they can provide high-resolution monitoring data down to individual appliance level. In this research, we view the smart meters as a type of smart object in the Smart Built Environments.

Another significant aspect that challenges energy management today is the penetration of DERs such as photovoltaic (PV) panels and micro wind turbines. With on-site DERs, the role of building changes from pure energy consumer to both energy producer and consumer (or 'prosumer'). Correspondingly, the role of a Smart Built Environment is also extended to include the tasks of performing energy generation forecast, load scheduling, storing and feeding energy back to the grid. The monitoring and control of DERs is therefore vital for energy management in Smart Built Environments.

In essence, smart meters and DERs can be viewed as real-time information objects, which are a type of smart objects that can be embedded into the BIM design of Smart Built Environments, and the energy management system can benefit from the profiling capability of BIM, as shown in Figure 1.

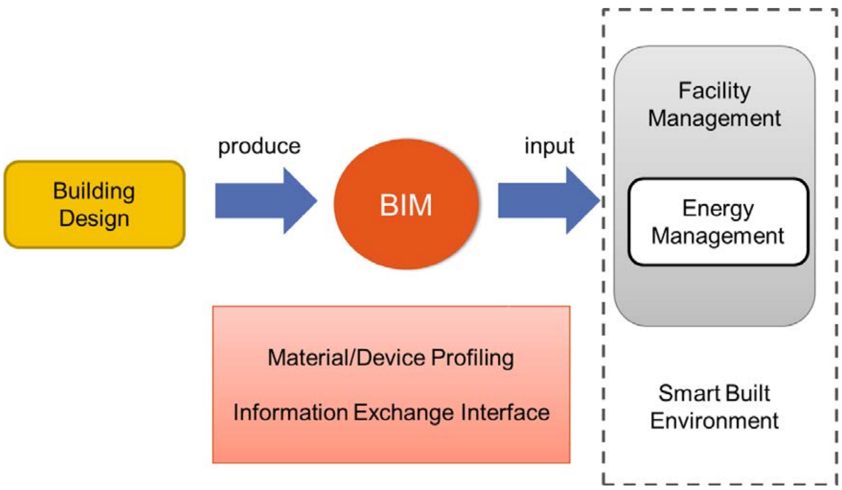
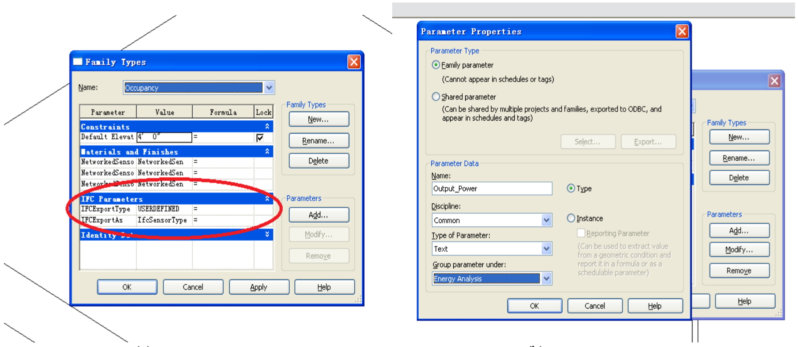


Figure 1. Role of BIM in Smart Built Environments

INTEGRATING BIM IN PRE-CONSTRUCTION DESIGN PHASE

In order to gain an understanding on how BIM can be utilised for energy management in Smart Built Environments, we started by investigating the use case of integrating Smart Built Environment design with BIM. To date, the most popular BIM software are the *Revit* suite from Autodesk and *Archicad* from Graphisoft. In this work, we have extended our BIM designs in Revit, but similar extensions could be made as well in Archicad.

The intention is to profile smart objects with Revit during the building design phase. The produced BIM model with smart objects should be correctly exported as an International Foundation Class (IFC) file, so that other BIM tools can parse the information. We adopted three methods for the profiling: *IFC shared parameter*, *family property parameter*, and the *mark tag*. Autodesk demonstrated how sensors can be modelled in Revit (Autodesk, 2010), and we took a similar approach which uses the IFC shared parameter field to indicate the sensor type in IFC, as shown in Figure 2(a).



(a) (b)

Figure 2 (a) Extending BIM design using "IFC shared parameter"; (b) Adding new parameter properties in Revit

The IFC shared parameter only enables the new smart object family to be a compatible type in BIM. For the information exchange interface which describes the data input/output behaviour of the smart object, family property parameters are added to the smart object. Since this work focuses on energy management, we specify parameters in the energy analysis properties.

As illustrated in Figure 2(b), in order to enable the BIM file (in IFC format) to provide information exchange interface for the facility software, family property parameters are designed to be a mapping from IFC text to the device software programming interface, which can be a middleware or another BIM software. Three types of smart object data operation are defined:

- *Output*: interface from which external software can read the output (generated power, grid signal, or sensed data) of the device. Format in IFC file is: "Output_xxxxx".
- *Input*: interface from which external software can read the power generation or consumption status of the device. Format in IFC file is: "Input_xxxxx".
- *Control*: interface from which external software can control the operation of the device, tilting angle of the PV panel/wind turbine, power consumption of the BACnet compatible smart appliances, etc. Format in IFC file is: "Control_xxxxx".

Finally, to map a smart object from BIM to an individual real-world device, the mark tag in BIM is used. The BIM software which parses the produced BIM file reads the mark tag for the smart object and determines, e.g. the Internet Protocol (IP) address, of the device from a database.

We created and installed sensors, smart meters, PV panel and wind turbine in an example smart house model in Revit. After completing our BIM design process for the smart house, a BIM file in IFC format is generated as shown in Figure 3.

(a)

```
……
#192496=
IFCSENSORTYPE('3Ea9KIygfFOf3hy58KLU_a',#52,'Occupancy',$,$,$,(#192495),'211594','Occupancy',.USERDEFINED
.);
……
#186580= IFCBUILDINGELEMENTPROXY('31vPjYM8b9$Aof7XNLJOFw',#52,'Wind Power Generator_modified:60"
High:60" High:201370',$,'60" High',#186579,#186574,'201370',.ELEMENT.);
#186581= IFCPROPERTYSINGLEVALUE('Mark',$,IFCLABEL('OutdoorWindTurbine'),$);
#186583= IFCPROPERTYSINGLEVALUE('Input_windspeed',$,IFCINTEGER(0),$);
#186586= IFCPROPERTYSINGLEVALUE('EnergyResource',$,IFCINTEGER(1),$);
#186587= IFCPROPERTYSINGLEVALUE('Control_angle',$,IFCPLANEANGLEMEASURE(0.),$);
#186590= IFCPROPERTYSINGLEVALUE('Output_power',$,IFCINTEGER(0),$);
……
```

(b)

Figure 3. (a) Example smart house model with PV, wind turbine, sensors and smart meters; (b) Code segment of the BIM IFC file

INTEGRATING BIM IN POST-CONSTRUCTION FACILITY MANAGEMENT PHASE

The BIM file generated from Revit in the previous section is an output from the designer or architect of the Smart Built Environments during the building design phase. In post-construction facility management phase, the building manager can apply the information in this BIM file to perform day-to-day building management, including energy management.

To parse the BIM file and read the profiled information, there are two possible options for the design of this research. The first is to extend the Revit using a native Software Development Kit (SDK) to perform the energy management task. The second is to develop a standalone BIM tool as a separate energy management engine. After much contemplation, we decided to go with the second option as we believe that building managers will be more familiar with using Building Management System (BMS) for their everyday work than with Revit, which is intended as a computer-aided design (CAD) tool for building designers and architects.

Therefore, we opted for the second option and a stand-alone BIM tool for energy management is developed. We developed the tool using the extensible building information modelling (xBIM, 2013) toolkit which provides IFC parsing and 3D presentation utilities.

As different smart objects may have different data input/output interface, the properties parameter specified in our BIM design in the previous section provides a convenient way for the BIM tool to

handle such low level operations. An *adapter layer* is designed in this research to process the requests from BIM software which parses the IFC file and demand data exchange for the smart object. The mapping/parsing operation is illustrated in Figure 4. The software architecture for our developed BIM tool is shown in Figure 5.

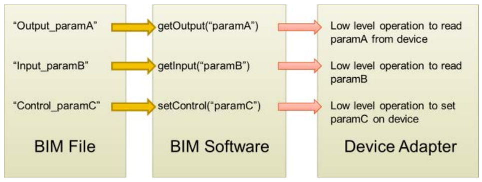


Figure 4 Mapping from BIM file to software information interface programming

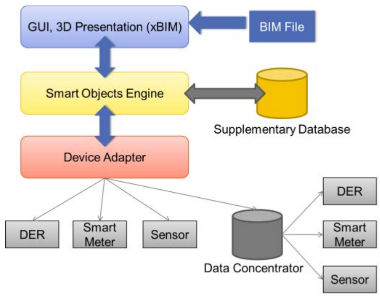


Figure 5. Software architecture

Real-time data from the DERs, smart meters and sensors are collected and stored in a database. Figure 6 shows an instance of the real-time monitoring data from a living room sensor displayed to the user, e.g. home owner or building manager.

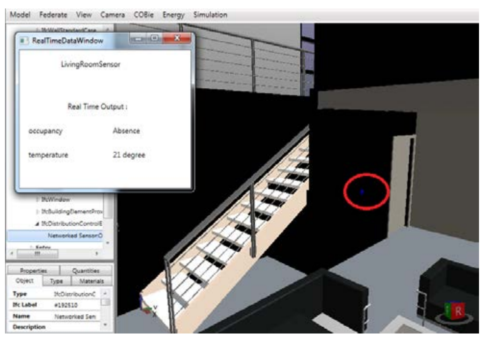


Figure 6. Real-time monitoring data display to user

With real-time data from the smart objects, energy management and analysis in BIM software are facilitated and achieved. Real-time generation data of on-site DERs show the current energy production capacity and indicate how many loads can be supplied off the power grid. Weather, temperature, building and occupant data from sensors forms a view of the present and future energy generation/consumption as shown in Figure 7. The pricing information from the smart meter allows the building to perform demand response actions in coordination with the power grid.

In our BIM tool, we demonstrated the energy management functionality through a simulation of demand shifting. When the real-time pricing information from the smart meter reaches a user-defined threshold, the software triggers the demand shift process and transmits control commands to the energy consuming appliances.

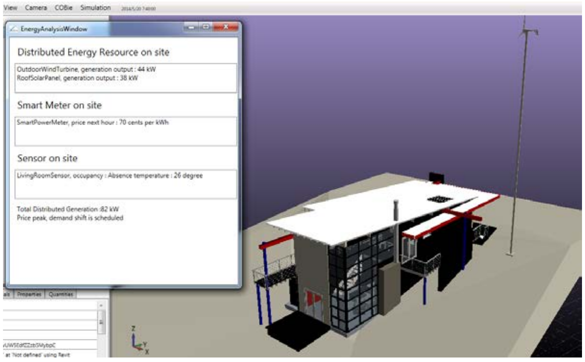


Figure 7. Energy analysis functionality

RELATED WORKS

To the best of our knowledge, there are no existing BIM-based solutions for energy management in Smart Built Environments which are Smart Grid ready. However, there are a number of existing works on integrating BIM with real-time information.

The Autodesk research group integrated BIM with sensors and meters to provide 3D visualisation of building performance and life-cycle operation (Attar et al., 2010).

The Virtual Real-time Information System (VRIS) combines the Onuma cloud-based BIM tool (Onuma, 2013) with a real-time sensor engine called Virtual Real-time Operating Centre (vROC) to provide building management functions (Lavelle and Onuma, 2014).

CONCLUSION

In this paper, the findings and experience gained from an investigation on how BIM can be developed and utilised for energy management in Smart Built Environments are reported. Our work covers the investigation of BIM extensions for both pre-construction design and post-construction management of Smart Built Environments in the Smart Grid era. We are currently extending our work to develop BIM software tools for automated management of BACnet compliant HVAC systems, and investigating the concepts of Virtual Power Plant for future Smart (Gridable) Built Environments.

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A FRAMEWORK OF THERMAL SENSITIVE URBAN DESIGN BENCHMARKS: POTENTIATING THE LONGEVITY OF AUCKLAND'S PUBLIC REAM

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ABSTRACT

One of the key objectives of contemporary urban design is to ensure the quality and activity within urban public spaces. Presented as a progressively emerging paradigm in this process, the effects of urban climatology are increasingly elucidating the need for further climate responsive environments. Having the possibility to contribute to the quality of life within cities, there is a strong developing interest in the quality of urban public spaces due to their role in establishing microclimatic thermal comfort levels (Katzschner, 2006). Moreover, this interest is one that shall increase along with the progression of climate change effects upon outdoor environments.

Nevertheless, it is often that climatic assessments lack bottom-up climatic indicators, tools and practical benchmarks (Matzarakis and Amelung, 2008). As a result, this obstructs local decision making, and practices of localised adaptive design.

This paper is launched with the view that the sustainable development of a city primarily depends on the capacity of architects and urban designers to offer outdoor urban spaces with high environmental quality. In this scope, the multifaceted practice of microclimatic attenuation plays a fundamental role (Reiter and Herde, 2011).

Accordingly, these interdisciplinary professions are now challenged with overcoming the distinct fissure between climatic knowledge and physical application. In an effort to address such discrepancies, the paper launches a framework of international precedents of built and conceptual projects that address thermal comfort levels in public spaces. This organisation will be cross-referenced with theory that supports its structure and typological division.

With Auckland as the focal case study, the solutions that are extracted from the framework will be hypothetically scrutinised in terms of options for alleviating given events of increased temperature and heat waves within the city. In this way, microclimatic concerns are hence framed into an opportunity to potentiating the use, and longevity, of Auckland's public realm.

KEYWORDS:

Urban Design; Public Space; Thermal Comfort; Climate Change

1. INTRODUCTION

Before reaching the mid-twenty-first century milestone, it is expected that population, urban density and CO_2 emissions shall significantly increase in Auckland. Consequently, sustainable decision making becomes fundamental in amalgamation with the council's aim to make Auckland the world's most liveable city by 2040 (Auckland-Council, 2013). In conjugation with this expansion, the practice of urban design is also presented with the interdisciplinary challenge of preparing for impending events as a result of climate change.

Although knowledge regarding outdoor thermal comfort has grown in recent years, its assimilation with climate sensitive urban design has been considerably limited. As a result, local decision makers and designers often lack the design indicators and benchmarks to: (1) address existing microclimatic implications in public space design; and more prominently, (2) prepare for the invigoration of these respective insinuations as a result of climate change. With the prospect of tackling such a discrepancy, and through a Research for Design approach, this article explores existing practices and measures that could potentially be used as design and/or policy benchmarks to address microclimatic implications in Auckland's public realm. Additionally, and as part of an ongoing doctoral research, Auckland will be used as a representative case study on how a framework of thermal sensitive urban design measures can be built to aid local climate-responsive public space design.

2. NEW ZEALAND'S CLIMATE AND FUTURE IMPLICATIONS

As a means to identify a basis for climatic regionalisation and comprehend variables from Global Circulation Models (GCMs) outputs, the Köppen-Geiger (KG) climate classification system has classified New Zealand as a Temperate/Mesothermal climate. More specifically, and supported by a top-down outlook, the updated world map of the KG system classifies this genre of climate as 'Cfb', meaning a 'Maritime temperate climate' or 'Oceanic climate' (Peel, Finlayson and McMahon, 2007). Resultantly, this is concomitant with temperature fluctuations associated with large-scale climate patterns over the Southern Hemisphere and the Pacific Ocean. These meteorological phenomena have a temporal timeframe that can range from seasons to decades, such as the El Nino-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO). Each of these oscillations can influence seasonal temperatures, wind patterns, and precipitation levels (MfE, 2008). Consequentially, this natural variability invariably blurs the superimposition with long term human-induced climate change trends.

Based on the disseminated figures from the National Institute of Water and Atmosphere research (NIWA), New Zealand does not have a broad temperature range, and it lacks extreme values that are commonly found in most continental climates. Moreover, and due to being located in the Southern Hemisphere, northern cities experience higher temperatures throughout the year. As shown in Table.1, Auckland is one of these cities and is one of the warmest city centres in New Zealand.

Table 1 – Summary climate information for the six main City Centres in New Zealand[1]

Location	Mean Relative Humidity	Wet-days	Sunshine	Temperature				Wind Speed
	% (9am*)	>= 1.0 mm	Hours	Mean °C	Mean Max °C	Mean Min °C	Hot Days (Max Temp.** > 25°C)	Av. Wind Speed m/s
Auckland	82.3*	137	2060	15.1	19.0	11.3	21	4.72
Tauranga	78.8	111	2260	14.5	19.1	10.4	21	4.44
Hamilton	85.0	129	2009	13.7	18.9	8.7	28	3.33

[1] * Average Relative Humidity levels were taken at 9am, hence these figures vary approximately if combined with afternoon RH levels – For the case of Auckland this would decrease annual RH approximately to 76%. ** Annual count of 'hot days' where temperatures exceeded 25°C – values presented are annual averages since mid-twentieth century. Wet-days, sunshine, temperature, and wind speed data are mean values from the 1981-2010 period. Average Relative Humidity data are mean values from the 1981-2010 period.

Wellington	82.3	123	2065	12.8	15.9	9.9	3	6.11
Christchurch	85.1	85	2100	12.1	17.2	7.3	21	4.17
Dunedin	73.1	124	1585	11.0	14.7	7.6	8	4.17

Source: Adapted from (National-Climate-Centre, 2013, Mackintosh, 2013a, Mackintosh, 2013b)

Due to being encircled by the Pacific Ocean, the country is expected to experience a delay in mean temperature change in comparison to global averages over the medium term (Gluckman, 2013). Notwithstanding, national climate change projections indicate 'very confidently' that until the end of the century there shall be: (1) a temperature increase of between 0.2-2.0°C by 2040, and between 0.7-5.1°C by 2090; (2) an increased frequency of high temperatures; and, (3) an accelerated rate of temperature increase in comparison to the temperature patterns recorded for the twentieth century (MfE, 2008).

At a regional scale, and returning to the case of Auckland, it is a projected that by 2100, there will be at least 40+ extra 'hot days' where maximum temperatures surpass 25°C (PMCSA, James Renwick, and NIWA in Gluckman, 2013). In retrospect with current values shown in Table 1, this implies that there will be a 200% increase in annual 'hot days'. Moreover, it is also worth noting that also due to the proximate 'ozone-hole', the county's peak Ultra Violet (UV) intensities can be 40% higher in comparison to similar latitudes in the northern hemisphere (e.g. the Mediterranean area). Although an UV index of 10 is already considered extreme, this index value can exceed 13 during the summer in cities such as Auckland.

In this light, perspectives towards the future adjoin the opportunity to deliberate upon more frequent and intense temperature levels in the city. Consequently, contemporary urban design embraces the need to certify that thermal comfort levels are addressed in the intricate balance between the urban microclimate, human characteristics, and the use of public spaces (Oliveira and Andrade, 2007). Regrettably, although the characteristics of urban climate have been well studied in the past two decades, there is little association with the possible application of physical urban design interventions.

In the case of Auckland, although it shall face more attenuated climatic effects in comparison to global averages, its Unitary Plan (UP) invariably recognises the need to "*increase the resilience of Auckland's communities and natural and physical resources to the anticipated effects of climate change such as (…) more frequent and extreme weather events*." (Auckland-Council, 2013, p.174). Moreover, and presented as a 'Quality urban growth objective' in the UP, there is also an ardent interest in a "*high quality network of public open spaces and recreation facilities that enhances quality of life (…) and contributes positively to Auckland's unique identity.*" (Auckland-Council, 2013, p.178). Given the recognition of future climatic implications, and the importance of Auckland's public spaces, urban resilience and adaptability becomes a fertile scope of opportunity for local action. In this way, local decision makers and designers are hence tasked with considering the long-term longevity of the city's public realm that shall determinedly face climatic hurdles until the end of the century.

3. URBAN DESIGN BENCHMARKS

Since the turn of the century, the maturing climate change adaptation agenda has gained a new weight, and has instigated local decision makers and designers to search for measures to address local 'risk factors' (Costa, 2011). This early, yet developing bottom-up perspective, is one that explores how urban design and climatic adaptation can tackle meteorological implications through an interdisciplinary approach. This section explores existing practices and measures that can potentially be used as benchmarks to address the impending threat of increased temperatures and heatwaves upon Auckland's public realm. In order to facilitate the typological differentiation between the discussed measures, and adapted from authors such as (Nikolopoulou, 2004, Erell, Pearlmutter and Williamson,

2011), four principal categories have been respectively established: (1) trees and vegetation; (2) Shelter Canopies; (3) Materiality; and lastly, (4) Water and vapour systems. Accordingly, existing practices are viewed as an opportunity to shape new potential measures based on global scientific discourse, and backed by mutual interest in adapting to climate change.

3.1 Trees and Vegetation

When considering the long term environmental adaptability of a city, it is consensus that vegetation can significantly contribute to the improvement of the urban microclimate due to its ability to reduce air temperature through direct shading[2], and evapotranspiration. More specifically, these processes induce the decrease of radiant temperature, influence wind patterns (both in velocity and direction), air regeneration (such as CO_2 absorption), and filter both dust particles and noise. Moreover, and besides these environmental attributes, vegetation can also provide additional psychological benefits to humans through aesthetic, emotional and physiological responses (Tsiros, 2010).

In existing studies relating to vegetation as a form of microclimatic control in urban open spaces, four principal green 'structures' can be identified: covering vegetation, isolated trees, groves or lines of trees (Picot, 2004). However, it is important to note that unlike inanimate devices, trees can change their dimension and degree of opacity during each season, and also during their lifetime. As a result, and although variations among trees may be considered aesthetically pleasing, the designer/planner needs to be aware of the shading pattern produced (Picot, 2004, Erell, Pearlmutter and Williamson, 2011). In terms of seasonal timeframes, there needs to be a consideration of: (1) how shade patterns can be provided in the summer when/where needed; (2) how solar penetration can be enticed during the winter period when/where needed; and, (3) which specific trees provide these desired effects during the pertinent time of year.

Regrettably, and although recognized as an effective way to alleviate higher temperatures, the incorporation of these vegetation reflections upon thermal sensitive urban design is limited. Yet, authors such as Shashua-Bar, Tsiros and Hoffman (2012) have explored the potential of passive cooling modelling design options on outdoor thermal comfort in urban streets in the shade of both trees and buildings. In their research, they analysed how street design scenarios benefited from the combination of vegetation with other measures in order to attenuate thermal comfort levels during the summer. To do so, the biometeorological index Physiologically Equivalent Temperature (PET) was used in order to assess levels in a typical street of Athens. Four theoretical design cases were undertaken: (1) increasing the trees canopy coverage area from its actual net level of 7.8% to 50%; (2) reducing traffic load from two lanes to one and thus approximately reducing 1500 vehicles down to 750 per hour; (3) increasing the albedo of the adjacent side walls from the measured 0.4 to 0.7 by implementing lighter colours; and lastly, (4) deepening the open space by increasing the aspect ratio (height/width proportions) from the existing 0.42 to 0.66 through elevating the side buildings by two additional floors (approx. 6m) (Shashua-Bar, Tsiros and Hoffman, 2012). The results of the study illustrated that the most successful passive design solution was that of increasing the vegetative canopy coverage that resulted in a decrease of 1.8K during noon hours. This is particularly interesting when comparing to the more drastic and expensive option of increasing the aspect ratio, which achieved a similar decrease of 1.9K.

Conversely, when applying this to Auckland, it is clear that due to its more temperate climate, considerations would need to be made upon the issue of overshading. Nevertheless, the constructed Parisian climate sensitive redevelopment-project, 'Place de la Republique' (also located in the KG classification of 'Cfb') can be used as a practical example of how these issues can be resolved (Case

[2] Although there is still a limited amount of research regarding the direct effect of vegetative shading at pedestrian levels, the doctoral thesis of Ana Almeida suggests that *"trees, just like other green spaces inserted in edified areas can lower temperatures by approximately 3°C"* Almeida, A. L. B. (2006). O valor das árvores: árvores e floresta urbana de Lisboa. Doctoral thesis in Landscape Architecture, Instituto Superior de Agronomia

1). Trevelo & Viger-Kohler Architects and Urbanists aimed at addressing the thermal comfort and Urban Heat Island (UHI) effect within the now largest pedestrian square in Paris. Today, an overall of 134 deciduous plane (*Platanacease*) trees and 18 deciduous honey locust (*Fabaceae*) trees encircle both the new perimeter and central area. Unlike the common segregation between vegetation and the thermal design of the public space, and in line with their environmental approach, the square is "*comfortable as a result of a strategy that is at once urban, landscaped and architectural*" (TVK, 2013, p.7). More specifically, this strategy consists of implementing measures that prevent the square from becoming a 'heat island', namely by: (1) increasing planting and creating a unit of vegetation to provide maximum mass effect; (2) allowing the sun to penetrate and position the pedestrian areas in the sunniest areas; (3) blocking the colder winter winds by thickening the vegetation in the north of the square; and just as importantly, (4) linking the presence of vegetation in order to consolidate usage dynamics in the square to suit prevailing conditions (TVK, 2013).

Returning to the temporal timeframe of 2040, Auckland is challenged with considering the specific implications of how vegetation can be appropriately introduced in order attenuate thermal comfort levels, and relieve symptoms caused by the UHI effect. Respectively, and strengthened by the approaches presented in this first section, it is suggested that future projects must consider vegetative: (1) annual shading patterns; (2) change in dimension and degree of opacity; (3) contributions to decreasing the UHI effect; and lastly, (4) effects upon the activity threads, and usage of the urban realm in accordance with prevalent microclimatic conditions. As an example, this will be particularly relevant in 'Move 6' of the Auckland's Masterplan; that suggests an ecological 'Green Link Network' that shall insert a 'wave' of green vegetation to enhance the environmental sustainability at street level as part of the redesign of Victoria Street and adjacent open spaces (Auckland-Council, 2013).

3.2 Shelter Canopies

When addressing canopies or roof structures in urban open spaces, the air temperature underneath the structure is predominantly affected by the existing solar exposure of the space. In turn, this directly relates upon the geometry of the structure, components, and the properties of its construction materials. The respective radiant temperature is interrelated to the temperature of the inner surface of the roof, which can be either lower or higher than the air temperature of the space underneath. Furthermore, the air velocity in the spaces underneath depends ultimately on the incoming wind/air patterns that are allowed to enter/penetrate the area.

In the case of Auckland's Central Business District (CBD), passive strategies to decrease solar radiation through shelter canopies are already present. Yet, and using Queen Street as an instance, most measures are only applied upon commercialised street sidewalks, and not within local open public spaces. With hindsight, civic spaces such as Aotea Square, Freyberg Square, and Queen Elizabeth Square are currently recognised by the UP as "*becoming increasingly important as Auckland's centres intensify and access to high-amenity open space is needed for residents*" (Auckland-Council, 2013, p.58). Perhaps due to the fear of overshading, these spaces do not accommodate passive structures that decrease and/or attenuate local solar exposure. Although this is beneficial during the winter months (i.e. June to August), there is limited shading that would otherwise entice the increased usage of these spaces during the summer. Interestingly, prominent studies in the use of New York's public spaces suggest that "*the days that bring out the peak crowds on plazas are not the sparkling sunny days with temperatures in the* [low 20°Cs] (…) *it is the hot, muggy days, sunny or overcast, the kind that could be expected to make people want to stay inside and be air conditioned, when you will find the peak numbers outside*" (Whyte, 1980, p. 44). Following this line of thought, the interplay of canopies regarding the provision of choice between experiencing sun, shade, or in-between areas becomes indispensable.

However, before any intervention can be considered, there needs to be a local and annual understanding of: (1) the patterns of existing solar radiation exposure (usually measured in hours); (2)

the shadows that are cast from on-site elements (i.e. such as vegetation and amenities); (3) the shadows that are cast from off-site elements (i.e. such as contiguous structures and buildings); and, (4) existing encircling wind patterns[3].

Once established, thermal sensitive urban design can present the opportunity to improve the current thermal response of these spaces in both colder and hotter months. More prominently, the long term response to increased higher temperature and frequency in Auckland can be tackled through a precautious approach. In this scope, both permanent and temporary measures can be considered to increase local shading opportunities.

In the pursuit for case studies that have used shelter canopies in their bioclimatic approach to the public realm, permanent solutions can be extracted from the entries from the European competition 'Re-Think-Athens'. Although situated and tempered for a hotter climate (i.e. 'Csa' in the KG classification), many of the proposed measures can be adapted to Auckland's public realm and enclosing climate. The winning proposal 'One Step Beyond' (Case 2) by OKRA Landscape Architects based their design upon a pedestrian-orientated space that incorporated contemporary ideas of climate control in order to address thermal comfort through microclimatic attenuation (Knuijt, 2013). In one of the public spaces within the redevelopment proposal (Omonia square), a limited amount of shelter canopies were introduced into the space. Although the four canopy structures shade less than 10% of the total area of the public space, they are strategically placed on the extremities of the square alongside kiosks and food/beverage units. As a result, the risk of overshading during the winter is null, nonetheless, effective shading is still accomplished during the summer in strategic locations.

Another noteworthy and runner up entry was the submission of ABM Architects 'Activity Tree' that although shall inevitably remain as a concept, offers nevertheless valuable precedents in terms of shelter canopies (Case 3). Established through an in-depth site analysis, the zones which would require protection/attenuation from solar radiation were to be protected by 'Activity/Bioclimatic Trees'. These canopies would cast shadows in specific areas and would serve as an advanced bioclimatic device that would be able to capture energy and water[4]. Through a detailed analysis of sun patterns, and in order to permit solar penetration during the winter, the structural celosias system allowed the winter sun to penetrate the covered spaces.

Additionally, it is also worth noting that short term interventions also find their niche in this category of thermal responsive urban design. Here, design can also be interlinked with ephemeral projects in order to tackle periods of higher temperatures and/or heat waves in public spaces. As an example of an Ephemeral Thermal Comfort Solution (ETCS), Ecosistema Urbano Architects launched the conceptual project 'This is not an Umbrella' (Case 4). Although a simple concept, it is a lightweight and low cost solution which enables the climatic control of a large outdoor space. The proposal is thought of as a citizen participation action that uses 1,500 hanging umbrellas to shade the patio of the Spanish Matadero Contemporary Art Centre. Lastly and also erected in the exterior of a contemporary Art Centre in New York, nArchitects built an ETCS to provide relief from the hot summer weather. With the use of a precise 3D model, the 'Canopy' was built with freshly cut green bamboo that provided armature for four different microclimates, which were also attenuated with three different water systems (Case 5).

Resultantly, both long-term and ETCS canopies find their role in attenuating urban thermal comfort levels. In the case of Auckland, this genre of intervention should be used to enhance availability of

[3] Although the detailed techniques to calculate such issues surpasses the scope of this paper, it is worth noting that these calculations can be accomplished through the use of 3D modeling software that enable the investigation of local Sky View Factors (SVFs), and Computational Fluid Dynamics (CFD) for indicative wind speeds beneath the Urban Canopy Layer (UCL).
[4] For more information on the device visit: https://www.abmarquitectos.com/ingles/indexIngles.html

choice between exposed and shaded areas throughout the year. Moreover, the necessity of providing such choice shall increase along with the projected escalation of annual hot days in light of climate change. However, in order to avoid overshading the city's public realm, careful analysis of existing solar patterns, shadows, and wind configurations is required. As demonstrated in the cases disclosed in this section, tempering of thermal comfort levels can only be accomplished through the understanding of local annual microclimatic implications.

3.3 Materiality

The phenomenon of UHI effects are becoming increasingly more intense in cities, and are consequentially coercing modifications in the urban microclimate. Apart from the risk of inducing thermal discomfort, increased air temperatures also can originate energy efficiency concerns due to increased energy consumption and inflated running costs (Santamouris, Papanikolaou et al., 2001).

Nevertheless, the thermal properties of the materials within the urban environment are amongst the most prominent factors in terms of influencing the UHI effect. With regards to the public realm, the presence of dark coloured surfaces in pavements result in the diurnal absorption of solar radiation, which is then released in the form of heat during the night. Accordingly, the use of high albedo urban surfaces can be an inexpensive measure that can potentially reduce summer time temperatures. In a study conducted by Synnefa, Santamouris and Livada (2006), it was concluded that, in general, the higher the reflectance and emissivity of material and/or coating, the cooler the surface remained. Accordingly, materiality also finds its niche in potentially attenuating urban surface temperatures within the public realm.

On reflection, the Parisian redevelopment La Place de Republic (Case 1) is a clear demonstration of how materiality can be directly used to address the UHI effect. More specifically, the local UHI effect was used as a design generator to reconfigure the area's surface materials, whereby: (1) the shady zones of the square were paved predominantly in darker colours; and, (2) the open spaces were paved predominantly with generally paler colours. Similarly, the 'One Step Beyond' project (Case 2) also state in their proposal that "*the benefit of using cool materials such as light asphalt, light concrete or light natural stones, is their high reflectivity and albedo. Cool materials guarantee less absorption of radiation and lower surface temperatures compared to other conventional materials. Through this reduction of heat storage in urban materials, the process of cooling down ambient air temperature at night accelerates, which moreover implies reduction of energy demand by air-conditioning at night*" (Knuijt, 2013, p.14).

In the long term and when considering the implications of UHI effects in Auckland, it is essential to ruminate that the city is expected to grow by one million inhabitants by 2040. Naturally, the increased urban density in juxtaposition with increased temperatures will lead to the effects of UHIs becoming an increasingly pressing issue for local thermal urban design. As demonstrated in existing theoretical and practical knowledge, materiality can play an effective, yet economical, way of tackling such challenges. Moreover, and considering that most of Auckland's CBD has an extensive amount of dark pavements, the deliberation upon urban surface albedo becomes a key issue in order to reduce surface temperatures during the summer.

3.4 Water and Vapour Mechanisms

This article has hitherto discussed the influences of vegetation, shelter canopies, and materiality upon thermal sensitive urban design. This section shall discuss the opportunities presented by water/vapour systems and shall examine their possible application in Auckland's public realm.

Previously, the presence of water and misting systems were customarily focused upon aesthetic and sculptural purposes in public space design. More recently however, there has been a considerably

greater emphasis upon their interconnection with bioclimatic comfort in outdoor spaces in terms of adaptation efforts to climatic conditions (Nunes, Zolio et al., 2013). As a result, water and misting systems have taken on a new meaning in public space design.

Awarded the first prize in a local competition to re-develop the Khan Antoun Bey Square in Beirut, PROAP Landscape Architects (Case 6) explored a conceptual solution to improve outdoor thermal comfort standards. The dominant bioclimatic measure used in this project was a misting system, which in combination with vegetation, canopies and materiality, tackled hot-humid summers, and high solar radiation rates. This launched a deeper research into the effectiveness of temperature control systems in outdoor spaces by inducing evaporation through misting systems. The research concluded that misting-cooling systems can be complex, and its associated equilibrium with encircling air humidity is fundamental. In warm-humid summer climates, such as that of Auckland, water spraying and evaporation are more complex due to the existing amount of water already present in the atmosphere beneath the UCL. Subsequently, water pressure, nozzle types, and functioning periods become crucial in forming the correct droplets with the adequate amount of temporal intervals (Ishii, Tsujimoto and Yamanishi, 2008).

Following this line of reasoning a little further, although smaller Sauter Mean Diameters (SMDs) may lead to faster evaporation; larger SMDs can lead to more effective cooling, though at the expense of prospectively wetting surrounding surfaces (Alvarez, Rodriguez and Martin, 1991). So far, results presented by Japanese CFD studies have shown that there is no significant difference in temperature reduction for different SMD sizes, yet larger water particles (≈ 32.6 μm) remain longer in the air (Yamada, Yoon et al., 2008). Notwithstanding, Yamada, Okumiya et al. (2006) undertook a field experiment in Japan to explore the actual effects of sprayed micro droplets under a canopy in an urban open space. With the objective of decreasing both local air temperature and UHI effects, the results of the test showed that a total reduction of 3K was accomplishable.

These studies illustrate that although Japan has relatively high humidity levels, lower evaporation rates still do not impede the application of misting systems to cool down temperatures and attenuate UHI effects. Moreover, studies by Farnham, Nakao et al. (2011) showed that surface wetting can be practically eliminated by elevating the height at which the misting nozzles are installed in semi open spaces[5].

Earlier, and within the European context, developed by an interdisciplinary group led by the department of Energy Engineering and Fluid Mechanics from the College of Industrial Engineering of Seville, the Expo of 1992 in Seville (Case 7) was approached as a method to synthesis bioclimatic techniques with public space design. The various new techniques that were tested and installed concentrated on misting systems and bodies of water, namely the: (1) continuous blowing of air through a fan that was permanently kept moist; (2) installation of 'micro' water nozzles in tree branches that created droplets with an average SMD of around 20.0 μm, where colder air then flowed downward, hence cooling the shaded areas; (3) 'sheets' of water in the form of ponds and waterfalls that cooled the spaces through evaporative cooling and strategically placed irrigation outlets (Velazquez, Alvarez and Guerra, 1992). Integrated with vegetation, canopies, and materiality, the public realm of the Expo was divided into three different types of spaces: (1) "Passage Areas" – with the prime functionality of supporting the main flow of pedestrians, with an expected 'use timeframe' of below 15 minutes; (2) "Rest/Stay Areas" – with the primary goal of offering places for resting, eating, and social congregation, with an expected 'use timeframe' of over 15 minutes; and lastly, (3)

[5] In this particular experiment, a total of cooling of 0.7K was observed without wetting adjacent surface temperatures. This was accomplished by single nozzles spraying mists with a SMD of 41 – 45 μm, moreover, the resultant increase of encircling humidity had little or no effect on the thermal comfort as demonstrated by the identified Effective Temperature (ET). However, mists with greater SMD will cause surface wetting even from heights of 25m and is hence not suggested for cooling urban pedestrian spaces. Farnham, C., M. Nakao, M. Nishioka, M. Nabeshima and T. Mizuno (2011). "Study of mist-cooling for semi-enclosed spaces in Osaka, Japan." Journal of Urban Environmental Pollution 2010 **4**.

"Adjacent Areas" – that were spaces of interconnectivity between the former. This theoretical division between Passage, Rest, and Adjacent areas aided thermal comfort design to be divided into medium level, high level, and low level thermal conditioning respectively.

Although Velazquez, Alvarez and Guerra (1992) argue that surface wetting leads to resource wastage, a more recent misting technique built into a French square can be explored to counteract such results. Also situated in a 'Cfb' climate, the project Le Miroir d'Eau (Case 8) by Michel Corajoud, Pierre Ganger, and Jean-Max Llorca initially aimed at reintroducing vegetation into the space in order to attenuate the local microclimate. However, and based on the concept of addressing thermal comfort levels and reflecting surrounding facades, the 'water mirror', and an incorporated on-site fog system (also based on a 'micro' nozzle system) were installed. In order to avoid algae and water wastage, the water which temporarily floods the square recedes back into the slabs after a few minutes, leaving the surface dry like in any other square. Grooves were installed in-between the granite slabs, to allow the water to be recollected, and re-prepared for the next induced 'flood'. In this way, wet surfaces become part of the design of the system which increases the climatic responsiveness of the once thermally problematic public space.

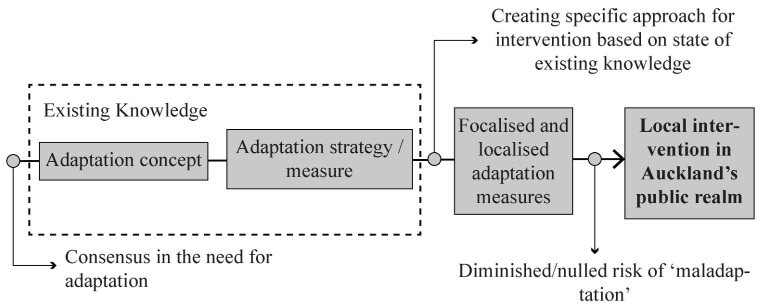
Returning to the ephemeral perspective, and as already discussed through the 'Canopy' project (Case 5), misting systems and water bodies have also been translated into ETCSs within the public realm. In this scope, one can also refer to the 'CoolStop' project (Case 9) by Chat Travieso Design, which in collaboration with the NYC Department of Transportation, designed a temporary misting system during an annual event that pedestrianized seven miles of the city's streets. Constructed out of PVC piping, and operated through a hydrant unit, the misting system cooled the microclimate during the summer heat in New York's public spaces.

Accordingly, and referring back to Table 1, Auckland's relatively high humidity levels need to be carefully deliberated when considering the application of water and misting mechanisms. As identified by Yamada, Yoon et al. (2008), such mechanisms tend to be more intricate in attenuating thermal comfort levels when the relative humidity surpasses the 70% mark. Nonetheless, this does not infer their inapplicability. Instead, three approaches can aid their applicability in Auckland's public realm, whereby: (1) surface wetting is undesired - requiring careful consideration of necessary water pressure, nozzle type, altitude, and functioning period/intervals; (2) surface wetting is permitted and water is reused within the system - requiring hence water runoff deliberation; (3) ETCS are installed as a temporary measure during the summer period. Even so, it is still necessary in all approaches that local microclimatic factors are considered in order to fully exploit the potentiality of such measures in attenuating thermal comfort levels.

4. FRAMEWORK ILLUSTRATION AND DISCUSSION

As aforementioned, climate change adaptation has grown exponentially within both the global scientific and political arenas. Accordingly, one can witness the increasing global ambition amongst decision makers and designers to diminish the gap between theory and action with regards to local adaptation measures (Nouri and Matos Silva, 2013). As shown in Figure 1, in order to introduce effective local climatic measures in Auckland's public realm without the risk of ineffectual adaptation (i.e. maladaptation), local agents must focalise their adaptation endeavours around specific local risk factors through a bottom-up attitude. In this way, existing knowledge within the adaptation agenda must subsequently be refined into an appropriate response through a 'case by case' attitude. All the same, the gap between theory and action with regards to thermal comfort attenuation is extensive, leading to a lack of precedential benchmarks, indicators, and examples that could otherwise aid local decision making and design. Having Auckland as the central case study, Table 2 demonstrates the bioclimatic case studies from the international arena that address similar microclimatic constraints that are already, or shall soon be, witnessed in the city.

Figure 1 – Proposing adaptation measures which focalise upon Auckland's public realm and local risk factors.



Source: Adapted from (Nouri and Matos Silva, 2013, Proceedings presentation slide)

Table 2 – Framework of relevant bioclimatic case studies within the international arena

N	**Project Title**	**Status**	**Location**	**Categorical Division**	**KG Climate Classification**	**Temporal Scope**
Case 1	'Place de la Republique' Re-Dev.	Cons. (2013)	Paris	Trees/Vegetation Materiality Water/Vapour	'Cfb'	Long-Term
Case 2	'One Step Beyond'	Under Cons. (2013-2015)	Athens	Trees/Vegetation Shelter/Canopies Materiality Water/Vapour	'Csa'	Long-Term
Case 3	'Activity Tree'	Conceptual (2013)	Athens	Trees/Vegetation Shelter/Canopies Materiality	'Csa'	Long-Term
Case 4	'This is not an Umbrella'	Conceptual (2008)	Madrid	Shelter/Canopies	'Csa'	ETCS
Case 5	'Canopy'	Cons. (2004)	New York	Shelter/Canopies Water/Vapour	'Cfa'	ETCS
Case 6	Khan Antoun Bey Square	Conceptual (2010)	Beirut	Trees/Vegetation Water/Vapour	'Csa'	Long-Term
Case 7	Expo'92 Seville	Cons. (1992)	Seville	Trees/Vegetation Shelter/Canopies Materiality Water/Vapour	'Csa'	Short-Term
Case 8	'Le Miroir d'Eau'	Cons. (2006)	Bordeaux	Water/Vapour	'Cfb'	Long-Term
Case 9	'CoolStop'	Tested Prot. (2013)	New York	Water/Vapour	'Cfa'	ETCS

Although some of the case studies were indeed based on warmer climates, they nevertheless suggest very pertinent benchmarks that can be adapted to New Zealand's more temperate climate. As discussed in the different sections of this paper, these revisions can straightforwardly be undertaken by considering the microclimatic implications encircling Auckland's public realm. In this way,

documents such as the regulatory UP, and non-regulatory Auckland's Design Manual (ADM), can introduce more concrete guidelines on how public spaces could be made more responsive in light of increased hot days, heat waves and managing UHI effects. Respectively, and with regards to the city's civic spaces, the ADM's 'Design for comfort and safety' can be aided by the framework as a starting point to diminish the gap between theory and practice. Following this approach, existing urban design practices can be recycled in a way to contour such gaps, and where local risk factors are met by informed focalised and context sensitive adaption measures to address thermal comfort levels.

CONCLUSION

As with most sectors in the maturing climate change adaptation agenda, there is considerable theory, yet limited practical benchmarks that can directly aid local decision making and design. This is particularly tangible in thermal sensitive urban design in its pursuit of increasing the environmental responsiveness to increased temperature averages and heat waves. Although New Zealand shall witness more attenuated climate change over the next few decades, existing national projections indicate that adaptation is still essential. On top of these meteorological projections, the considerable increase in population, urban density and CO_2 emissions until 2040 augments such needs even further.

Arguing that thermal urban design is required in Auckland's excursion in becoming the world's most liveable city, this paper explored indicators and benchmarks that can aid local decision makers and designers. Using existing theory as a guiding organisational catalyst, a framework of practical bioclimatic case studies was used to explore solutions that addressed similar climatic issues as those identified in Auckland. The exploration provided various insights into the different categorical types of measures used in international projects, and how they attenuated both thermal comfort levels and also UHI effects.

Although climatic uncertainty will always taunt local adaptation, the paper has argued that bottom-up approaches aid its preciseness through the definition of local risk factors. With regards to thermal comfort, microclimatic analysis is hence crucial in tackling issues such as solar radiation, temperature, humidity and wind patterns. When considering the longevity of Auckland's public realm, the significant increase of average annual hot days and elevated UV levels alone require a rethinking of the city's public spaces. These represent spaces that ultimately, shall continue to act as beacons of urban identity and social-congregational activity threads in eventful horizons. In this way, thermal sensitive urban design is launched into a fertile arena that's application in a world of climate change, is required in building a better New Zealand.

ACKNOWLEDGEMENTS

This paper would like to thank the AUSMIP Erasmus Plus Program for providing the + PhD Mobility Scholarship, which enabled the author's stay in New Zealand and the writing of this academic paper.

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RETHINKING SUBURBIA: UNDERSTANDING THE RELATIONSHIP BETWEEN URBAN AMENITIES AND A MORE COMPACT FUTURE

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ABSTRACT

Along with many Pacific Rim cities in Australia and North America, Auckland has enacted an urban growth management strategy premised on two concepts: 'liveability' and a 'quality compact city'. The effective implementation of this strategy will, in part, require higher density housing typologies to be developed within the existing suburban fabric. This idea raises two fundamental questions:

1. Are our growth strategies designed to help us address the intensification of suburbia?
2. If they develop, will these higher density neighbourhoods meet the aspirations and needs of future residents?

The urban amenities in a neighbourhood play an important role in providing a sense of liveability for residents. This paper examines these issues by evaluating and reporting on the outcomes of 57 qualitative interviews with residents who currently live in medium density housing in four Auckland suburbs; Takapuna, Kingsland, Botany, and Te Atatu Peninsula.

Findings consider the trade-offs residents make when choosing to live in medium density housing typologies, how they value the urban amenities in their neighbourhood and the role they think these amenities play in their location satisfaction. Conclusions are drawn around how the resident-derived information may inform the market on the supply side of housing, and comment is made about how these preferences may, or may not, respond to the objectives of the underlying urban management strategies involved.

KEYWORDS:
Urban intensification; Suburban intensification; Quality of life; Liveability; Urban Amenities

INTRODUCTION: SUBURBIA, THE NEXT FRONTIER FOR URBAN INTENSIFICATION?

Framing urban intensification in Auckland at a macro level is Auckland Council's 'quality compact city' approach to growth (AC 2013; AC 2011d, 10; AC 2011e, 2; AC 2011f, 10; ACC 2003, 12, 25; Knox & Smith 2007, 89). Although there is an on-going debate about the viability of compact city models, such models continue to be applied by cities internationally as optimal growth management scenarios to meet environmental, economic and quality of life objectives (Boffa Miskell 2007). To achieve this compact city vision, Auckland Council acknowledges that it will need to look at "new and bold approaches" (2011c, 134) to deliver urban intensification in a city that is accustomed to car-dominated suburbia.

The Unitary Plan, as the statutory planning document for the city, also identifies that a 'quality compact urban form with a clear limit' (AC 2013) is the strategic growth goal of Auckland Council. This includes the co-ordinated delivery of urban amenities to encourage growth in neighbourhood and town centres (AC 2012b p, 30-31, 110, 145; AC 2011a, 30; AC 2011f, 52; ACC 2003, 12; Boffa

Miskell 2007; Fontein et al. 2011). Transforming and intensifying Auckland's suburbs, while still maintaining and then enhancing their distinct character and perceived liveability, is the next big challenge for the city's urban planners and designers.

In Auckland, a 'legacy of low density development' has shaped urban form (AC 2012b, 111; Dixon et al. 2001b, 1) and despite on-going attempts by Auckland Council to encourage density, the majority of growth has occurred outside the designated growth centres and corridors (ARC 1999, 29). This growth has been most notable in the suburbs, where dwelling patterns have taken the form of single-storey owner-occupied detached houses (Boon 2010, 297; Dixon & Dupuis 2003, 353; Dixon et al. 2001b, 1). While "housing patterns in New Zealand are changing" (Preval et al. 2010, 34), the changes have been considerably slower than what had been forecast or identified in the planning documents by numerous previous councils in Auckland.

Auckland Council acknowledges that "currently, 'Auckland' and 'quality compact' are mutually exclusive and diametrically opposed" (2011a, 2) and identify that "more research is needed on trends in housing preferences and trade-offs" (AC 2012a, 273). Haarhoff and Beattie discuss the quality compact city vision for Auckland and put forward the notion that "compact and complete communities that combine a concentrated, well-designed mix of housing types, job space, shopping, local gathering places, and community facilities make neighbourhoods more walkable, livable and sustainable" (2011, 10). In a recent research report for Auckland Council Haarhoff et al. also identify that "we need to better understand what the necessary 'trade-offs' are between the suburban lifestyle (whether affordable or not) and the urban lifestyle envisaged for a majority of future Aucklanders" (2012, 202).

In this research it is argued that a key element in this transition to more urbanised environments is related to the extent to which urban amenities have a role in resident perceptions of quality of urban life. Mulligan and Carruthers identify that "amenities are key to understanding quality of life (QOL) because they are precisely what make some places attractive for living and working, especially relative to other places that do not have them and/or are burdened with their opposites, disamenities" (2011, 107).

WHY ARE URBAN AMENITIES IMPORTANT?

Urban amenities are understood in this research to mean specific urban facilities that contribute to the urban living experience of residents (Kelly 2006). Urban amenities are linked to the daily life needs of residents in a neighbourhood. Some examples given by Randall include: "grocers, convenience stores, access to public transit, schools and professional services (doctor or dentist)" (2008, 47). There are both public sector amenities provided by councils, such as parks, public squares and recreational facilities, as well as private sector amenities such as cafes, restaurants, retail and other goods or service providers.

Gottlieb confirms that "residential amenities may be defined as place-specific goods or services that enter the utility functions of residents directly" (1999, 1413) and Schmitz et al. (2003, 62) propose that to consider urban amenities is to consider how to programme the urban environment to meet residents' needs. Both Mathur and Stein (2005, 252) and McNulty et al. (1985, 30) refer to urban amenities as 'quality of life factors' and Howie et al. confirm that "urban amenities are generally accepted as being important to a household's sense of place" (2010, 235).

There are two main reasons given in the literature as to why focusing on the role of urban amenities in the delivery of urban intensification is important. Firstly, in an economic sense, it is argued that a diversity of urban amenities attract economic activity to a city in terms of firms and labour wanting to be located in a place of high amenity value (AC 2011c; Hansen & Winther 2010, 1; MfE 2002, 7; Mulligan & Carruthers 2011). In other words, "the provision of amenities generates urban advantages that perpetuate the concentration of economic activity and population in, and in closer proximity to,

them" (Partridge, Olfert, & Alasia 2007, 40). Mathur & Stein also confirm that “the emerging literature on amenities seems to indicate that one of the most effective ways to attract knowledge workers in the regions and promote economic development is the creation of amenities" (2005, 265; See also AC 2011c, 93).

In line with economic reasoning, the second broader reasoning is that the accessibility and convenience of urban amenities contribute to quality of urban life experiences (AC 2011f; JGC 2007; MfE 2010; Rappaport 2008; Wheeler 2004, 199). The Ministry of Environment in New Zealand confirms that “high quality urban services and amenities, including open space, are crucial to cities’ long-term attractiveness and competitiveness and quality of life” (2010 p, 7-8). Auckland Council echoes this notion and also states that “experience indicates that people are generally accepting of the idea of trading off private outdoor space for proximity to public open spaces and amenities” (AC 2011f, 50).

As society changes and evolves so too do people’s quality of life requirements and aspirations. Schmitz et al. identify that “as more people work at home either full- or part-time, homes have changed to accommodate work spaces. But communities need to change as well” (2003, 6). The Ministry for the Environment in New Zealand confirms that:

> “We are beginning to enjoy urban as well as suburban lifestyles. The role of the house and home is changing as we change. Shopping is a favourite pastime, education is big business and cafés have reinvented the main street. Business is no longer just conducted in an office building downtown or in a warehouse in an industrial area. We now also work from home, in the car, or at the café. These diverse trends mean our towns and cities fulfil a much wider range of functions than in the past.” (2002, 12)

An example given by Schmitz et al. is that the increasing number of ‘work-at-homers’ “often feel isolated in typical suburban communities and would like access to the amenities that are available to downtown office workers (2003, 6). They consider that options such as the corner coffee shop, lunch bars, a print centre, local gym or recreation area, and retail facilities should be better integrated in to suburban environments. Auckland Council also acknowledges that the city needs “more housing adjacent to local shops and services, public open spaces and areas with expansive views” (2011f, 70). And yet, research into how this might occur and how different amenities are valued by residents is very limited in New Zealand. In this paper, understanding the relationship between urban amenities and perceived quality of life is based on the premise that “dwellings are important, but so too is the location of the dwelling” (Beacon Pathway Ltd 2010, 98). Furthermore, it is acknowledged that issues of affordability must be considered alongside the relationship between urban amenities and quality of life.

THE CONTEXT OF URBAN INTENSIFICATION IN AUCKLAND

There are clear linkages acknowledged in the literature between the provision of varied urban amenities and changing lifestyles and aspirations (Knox & Smith 2007, 48; North Shore City Council 2005, 6; PCE 1998, 38). Demographic changes also have a direct impact on the spatial configuration of the city and are closely tied to changing lifestyle preferences. Internationally, authors such as Clark (2002) have recognised that demographic and ethnographic changes alter the way cities are viewed and experienced and as such, the provision of urban amenities and their integration in to urban areas must also be reconsidered. Randolph (2006) in particular, writing about Australia, highlights the need for planners to understand the amenity requirements for higher density neighbourhoods, particularly if more children are going to be living in these urbanised environments, thus increasing the need for schools, child care facilities, and recreational areas. Auckland Council acknowledges that planning for demographic change “underpins the strategic directions set out in the Auckland Plan” (2012b, 18). It has long been established by Council that understanding demographic trends is

“important to ensure that urban form and housing choice reflect the different and changing needs of residents” (ARC 1999, 26).

Established demographic trends in Auckland include; increasing ethnic and cultural diversity (ARC 1999, 26; ARC 2006, 6–4-6–5; ARC 2007, 1; Schmitz et al. 2003, 9), an ageing population structure (ARC 1999, 26; ARC 2006, 6-4; ARC 2007, 8; Gray & Hill 2010, 24; Knox & Smith 2007, 1; Mitchell 2011, 42) and the associated increase in labour force participation for residents aged 65 and over (AC 2011c, 45; ARC 2006, 6–4-6–5). Furthermore, family structures are becoming increasingly divergent (Beacon Pathway Ltd 2010; Dixon & Dupuis 2003, 355; Knox & Smith 2007, 20). As such, “it will be important to develop more diverse, urban-style communities that provide the lifestyle that the next wave of consumers will demand” (Schmitz et al. 2003, 9).

As well as the broad typological and area-based trends being identified in the literature, patterns of housing consumption are a result of varied supply and demand issues including personal choices (Mead & McGregor 2007, 14) and trade-offs related to “affordability, tenure and stock distribution, as well as place attachment, (perceived) neighbourhood liveability and access to amenities, transport and infrastructure conditions, familial and employment obligations” (Beacon Pathway Ltd 2010, 3). Adding to this, Mitchell considers the drivers of housing supply and the implications for housing affordability to be: “central government policy; availability of land; infrastructure provision; fragmentation of land ownership within the urban area; cost and availability of finance; compliance costs; development contributions; construction costs; and cost of labour (2011, 43). Gray and Hill divide housing demand forces in to two categories: “subjective factors (such as changing lifestyle preferences) and objective factors (such as demographics and housing affordability issues)” (2010, 40) which they denote will increase the demand for higher density housing in Auckland, adding that “the traditional ‘family suburb’ should decline in both popularity and relevance” (Gray & Hill 2010, 40).

Mitchell observes that “household formation has increased faster than population growth” (2011, 37) and attributes this to the increasing number of smaller households. By 2040, households with children will decline from half to around one third of all households, whereas “single person households and couple-only households will increase significantly to make up about 60% of total households” (AC 2011c, 42). The cause of smaller households is identified in the literature as being twofold; on the one hand Mitchell attributes this trend in part to New Zealand’s ageing ‘baby boomers’ who want to ‘age in place’ and stay in their family home (2011, 37). The second trend is the socio-cultural tendency of later family formation, where couples are both meeting later and waiting longer to have children and thus increasing the smaller household demographic (Mitchell 2011, 37). Much research has noted that these changes in household formation will likely increase the demand in Auckland for smaller dwellings and multi-unit housing typologies that are located in close proximity to a range of urban amenities (AC 2012b, 138; AC 2011c, 41; Beacon Pathway Ltd 2010, 1, 117; Darroch Ltd 2010, 36, 228; Harrison Grierson 2008; Knox & Smith 2007, 48; Mitchell 2011, 37). In a CRESA Public Policy & Research Report (2009, 37) it was identified that due to the increasing smaller household demographic there will be an increasing demand for housing in neighbourhoods well serviced by public transport and with services and amenities at walkable distances. Dixon et al. (2001, 9) identify that this medium density housing trend is a response to changing urban lifestyles and the outcome of a regional commitment by Council to intensification. They also acknowledge that "the rapid growth of medium density housing over the past few years has made a definite change to the appearance of the Auckland landscape" (Dixon et al. 2001b, 1).

Increasing ethnic diversity has meant that the number of multi-generational and extended family households are also growing (Darroch Ltd 2010, 36) and the market result is that “there is growing demand for houses with more bedrooms for larger or extended families” (AC 2012b, 138) and an “on-going trade-off between housing performance and price in both the home ownership and rental sectors” (Beacon Pathway Ltd 2010, 117). Increasing ethnic diversity also means a broader view is

needed about how urban amenities are perceived by these residents and which urban amenities best respond to the quality of life aspirations and expectations of these residents.

The proportion of dwellings that are owner-occupied is set to decrease as co-ownership and renting become of necessity more and more common (AC 2011c, 42; ARC 1999, 26-28; Darroch Ltd 2010, 18; Dixon & Dupuis 2003, 355). Randolph (2006, 477, 482) and Rowland (2010, 33) comment on changing ownership patterns by questioning if the current trend away from owner-occupied dwellings is sustainable. They ask what the implications will be if the rental market continues to grow as prospective buyers are priced out of the ownership market.

Despite the above demographic indicators, it is often discussed in the literature that there is considerable resistance in Auckland to medium and high density typologies, particularly multi-storey apartments (AC 2011a, 12; Arbury 2005; Gray & Hill 2010, 7; Harrison Grierson 2008; Syme et al. 2005; Vallance, Perkins & Moore 2005). Reasons given for this resistance include: the 'newness' of this typology to New Zealand (AC 2011a, 13; AC 2011b, 6, 8; Dixon & Dupuis 2003, 353) and negative associations to the 'leaky buildings crisis' (Arbury 2005). 'Perceived density', where two areas of closely similar density can be perceived by visitors and residents with differing environmental expectations and socio-cultural backgrounds, as having significantly different densities, is an associated issue also identified in the literature (AC 2011a, 13; Mead & McGregor 2007; Raman 2010, 65; Wheeler 2004, 192).

Other barriers to urban intensification in Auckland include: land fragmentation, because small suburban lots are privately owned, and the difficulties around amalgamating these parcels (Gray & Hill 2010, 7; Mitchell 2011, 45), building and financing costs (Gray & Hill 2010, 7), land holding costs, and the cost of processing consents (Knox & Smith 2006, 5). Furthermore, in New Zealand the development and construction industries are "heavily geared towards low-density housing on greenfields land" (Gray & Hill 2010, 7) and are yet to comprehensively engage in brownfields redevelopment as the future direction for urban intensification and housing provision in Auckland. Udale identifies that the development economics in Auckland are such that it is often uneconomical in the current market to build multi-storey multi-unit dwellings because they are "typically more expensive to develop, and thus to buy, than the equivalent stand-alone or attached house" (2012, 20). Gray and Hill also identify that "developers also struggle to obtain finance for innovative high density housing projects – at least in comparison to lower density housing" (2010, 7).

However, many researchers feel that resident resistance to urban intensification in Auckland is set to change as urban, rather than suburban, environments become more socially acceptable and even expected (AC 2011a; AC 2012a; Gray & Hill 2010; Haarhoff et al. 2012; Heng & Malone-Lee 2010). While this preference for medium density will by no means be across-the-board (Syme et al. 2005, 20), Mitchell identifies that the demand for medium density multi-unit housing has been on Auckland Council's agenda since the 1990's and steadily increasing in Auckland since 2006 (2011, 40). Paling affirms this notion, stating that due to changing "lifestyles and employment and following shifting demographics in the Auckland Region, there is an increasing degree of intensification across the urban area" (2007, 8).

Reasons cited in the literature for this shift towards urbanism include globalisation and a growing awareness by consumers of the 'true costs' of sprawl and its unsustainability (AC 2011a, 9). Latham identifies that because new housing consumers may have "spent time in metropolitan centres such as London, Sydney or Melbourne, and brought back with them a taste for the cafes, restaurants, and bars, the urbanity, they had encountered in these centres" (2000, 290), they are more likely to want to live in high amenity, higher density neighbourhoods in New Zealand. Similarly, Giradet also observes that "many people are asking how such examples of 'compact liveability' can be implemented in their own cities" (2004, 164). He asserts that because of the "explosion in international travel in recent years, many people have experienced a great variety of urban environments" (Giradet 2004, 163). The increasing ethnic diversity in the city may also be contributing to these urbanism trends as residents,

originally from established higher density urban environments, bring to Auckland their own understandings of intensification and the relationship between urban amenities and perceived quality of life. There are also the aforementioned issues of affordability and potential new home owners now being priced out of the market who may turn to higher densities as a way of entering the property market if affordable options can be delivered by the market.

Whatever the reason, the question remains: if they develop, will these higher density neighbourhoods meet the aspirations and needs of future residents? It is therefore necessary to ask residents about the urban amenities they use and value and the relationships they see between these amenities and their sense of location satisfaction.

METHODS

Resident interviews were conducted to identify a broad range of characteristics and qualities that define how urban amenities are valued and their role in promoting quality of urban life experiences. A total of 57 qualitative interviews were completed with residents[1] who currently live in medium density housing, greater than 40 units per hectare. This meant a mix of typologies ranging from three- and five-storey apartment complexes to attached townhouses and units.

Interview questions covered household structure, dwelling tenure, current employment and travel habits as well as housing histories and aspirations. Interviewees were asked about the urban amenities they use, how often, their accessibility, and how they valued them. How residents defined quality of life and their perceptions of urban intensification and density were also explored.

Four suburbs were chosen as case study areas: Takapuna, Kingsland, Botany, and Te Atatu Peninsula. These areas represent both inner and outer fringe belt suburbs (Gu 2010) that have all experienced strong increases in both rental and owner-occupier medium density developments. They range from being 4.3 kilometres to 20 kilometres away from Auckland's CBD and are located to the north, west, and south-east of Auckland.

Within these suburbs, case study developments were chosen; from within which the residents interviewed must reside. The criteria for selecting these developments included; that each of the developments was multi-unit, at a density greater than 35 units/hectare, and in a location that provided local amenities (i.e. in a town centre or established neighbourhood). Developments also had to be established in their communities for a period of more than 3 years and accessible for interviews.

Case Study 1: Takapuna

Takapuna is a city fringe suburb in the north of Auckland, 9.6 kilometres from the CBD. It has been extensively considered for intensification by North Shore City Council and Auckland Regional Council. It has also been identified as a key growth area in the Unitary Plan (AC 2013) and the Auckland Plan (2012a, 33). Takapuna was also identified by Patrick Fontein (Studio D4) as an area that is well placed for market-led intensification due to its access to a range of amenities; including, transit, employment opportunities, mixed use residential and business land, and natural amenities (AC 2011a, 33-35). Residents from three developments were interviewed. These developments ranged from townhouses that were 37 units/hectare to three-storey apartments that were 60.8 units/hectare to even higher density six-storey apartments that were 167.8 units/hectare (see figure one).

[1] Interviewees were approached through a mail box drop where they could choose to respond and take part in the research.

Figure 1: The Takapuna case study area (interviewees were from the developments shown in yellow)

Case Study 2: Kingsland
Kingsland is a city fringe suburb, just 4.3 kilometres from the CBD, and one of the top five rental growth suburbs in Auckland (Realestate Investar 2012). While it has grown in popularity because of its proximity to a range of urban amenities and access to the CBD, it remains predominantly suburban, made up of single-storey detached dwellings. However, the number of medium density projects is increasing; although currently these are largely apartments rather than a mix of medium density typologies (including terraced houses and units). Residents from two developments were interviewed. These developments were both four-storey apartment buildings at densities of 287 and 295 units/hectare (see figure two). One was a mixed-use typology with apartments built above the high street shops.

Figure 2: The Kingsland case study area (interviewees were from the developments shown in yellow)

Case Study 3: Botany
Botany is the furthest suburb considered in this paper, at 20 kilometres south-east from the CBD. It is an area that has seen considerable growth in the last 5-10 years, frequently in the form of two-storey attached dwellings in large scale, partially gated communities. The four developments selected fit this typology but ranged from 49.7 to 114.5 units per hectare (see figure three).

Figure 3: The Botany case study area (interviewees were from the developments shown in yellow)

Case Study 4: Te Atatu Peninsula

Te Atatu Peninsula is 15.3 kilometres to the west of Auckland's CBD. While it is dominated by low density single-storey detached dwellings its popularity and increasing levels of gentrification have seen attached and semi-attached two-storey townhouses develop to the east of the town centre (see figure four). These developments range in density from 38 to 72 units/hectare. One six-storey apartment building, with retail on the ground floor, has been developed on the main street leading in to the town centre. It has a relatively high density of 238 units/hectare; considerably greater that the surrounding suburban area that measures between 10 and 20 units/hectare.

Figure 4: The Te Atatu Peninsula case study area (interviewees were from the developments shown in yellow)

SUMMARY OF FINDINGS

In total 36 females and 21 males responded to the mail-box letter drops. Interviewees were spread between the ages of 23 and 87; the average age of respondents was 44. Of the 57 interviewees, 26 were owner-occupiers and 31 were renters. The average length of dwelling tenure was three years; the shortest time being one month and the longest 13 years. Seven interviewees lived alone, 25 were couples, six interviewees lived with flatmates, and two lived with extended family members. 17 had a

least one child living at home, of these 10 had children under seven. Only three had two or more children living at home.

36 of the interviewees were born in New Zealand and nearly half of these had also spent time living overseas where they were exposed to a range of different lifestyles and housing norms. Of the 21 born overseas, only 11 were from countries where English was not their first language. Countries of origin included The United States of America, Australia, Scotland, England, China, Korea, Malaysia, Vietnam, Singapore, India, Portugal, Bulgaria, Slovakia, Serbia, Jordan, Mozambique, and South Africa. 19 of the interviewees had had experience living outside of Auckland in areas ranging from Christchurch and Wellington to rural Otago, Napier, Gisborne, Palmerston North, Tauranga, Rotorua, and Tairua. Despite the geographic, demographic, and socio-economic variations between the case study suburbs and the interviewees, clear patterns emerged among the findings.

All the interviewees, excluding two, had had previous experience living in stand-alone houses; most often it was the housing norm they had experienced the most. Over half (33) had also experienced apartment or townhouse living at some stage prior to their current housing experiences; whether it be as students, while living overseas, or while living in a flatting situation away from their regular family home. A majority mentioned proximity to urban amenities and the resultant convenience that added to the quality of life they experienced as their main reasoning for moving in to their current housing. Safety, security, ease of maintenance, proximity to work, affordability, and place attachment created due to proximity to friends and family were other reasons frequently mentioned by interviewees as reasons that had influenced their decision making when deciding to live in their current location. A number of interviewees mentioned trading-off living in a stand-alone house for an apartment or townhouse because they found them to be warmer and cleaner than the available stand-alone housing stock they could rent for a similar price point.

These findings are in line with the work of Beattie and Haarhoff (2013), Haarhoff et al. (2012), Mead and McGregor (2007), and Syme et al. (2005) who all found that residents living in medium density developments in Auckland rated highly the convenience of living in close proximity to the urban amenities that they valued in their daily lives; including shops, cafes and restaurants, schools, their workplaces, public transport, and public spaces (particularly if they were park and recreation facilities). These studies also all identified that the locations of these urban amenities and their convenience was a significant factor for residents in choosing to live where they did.

Interestingly, when questioned about how they defined urban amenities the overwhelming majority of interviewees thought of them as all the services and infrastructure they used in their daily lives. This contrasts with much of the planning policy and strategy in New Zealand as well as international literature where amenities are often considered in silos; for example as 'natural amenities', 'entertainment amenities', or public amenities provided by council. It was found in this research that in order to begin understanding the dynamics of liveability in our current suburban neighbourhoods, 'how' residents use and value urban amenities seamlessly across their neighbourhood must be investigated. This means to consider all urban amenities simultaneously as they relate to liveability, whether they be public sector amenities provided by councils, such as parks, public squares and recreational facilities, or private sector amenities such as cafes, restaurants, retail and other goods or service providers. The biggest disjunct between the findings of this research and current planning policy and strategy in Auckland is just how seamlessly interviewees thought about the spatial relationship between their dwellings and the urban amenities they wanted to live in close proximity to. Current residential zoning, for example, is at odds with this very intimate integration of urban amenities in to the suburban fabric.

Food related amenities, such as supermarkets, cafes, and restaurants, were by far the urban amenities considered to be the most important by interviewees. Supermarkets were specifically mentioned the most frequently. Recreation amenities and public spaces were also favoured. The areas where residents reported using their local amenities daily and usually accessing them by foot (this was

weather dependent) were Takapuna and Botany. Te Atatu Peninsula had similar responses for a variety of food and community amenities but many interviewees commented about their needing to drive for retail amenities. While Kingsland residents were positive about their local café and restaurant culture, walkability for urban amenities such as chemists, clothing stores, dairies and supermarkets was questioned by the interviewees who predominantly drove to areas like Mt Eden or St Lukes for these urban amenities.

As well as discussing the urban amenities residents used and valued and the sense of liveability these created, their housing aspirations were also discussed. The majority of interviewees saw themselves continuing to live in the same suburb where they currently resided over the coming five years. Where this wasn't the case the predominant aspirations held were to move to a more rural environment as part of long term lifestyle ambitions, or to look at land on the urban fringe for affordability reasons. Retirees interviewed were split between moving out of Auckland or to fringe areas where they could live quieter lives and staying in apartment where it would be easier for them to maintain or lock up and leave if they planned to travel.

A number of interviewees mentioned proximity to work or proximity to their children's education as part of their reasoning for wanting to stay in the same area. This largely came down to the notion that interviewees didn't want to be "sitting in traffic half the day". Place attachment due to family and friends living in the same area was also frequently mentioned as a factor affecting the interviewees' location aspirations.

When asked about the type of housing they saw themselves living in in five years' time a slim majority of interviewees saw themselves in medium density typologies, including low rise apartments (of three to five storeys) or terraced housing (similar to their current typologies). This is a surprising change from previous studies where stand-alone houses featured prominently as the favoured typology residents saw themselves living in. Low rise apartments and terraced houses were also the notably favoured 'back-up' plan for interviewees when they were asked where they might be happy to live if their first choice wasn't available for whatever reason. However, stand-alone houses on both small and large sections still featured strongly as an aspirational preference for a number of interviewees either in the next five years or as a long term goal when they "wanted a family home".

The concept of 'lifestyle' was used by interviewees as a reason to justify both their low and medium density preferences. Those who wanted stand-alone houses as their first choice usually spoke about wanting space, peace and quiet, the ability to have pets and a garden, and "the ability to cater for acquisitions which you can't do in a smaller apartment". A small number of interviewees who aspired to live in a stand-alone house dud acknowledge that many of the issues they currently had with medium density typologies, particularly related to storage and shared garden space, could be addressed if the apartments or terraced houses were well designed, built from quality materials, and larger than the CBD "shoeboxes" that they currently associated with the idea of 'higher density living'.

Those who wanted to live in low rise apartments or terraced houses cited proximity to urban amenities as their main reason for choosing this typology over others, stating that they "like going out and doing things and having everything on our doorstep". One interviewee commented; "I'll compromise on smallness… I don't actually mind the smallness, but I like to be close to the city". When asked why, the interviewee commented about the liveliness of the city contributing to their quality of life because they were always busy and engaged with what was going on around them.

Other reasoning given for preferring medium density typologies included security and their low maintenance nature. One interviewee commented that they wanted to live "somewhere that is clean, tidy and nice. I really don't want a garden that gets neglected because I don't have the time for it. I'd rather not have it at all." Another interviewee saw living in an apartment as meaning they could pay

off their small mortgage and “make a bit of a nest egg” so that they could travel and enjoy their upcoming retirement.

A number of interviewees who saw themselves living in medium density dwellings over the next 5 years, and in some cases longer term, tempered their aspiration with the concern that many apartments currently available were very small and did not always meet their needs; lack of storage, lack of car parking for multi-bedroom apartments, and small kitchens rather than four burner hobs were the most frequently mentioned concerns. One interviewee spoke of wanting to live in ‘stacked villas’, a villa on the third or fourth floor; in other words a spatial layout that they were familiar with that had larger shared spaces, more storage, and a larger outside living area (deck) than the majority of apartments they had seen. This suggests a disjuncture between the current supply and potential demand for higher density typologies in Auckland’s suburbs. The notion that current medium density typologies didn’t meet the daily life needs of residents was an issue for a number of interviewees. This raised questions about how some interviewees might have responded to questions about their housing aspirations if more medium density typology options were available to them within their current suburban areas.

Additional reasoning given by those interviewees who stated that they would prefer to live in a stand-alone house related to their desire to renovate and because they thought that owning a home was part of the “kiwi dream”. Fear that the build quality of apartments could become an issue was also cited as an issue by some interviewees. A further concern was that they thought buying an apartment would disadvantage them financially because the capital gains were perceived to be higher for properties with stand-alone houses. One interviewee who currently owned their apartment commented that they would eventually like to buy a house ‘out in the suburbs’ but that it “purely would be an investment property and we’d stay living in the apartment”. This response raises questions about how common this idea might be among potential home buyers in Auckland.

CONCLUSION

A better understanding of how residents are making trade-offs between suburban and urban lifestyle options is critical to understanding the relationship between urban amenities and perceived resident quality of life experiences. Schmitz et al. (2003 p.62) propose that to consider urban amenities is to programme the urban environment to meet residents’ needs. By this thinking, it will be the successful integration of urban amenities in to suburban areas that will enable the perceived quality of life experienced by residents to be maintained or even enhanced during the transition to higher density urban environments to accommodate growth rather than the current low density suburban norm. The apparent risk of not considering urban amenities in this way is to misunderstand the nature of contemporary urban life and the effects of changing demographics and household structures on housing choices.

This research has raised questions about the factors that affect how residents make trade-offs between low density and higher density housing choices; and as such it has raised questions about the effect of the current supply on the future demand for housing in Auckland. Most interestingly, it can be concluded that the majority of those interviewed would trade-off stand-alone living for low-rise apartment or terraced house living in their current neighbourhoods if the medium density options available to them were of a size and spatial layout that were more similar to the traditional New Zealand home and if urban amenities were integrated in to their neighbourhoods in line with the increasing numbers of residents. Higher amenity must go hand-in-hand with higher density if quality of life is to be experienced in tomorrow’s urban Auckland.

ACKNOWLEDGEMENTS

I would like to acknowledge the guidance of my supervisor, Professor Errol Haarhoff, and my advisor, Dr. Lee Beattie.

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DESIGNING FOR RESILIENCE: iDEAL HOUSE AUCKLAND

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ABSTRACT

The iDEAL house is a private family home, located in suburban Auckland and due for completion in July 2014. The design brief by the client, asked for a highly energy efficient and net zero energy home within a modest budget, whilst maintaining a high level of indoor environmental quality. Outstanding thermal performance of the building envelope was essential to achieving the aspirations of this brief.

In order to safeguard the performance targets, the project underwent Passive House Certification (pending).

A far more detailed analysis was undertaken than would normally occur for a family home. Interstitial condensation, mould and structural decay issues were particular concerns that were evaluated and addressed. This paper will discuss the results of this analysis, and the hygrothermal performance of the building envelope that can subsequently be expected.

Results were obtained using the following analytic tools:

- Passive House Planning Package (PHPP)[1], for Passive House Certification, to ensure compliance with the Passive House performance targets;
- Wärme und Feuchte Instationär (WUFI®)[3] for calculation of the transient coupled heat and moisture transport in multi-layer building components exposed to natural indoor and outdoor environment.
- Psi-Therm[4] for the calculation of thermal bridging coefficients to limit the additional heat loss, as well as assessing resulting interior surface temperatures, to prevent discomfort and surface condensation throughout the building.
- On site testing for airtightness of the building envelope.

Measures and construction details that were identified to meet the performance targets are presented, also with regard to their fit with the requirements of the New Zealand Building Code Clauses[5-8], and the budget constraints of the project.

This paper will demonstrate that an aspirational brief can be answered with limited additional cost when proper design strategies are employed.

KEYWORDS:

Managing moisture; thermal, isothermal and hygrothermal analysis; airtightness; resilience; blower door testing.

INTRODUCTION

The iDEAL home is intended to provide a working example of how a resilient home could be constructed in suburban Auckland using common building materials. It was important for the home to not only be highly efficient but also be aesthetically appealing to the modern urban family. It was essential to understand that there was to not only be a dramatic improvement in energy efficiency and thermal performance, but this was not to come at the expense of modern comforts or compromise the indoor air quality and health of the occupants.

To ensure the home meets these aspirations it has been designed with the goal of becoming a Certified Passive House (pending). At such high levels of energy efficiency, energy demands can be met with a modest solar PV array allowing the home to operate with net zero energy.

In this paper we will detail the analysis process that was undertaken during the design process to ensure that actual thermal energy demands match those that were predicted for the design.

Figure 1. Rendering of the iDEAL House, supplied by S3 Architects Ltd

The home is a rectangular shape with a second storey mezzanine for part of the plan area. The adjoining garage is outside of the thermal envelope and has been positioned such that it provides an interesting form to the building without compromising the thermal or airtightness performance.

The form of the house was the first key factor in ensuring good performance. A simple two storey rectangular form has a limited surface area for heat losses and containing a reasonable volume for the internal spaces. Having a surface area to volume ratio less than 1.0 ensures an optimised design. Reducing the surface area also ensures a more cost efficient construction; there is less cladding area material and other associated material volumes such as insulation, linings, paint etc. A larger surface area would also have required a portioned increase in the levels of insulation required for the building to make up for the increased heat losses; heat loss being directly proportional to surface area.

PASSIVE HOUSE CERTIFICATION

A Passive House is well planned during the detailed design phase however, the certification of a building is undertaken at the completion of construction. The process involves a combination of on site quality assurance checks together with a review of the as-built design details, product data sheets, analysis reports and calculations. These are compiled by the Passive House Designer and are submitted to an independent Passive House Certifier for verification.

The core performance criteria for a Certified Passive House: -

- Meeting an envelope airtightness level less than 0.60 air changes per hour (ACH) at 50 Pascals pressure differential. This is tested on site at the project completion through a Blower Door test under both pressurisation and depressurisation in accordance with Method A of EN 13829[12].
- The specific heat (and cooling) demand is to be less than 15kWh/(m^2) per annum. The New Zealand Building Code[8] has no specified performance benchmark for New Zealand homes however from experience we believe that the average modern code minimum home in Auckland would have a specific heat demand in the order of 40 to 50kWh/(m^2) per annum. Thus a Certified Passive House would have a performance improvement of around 60 to 70% to the average code minimum home in the region.
- The heat load must be less than 10w/m^2.

- The primary energy demand must be less than 120 kWh/(m^2) per annum.
- Using a balanced heat recovery ventilation system with a least 75% efficiency through the heat exchanger. A large number of heat recovery ventilation systems have been independently tested by the Passivhaus Institut and are Certified Components. Using Certified Components means that no additional documentation needs to be supplied to verify compliance and the performance of the system is guaranteed.
- Having an essentially thermal bridge free construction so that the specific heat energy demand criterion is achievable and to keep internal surface temperatures well above dew point temperature. This is essential to ensure there is a condensation and mould free construction.
- Ensure the building envelope is not at risk of interstitial condensation.

The bulk of these calculations are completed in a spread sheet developed by the Passive House Institute called the Passive House Planning Package (PHPP)[1].

Thermal bridging calculations are prepared using isothermal analysis software called Psi-Therm[4] that enables the calculation of the thermal bridging coefficient or Ψ-factor. These are subsequently input into the PHPP[1]. Checks on the building envelope details for the transfer of water vapour and condensation risk are conducted through hygrothermal analysis using WUFI® Pro 5.0[3].

THERMAL MODELLING

Passive House Planning Package (PHPP)[1]

PHPP uses an energy balance method as the basis of verifying that the Passive House Standard has been met. PHPP is regarded as being highly accurate, up to +/- 0.5kWh is claimed, and has been repeatedly verified through validation using dynamic simulations as well as testing of actual realised buildings through meticulous measurements over several years.

The tool is based on physical principals using European norms, calculating heating, cooling and primary energy demand, as well as determining summer overheating periods. We have also undertaken independent verification using Integrated Environmental Solutions <Virtual Environment> (IES <VE>)[2] thermal analysis of the building envelope to establish specific heat energy demand.

The climate data set for the Auckland region is now pre-loaded in the latest version of PHPP8.5. This data set originated from IWEC (International Weather for Energy Calculations from ASHRAE) and was compared with NIWA data. The Passivhaus Institut independently tested the data set.

Opaque components

The U-Value calculations for the opaque building elements are based on International Standard, ISO 6946[9]. There are a number of notable differences with this standard compared with NZS4218:2009[11] that are worth discussing: -

- ISO 6946 uses a slightly different set of interior and exterior surface resistances offering more alternatives of heat flow scenarios that are ore realistic for heat loss calculation.
- Any cladding to the outside of a ventilated cavity is excluded from the U-Value calculation unlike NZS4218, which uses a method of de-rating those layers. ISO 6946 allows still areas to be considered, however a vented cavity should not be considered still air.

The final U-Values calculated for the iDEAL house are tabulated in Table 1 based on ISO 6946.

Table 1 – Opaque building component U-Values from PHPP compared with minimum NZBC[8] R-Values

Element	U-Value, W/(m^{2}K)	Total R-Value, (m^{2}K)/W	H1 minimum code R-Value, (m^{2}K)/W
Ground floor	0.433	2.31	1.3
Exterior walls	0.282	3.54	1.9
Southern exterior wall	0.209	4.78	1.9
Roof	0.183	5.46	2.9
Mezzanine overhang	0.208	4.81	1.3

The areas of each of the building assemblies are tabulated in the PHPP and the respective heat losses are calculated. We have made a comparison using NZBC H1 minimum code requirements in Table 2 and we can see there is a 53% reduction in heat loss of the opaque building components compared with a code minimum home.

Table 2 – Opaque building component heat losses compared with minimum NZBC levels

Element	Area, m^2	Element Heat loss W/K	H1 minimum code heat loss, W/K
Ground floor	163.3	70.7	125.6
Exterior walls (net)	216.32	61.0	113.9
Southern exterior wall (net)	29.51	6.2	15.5
Roof	186	34.0	64.1
Mezzanine overhang	6.25	1.3	4.8
Total		173.2	323.9

The PHPP element areas are measured using exterior dimensions using the convention given in ISO 13789[16]. This yields a more conservative result as there is a degree of double measurement at the junctions and corners. Junctions have slightly larger heat losses due to geometrical thermal bridging.

To adjust for the thermal bridging that occurs at the junction of elements a thermal bridging coefficient (Ψ) is calculated using Psi-Therm, in accordance with ISO 10211[10], and is entered into the PHPP together with the respective lengths of the thermal bridges. As there was some conservatism in the measuring of the overall element areas, taking the thermal bridging effects into account will often reduce the total heat loss so long as the proposed junction detail is sensible.
For example, the external roof barge was calculated to have Ψ = -0.199 W/(mK) with a length of 61.2m, this results in a heat loss reduction of -12.2 W/K. Examples of this calculation are discussed in more detail further on in this paper.

Heat losses through the ground follow EN ISO 13370[13] standard, taking building geometry into account. The larger the floor slab the lower the heat losses are due to the insulating effect of the soil. Seasonal ground storage effects are also included in the calculation as it separates heat flow into steady state and harmonic components.

Windows

The windows selected for the iDEAL house are a Passive House Certified Component. This means the windows can be easily selected from the list of components and performance data is pre-filled in the tables. Aluplast PVC windows with ClimaGuard triple glazing were selected for the project. This has glass U-Value = 0.69 W/(m^2K), frame U-Value = 0.81 W/(m^2K), and edge spacer Ψ = 0.027 W/(mK). The total window area is 84.58m^2 with a ratio of glazed area of 55.87m^2 and frame area of 28.71m^2.

The breakdown of heat losses through the window components as determined through PHPP is given in Table 3.

Table 3 – Window component heat losses

	Glass, W/K	Frame, W/K	Spacer, W/K	Installation, W/K
South	1.10	0.97	0.29	0.43
East	9.99	7.00	2.05	2.57
North	10.9	6.03	2.68	1.90
West	16.6	9.26	1.76	2.60
Total	38.6	23.3	6.78	7.5

Total window heat loss = 76.18 W/K and the total average window U-Value = 0.90 W/(m^2K) or R-Value = 1.11 (m^2K)/W using ISO 10077.1.

When comparing with minimum H1 requirements from the New Zealand Building Code we only need a window R-Value of 0.26 (m^2K)/W giving a heat loss of 325 W/K. Passive house windows for this example offer approximately 77% reduction in heat losses compared with a standard aluminium window with double glazing. The windows are where a Passive House makes significant performance improvements.

We note that NZ4218 takes a highly simplified approach to window losses where many variants are not taken into account. This subsequently leads to a higher level of inaccuracy, which is problematic when analysing energy efficient buildings. The effect of the spacers and installation thermal bridges can be significant.

Consider if standard aluminium edge spacers were used in the iDEAL house windows, the heat losses for this element would increase from 6.78 W/K to 27.9 W/K. This is greater than the heat losses through the PVC window frames. This indicates that to obtain a return on investment on any thermally broken frame a high performance glass edge spacer is essential.

Certified Passive House windows consider more than just the thermal and airtightness properties. The hygiene requirement restricts the minimum interior surface temperature on the window. This is to ensure that condensation cannot consistently form on the window that subsequently leads to mould growth. The relative humidity in either the window materials pores or directly on its surface cannot exceed 80%. This ensures a healthy living environment.

The other requirement is for comfort. This restricts the average indoor temperature to the minimum surface temperature of the window by a maximum of 4.2K. With a 20^{o}C indoor operative temperature environment the window surface temperature must effectively not fall below 15.8^{o}C. This ensures there is no downdraft effects and no perceptible radiant heat deprivation and thus there is a comfortable living environment.

The New Zealand Building Code Clause E2[6] has a prescriptive approach to the installation of windows as a measure to prevent water ingress from wind driven rain. Ironically the windows have large thermal bridges which causes condensation on the interior face of the window components during winter months. In many cases, if the thermal bridging was addressed and the window was installed in an airtight manner the moisture issues could be eliminated.

Having to install the windows to New Zealand Building Code requirements meant that the installation thermal bridging effect was exacerbated. We used a higher performance frame than would normally be required to overcome this performance limitation. The PHPP assumes a very conservative installation Ψ = 0.04 W/(mK) as default with the worst case always occurring at the window or door sills.

Uncertified windows would require calculation of the frame U-Value to be determined based on ISO 10077[14], similar applies to the glazing U-Value, together with the edge spacers and installation thermal bridging co-efficient. Analysis to check the hygiene and comfort requirements should also be undertaken. We initially worked through such calculations using thermally broken aluminium window suites for the iDEAL house. However, the restrictive nature of how the window had to be installed meant that we could not meet the hygiene or comfort criteria necessary for Passive House Certification. We therefore moved to using an imported PVC window frame that was Passive House Certified.

New Zealand aluminium window manufacturers are only just starting to adopt ISO 10077 for the calculation of the window component U-Values, this will allow a more consistent approach and allow performance to be properly compared with overseas products. So far the fabrication and installation of locally manufactured aluminium framed windows has not been consistent enough for us to be confident that they could always meet the airtightness requirements for a Certified Passive House.

To ensure solar gains are accurately calculated in the energy balance shading effects are taken into account. This includes, eaves, screening devices and overshadowing structures and topography.

Heat Recovery Ventilation

Although not directly related to our analysis it is worth mentioning the balanced heat recovery ventilation system as it is often queried. A balanced heat recovery ventilation system is an important asset for a Certified Passive House. It enables fresh air to be brought into the home in an energy efficient manner. During mild weather opening windows can be satisfactory for providing the fresh air requirement however in colder months this would introduce cold air indoors which would require heating energy to bring it back up to the ideal operative temperature of 20^{o}C.

There are other practical benefits of having a balanced heat recovery ventilation system: -

- All of the incoming air is filtered and aggravating allergens and pollutants can be scrubbed.
- There is greater security than having to leave windows open at night or when the house is left unoccupied.
- It is much quieter when in urban environments; it quells airborne street noise coming in through open windows.
- It ensures that there is always ample fresh air throughout the house and pollutants such as VOCs don't accumulate.

A Certified Passive House ventilation system is very quiet as it can run on low air speed through the benefit of having an airtight construction. They operate with very minimal cost and can often return enough heat energy to the home as to avoid needing any additional space heating.

ISOTHERMAL ANALYSIS - Psi-Therm

The principal of 'thermal bridge free construction' is elemental to having a successful low energy building or Certified Passive House. We mentioned previously that areas are measured to the exterior dimension to be conservative, thus the losses occurring from geometrical thermal bridges are already accounted for in the PHPP. The heat loss coefficients for overlapping geometries normally work out to be negative when assuming exterior dimensions. Therefore the heat losses are overestimated using this simplified method in the PHPP.

Calculating the linear thermal transmittance coefficients or Ψ-value can allow the heat loss to be determined with more precision. For a Certified Passive House Ψ-values greater than 0.01 W/(mK) must be taken into account. The designer can decide whether to incorporate values less than 0.01 W/(mK) for improved accuracy.

We show the example of the roof junction with the exterior wall for the iDEAL in Figure 2. Here a geometrical thermal bridge is occurring but to ensure good performance with low risk of interstitial condensation there is an uninterrupted layer of insulation. To further insure there is no thermal bridging of concern the detail is modelled using isothermal analysis.

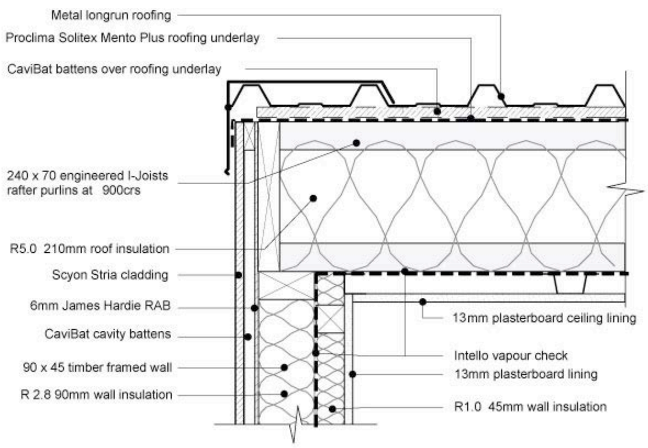

Figure 2. Roof junction to exterior wall barge detail, supplied by S3 Architects Ltd

The first stage of the analysis determines the interior surface temperatures. We used the software package Psi-Therm[4] which also post processes the data to calculate the Ψ-factor to avoid us having to manually calculate using ISO 10211[10] based on the surface temperatures. Setting the indoor and

outdoor boundary conditions correctly is important to ensure the surface temperatures are matching the appropriate thermal bridging criterion.

As the dwelling is to be a Certified Passive House we can be confident that the indoor temperature will be 20°C. The exterior temperature settings are based on the Passivhaus Institut's regional classification[17] being warm-temperate for the north island of New Zealand. The exterior temperature boundary condition for the hygiene criterion is, θa = -5°C. From the analysis we determined the lowest surface temperature at the corner of the detail to be 17.04°C. This equates to Ψ = -0.045 W/(mK).

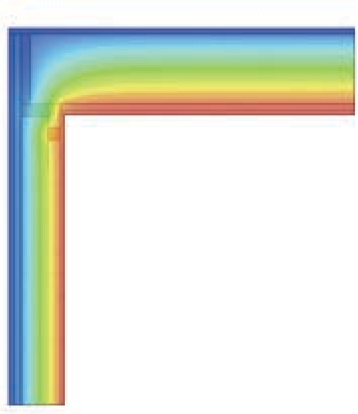

Figure 3. Roof junction to exterior wall isothermal modelling results using Psi-Therm software

The lineal length of the thermal bridge is 61.2m, effectively reducing the overall heat loss by 2.75 W/K, reducing the overall heat loss from 173.2 to 170.5 W/K. This is modest but once all the other thermal bridges are taken into account we can typically reduce the heat loss by around 5% and mean a borderline design can manage to meet the Passive House Criteria.

HYGROTHERMAL MODELLING - Wärme und Feuchte Instationär (WUFI®)

Hygrothermal modelling has shown to be an essential part of verifying the suitability of the construction elements for the iDEAL house. The Fraunhofer IBP simulation software[3] is use to predict one-dimensional heat and moisture transfer in multi-layer building components exposed to variable climate conditions to both the indoor and outdoor surface.

With super insulated elements the risk of interstitial condensation can be heightened, particularly during winter months. This is one reason why the Passive House Institute requires such a high standard of airtightness, which controls the ingress of moisture-laden air through convection into the construction element.

Simple building physics predicts the point of the theoretical dew point in a construction; theory has it that if water vapour is generally prevented to flow into the construction the resulting condensation cannot form. A common international method a creating a sealed environment is through the use of polyethylene vapour barriers to the interior face of the framing. Failures of these systems are becoming well documented in Europe and North America.

When simulated in WUFI® it becomes apparent why such a construction element would fail, moisture becomes trapped behind the vapour barrier allowing the moisture content in the materials to rise, condensation and mould then occur. This will occur for a number of reasons, if the vapour barrier is not fully sealed and airtight the leakage points exacerbate problems. The energy driver moving from warm to cold can also be reversed in summer months allowing water vapour to be carried into the

construction from the exterior. Very few building wraps can resist this infiltration and they would need to be installed with greater care with all the gaps fully sealed.

In practicality these techniques are hard to implement, the materials can be hard to work with, construction workers don't always understand the impact of their work and the competition in the housing market means that quality standards can easily slip. Climate differences also mean that some details are not suitable universally.

There are two main construction details we analysed for the iDEAL house, the skillion roof and the exterior wall section. The construction details for these elements were illustrated in Figure 2. The insulation material used in the construction was Knauf Earthwool® fibreglass. The roof construction has proven to be the more critical case and is examined here is more detail.

The roof construction utilises a ventilated cavity design approach between the metal roofing and the roofing underlay. This ensures that there was complete back diffusion capability in the construction and that moisture can move out when necessary. The interior face is lined with INTELLO® for airtightness and prevention of water vapour transport into the construction under an outward energy flow. Moisture can however move out of the construction on the interior face as the INTELLO® vapour check can remain diffusion open under these conditions.

To explain we prepared four different cases, the as-built construction, removing the vapour check, replacing INTELLO® with a vapour barrier and adding an additional layer of plywood sarking on top of the rafters.

The two critical zones in the construction are the two outer extremes of the fibreglass insulation layer. To ensure the results at these points are not averaged over the full depth of the layer we model a 10mm slice of fibreglass at each face. The WUFI® analysis results are run through a post processor called WUFIBio which is a tool that predicts mould growth, results are presented in Figures 4 and 5.

The first output graph shown as Figure 4, shows the mould growth over time through the inside slice of fibreglass insulation. The performance is considerably worse when a vapour barrier is used compared with a layer of INTELLO® or even no vapour check. The program indicates an amber light as a warning that mould growth risk is high for the vapour barrier case and the graph clearly indicates that mould is building up over time each time the water content is raised over the critical moisture content. This is generally in line with industry advice in New Zealand.

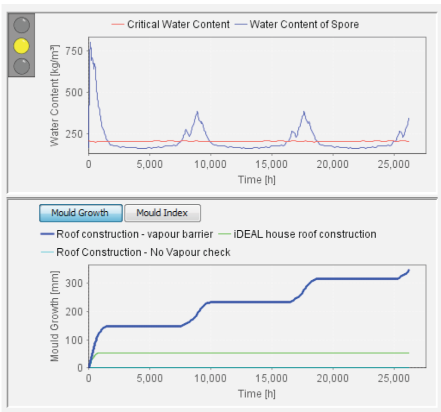

Figure 4. WUFIBio graph results for inner face of fibreglass layer

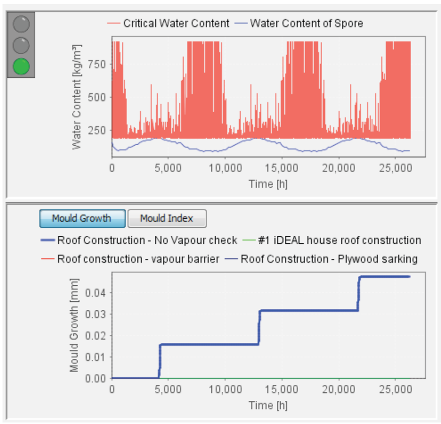

Figure 5. WUFIBio graph results for outer face of fibreglass layer

What is interesting is how the vapour check effects moisture on the outer surface of the insulation layer. If there is no vapour control layer there is again a continual increase in mould activity over time

as the moisture content is very close to the critical water content. If there are any exacerbating situations such as extended cold and wet periods or if the interior relative humidity is allowed to become elevated for periods of time, mould problems will become evident. If we were in a slightly colder climate this behaviour would become far worse. Changing the climate zone from Auckland to Queenstown increased mould growth from less than 1mm over three years to a theoretical 750mm depth. The structural decay would overwhelm the building within early life as indicated by Figure 6.

Figure 6. WUFIBio graph results for outer face of fibreglass layer, Queenstown climate

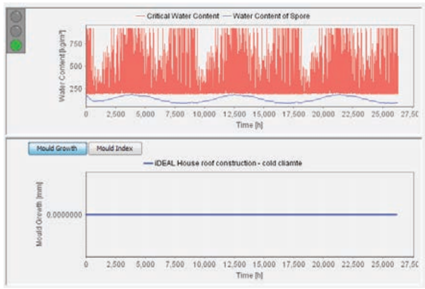

Figure 7. WUFIBio graph results for outer face of fibreglass layer, Queenstown climate, with INTELLO®

Using a vapour check such as INTELLO® completely eliminates the mould risk for this same detail with Queenstown climate applied as can be seen in Figure 7. Queenstown is regularly seen as a dry environment.

Thus we can conclude that a vapour barrier is not advisable as this could lead to a risk of mould to the interior surface of the insulation. Conversely if there is no vapour control layer at all, the outer layer of the insulation can become at risk of mould. The best balance between these two opposing physical behaviours is to use a humidity-variable vapour check such as INTELLO®.

BLOWER DOOR TESTING - AIRTIGHTNESS

High levels of airtightness for the building envelope are a core feature of a Certified Passive House. This has been controversial and often misunderstood. An airtight building does not mean it is sealed, there are still opening windows that the occupants are free to use as in any normal building.

The airtightness envelope prevents unintended air infiltration through the building construction elements. This is a form of heat loss from the building and can be considerable if left unchecked. When working with high-energy efficient buildings there are usually more efficiency gains to be made through eliminating infiltration than there is by simply adding more insulation.

As was evident from our previous discussion of the hygrothermal analysis, an airtightness layer can be used as a vapour check and is essential to avoid unwanted moisture vapour transfer entering into a building component. Effective airtightness eliminates much of the dust and pollutants entering the indoor environment. It makes ventilation and convective heating systems work far more effectively.

Airtightness is readily measured on site through a Blower Door test, which can pressurise or depressurise the building. Performance measures are in terms of volume air changes per hour (ACH) with a 50 Pascal pressure differential (n_{50}). A Certified Passive House must have an airtightness measure less than 0.6 ACH. Final verification is conducted when the building is completed so that the measure is effectively an in use value. This is known as a Method A Test in accordance with EN 13829[12].

As the iDEAL house is not quite complete at the time of preparing this paper the final air tightness verification has not been completed.

CONCLUSION

Having an accurate model of a building allows tuning of the building component design, which is especially important when investing in a high energy efficient or net zero building. Overinvestment in some building components may not be realised whereas underinvestment in essential elements could lead to serious early demise of the building. The analysis procedures provide a methodology to determine these priorities.

The detailed analysis completed for the iDEAL house allowed us to verify during the design stage, that there were no long term performance issues in the home. We can be confident that the design does not have excessive thermal bridging, which not only leads to inefficiency through heat losses but can also put the structure at risk through surface condensation. We also established that the construction elements were free from risk of structural decay and that a vapour check was a necessary investment for long term structural durability.

For a resilient home the long term thermal performance and comfort needs must be met to ensure security for a low energy future. A resilient home must also be durable and resistant to structural decay so that it can endure and realise the investment that has been made.

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CONDENSATION IN LARGE-CAVITY, STEEL-FRAMED ROOF SPACES: CAUSES AND CURES

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ABSTRACT

In recent years, there has been an increasing number of reports of excessive condensation within the roofs of institutional buildings such as schools, halls and commercial structures in New Zealand. These types of building share some common design features such as large roof cavities, metal framing and profiled metal roofs with standard underlay, fibreglass insulation and suspended ceilings.
These condensation problems differed to those associated with 'classical' thermal bridging and so a test structure was designed where four roof specimens with different insulation specifications could be characterised experimentally. The experimental findings gathered during a New Zealand winter were also used to underpin the development of a numerical model.
The results indicate that the common practice of simply inserting thermal breaks in between the steel elements and the roof cladding is not always sufficient to prevent condensation and a full cover board insulation may be necessary. It was also observed that condensation events did not happen at the predicted times, i.e. during frosty nights and early in the morning. Ventilation rates for theses roofs can vary by an order of magnitude and are shown to be dominant over moisture diffusion and hygroscopic storage processes. Utilising the modelling approach, design guidelines are given on how to limit the amount of condensation by optimising insulation thickness and roof ventilation or indoor climate modification. These findings are presently being extended to residential skillion roofs.

KEYWORDS

Condensation; Ventilation; Roof spaces; Steel-framed roofs; Thermal bridges

INTRODUCTION

There has been an increasing number of reports of excessive condensation within the roofs of institutional buildings such as schools, halls and commercial structures in New Zealand over the last few years. BRANZ has been engaged with investigations of several of these roofs, finding that many of the cases were of a similar design. They all typically had large roof cavities, profiled metal framing with underlay, fibreglass insulation and a suspended ceiling, typically acoustic tiles. They also typically had a large number of people in the indoor space, generating a high moisture load.
The reason for the excessive condensation can be found in high humidity air from below, for instance a classroom penetrating into the roof cavity and condensing on some parts of the metal framing when it was sufficiently cold. This problem was not explained by classical thermal bridging, where there is a direct path of high thermal conductance from the cold outside to the warm inside. In these buildings condensation was occurring on metal structures which were not directly in contact with the warm inside and therefore not a standard thermal bridge. This phenomenon has since been summarised under the term of *aggravated thermal bridging* (*Cunningham 2014*). The risk of condensation is increased if large amounts of moisture can find its way into the roof cavity aided by a ceiling which is very vapour or air permeable, a roof cavity with inadequate ventilation to the outdoors and a high level of thermal insulation at lower levels in the roof. In the latter case, the temperature of the roof framing will be more governed by the cavity and outside air temperature than by the inside temperature, effectively bringing the higher levels of the structures temperature closer to the dew point and thus aggravating any

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[1] Formerly at BRANZ Ltd.

condensation issues. To prevent condensation events under such circumstances a 'warm-roof' approach can be adopted. A plywood/phenolic insulation sandwich retrofitted in between the roofing cladding and the metal purlins will raise the temperature to a level in the roof cavity where the dew point is avoided. However, such remedial action is difficult to construct and expensive.

This study complements the work in the WAVE programme (Weathertightness, Air Quality and Ventilation Engineering) of BRANZ. In particular, it was the goal to gather firm data for the psychrometric conditions of large-cavity roof structures under various hygrothermal loads and to suggest economical remedial actions meeting structural, fire and acoustic requirements. The data is also used to benchmark numerical models which will allow us to explore a larger parameter space. In this paper, we specifically compare the plywood/phenolic insulation sandwich to three other roof designs. It was taken as a given that the suspended ceiling would remain unchanged and the inside climate profile was fixed, leaving the roof structure, insulation and the roof cavity ventilation levels as the main parameters. It is not primarily our intention to study the condensation under the roof cladding, but rather the unexpected condensation on the steel elements including the metal purlins. Small amounts of condensation under the roof metal is usually acceptable in the New Zealand building environment, with the roof underlay designed to catch condensation drip and prevent it penetrating deeper into the roof structure.

With an experimental and modelling approach it is demonstrated that the traditional practise of using a thermal break between steel elements and the roof is not always sufficient to avoid condensation, and that a full cover board insulation system above the main cavity is often required. We also find that for the investigated roofs, moisture contents and condensation episodes are largely governed by ventilation from indoors and outdoors and that diffusion and hygroscopic storage effects were usually unimportant, except during some rain events. WUFI-modelling (WUFI®, Software package to simulate air, heat and moisture transfer, Fraunhofer Institut) was used to give design charts allowing the user to choose the insulation thickness and the roof ventilation levels or modify the indoor climate in order to limit the amount of condensation that may accumulate in these roof structures.

While the literature on simple thermal bridges and how to avoid them is considered to be mature and standard methods to avoid them are available (EN ISO Standard 14683), little is found on the issue of aggravated thermal bridging described above. British Standard 5280 contains extensive advice on avoiding condensation in pitched roofs but is not intended to address the presence of cold metal framing.

EXPERIMENTAL

Experimental Rig and Instrumentation

In order to conduct experiments representative of a full-scale section of a commercial or institutional roof we have modified a standard shipping container to support different roofs that could easily be disassembled and exchanged. The container is intended to then represent a section of the commercial building as show in Figure 1.

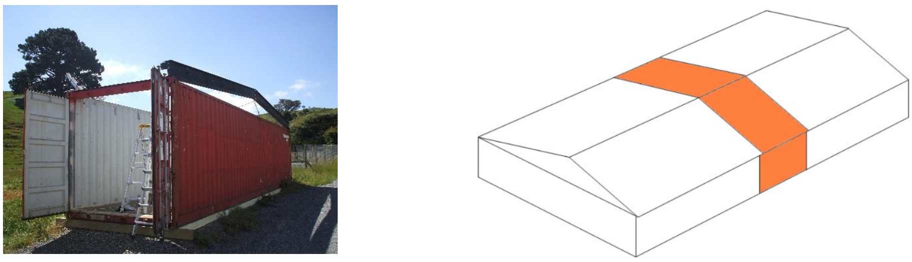


Figure 1: Modified shipping container for experiments with different roof designs representative of a full scale commercial roof as indicated in the sketch on the right.

The advantages of this set-up are two-fold: the experimental rig can easily be transported to different climatic zones within New Zealand where the conditions are more prone to condensation problems and it is flexible enough to allow the installation of different roof structures with minimal effort. All tested roof specimens had some common design features: one of the symmetrical roof slope was oriented due-north the other due-south. The roof frame is made up of three pairs of universal beams resting on top of the short container walls (see also Figure 1). Twelve pairs of C-shaped metal purlins span perpendicular between the universal beams. All roofing elements were screwed together so that the roof specimen can be easily dissembled and exchanged for another roof design.

Each roof was fitted with a range of monitoring and data acquisition equipment in order to gather information on how the different roof designs are performing. Temperature (T-type thermocouples referenced to an isothermal block monitored by a platinum resistance temperature sensor) and relative humidity (Honeywell HIH 4000, capacitance method) sensor pairs were located at various points throughout the structures. Figure 2 shows how the critical areas of the timber/metal purlin roof structure have been fitted with sensor pairs. Further sensor pairs are placed at various points throughout the roof, depending on the roof specimen (outdoors, above roof underlay, above ceiling insulation, above ceiling and indoors).

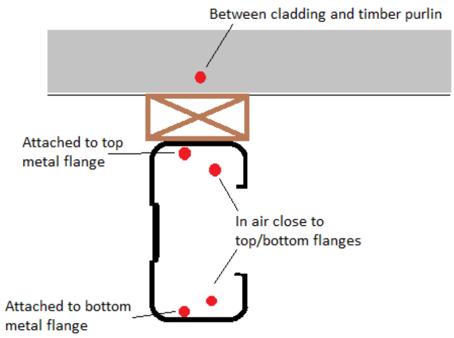


Figure 2: Location of selected sensor pairs, here indicated for the roof with timber thermal breaks above the metal purlins. Each red circle represents a temperature and relative humidity sensor pair.

Very accurate relative humidity measurements of between 95% and 100% are crucial to this study. However, relative humidity sensors are often calibrated up to only 90% using a linear calibration, which is not sufficient for our purposes. In order to improve our sensor calibration we utilised a BRANZ-manufactured two-pressure relative humidity generator to give a more accurate calibration in the 95 to 100% regime. These calibrations showed quite clearly that at high relative humidities the calibration is non-linear.

Other quantities recorded include timber moisture content (depending on the roof design), wind speed and direction as well as ambient relative humidity and temperature.

Control of the Indoor Climate

The indoor environment was actively controlled to follow an idealised school room climate based on actual measurements in New Zealand schools. Indoor climate control was achieved with two convective heaters, a centrifuge humidifier and a dehumidifier. The data acquisition setup measured indoor temperature and relative humidity every 60 seconds and decided which devices needed switching to follow the desired temperature and humidity profile. We distinguish four different profiles as shown in Figure 3: Dry, Moderate, Wet and Very Wet.

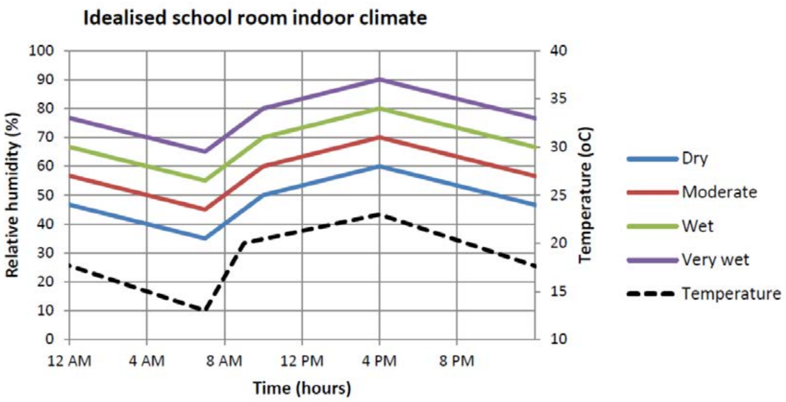


Figure 3: Indoor climate profiles used for this study. Temperature and relative humidity values during the day are derived from actual measurements in New Zealand schools.

Roof Specimens

Figure 4 depicts the four different roof structures that were used in this study. All roof specimens except the *EPS Metal Panel* roof had a common roof cladding system and building underlay. The roof cladding was metal with a trapezoidal profile and was fixed to the metal purlins with screws which traverse whatever thermal break system was installed in between.
The building underlay was Kraft paper with the addition of fire retardant salts and is hygroscopic with 13% equilibrium moisture content at 100% relative humidity. It had a water vapour resistance of 2.5 MN s/g at 75% relative humidity, at which RH it had an area density of 450 g/m^2.

(1) EPS Insulation Board specimen: Expanded polystyrene (EPS) sheets were fitted in between the timber purlins which are fixed on top of the metal purlins. A wire mesh spanning over the metal purlins supports the EPS panels and keeps them in place.

(2) Phenolic Insulation Board specimen: This roof design had a full, homogeneous insulation layer in between the metal roof cladding and the support structure. The panels were formed by an insulating material sandwiched within two sheets of plywood. For the insulating layer, a phenolic material was chosen for its fire retardant and structural properties. The panels are interlocking using a system of timber shear keys giving the structure more stiffness, preventing the panels from sagging.

(3) Timber Thermal Break specimen: A timber purlin was fixed on top of the metal purlin, acting as a thermal break. The cladding can radiatively cool well below ambient temperatures on frosty nights but is now thermally separated from the metal purlin. One obvious drawback here is that the air inside the roof cavity can be easily cooled down by the cold cladding because most of the roof is in direct contact with the air inside the roof cavity.

(4) EPS Metal Panel specimen: This design was another version of the fully-insulated solution. Interlocking commercial cladding elements formed by expanded polystyrene (EPS) panels sandwiched between two thin metal sheets replace the traditional metal cladding.

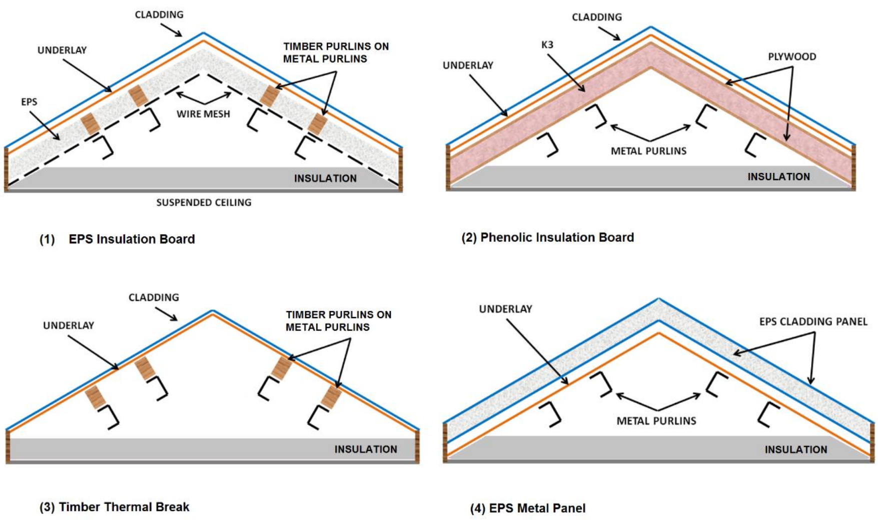


Figure 4: The four roof specimens used in this study. *EPS* stands for expanded polystyrene. *K3* is a commercial insulation product based on a phenolic foam.

Air Flow Characteristics

Ventilation is essential in determining the hygrothermal environment in roof spaces. Ventilation from the outdoors and the indoor space into the roof cavity can strongly influence the moisture balance of the roof environment. In order to gather some insight into the magnitude of the air exchanges in the roof cavity, airtightness measurements were conducted.

The air flow characteristics were described in terms of air flow resistances of the various openings and expressed by the relation

$$Q\ [\mathrm{m^3/h}] = C\ |\Delta P|^{\,n} \qquad [1]$$

where Q is the air flow rate, C is the characteristic coefficient, ΔP is the pressure difference between the two spaces for which the air flow resistance is to be determined and n is the characteristic exponent. The latter is close to 0.5 for fully turbulent flow and close to 1 for laminar flow.

The air flow resistances were measured using a commercial blower door apparatus. The air flow rate Q through the fan and into the cavity was obtained by evaluating the pressure drop across the calibrated fan unit. The pressure difference ΔP between the two spaces for which the air flow resistance is to be determined (for instance the ceiling between the inside and the roof cavity) was measured by a second pressure gauge. By stepping through a series of pressure differences ΔP and air flow rates Q, the two coefficients C and n can easily be obtained by means of a least square fit describing the ensemble of openings.

A given cavity will typically have a number of different openings to the surrounding spaces. In our case of the roof cavity four major openings can be identified: at the eaves, at the ridge, along the sides and at the level of the suspended ceiling. Ideally, all of these openings would be characterised. Specific openings were isolated by sealing off all the other openings before conducting the pressure test. With

all opening sealed bar one, the air flow through the fan will be forced exclusively through the opening to be characterised.
If an opening could not be easily be sealed, a second fan was used to cancel the pressure gradient across this opening. More details can be found in Cunningham (2013).

RESULTS

The experimental rig was shipped to Dunedin, New Zealand and the four different roof specimens tested over the period from 4 July 2012 to 8 October 2012, i.e. the second half of a Southern Hemisphere winter. During this time the average outdoor temperature was 8.2 °C, with a minimum of -1.4°C and a maximum of 25.2 °C. The average outdoor relative humidity was 81%.

Estimation of Ventilation Rates

The average air flows through the different openings of the roof specimen and the container can be estimated using the previously measured air flow characteristics and from the average pressure differences across them. Figure 5 indicates approximate air exchange rates during a windless night, where the given averaged pressure differences have been measured. Although these are small in absolute terms, they are statistically robust and in the ranges expected (Cunningham 2013). Using this pressure data we arrived at ventilation rates of approximately 15 air exchanges per hour (ach) for the roof cavity to the outdoors.

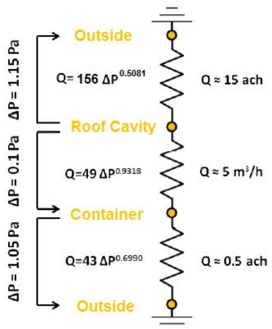


Figure 5: Simplified resistance network schematic of the air flow across the various spaces for the measured averaged pressure differences on a calm day and the derived air exchanges per hour (ach).

We can further define a ventilation fraction α of the roof cavity as the ratio between the ventilation of the roof cavity to the outdoors to the sum of the total ventilation (see section "Modelling and Design Guidelines" below). For the data in Figure 5 we derive a high ventilation fraction of approximately 0.97. This high value is achieved even without the introduction of additional vents.
Ventilation is found to be the dominant mechanism of moisture transport, with diffusion and hygroscopic moisture fluxes being of secondary concern (Cunningham 2013).

Roof Performance

Figure 6 shows the psychrometric conditions through each roof specimens at selected times. While the outdoor climatic conditions are not absolutely identical, the data nevertheless points out some critical performance difference namely around the upper flange area.

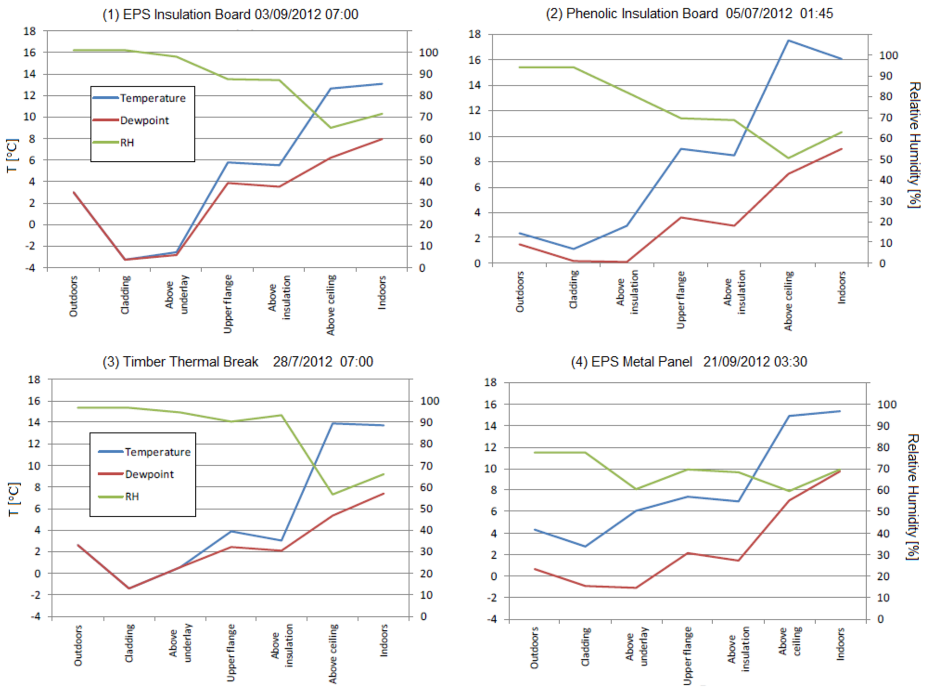


Figure 6: Temperature, relative humidity (RH) and dew point for all four roof specimens at selected times and for relevant locations.

For both the EPS Insulation Board and for the Timber Thermal Break specimen the temperature around the upper flange of the metal purlin comes close to the dew point, increasing the risk of condensation. Not surprisingly, the fully insulated roof specimens (2) and (4) maintain a significant gap between the flange temperature and the dew point. Also visible is the temperature of the roof cladding material dropping below the ambient outdoor temperature, the physical reason for this being the radiative heat loss into the sky.

The data from the Timber Thermal Break specimen is shown in more detail during a critical event on 14/09/2012 in Figure 7. During the early morning hours up until close to midday the vapour pressure close to the top flange of the metal purlin have reached the saturation vapour pressure resulting in a condensation event.

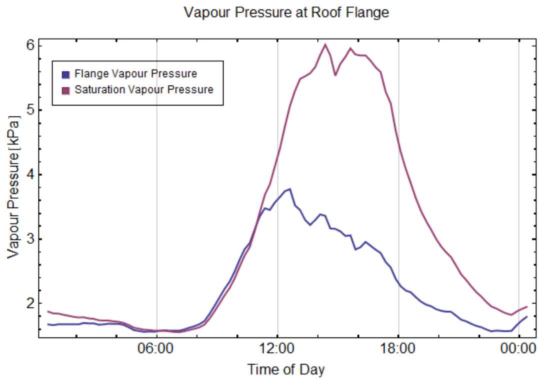


Figure 7: Measured vapour pressure in comparison to the saturation vapour pressure of the Timber Thermal Break specimen (3). Measurements are taken from in the air close to the top metal flange. Between approximately 04:00 and 11:00 there would have been a condensation event.

This shows that even with the timber thermal break installed in between the metal purlin and the roof cladding, condensation can still occur. In order to quantify condensation event more rigorously we make the definition that while relative humidities are above 98% there is a condensation event. Figure 8a shows relative humidity data for the air close to the upper metal purlins for all four roof specimens displayed as a histogram with 5% bins. Only the Timber Break (3) and the EPS Insulation Board (1) roof design have relevant events in the category above 95%. This region is displayed in more detail for these two roofs in Figure 8b.

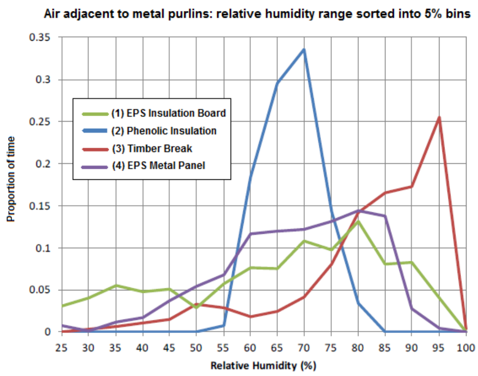
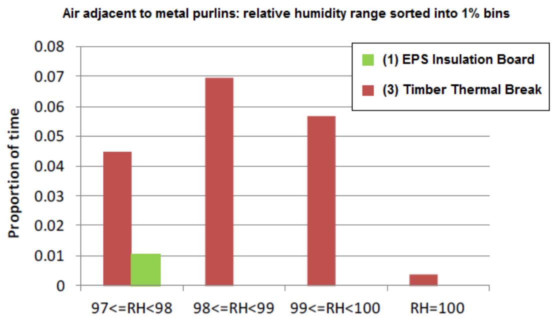


Figure 8a: Histogram of relative humidities as a proportion of time of the air adjacent to the metal purlins of all four roof specimens.

Figure 8b: Detail of Figure 8a with 1% bins for relative humidities from 97% to 100% and for the Timber Thermal Break and EPS Insulation Board specimens only.



The figures above point to the Timber Thermal Break (3) specimen as most vulnerable to condensation events at the metal purlins, while the Phenolic Insulation Board (2) roof design seems to avoid any such occurrences during the period covered. It is noteworthy that the condensation events in the Timber Thermal Break roof are often associated with rain events (data not shown here, details in Cunningham 2013), and that the precipitation of moisture did not occur, as one would expect, in the early hours of the morning when the temperature reaches a minimum. As visible in Figure 7, the condensation is maintained during the morning hours when the sun starts to warm the structure. The proposed mechanism here is that the timbers of the specimen absorb moisture from the close to 100% humidity air in the cavity during rain and discharge this excess moisture when the timbers are heated up, giving rise to a condensation event.

MODELLING AND DESIGN GUIDELINES

In order to be able to give some design recommendations we have extended the experimental studies with modelling data obtained using the two dimensional software WUFI-2D (WUFI®, Fraunhofer Institut). As shown in Cunningham (2013) a reasonably good agreement is obtained for temperature and relative humidity in the roof cavity.

The main factors determining theses roofs' performance are: the roof type, the indoor and outdoor climates, the amount of insulation and the ventilation levels. The indoor climate was modelled as given in Figure 3, the outdoor climate was taken as the Dunedin late winter climate from 18.08.2012, to 09.09.2012.

Each roof specimen was modelled with 200 mm of fibreglass insulation on top of the ceiling. The Timber Thermal Break specimen was given no further insulation. Rigid insulation systems were modelled with R-values of 0.75, 2.25 and 4.50 m^2 °C/W.

In line with our experimental measurements, total roof cavity ventilation was taken as at least 1 air exchange per hour (ach) allowing diffusion and hygroscopic performance to be ignored. The critical parameter then becomes the ratio of the outdoor ventilation rates to the indoor ventilation rates. Alternatively we can also use the ratio of the outdoor ventilation rate to the total ventilation rate, which we call "Ventilation Fraction". A ventilation fraction close to one representing almost exclusive air exchange with the outdoors, a fraction of close to zero a dominant air exchange with the indoor space.

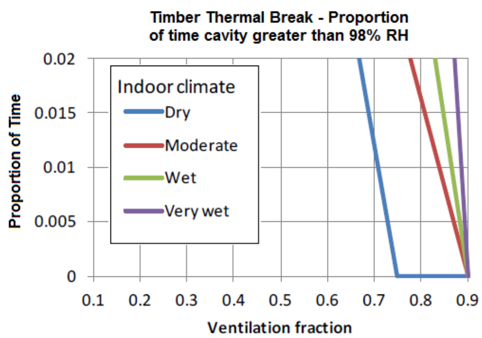


Figure 9: Simulation of a 90 mm thermal break between metal purlin and roof cladding. Shown is the proportion time the cavity has a relative humidity greater than 98% as a function of the ventilation fraction for the four different indoor climate profiles.

Figure 9 shows the result for the simulation of a 90 mm thick timber break in between the metal purlin and the roof cladding. We find little difference between a timber and an EPS thermal break. It is very difficult to design a roof that avoids extensive periods of time above 98% relative humidity. On the other hand placing an insulation system above the main cavity increases the temperature of the metal purlins and the cavity air and provides a system with good hygrothermal performance.

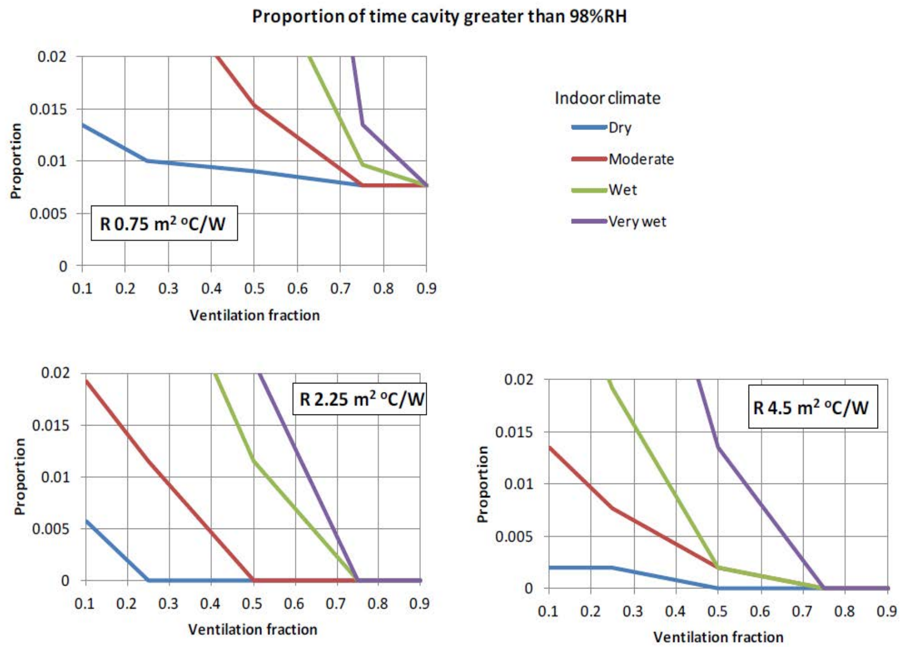


Figure 10: Simulation of an insulation system above the main cavity. Displayed is the proportion of time the cavity has a relative humidity above 98% as a function of the ventilation fraction and for the four different indoor climates. The three graphs give the results for three different levels of thermal insulation, ranging from R=0.75 to 4.5 m^2 °C/W.

The simulations for such roofs are shown in Figure 10. It is indicated that the insulation above the main cavity should at least be 2.25 m^2 °C/W and that values higher than this are reaching the level of diminishing returns. The result from the modelling also suggest that the ventilation fraction should be kept above 0.75 in order to minimise the risk of condensation.

CONCLUSION

The hygrothermal performance of four different roof specimens has been examined experimentally and with 2-dimensional modelling. It was found that the ventilation rates in these roofs will be in the range of 1 to 20 ach and that the roofs' performance was dominated by ventilation-driven moisture fluxes. The roof specimen with only timber thermal breaks in between the cladding and the metal purlins was found to absorb moisture hygroscopically during rain and release that moisture the next morning as the sun heats the roof. The quantity was found to be enough to trigger a condensation event. Thus, the traditional practise of using a thermal break between steel elements and the roof is not always sufficient to avoid condensation in these institutional roofs. A modelling approach was used to draw up graphs that enable the designer to choose the insulation thickness and the roof ventilation levels or modify the indoor climate to limit the amount of condensation that may accumulate in these structures.
This work is presently being extended to condensation in skillion-type residential roofs.

ACKNOWLEDGEMENTS

This work has been funded by the New Zealand Ministry of Business, Innovation & Employment and the Building Research Levy.

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HEATER CHOICE AND MOULD GROWTH IN NEW ZEALAND HOMES: AN INTERVENTION STUDY.

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ABSTRACT

The relationship between use of unflued gas heaters (UGH, N=14) or heat pump heaters (HP, N=12) and mould growth was investigated in the living rooms and bedrooms of 26 New Zealand homes during the winter season. The suitability of the wall environment for fungi development was estimated *via* a fungal detector. This fungal detector consists of three permeable fungi inclusions of pre-culture spores between two plastic slides. Two inclusions were xerophilic fungi (grow under relatively dry conditions i.e. >70% RH) and the third was hydrophilic fungi (grow under relatively humid conditions i.e. >90% RH). After 85 days of exposure, the hyphal lengths of each inclusion were measured under a microscope and were compared to the measured wall psychrometric conditions.

The average wall psychrometric conditions were found significantly different in the two heater type groups in both the living rooms (15.2°C/63.6% for UGH users vs. 17.4°C/53.5% for HP users) and the bedrooms (13.9°C/68.6% for UGH users vs. 16.0°C/60.9% for HP users). For both xerophilic fungi, the average daily hyphae growth rates were 4 times higher in the livings rooms of the UGH users than the HP users (1.17 µm/day vs. 0.30 µm/day), and 16 times in the bedrooms of the UGH users than the HP users (10.8 µm/day vs. 0.48 µm/day). No differences were found for the hydrophilic fungi between the heater users. Darby et al (2007) and Flannigan et al (2011) showed that xerophilic fungi are considered as first colonizers (first to react to environment changes) whereas hydrophilic fungi need very humid condition to start germinated.

The UGHs were found to be a significant additional source of moisture which dramatically increases the capacity for xerophilic fungi to grow on wall surfaces. The potential adverse health effects related to such heaters mean that unvented gas heating appliances should not be operated in homes and should ideally be more regulated.

KEYWORDS:

New Zealand Homes; Heater usage; Psychrometrics; Mould growth.

INTRODUCTION

Houses in New Zealand are on average too damp and cold (Isaacs et al., 2004). The dampness and low indoor temperature is mainly due to two factors: building insulation deficiency (houses constructed before April 1978 were not subject to regulations requiring insulation) and low efficiency heating systems (only around 5% of dwellings have central heating systems). Unflued gas heaters (UGH) are used in 25% of the dwellings (Howden-Chapman et al., 2005, Wilton, 2005), and they are mainly operated on low or medium setting, that give an estimated average heating capacity of 2.6 kW (Boulic et al., 2007).

UGH, also called Liquefied Petroleum Gas (LPG) cabinets or portable gas heaters, are known to release combustion gases in the indoor environment (Francisco et al., 2010). Amongst the gases released during the combustion process, is water vapour at a rate of 1.6 kg per kg of LPG consumed dependent on the proportion of butane and propane in the bottle. Therefore, the use of UGH increases the indoor moisture (Francisco et al., 2009).

Temperature and moisture levels are critical factors for fungi development. Viable spores are always present in the dwellings and germination and subsequent hyphae development can occur if the nutrients, temperature and the moisture availability are suitable. The mould and fungi by-products could be harmful for people, particularly immune deficient people or people with asthma (Mendell et al., 2009).

The Housing, Heating and Health Study (HHH Study) was a community trial to investigate the relationship between domestic heaters and health and the indoor environment. Four hundred families with a child with doctor diagnosed asthma (index child) and using an UGH or portable electric heater as their main heater were enrolled in this interventional study. Baseline health and environmental parameters were measured in all homes during the first winter/spring season. Before the second winter season, a higher capacity and non-polluting indoor heater such as heat pump heater (HP) was installed in randomly selected half of the dwellings (*Treatment group*). The *Control group* received their new heaters at the end of study. Health and environmental measures were repeated in all homes during the second winter (Howden-Chapman et al., 2008).

For a subset of the HHH Study households operating either an UGH or a HP, the indoor climate was investigated via a fungal detector, correlated to a temperature/relative humidity measurement. The objective was to determine if the fungal detector could be a useful device to evaluate the suitability of the indoor environment for fungi development during winter time in New Zealand.

METHOD

This study was carried out in winter in 26 dwellings in the Hutt Valley, a semi-coastal area that is part of Greater Wellington, New Zealand. The dwellings had been insulated (roof and under floor) before the study started, according to the Energy Efficiency and Conservation Authority (EECA) standard specifications (NZS, 2004). In these 26 monitored dwellings, 12 households received a HP (*Treatment*) when 14 households were still using their original UGHs (*Control*).

For each dwelling, the “close to the wall” temperature and relative humidity (RH) measurements were carried out in the living room and the index child’s bedroom, using wall-mounted Hobo® H8 sensors (Onset Computer Corporation, Bourne, Massachusetts, USA). The loggers were attached on the interior lining of an external wall at a consistent height of 1.8 metre above the floor level (Figure 1). The loggers were set to monitor the temperature and the RH continuously every 15 minutes for up to a 41.4 day period (maximum memory capacity). As the logger thickness leaves the sensors about 15 mm away from the wall surface, “close to the wall” was used instead of “wall surface”.

In close proximity to this temperature/relative humidity sensor, a fungal detector (JDC Corporation, Kanagawa, Japan) was located (Figure 1). The detector consisted of three inclusions; two xerophilic fungi (*Eurotium herbariorum, Aspergillus penicilloides*) and one hydrophilic fungus (*Alternaria alternata*) on a transparent plastic slide (Abe, 2003). Xerophilic fungi grow under relatively dry conditions and hydrophilic fungi need humid conditions to grow. Each fungal inclusion contains one drop of suspension at 10^6 spores per ml concentration (Abe, 1993). The fungal detectors were exposed to the living room and bedroom wall climate for an average period of 84.8 days. At the conclusion of the winter monitoring period, the three fungal inclusions (*Aspergillus penicillioides*, *Eurotium herbariorum* and *Alternaria alternata*) were examined under a microscope and the hyphae lengths were measured.

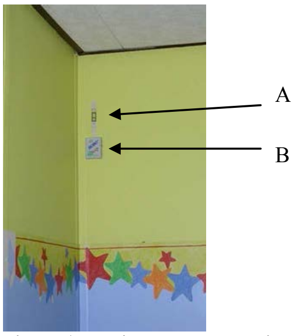

Figure 1: Typical sensors location on the inside of the external wall. A: Fungal detector, B: temperature/RH logger.

RESULTS AND DISCUSSION

The "close to the wall" climate

The temperature/RH loggers operated to full memory capacity (41.4 days). Table 1 shows the average psychrometric conditions close to the wall in households operating an UGH (N=14) and in households operating a HP (N=12).

Heater use in the living room	"Close to the wall" psychrometric conditions: Temperature (°C), relative humidity (%) and humidity ratio (g of water per kg of dry air)		
	N	**Living room**	**Bedroom**
Unflued Gas Heater (UGH)	14	**15.2°C**, $_{95\%}$CI [14.3°C – 16.2°C] **63.6%**, $_{95\%}$CI [60.7% – 66.5%] **6.9g/kg**, $_{95\%}$CI [6.6g/kg – 7.1g/kg]	**13.9°C**, $_{95\%}$CI [12.9°C – 14.8°C] **68.6%**, $_{95\%}$CI [64.1% – 73.1%] **6.8g/kg**, $_{95\%}$CI [6.4g/kg – 7.2g/kg]
Heat Pump (HP)	12	**17.4°C**, $_{95\%}$CI [16.0°C – 18.9°C] **53.5%**, $_{95\%}$CI [48.9% – 58.1%] **6.6g/kg**, $_{95\%}$CI [6.3g/kg – 6.9g/kg]	**16.0°C**, $_{95\%}$CI [14.8°C – 17.2°C] **60.9%**, $_{95\%}$CI [57.6% – 64.1%] **6.9g/kg**, $_{95\%}$CI [6.6g/kg – 7.2g/kg]

Table 1: Average [$_{95\%}$CI] "close to the wall" temperature, relative humidity, humidity ratio in living rooms and bedrooms of households operating either an unflued gas heater or a heat pump heater.

In the living rooms, the "close to the wall" climate was on average colder (15.2°C vs. 17.4°C) and damper (63.6% vs. 53.5%) in the UGH group than in the HP group. Similar results were found in the bedrooms (13.9°C vs. 16.0°C and 68.6% vs. 60.9%) for UGH and HP groups respectively. For both groups, the bedrooms were colder and damper than the living rooms. In the living rooms, Table 1 shows a higher humidity ratio in the UGH group than the HP group. This result is consistent with UGH being an additional source of moisture for the living environment. In the bedrooms, for both groups of households, the humidity ratio was similar (6.8g/kg vs. 6.9g/kg). With a similar level of humidity ratio, the lower "close to the wall" average RH for the HP user group appears to be mainly due to a higher average temperature. This result indicates that the HP seemed to be more effective than the UGH for heating more than one room in the house. The moisture released from the UGH operated in the living rooms appears to have little effect on the bedroom humidity ratio.

Optimal RH is the primary parameter for fungi to grow. When the RH of the air surrounding the building material is in a steady state condition (equilibrium), this RH is called the equilibrium RH

(ERH) and is equivalent to the water activity (a_w) of the building material when expressed as a fraction. A building material in a steady state condition with a surrounding RH of 70% (ERH = 70%), will have a_w = 0.70. This threshold was chosen, as it represents the minimal ERH/a_w for xerophilic fungi to start growing (Flannigan and Miller, 2011) and two of the three fungal inclusions contained xerophilic fungi (*Eurotium herbariorum, Aspergillus penicilloides*).

Table 2 shows the percentage of time, in the living rooms and in the bedrooms, with a “close to the wall” RH above 70% for both types of heater being operated in the living rooms.

Heater used in the living room	**Percentage of time with the close to the wall relative humidity > 70%**		
	N	Living room	Bedroom
Unflued Gas Heater (UGH)	14	29	46
Heat Pump (HP)	12	9	18

Table 2: Percentage of time with the “close to the wall” RH above 70% in the living rooms and in the bedrooms.

Table 2 shows that the bedrooms had greater exposure to RH levels above 70% than the living rooms. The households operating an UGH showed a higher percentage of time with the “close to the wall” above 70% RH, in both the living rooms and the child’s bedrooms than the households operating a HP. In fact, the “close to the wall” psychrometric conditions were substantially different in the UGH and HP homes which would impact on the capacity for mould to grow on the wall surface.

Capacity for mould to grow on external wall surface

The 52 fungal detectors (one in each living room and one in each bedroom of these 26 homes) were exposed for an average period of 84.8 days, $_{95\%}$CI [80.5 – 89.1], with an exposure range between 62 and 109 days except for one dwelling where the fungal detectors stayed for 154 days, because the household was not available at the collection time. Following the exposure period, each of the three fungal inclusions (*Aspergillus penicillioides, Eurotium herbariorum* and *Alternaria alternata*) was examined under a microscope and the hyphae lengths were measured. The daily growth rate outliers were removed from the analysis. The lower outliers were identified as values lower than the value of (P75- ((P75-P25) × 1.5)) and the upper outliers were identified as values greater than the value of (P75 + ((P75-P25) × 1.5)). Wilcoxon’s rank tests were applied to test if the daily hyphae growth rate (μm/day) was different between households operating an UGH and households operating a HP.

Figure 2 shows the average daily hyphae growth in the living rooms and in the bedrooms. In the livings rooms, the daily hyphae growth rates for both xerophilic fungi were four times higher in the UGH user group than in the HP user group, however these results were not statistically significant due the small sample size. The daily hyphae growth rate for *Alternaria alternata* was slightly higher in households operating a HP than in household operating an UGH (0.90 μm/day (HP) vs. 0.77 μm/day (UGH), p-value = 0.07).

In the bedrooms, the daily hyphae growth rates for both xerophilic fungi *Aspergillus penicilloides* and *Eurotium herbariorum*, were 7 and 26 times higher in households operating an UGH than in households operating a HP respectively (p-value < 0.01). No significant differences were found for *Alternaria alternata* between both household groups in the daily hyphae growth rates.

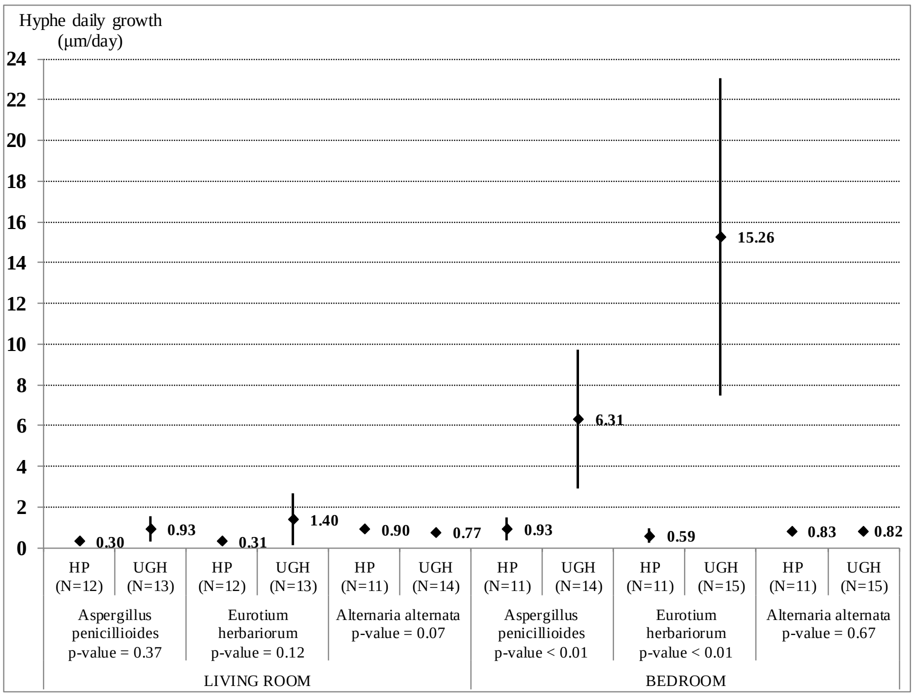

Figure 2: Average daily hyphae growth ($\pm_{95\%}$ CI) in the living rooms and in the bedrooms (outliers removed).

The "close to the wall" climate was found to be more suitable for mould development in the bedrooms than in the living rooms. These results are consistent with the percentage of time that the "close to the wall" RH was above 70%, being twice higher in the bedrooms than in the living rooms (Table 2). The factor contributing to the different room climates was the use of the UGH in the living rooms which have insufficient capacity to warm the bedrooms.

However, the higher capacity for fungi to grow, in households who operated an UGH, was only true for the two xerophilic fungi *Eurotium herbariorum* and *Aspergillus penicilloides*. Consistent with the fact that these two fungi are the first to react to environment changes, they are considered as first colonizers because they can grow under relatively dry conditions (a_w > 0.70) whereas hydrophilic fungi like *Alternaria alternata* need very humid conditions (a_w > 0.90) to start germination (Darby and Caddick, 2007, Flannigan and Miller, 2011). Such conditions were infrequent in all studied houses, even those with UGHs.

Laboratory Hyphae development compared to fieldwork hyphae development.

"Close to the wall" average temperature and RH were plotted on a climograph (isopleths) for *Eurotium herbariorum* (Figure 3), and *Alternaria alternata* (Figure 4). The isopleth for *Aspergillus penicilloides* is similar to the *Eurotium herbariorum* isopleth as both fungi have very similar temperature/RH requirements; therefore the *Aspergillus penicilloides* isopleth is not shown. The temperature/RH values found in the fieldwork were grouped as UGH living room, UGH bedroom, HP living room and HP bedroom and were compared to optimum climate zone for fungal germination which were obtained under constant conditions of temperature and RH in a laboratory. The laboratory data shown in Figure

3 were adapted from published work reported in Abe (1993). The laboratory data shown in Figure 4 was kindly provided by Abe (personal communication) and are unpublished.

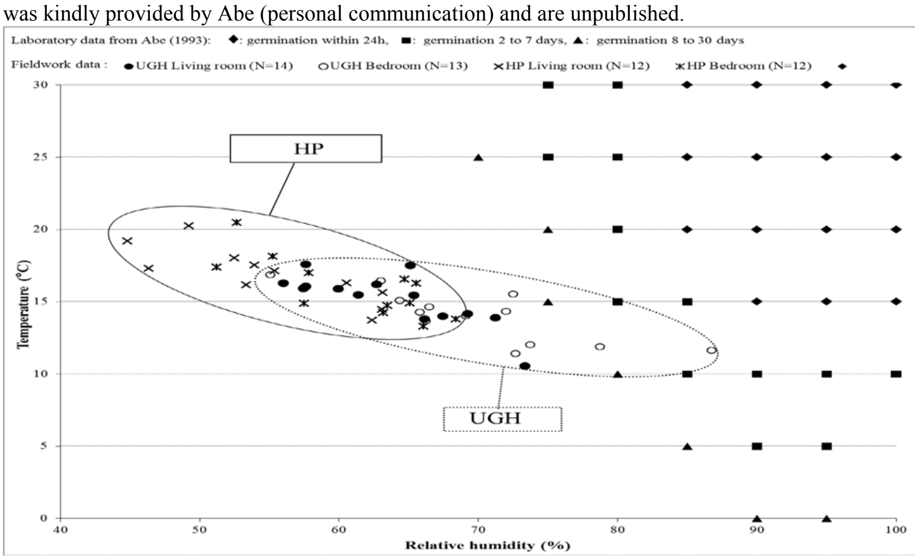

Figure 3: Climograph with germination of *Eurotium herbariorum* spores; laboratory data compared to fieldwork data (adapted from Abe 1993).

In Figure 3, the germination zone starts at RH = 70% and temperature = 25˚C. Figures 3 shows the average climate in the UGH user group closer to the germination zone than in the HP user group. Six bedrooms and two living rooms from the UGH user group had an averaged climate that was either close or within the 8 to 30 day germination zone, whereas no room from the HP user group was within the germination zone. For both groups of households (UGH and HP users), the conditions for mould to grow were more favourable in the bedrooms than in the living rooms.

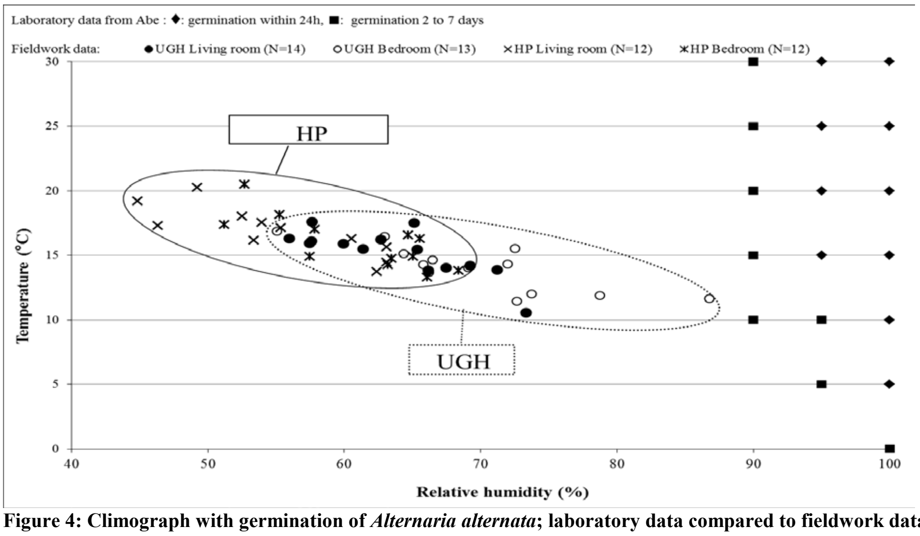

Figure 4: Climograph with germination of *Alternaria alternata*; laboratory data compared to fieldwork data (Abe, personal communication).

Figure 4 shows different requirements in terms of temperature/RH for the growth of the hydrophilic fungus *Alternaria alternata*. In Figure 4, the germination zone starts at RH = 90%. None of the households from either group was within the germination zone. One bedroom from the UGH user group showed an average RH of 86.8% which is close to the germination zone but did not show higher hyphae development than the group's average hyphae length.

These results are consistent with the very low daily hyphae growth found in both groups for *Alternaria alternata* (Figure 2).

These results support the previous findings that the daily hyphae growth rates, for both xerophilic fungi (*Eurotium herbariorum* and *Aspergillus penicilloides*), were higher in the bedrooms than in the living rooms and also higher in the households operating an UGH than in households operating a HP. The measured "close to wall" temperature/RH values were well below the laboratory germination zone for the hydrophilic fungus *Alternaria alternata* development (RH=90%), consistent with a low daily hyphae growth rate found for this fungus.

Hyphae development in response to favourable climate exposure

The measured daily hyphae growth rate was compared to the time of exposure in favourable psychrometric conditions. This analysis was done using a methodology developed by Building Research Association of New Zealand (Cunningham, 2001).

The "close to the wall" temperature from 0°C to 30°C and the RH from 35% to 100% were divided into 5°C and 5% RH ranges, respectively. Next, "bins" were created for each 5°C and 5% RH range. For example, the temperature and RH combination of 0°C - 5°C and 35% - 40% was the first of the 78 created bins. Spearman's rank correlation tests were applied to test the correlation between the time of exposure in the defined bin and the measured daily hyphae growth rate for all three fungi.

Living rooms and bedrooms with a high measured hyphae growth rate (above the 75th percentiles) were selected for the analysis as these living rooms and bedrooms gave the best fungal development in response to the psychrometric conditions. A total of 13 rooms were selected consisting of 9 bedrooms and 4 living rooms in order to compare the *Eurotium herbariorum* hyphae development to climate exposure. A total of 14 rooms were selected consisting of 10 bedrooms and 4 living rooms to compare the *Aspergillus penicilloides* hyphae development to climate exposure, and a total of 11 rooms were selected consisting of 6 bedrooms and 5 living rooms to compare the *Alternaria alternata* hyphae development to climate exposure.

For *Eurotium herbariorum* (N = 13), the strongest positive correlation value (R^2 = 0.40, p-value = 0.02) was detected for the bin 10°C - 15°C and 80% - 85%. For *Aspergillus penicilloides* (N=14), the strongest positive correlation value (R^2 = 0.28, p-value = 0.05) was detected for the bin 15°C - 20°C and 85% - 90%. For *Alternaria alternata*, no significant positive correlation between the measured hyphae growth rate and any climate bin were detected (p-value = 0.54). Figures 5 and 6 show the number of hours per day in each 5% RH range for *Eurotium herbariorum* and *Alternaria alternata* respectively. As *Aspergillus penicilloides* show similar curve trend to *Eurotium herbariorum* (Figure 5) therefore curve for *Aspergillus penicilloides* is not shown.

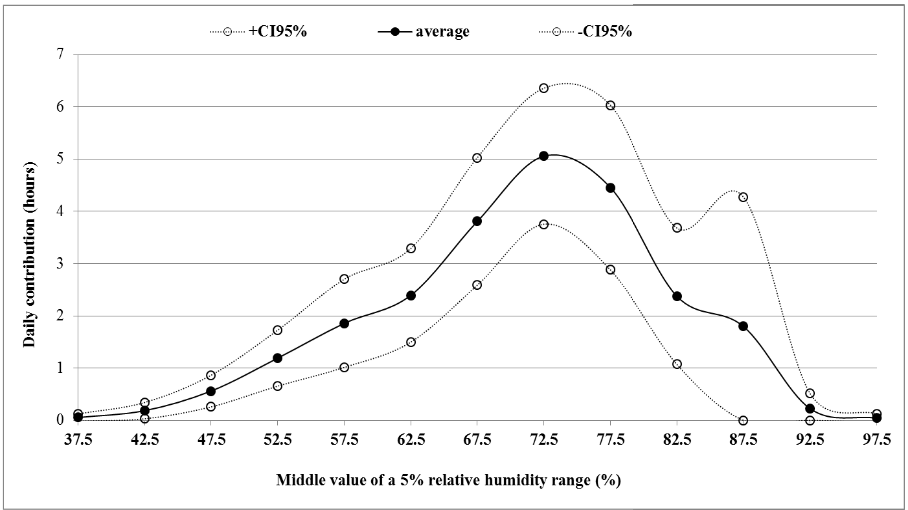

Figure 5: Daily contribution (hours) per 5% RH range for the 13 higher *Eurotium sp.* growth rates (>75th percentiles).

Figure 5 shows that in the rooms where *Eurotium herbariorum* had the largest hyphae development, the RH was above 80% for an average of 4.4 hours a day. This result is consistent with another study which found that *Eurotium herbariorum* needed to be exposed for at least 3.6 hours per day with a RH above 80% for hyphae development (Cunningham, 2001).
Similarly, the rooms where *Aspergillus penicilloides* showed the largest hyphae development had a RH above 85% for an average of 1.9 hours a day (not shown here).

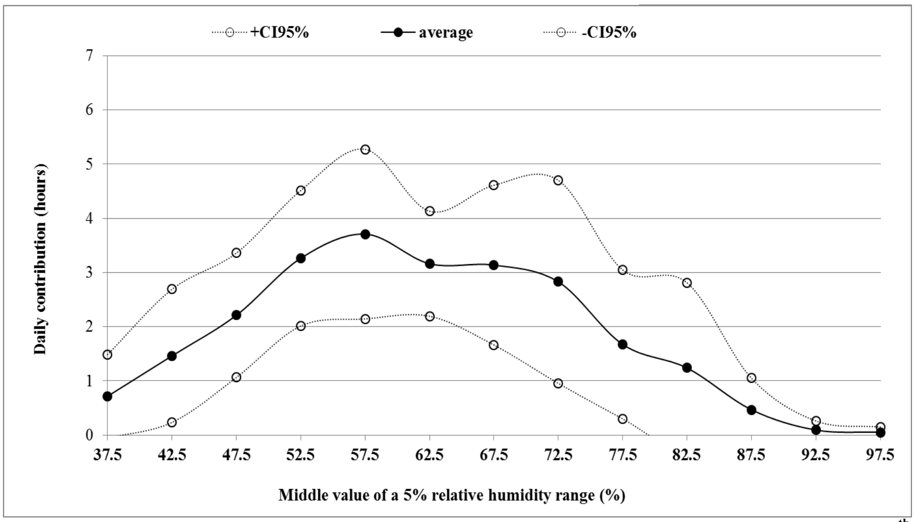

Figure 6: Daily contribution (hours) per 5% RH range for the 11 higher *Alternaria sp.* growth rates (>75th percentiles).

Figure 6 shows that in the rooms where *Alternaria alternata* had the largest hyphae development, the RH was between 35% RH and 70% RH for 77% of the time. This exposure was too dry for this hydrophilic fungus to develop. The climate was suitable for *Alternaria alternata* (above 90% RH) for only an average of 0.1 hours a day (0.4% of the time). This finding supports the lack of correlation found between the daily growth rate and the climate exposure, and was consistent with the low daily hyphae growth rate found for this fungus.

CONCLUSION

The households operating an UGH experienced a significantly different "close to the wall" climate than the households operating a HP. The fungal detectors were useful to predict the capacity for three species of fungi to grow on the inside surface of an external wall. The results showed that the bedroom climate was more suitable for xerophilic mould growth than the living room climate. The operation of UGHs altered the indoor climate and dramatically increased the capacity of xerophilic fungi to grow on the bedroom wall surface. These results were supported with a positive correlation between the hyphae development and the time of exposure in the germination psychrometric condition zones. However, it was found that the "close to the wall" RH levels were too low and therefore not suitable for hydrophilic fungus development like *Alternaria alternata*.

This intervention had a positive impact on the wall psychrometric conditions with reduced water availability for mould to grow. The use of UGH was found to be a significant additional source of moisture in the living room and to have an insufficient capacity to warm the bedrooms.

A meta-analysis showed strong associations between home dampness and respiratory/allergy effects, but the mechanisms linking the specific causal dampness and the related agents are still not clarified (Mendell et al., 2011). Mould and other microbiological organisms are probably the link between dampness and adverse health effects (Fisk et al., 2007). The potential adverse health effects related to such heaters mean that unvented gas heating appliances should not be operated in homes and ideally more regulated.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Keiko Abe from JDC Corporation Japan for help with interpreting the fungi germination data and for kindly providing some laboratory data for Figure 4. The hyphae measurements were undertaken thank to the microscope facilities in the Institute of Veterinary, Animal, and Biomedical Sciences, Massey University.
Participating families from Hutt Valley and community workers from Waiwhetu Marae, Kokiri Marae and Mid Valley PHO are thanked for their valuable contribution to the study. This study was funded by Health Research Council of New Zealand and Building Research Ltd.

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THE COST AND VALUE OF CARPENTRY APPRENTICESHIPS TO EMPLOYERS IN THE AUCKLAND AND THE WIDER NZ CONSTRUCTION INDUSTRY

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ABSTRACT

The Auckland construction sector is currently faced with a skills shortage which has the potential to impede the industry's further development. The research focused on the potential of carpentry apprenticeship programmes to assist with this shortage, and evaluated the cost-benefit relationship of such apprenticeships within medium/large scale commercial construction companies in the Auckland construction sector, to determine the value to employers of this form of vocational training.
Semi-structured interviews were conducted with senior management level staff of established construction companies within the Auckland sector, to explore employers' perceptions of the value of apprenticeship training to employers. In addition, a quantitative analysis of data provided by the participating companies was carried out, to identify the overall cost of an apprentice to the employer over the vocational training period. Responses suggested growing concern within the industry about the skills shortage currently facing Auckland construction. Whilst the findings indicated an overall financial cost to employers during the four year training period, the respondents agreed that the practical benefits to the company and to the industry as a whole outweighed any financial implications. Apprenticeship training could therefore mitigate future risk by focusing on developing the knowledge capital of apprentice carpenters within the industry.

KEYWORDS:
Apprenticeship; cost-benefit; work place learning; knowledge capital; vocational training.

INTRODUCTION

Currently the New Zealand construction industry is undervalued, and is facing an increasing skills shortage. This situation can be partly attributed to the recent leaky building debacle that crippled the industry's reputation and cost-effectiveness, in turn bankrupting many high profile construction firms. Whilst the immigration of skilled workers offers a short-term response to the skills shortage, a long-term strategic plan needs to be created. One valid option would be an increased focus on carpentry apprenticeships/cadets in order to build a wider number of skilled practitioners with a significant knowledge of the industry and committed to' best practice'.
The issue of apprenticeship training and its importance to the New Zealand construction industry has recently gained significant attention with the government initiatives announced in July 2013 by financial minister Hon. Steven Joyce. The initiatives involve government allocated financial aid to both newly recruited apprentices and their employers, in a bid to promote and increase the number of apprentices in New Zealand by 3,500 personnel.
Whilst there is a need for training apprentices, the cyclical 'boom–bust' nature of the construction industry, coupled with increased manufacturer and design complexities, has resulted in employers' perceptions of the value and costs of training apprentices to be questioned.
One particular Australian study researched the net costs of modern apprenticeship training to employers and suggested that whilst apprenticeship programmes cost an employer over the training period, there are many valuable returns which cannot necessarily be measured financially (Hogarth and Hasluck, 2003). This investigative studies by Hogarth and Hasluck (2003), and Hoeckel (2008), focused specifically on the core values gained by employers, and the costs associated with training

apprentices in the wider construction industry, in a bid to understand whether and how apprenticeship training is advantageous to employers.

LITERATURE REVIEW

The cyclical nature of the New Zealand construction industry has recently seen businesses struggling for work, which has resulted in the liquidation of many, and the significant restructuring of others. With these changes, businesses have had to lay off skilled staff and apprentices who have either gone out on their own, left the sector altogether, or gone overseas, particularly to Australia (Quinn, 2011).
The New Zealand construction sector has been building 14,000 – 15,000 new homes per annum for the last few years, with a slight decrease predicted for 2012/13. The sector has adjusted to a level equal to those demands, with capacity for minor growth in the near future. The industry's capacity needs to be combined with the knowledge that the Christchurch rebuild requires approximately 10,000 new homes, 100,000 still need to be repaired, and significant commercial redevelopment is planned for the CBD. The skills shortage is therefore potentially very significant and will continue for a reasonable length of time. In addition, there is consensus that the impending Auckland housing shortage may be as high as 20,000 (Quinn, 2011). The Christchurch rebuild and Auckland's city housing crisis, has the very real potential to impede the industry's ability to cope with the demand.
The NZ Building Construction and Training Organisation recently stated that "there are only around 5000 building apprentices currently training, with the turn of the financial crises, and the subsequent building lull, an estimated 8,500 apprentices will be needed".
As a form of vocational training, the distinguishing feature of a building apprenticeship is the existence of a contract between the apprentice and employer that the apprentice will serve under the employer for a set period, typically four years. In return, the employer undertakes to impart the skills required in the building trade through on-the-job training, whilst in conjunction with the apprentice completing off-the-job technical training through a tertiary institution, (Dockery et al., 1997). Carpentry apprenticeship programmes are the acknowledged platform for the transfer of both tacit and explicit knowledge from the established trained workforce to the trainees entering the construction industry and play a critical role in the construction industry's ability to up-skill and prosper.
There is an abundance of literature pertaining to the costs and benefits of training apprentices. However, the majority of the selected literature comes from Australia, the United Kingdom, France and Germany. The literature was found to be applicable to the New Zealand context, as the construction industry training is relatively similar in terms of content, duration and costs.

The recent National Government changes to the apprenticeship scheme in New Zealand is set to boost the number of people in apprenticeships to fill the gaps currently faced in Auckland and Christchurch by combining all apprenticeships into a single nationwide scheme, and providing new financial incentives for employers and workers in a bid to increase the number of apprenticeships, (Joyce, 2013). The initiative was setup to give the first 10,000 new apprentices who enrol after April 1st 2013, $1,000 towards their tools and off-job costs, or $2,000 for newly recruited apprentices, if they are in priority trades. This amount to be paid to the employers as well.
The new initiative also includes:

- •The 'rebooting' of the apprenticeship scheme to potentially increase the number of apprentices by 14,000 over the next five years, this is in addition to the 7,000 who already enrol every year, (Joyce, 2013).
- The unification of modern apprenticeships and other apprentice-style training to form an improved scheme called New Zealand Apprenticeships. Fewer than half of the people

undertaking apprenticeship-type training are actually funded as true apprentices, but with the newly implemented scheme this will change.

- A significant boost in overall funding for apprenticeships with subsidy payments set to increase by around $12 million in the first year, rising over time. The increased funding will allow industry training organisations to invest in the quality education provided.
- The educational content of apprenticeships is set to be boosted to a minimum 120 credits which will result in a level 4 qualification.
- A clearer set of roles and guidelines, coupled with performance expectations for industry training organisations which has been implemented to give employers other options if the ITOs do not perform (Joyce, 2013).

The key features of the New Zealand are that :

- Theory work training typically spans a 3-4 year period, and this is dependent upon a student's ability to pass the required credits at each level.
- Practical work typically is based on the completion of an 8000 hour apprenticeship, which translates to approximately four years (dependent upon hours worked).
- Training takes place either via correspondence through the Building Construction Industry Training Organisation (BCITO) or through tertiary institutions such as Unitec Institute of Technology (Unitec), or Manukau Institute of Technology, (Smith et al.).

Listed below are the approximate durations of international apprenticeship programmes, that according to the reviewed literature, are comparable to the New Zealand apprenticeship schemes.

- British apprenticeship system tends to take 3 years (Hogarth & Hasluck, 2003).
- Swiss programmes are spread over a 4 year period (Wolter et al., 2006).
- German and French programmes tend to span 4 years (Fougere and Schwerdt, 2002).

In addition, the apprenticeship training structures internationally, are similar to those in New Zealand, in terms of the on-the-job training and theoretical study for both employers and apprentices. The maximum standard incentive that is payable for an apprenticeship at certificate level 3 or higher is fixed at $4,000. The government has removed the progression incentives, and increased the proportion of the total amount payable upon the apprentice completing the trade certificate, from 37.5% to 62.5%. The change places more emphasis/incentive on increasing completion rates, (Knight and Karmel, 2011).

The Australian government has a detailed incentives scheme and also makes personal benefit payments to apprentices and trainees, through the Australian Apprenticeships Centre. The benefit payment structure is far more detailed than the New Zealand structure described above. Currently the personal benefit payments include:

- A long standing Living Away From Home Allowance, pays $77.17 (AUD) a week in the first year, $38.59 in the second, and $25.00 as the final year payout.
- A $13,000 (AUD), (with income tax benefits) over the first two years under the 'Support for Mid-Career Apprentices Initiative'.
- A $2,000 (AUD) in tax-exempt payments, under the Apprenticeship Wage Top-Up for trade apprentices in national skills shortage occupations, (Knight and Karmel, 2011).

Studies investigating the factors determining a firm's willingness to train apprentices tended to be based on the assumption that profit-based companies calculate the likely cost-benefit ratio of training an apprentice. From this calculation the companies make a decision as to whether they proceed with offering an apprenticeship training programme, (Wolter et al., 2006).

German economic research suggested that most apprentices offset the cost of their training during their apprenticeship on the basis of the productive contributions of the work they perform. Therefore the real benefit for firms in training apprentices revolves around the productive contribution apprentices make to the business (Wolter et al., 2006).

Research conducted in an Australian study by Hogarth and Hasluck (2003), found that whilst an apprenticeship programme does not necessarily benefit the firm in a financial manner, (it in fact costs the firm over a three year period), it does however provide the opportunity for the firm to reduce labour turnover and helps create a supply of future supervisors and management level staff. Additional benefits mentioned in the study included the enhanced reputation of the firm as a 'good employer', social benefits, and the promotion of links with training providers and schools.

Hoeckel (2008), found that employers benefit as productivity increases, and also from government and industry training organisation incentives, reduced costs of recruiting external skilled workers, and reduced outage costs when skilled workers are in short supply. Employers reap benefits by saving costs incurred when hiring new employees, including the recruitment process, integration of new employees and the risk of hiring a person not previously known to the company.

In terms of the various cost components associated with apprenticeships, Hoeckel (2008) suggested that costs were divided into direct costs (including apprentice wages, salaries for training personnel, teaching material, and equipment), and indirect costs such as tax expenditure or subsidies, but also opportunity costs, and drop out costs. Nechvoglod et al., (2009) research concluded that apprenticeship training involved a substantial financial commitment from both employers and apprentices, and the highest cost for employers was supervision costs. Wages were structured more-or-less to their productivity rates. In addition to indirect costs, Nechvoglod et al., (2009) also included administrative costs, extra maintenance and material wastage costs of apprenticeship training.

The literature review underlined key themes associated with the benefits of apprenticeship training. Significantly, studies by Hoeckel (2008) and Dockery et al. (1998), identified comparable key findings relating to employer based benefits in trade industries.

METHOD

The research question was, "what is the cost-benefit relationship of apprenticeship programmes to employers in medium-large scale construction companies in Auckland, and the wider New Zealand construction industry?"

A mix of qualitative and quantitative research methods were selected to provide answers to the research question. Qualitative face-to-face semi-structured interviews were conducted with five senior management personnel from four well established medium –large scale construction companies, based in Auckland.

The sample group of participants for the research project consisted of team members within four medium – large scale construction companies within Auckland, with the following roles:

- Senior management in charge of contracts/employment
- Site management/superintendent roles.

The five participants had been responsible for 47 apprentices whilst they were completing their training over the immediately previous 5 year period.

The interview questions were developed from the findings in the literature analysis, and in addition

a quantitative cost document analysis was undertaken. The quantitative statistical analysis used in the research project followed a simple layout in table form. Data relating to tuition costs was sourced directly from the training institutions, and being public knowledge posed no ethical difficulties. Other cost components absorbed by employers were detailed during the interview process, and raw data ascertained after the interview through the use of a follow up emails and

phone conversations with the participants. This allowed the participants sufficient time to detail costs accurately.

DATA FINDINGS AND ANALYSIS

Skills shortage within the wider construction industry

The findings on the supposed skills shortage within the construction industry are in line with the literature findings, (Quinn, 2011) suggested that there is a definite skills shortage within the wider construction industry. The literature review did not indicate a period of time that the skills shortage had been developing, whereas the research findings indicated that a skills shortage has been developing for the last 10 – 15 years, and more alarmingly an estimate that there has been 25 years of decline in construction workers skills. All of the participants underlined the following key skills lacking in the current wider industry:

- Ability to read plans.
- Understanding and implementing manufactures correspondence.
- Work unsupervised.
- Ability to use set out equipment such as theodolites, dumpy and levels.

Consistencies among the participantsts identified that the larger more established companies played a significant role in bridging the skills shortage by placing an emphasis on training apprentices, investing heavily in training and up-skilling of apprentices, as they play a vital role in filling the current skills shortages within the industry Quinn, (2011).

Tuition costs and payment methods

Four of the five participants interviewed paid for the apprentices' tuition costs. One of those employers paid the costs upfront whilst the other three employers opted for a reimbursement strategy whereby the initial costs were divided equally between the apprentice and the employer with a reimbursement payment to cover the apprentice's investment once he/she had passed their year's unit standards.

The remaining rparticipant worked on a split payment method (50/50) with the apprentices, no reimbursement payment method was in place. The participant paid apprentices slightly more than the average going-rate to offset the apprentices' contributions for their tuition. The tuition costs through Manukau Institute of Technology comprise:

- Year 1 $2570.00
- Year 2 $2463.00
- Year 3 $3186.00

Total fees for a level 4 certificate in carpentry (qualified carpenter) is $8,219.00 , whereas BCITO training fees are $7,585.00 approximately.

Remuneration level whilst training

The literature did not delve into remuneration levels, but it did place an emphasis on the associated financial risk of remuneration, (Dockery et al., 1997). Remuneration levels were viewed by many as an important factor when assessing the financial feasibility of vocational training, (Wolter et al., 2006).

The research findings identified a common trend among participants that an apprentice's wage was not a determining factor when assessing the feasibility of carpentry apprenticeships. When asked, "would you employ more apprentices if the wage level was reduced?", the participants universally answered no. Participants commented that a reduction in wage levels would have an adverse effect on the apprentices training by placing unnecessary financial strain on the apprentice. This response suggested that employers did not view an apprentice's wage level as a

risk. More importantly, the findings suggested that wage costs had no effect on a firm's decision to hire an apprentice, and that employers undertake apprenticeship training programmes for the benefit of the business, and also the employee.

Government apprenticeship initiative

Each of the participants were asked whether they were aware of the recent government initiative around apprenticeships in New Zealand. Four of the five participants had heard of the July 2013 initiative with just one unaware of the new scheme. Whilst four participants saw value in the scheme, only one was planning to involve two of his apprentices under the new scheme.

Whilst respondent 4 did not see any value in the scheme for his specific business (due to its scale), he did however see value in it for smaller 'labour only' contractors, who have used it to secure a younger work force whilst aligning themselves with training institutions such as BCITO and Manukau Institute of Technology.

Perceived productivity contributions by apprentices whilst training

The research findings showed that productivity increases by apprentices were rated the least valuable benefit by employers in terms of the five options presented. This was surprising in the sense that productivity and monetary gain are usually closely related. Generally, businesses are able to recoup the money invested in an employee through their productive contributions on-site, (Dockery et al., 1997). Hoeckel (2008) though, asserted that benefits accruing to employers can be measured in different ways, such as productivity performance contributions by apprentices.

When asked what an apprentice's contribution might be during each year of their apprenticeship, the participants' answers were typically similar, with only one offering a contrasting view, refer Table 1 below.

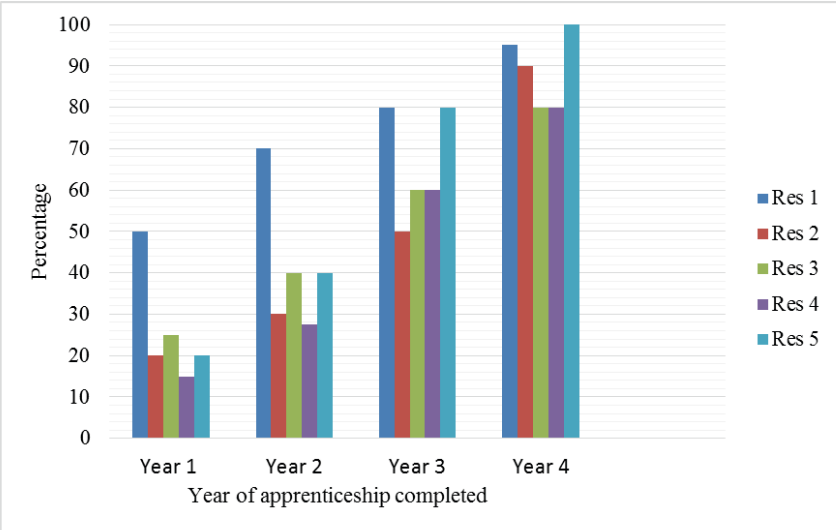


Table 1 Perceived Productivity Contributions of Apprentices

Perceived main benefits of training an apprentice

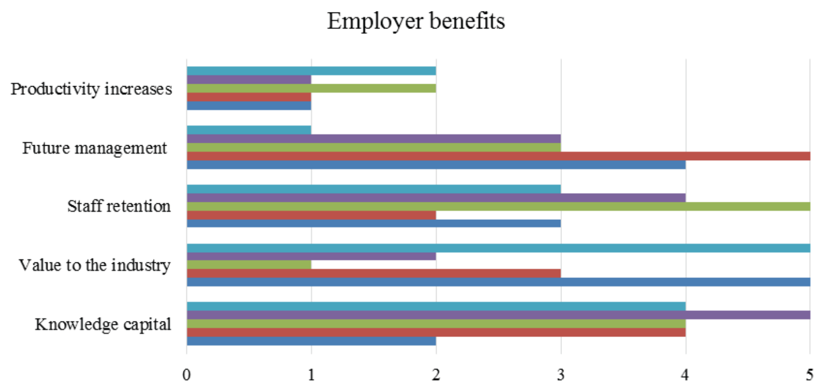
The literature review identified that the driving factor behind an employer's involvement in apprenticeship programmes was the benefit the employer received throughout the course of the apprentice's training period. The benefits highlighted in the literature review informed the

interview questions provided to the participants to rank in order of priority. The research findings on the perceived benefits of apprenticeship training, showed that participants ranked ‘added value to the industry’ as being a primary benefit, refer Table 2. In order for the wider construction industry to develop and successfully meet the sectors demands, participants suggested that a focus must be placed on training the future generations to ensure the transfer of knowledge and experiences

One participant ranked this factor as the highest priority stating that he was *“appalled that the major players in the commercial industry are not investing more heavily in training”* he continued by asserting *“that we have moved to a sub-contract or labour only contractors to cap our risk as opposed to self-performing.”* The result of this view has seen a deterioration in in supervision on site.

The findings established that staff retention was ranked as the second highest priority for employers training apprentices, and that a business was able to recoup the money invested in training an apprentice rapidly through increased charge-out rates, and the productivity of the ‘now’ qualified worker.Training of future management level staff was considered of marginally less benefit than‘staff retention’, and similar to ‘added value to the industry’. Only one participant scored it as the least beneficial element of apprenticeship training to employers. This could be related to the particular business structure and the typical scope of works.

The findings tended to imply that from an employer’s perspective, there is in fact more value to the business for a newly qualified carpenter continuing as a productivecarpenter, than progressing them to a management role.



	Knowledge capital	Value to the industry	Staff retention	Future management	Productivity increases
Res5	4	5	3	1	2
Res4	5	2	4	3	1
Res3	4	1	5	3	2
Res2	4	3	2	5	1
Res1	2	5	3	4	1

Table 2. Employers perceived benefits of apprenticeship training

Contrary to this information, the literature suggested that the cost effective screening of future management level employees is of value to employers (Fougere and Schwerdt, 2002),

CONCLUSION

The importance of carpentry apprenticeships has recently been emphasised by the skills shortages currently impacting on the construction industry's ability to perform. Whilst there are options to fill this skills shortage with imported skilled labour, a longer term answer is required.
The research conducted built on the literature available to assess the cost-benefit and value of carpentry apprenticeship programmes to employers in medium-large scale construction companies in Auckland and the wider construction industry.
The findings suggested that whilst a carpentry apprenticeship poses a financial risk to employers, the value gained by both the employer and the value added to the wider industry eclipses these costs, making carpentry apprenticeship programmes an essential part of the construction industry.
These findings agreed with the research conducted by Hoeckel (2008), and Hogarth and Hasluck (2003),where the main cost items associated with carpentry apprenticeships were supervision costs, tuition costs and to a lesser extent, remuneration. Similarly, the findings showed that the predominant benefits linked to apprenticeship training were, 'developing knowledge capital within the business', 'staff retention', 'added value to the construction industry', 'training of future management level staff' and 'increased productivity. The current government stance on modernising apprenticeships in New Zealand has suggested an increased focus from all parties involved in apprenticeship that training is beneficial to the country's various related industries. The newly announced apprenticeship scheme and financial aid in 2013 is proving to be beneficial to employers who have, or are in the process of employing apprentice carpenters.

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EDFAB: IS A DIGITAL REVOLUTION POSSIBLE FOR THE CONSTRUCTION INDUSTRY?

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ABSTRACT

As the noise and furore surrounding digital fabrication dissipates, where do we as designers and builders find ourselves? Contrary to media hype there is not a factory in every garage, nor are designers and builders becoming unnecessary. On the contrary, new models of manufacturing are emerging and new ways to design are developing in other industries where these innovations are not only profitable but radically improve the consumer experience. With early adopters well seasoned and leveraging benefits from digitally sponsored fabrication, where does this leave design and construction? In this paper we outline EDFAB: eco-digital fabrication, a research project partly funded by Transforming Cities: Thematic Research Initiative (TRI) of the University of Auckland, to develop new consumer-friendly forms of design and timber construction. The aim of the project is to challenge conventional processes and relationships, proposing radically new viable design and building alternatives that address problems of affordability, space adaptability, energy performance and indoor comfort. To do that, the project develops a system that introduces both process and product innovation. It combines enhanced construction technologies, new materials and digital fabrication methods to produce distinctive, high quality, healthier and cost effective residential buildings that conform to the international Passive House standard. The paper discusses the specific contribution to the project from the different involved research areas – building technology, architecture and sustainable design, and digital fabrication – and presents the early achievement of the research: a $10m^2$ prototype domestic scale 'sleepout', designed and built using digital fabrication, and novel plywood construction methods that produce a kit-of-parts very easy to build and handle. Easy to use software that enable consumers to tailor their designs and an expert interface that automatically creates the building components, that will permit the delivery of site-specific comfortable and energy efficient solutions are being developed. Contrary to popular myths, the research points to material skill and traditional craft and knowledge being more important than ever in the imminent digital revolution for construction.

KEYWORDS:

Digital Fabrication; Passive House standard; Prefabrication; Software

INTRODUCTION: REVOLUTION… AGAIN… REALLY?

Technology is synonymous with revolution, from machines of war to the industrial and information revolutions; technological innovation and disruption go hand-in-hand. The design and construction industry is no stranger to this, the industrial revolution shaped processes that would have a marked effect on the industry and more recently computers, CAD (computer aided design) and BIM (building information modelling) bring with them a wave of changes and transformations for construction. Novel forms of fabrication, made possible by these new technologies and processes, feature heavily in the literature. Prefabrication and its many incarnations hold promises of efficiency and productivity gains, although the potential benefits often suffer with widespread perceptions that choice and individual tastes have to be surrendered.

The aim of EDFAB is to take a fresh look at the situation and draw from current trends in consumer culture; from Amazon to iTunes other industries have been transformed by technology. While a single

innovation often serves as a catalyst for these transformations, they eventually combine and automate other pre-existing resources to increase efficiency, choice, accessibility or ease of use. As the sector ecology transforms as a whole it become more competitive and productive, capitalising on efficiencies elsewhere and automating transactions through business-to-business services.

EDFAB looks at current innovations in digital fabrication and explores how other aspects within design and construction processes might capitalise on these efficiencies. What parts of the design and delivery process be automated or integrated? How will such a transformation impact skills and knowledge practices? Where can opportunities for near-term and long-term gains be found?

EDFAB: RETHINKING DESIGN TO DELIVERY

EDFAB (eco-digital fabrication) is a research project funded by the University of Auckland and its Thematic Research Initiative 'Transforming Cities'. The project is trying to answer some, or parts, of the questions that emerge as people and devices within the building industry become highly interconnected. Its aim is primarily to deepen our understanding of how changing technology alters skills, knowledge practices and processes within the building sector. Also, with the help of industry, the aim of the project is to identify pathways, areas and aspects of digital fabrication that are likely to have a meaningful impact on the industry itself and on housing quality and/or affordability.

Digital Seduction

If some of the key anthologies on digital fabrication (Kolarevic and Klinger, 2008; Kolarevic, 2003) and its stakeholders are examined (Burry, 2010, 2005) a preoccupation with form becomes apparent. This is perhaps because digital fabrication most obviously lends itself to the production of complex form. The primary structural elements in the spectacular roof at Oslo Gardermoen airport, Norway are massive glued laminated timber elements in the form of airplane wings as shown in Figure 1. Such geometric complexity would be difficult to produce by manual techniques.

Figure 1. Complex structural geometry in timber engineering

However it now appears the next phase beyond the initial fascination with novelty must take place. As both professionals and students alike are becoming more familiar and desensitised to the seductive possibilities of digital fabrication, a new criticality is emerging, questioning the value and benefit of emerging tools and techniques. 3D printing has been receiving considerable hype in the consumer domain for many years, without it finding its 'killer application' just yet. Although some small houses have been constructed using 3D printing technology in China (Balinski, 2014), they bring to mind

Karl Marx (Marx, 1977, p. 379) exhortation that the potential of automation is not about prosperity, but about dehumanisation. Marx was referring specifically to the workers who are replaced by technology but we might also apply this critique to owners and occupiers that might end up residing in potentially unpleasant, highly repetitive mass-produced housing. Currently robotics are gaining ground rapidly in the architectural domain, with Gramazio and Kohler (2008) having been, for some time, at the forefront of innovation with robotics and, more recently, drone assembled architecture. Like CNC (computer numerical controlled) routers, these linear kinematic robots have been used in the high value manufacturing sector for some time and are finding new uses in the building and creative arts sector. Which brings us to our research and a burning question concerning digital fabrication technology: how can we critique its value when it has already been highly valued in other sectors? In 'The question concerning technology', Martin Heidegger argues:

Because the essence of technology is nothing technological, essential reflection upon technology and decisive confrontation with it must happen in a realm that is, on the one hand, akin to the essence of technology and, on the other, fundamentally different from it. Such a realm is art. (Heidegger and Lovitt, 1977, p. 35)

In which case the design and construction of a piece of architecture is well suited as a vehicle to critique technology.

Big things and small beginnings

The EDFAB project (Figure 2) began by proposing to build and test a small timber based unit using some digital fabrication techniques that we see emerging in Europe and North America. The aim was initially to test if such a system could conform to New Zealand standards, because the system had the potential to deliver some unexpected benefits. It was very easy to construct, consequently reducing highly skilled labour costs, while the high accuracy possible with digital fabrication was able to deliver a very thermally efficient building envelope. Because the system consisted of essentially repetitive plywood cabinets, it was possible to programme software to create them automatically. Using Rhinoceros and Grasshopper 3D modelling software it was possible to create a parametric description of our unit or 'sleep-out.' This software could automatically subdivide the unit into a number of parts and then automatically create the cutting templates that could be fed directly into a CNC router for fabrication.

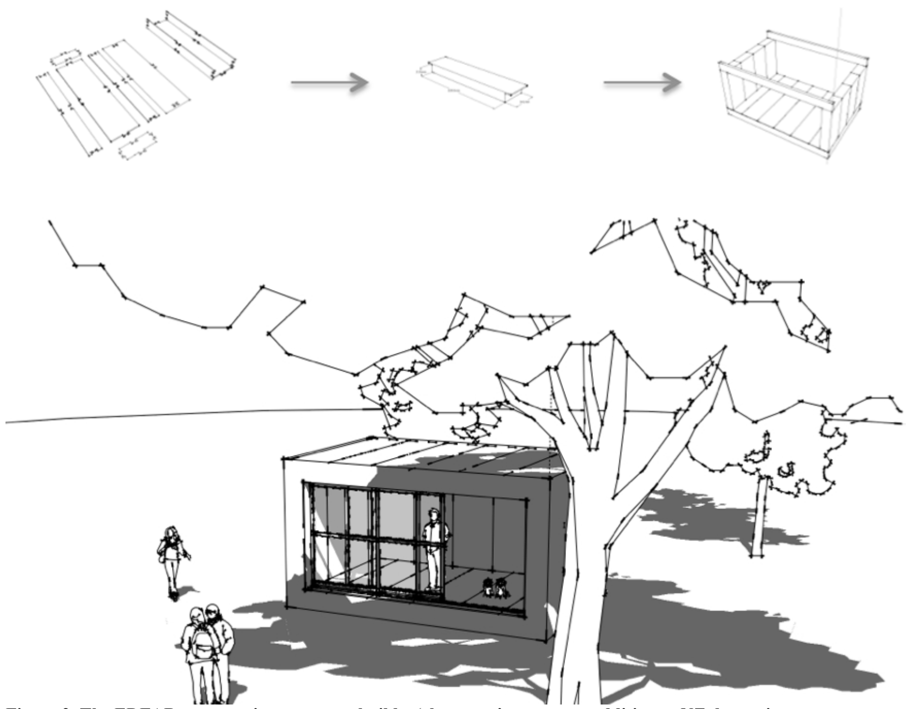

Figure 2. The EDFAB construction system to build a 'sleep-out,' a common addition to NZ domestic space

Through this process, constraints became opportunities. The depth of the unit was limited by the length of available plywood boards (2400mm) and the length was limited by the span possible using our chosen size of timber beam. By encoding constraints into the software, it was possible to prevent a user specifying dimensions that would create a situation where the unit could not be fabricated or, if fabricated, was structurally unsound. With these constraints encoded in our expert software, it became obvious that we could create a very easy-to-use computer desktop application that would enable a user to manipulate and tailor a unit's size to their specifications (but within the encode constraints). When a particular size was agreed upon, the information could then be communicated to the expert software that would then generate all the cutting component templates necessary. Making available a variety of customised solutions matching the pre-set constrains return certain freedoms to the end user (a client or prospective owner), freedoms that typically have to be carefully managed as they can easily delay or complicate a careful programme of design and construction. Traditional skills such as structural and environmental design expertise remained critical, but they could be shifted from the late design phase to the initial one, i.e. during the development of our software and data interchange protocols. New skills were also required in the form of software developers, in particular ones that were attuned to design and construction. For this stage of the project we were able to find them within the Department of Architecture, confirming what McMeel and Amor (2012, 2013) have discussed elsewhere, i.e. that the skillsets of emerging Architects increasingly involves programming abilities of varying degree.

Early questions

Having assembled a team of specialists from domains such as architectural, structural and environmental design, and software development, a number of provocative questions soon came to centre stage:

1. Does this digital fabrication work in the New Zealand context?

New Zealand Building Code differs in many ways from European and North American building regulations. In particular the system has been tuned to take into account the seismic activity and the potentially high wind loading. Buildings in New Zealand must be able to withstand twice the wind loading of buildings in England. Furthermore, materials and components currently available in New Zealand have different physical and mechanical properties compared to the same products manufactured overseas: plywood is such an example. This material could have been easily imported from overseas. However, a self-imposed criterion was to utilise local products where possible - for both environmental and economic reasons.

2. What constraints can we encode within the software?

As a consequence of using parametric modelling software - which will be explained in some detail in the following sections - we could quite easily impose constraints that ensure structural stability. Alternatively we could automatically alter the size of structural elements in response to a user creating larger spans. Returning to Heidegger for a moment, the fact that we can do this should not preclude asking why are we doing it and to what ends.

3. Where can communicating with digital data improve upon traditional techniques?

It is not always desirable or possible to automate; it is necessary to call upon expertise. Even when information is exchanged digitally it is often necessary to extrapolate from a complex model the specific information that is required by the specialist, taking both time and resource. In the event of a change this manual extrapolation has to be repeated for the expert to render a decision or service based on the new information. If we cannot automate a particular expertise can we automate data extrapolation, thus saving time and resources?

To help answer some of these questions, in the next section we will give a more detailed account of the process of developing the construction system as well as some end user and expert software.

COMMUNICATING: AU NATUREL

Communication is critical during design and construction. Paper drawings are a long established means of transferring information between the multitude of professions and trades necessary to deliver a finished building. Drawings have evolved into a very effective tool to communicate, coordinate and help disparate stakeholders converge on a common understanding. DWG (the proprietary file format of AutoCAD) and DXF (Drawing eXchange Format) are the digital equivalent and have been used successfully since the 1980s for exchanging geometry in the form of drawings and models. We are however in the Information Age where CAD (computer aided design) has given way to BIM (building information modelling). Geometric models have given way to information models and exchange formats such as DXF and DWG have give way to IFC (Industry Foundation Classes) and CoBIE (Construction Operations Building Information Exchange). These digital standards and conventions seem in keeping with their paper predecessor, but there is a stark difference. Whereas drawings are a means to mediate the different languages, grammars and ontologies that make up the building process, these emerging standards are languages of themselves and, although they are descriptively adequate to communicate between virtual stakeholders, they are neither particularly efficient or particularly optimal for communication between any roles or disciplines. McMeel and Lee (2007) have scrutinized construction ontologically and theorized an emerging pre-ontology, which provides a framework to conceptualize these communication conventions. Although they appear highly problematic and the industry’s resistance to the uptake of these communication conventions is well documented. The notion of a pre-ontology, be it in the form of IFC or CoBIE, does not seem to have a natural resonance with industry stakeholders. Design and construction is—like nature—a competitive ecosystem where the fittest and leanest survive. There is no room for inefficient communication, no matter how comprehensive it is.

Let us turn for a moment to the natural world’s complex ecologies and communication systems. Where one insect uses colour to fend a predator, another uses scent to attract a mate; they are specific

and clear channels of communication. In *Life Itself*, Robert Rosen (1991), the theoretical biologist, has conceptualized this in terms of 'dictionaries.' Each channel of communication has two dictionaries associated with it, one at each side of the communication channel, for encoding and interpreting the signal. Rosen makes it clear these dictionaries are not necessarily the same, but they are highly efficient. As an ecology grows so do the number of dictionaries, but importantly they are quite simple. It is the aggregation of these channels that makes for a complex ecology. This is in stark contrast to communication within the AEC (Architecture, Engineering and Construction) industries, where best practice is often to implement a complex interoperability protocol, which is highly technical and somewhat overwhelming. It is perhaps then natural that they are resisted. In EDFAB we took a fresh look at communication and used Rosen's concepts of natural communication to inform our strategy. In this section we will detail the three parts of the project, the construction method, expert user interface (xUI) and the end user interface (eUI). We will discuss the parts of the EDFAB ecology and how the efficiency of the communication protocol was addressed.

Digitally sponsored construction

Exhaustive surveys of the impact technology has on human interactions in office environments have been carried out by Robert Kling (Kling and Iacono, 1984; Kling, 1980, 1996), an expert on the study of social informatics. One of Kling's key findings, which we might take for granted today, is that where technology is introduced unexpected things happen. Often this is as a consequence of technologies' effect on human interaction. Technology alters the ease or difficulty with which we communicate, skill sets need to change and roles become redefined. He also recognised that technology is sometimes implemented for political reasons, in such cases Kling found there is often little evidence that politically motivated change actually delivers overall improvements. Turning to construction, we have lessons that can be learned; firstly to exploit digital fabrication technology change is necessary and secondly these changes will likely have consequences well beyond the places they are implemented.

In the last ten years a method of construction has been emerging and documented (Bell and Simpkin, 2013) that capitalises on digital fabrication. This method has been used successfully by Facit Homes, a bespoke house design and manufacturing company in the UK. The system breaks a design down into building blocks; one might draw the analogy of a LEGO system for grownups. Each block is then broken down further into flat pieces that can all be cut out of standard sheets of plywood by a CNC router and easily assembled. The blocks are easily carried by two people and built up on site. The system was modified to accommodate the plywood availability and building standards in New Zealand. A 1:1 scale prototype of one section of the sleepout was built (Figure 3) to test the system, detailing and tolerances. This information will be built into the digital models and software interfaces to ensure some similitude between the digital model and the final real building. The system uses a 'butterfly' plug that is hammered into place between each block; this interlocks the blocks and creates a robust structure. In Europe the current best practice is to tape the joints in lieu of wrapping the structure in a vapour barrier membrane.

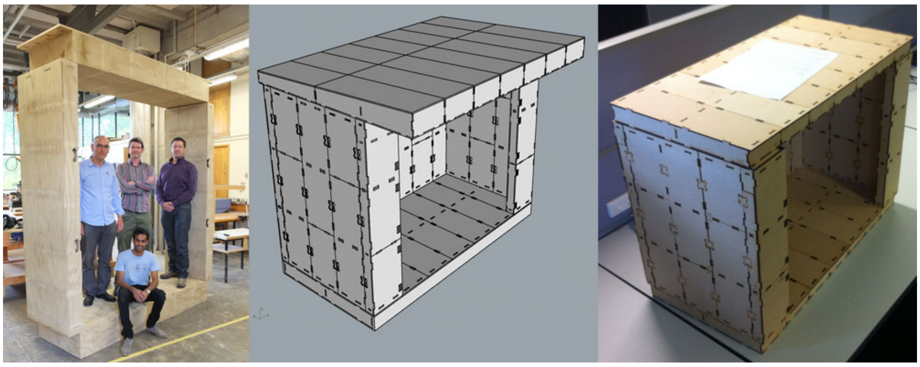

Figure 3. 1:1 prototype, digital model and 1:6 scaled model of the sleepout

During this process a number of factors emerged. Locally available New Zealand plywood for general building construction is not as dimensionally stable as its European counterpart; Latvian Birch appears to be the plywood of choice for this method of fabrication and construction. Indeed imported Chilean plywood was also used and also found to have deviations that cause problems for digital fabrication. Even with these stability issues it was possible to construct the 1:1 section. Having completed the section of the 1:1 model and modified some details, a 1:6 scaled model (Figure 3) was construed to assess the new details, the over all construction concept and also to check for 'creep', i.e. the phenomenon where small deviations in the physical construction are aggregated over the length of the building causing the combined components to be of a different length than intended.

xUI: Expert user interface

The expert user interface is closely linked to the construction technique, as much of what was learned through the building the prototype and model was necessary, as aspects of it would be encoded into the software interface. The interface is built using Rhinoceros (http://www.rhino3d.com/), a popular 3D modelling software, in combination with Grasshopper (http://www.grasshopper3d.com/), a parametric plugin that provides a 'procedural' interface for Rhino.

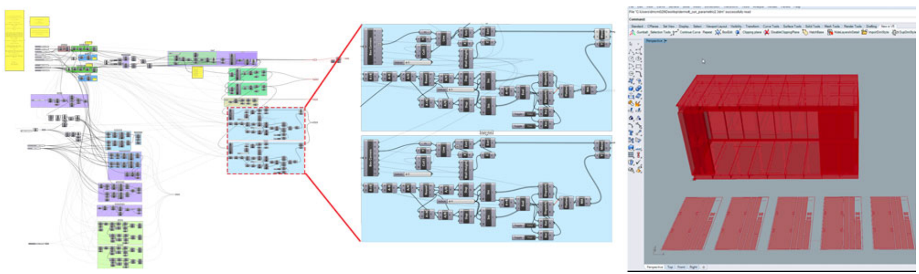

Figure 4. On Left the xUI Grasshopper description; Centre a detail of its complexity; On right a screenshot of the xUI building the model and its components

A sense of the complexity of this process can be gleaned from Figure 4. At the extreme left we have an illustration of the software, the centre diagram is a detail of its complexity - each box represents a calculation or decision. For example one of these boxes contains a detail drawing of our butterfly joint. If we decided to change the joint we could change the detail once and have it changed throughout the project automatically. The illustration on the left of Figure 4 represents only fifty precent of the software, which executed choices and decision based on what we have learned from building the prototype section and the 1:6 model. It is interesting to look at an image of what is essentially a digital encoding of the design decisions necessary to create the construction components from a 3D model. It

gives us pause for though about the complexity of a typical design and construction process, where here there are literally hundreds of interconnected decision and choices necessary to deliver a relatively small and regular shaped building.

The only input the expert system needs is three Cartesian coordinates that represent the length, width and height of the sleepout. With the deepened understanding of the system we could impose limits on these dimension to ensure constructability and structural stability. With this in mind we commissioned a standalone easy to use application that could be downloaded by an end user to tailor their design requirements. Concurrently we were devising a communication protocol to exchange information between the end user interface (eUI) and the expert user interface (xUI).

eUI: End user interface

The end user interface (Figure 5) was written in C++, which was chosen because it can be compiled to run on almost any computing device, such as Windows PC, Mac OSX or handheld devices running the iOS operating system from Apple. None of the sophisticated construction information is replicated here. This is a simple application that gives the end user the visual appearance of the sleepout construction, and offers the ability to easily change some of the dimensions within the limits we have specified. A silhouette gives a sense of scale and there is an approximate floor area provided – a value that is useful to a potential end user. In essence, having worked through a processes to capitalise on digital fabrication and build software that enable us to leverage the benefits, we have been able to pass certain freedom, in this case design freedoms, onto the end user. These design freedoms are not afforded under traditional design and build processes as they have the potential to compromise the construction programme.

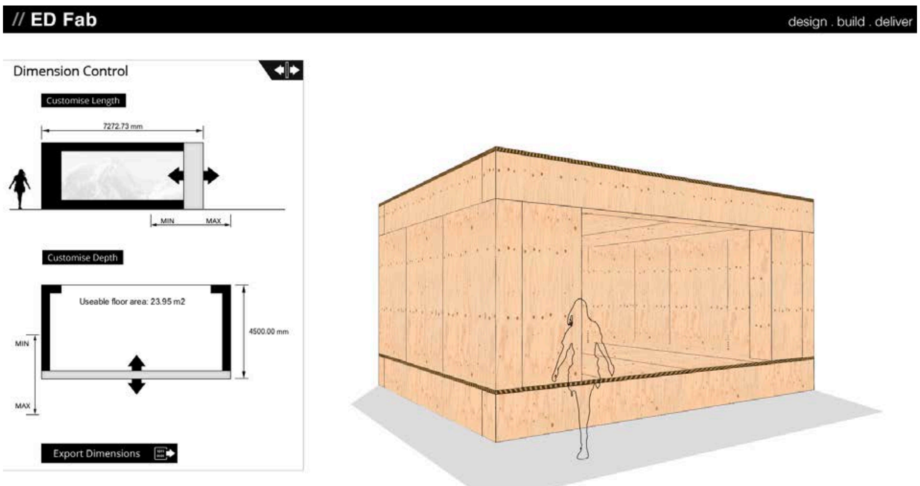

Figure 5. EFFAB end user interface software

Under a traditional design and build programme when the need for information exchange arises a geometric model interchange standard is used. Most of the standards for digital information exchange in the AEC industries are for communicating geometry (OBJ, DXF, DWG, 3DS). Within our ecosystem we have no need for communicating geometry. Instead, we need to send some coordinate information and the xUI will build the geometric model according to its needs, initially we explored IFC and CoBIE, which have been mentioned earlier in this paper. Both are very comprehensive but IFCs have a very complex syntax associated with them and CoBIE seems to privilege a spreadsheet layout, which is not optimal for application data interchange. We instead adopted a CSV (comma separated variable) file syntax, which has a very simple structure (Figure 6). This file type is quite

common for transferring information to and from databases and subsequently is suited to both data exchange and to efficient digital communication.

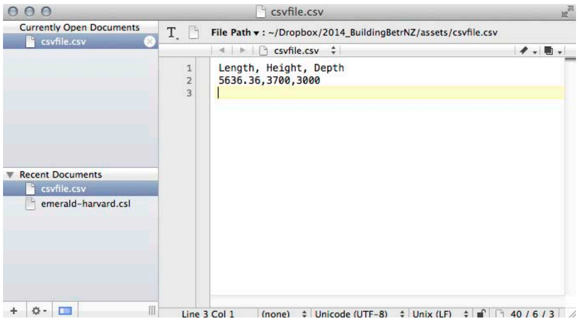

Figure 6. The CSV file for exchanging information between the eUI and xUI

This was the simple ecosystem we developed to leverage the possibilities of digital fabrication. It is still a work-in-progress and at the time of writing we are exploring the possibilities of further structural encoding as well as utilising JSON (Javascript Object Notation), a file type that is very popular for data exchange, particular in the burgeoning area of GIS (geographical information systems) and geospatial data, when vast quantities of data need to be transferred quickly and reliably.

CONCLUSION

This is a project that is modest in scale and scope, but has revealed a number of highly interesting factors. Traditional construction skill and structural knowledge remain critical, even within this extreme adoption and implementation of digital fabrication; people with these skills continued to be key parts of the team and the design development process. However compared to a traditional design and construction process their presence was more critical at an earlier stage.

Communication is critical, although for the projects initial needs, it was chosen not to implement a standard. Instead we asked ourselves what we need to communicate and why. That gave us a framework to scrutinise some of the options that were available. When a communication standard was implemented (CSV), it was from the IT industry not the construction industry. The IT industry has been wrestling with large datasets and communication for several decades and it is not unexpected that may have standards that we can utilise as we develop our own. Communication remains a critical issue and it is telling that many current successful BIM case studies involved integrating the team, often relocating the entire project team to a single unified location. There is still a lot to be understood about what and why information should be communicated, and perhaps taking our lead from the natural world, these channels and purposes should be clear and efficient.

Most interesting perhaps was the newfound freedom that could be passed onto the end user, the person or persons that might consume such a piece of architecture. When we see the entire construction and software ecology it is not dissimilar to music and book buying, where technology has changed the market from a supply driven to a demand driven one. Giving choice and power to the end user and taking it from corporations. Given that a home, for many, is the single biggest purchase they will ever make and environmental imperatives, including aspects such as energy efficiency, comfort and health, are too often translated in overwhelming set of rules (as they require expertise and cannot be managed by the end users) that necessarily affect the design freedom. In our system instead these rules are simplified and metabolised within the digital framework, ironically it might be digital fabrication and automation that is returning freedoms to the consumer.

ACKNOWLEDGEMENTS

This project was made possible with funding from Transforming Cities, a Thematic Research Initiative at the University of Auckland. Many thanks to Yusef Patel, whose PhD is supported by the BRANZ Building Levy, Sindre Johnsen, who developed the expert interface and Kent Van Velden, who developed the end user interface.

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Driving innovative thinking in the New Zealand construction industry

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Innovative thinking is one of the key areas of interest for the New Zealand construction industry because it can lead to improved performance, decreased costs and improved quality. This paper examines the relationship between innovation and productivity improvement. It is argued that this relationship is not well understood due to lack of in-depth understanding of innovation in construction. To overcome this obstacle, the authors present a multi-dimensional innovation classification system which aims at better defining and classifying what is meant by innovation in construction. The use of this classification system is demonstrated by applying it to a database of 500 innovations reported by the construction alliance, the Stronger Christchurch Infrastructure Rebuild Team (SCIRT). SCIRT placed innovation at the core of its business with innovation measures as one of its key performance indicators. The results clearly demonstrate the diversity of types, degree of novelty and performance improvement benefits among construction innovations. Such diversity means that the impact of the reported innovations on productivity and performance are of different levels of significance. The classification system developed in this study can be used by construction organisations and alliances in future to develop more detailed methods of calculating innovation KPIs, based on the innovation type, novelty and benefits factors. Using the classification system they can also put in place mechanisms to influence the types of innovation developed in their projects with the aim of maximising their productivity performance.

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Keywords: Innovation, SCIRT, Performance

Introduction

The Construction industry is critical to the functioning of a domestic economy in many countries (Murray, Murray and Langford, 2003). In New Zealand, the construction industry is one of the largest sectors of the economy accounting for 8% of total employment in the country (Smith, 2011). However, in spite of its importance to the national economy in terms of size, the construction industry seems to be lagging other sectors in terms of productivity (Wilkinson, Kempton and Gleeson, 2012). In 2010, the construction industry in New Zealand established the Building and Construction Sector Productivity Partnership to actively address the issue of low productivity in the sector. Although the early focus was on identifying and quantifying the problems that lead to low productivity, over the recent years the focus has shifted to problem solving and addressing the cultural and mechanistic change that is need to resolve the well documented problems (Wilkinson, Kempton and Gleeson, 2012).

One of the areas that the partnership has identified as critical for achieving significant improvements in the sector's productivity is innovation. The ultimate goal of 20% productivity improvement by 2020, cannot be achieved by repeating the old ways of doing things. New innovative approaches are required in order to significantly improve performance at the same cost or maintain the same level

of performance at much lower cost. Unfortunately the construction industry is one of the least innovative sectors compared to other industries such as manufacturing and Traditional Services, (Reichstein, Salter and Gann, 2005). The R&D report produced by Statistics New Zealand indicates that R&D expenditure in the construction industry accounts for a low 5% of the total expenditure in the sector (Statistics NZ, 2012). Indeed, this problem is not limited to New Zealand as internationally the construction industry is seen as a traditional or low-technology sector with low levels of expenditure on activities associated with innovation (Seaden, Guolla, Doutriaux and Nash, 2003).

Furthermore, it appears that the link between innovation and productivity in construction industry is not well understood. (Loosemore, 2014) observes that in spite of many recent developments in the field of construction innovation, none of these studies feature in the mainstream construction productivity literature.

In contrast, the link between productivity and innovation has been well researched and explored in the manufacturing literature (Huergo and Jaumandreu, 2004). However, while certain parallels can be drawn from the manufacturing literature, it is generally agreed that there are significant differences between manufacturing and construction. (Koskela and Vrijhoef, 2001) identified the one-of-a-kind nature of construction project, site production, temporary multi organization and regulatory intervention, as differentiating characteristics of the construction industry accounting for lower innovation. (Reichstein, Salter and Gann, 2005) also identified a number of "liabilities" which sets construction industry apart from other innovative industries such as manufacturing. These are Immobility, Project-based, Uncertainty of demand, Smallness, Separation and Assembly.

There is a need for more construction specific research to explore the relationship between innovation and productivity. The study presented in this paper, aims to make a contribution in this area by taking a deeper look at the relationship between innovation and productivity. The authors contend that while productivity is a well-defined term, innovation in contrast is poorly defined for the construction industry and is only understood in abstract terms. This is a major obstacle in the attempt to clarify the relationship between innovation and productivity in the construction industry. To overcome this obstacle, the authors have developed a multi-dimensional innovation classification system which aims at better defining and classifying what is meant by innovation in construction.

The paper will first present this classification system from a theoretical perspective and illustrates how it can be used to better understand the relationship between innovation and productivity. The use of this classification system is then demonstrated by applying it to a database of 500 innovations reported by the construction alliance, the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), responsible for rebuilding the horizontal infrastructure after the earthquakes in Christchurch. SCIRT, are an organisation who put innovation as one of the main key performance indictor (KPIs) for its construction project delivery team. The results will highlight the diversity of innovation types that have been reported by the alliance group, and the classification system used in the paper makes sense of these innovations, and suggests ways of improving productivity through innovation use in construction.

Innovation and productivity

Productivity is generally defined as a ratio between output produced and input used (Park, Thomas and Tucker, 2005). Innovation on the other hand is more ambiguous in its definition. (Brown, 1994)

provides a broad definition of innovation as “doing things differently or better across products, processes or procedures for added value and/or performance”. (West and Altink, 1996) provides a similar but perhaps more complete definition of innovation as the “intentional introduction and application within a role, group or organisation of ideas, processes, products or procedures, new to the relevant unit of adoption, designed to significantly benefit the individual, the group, the organisation or the wider society”.

When comparing the above definitions and other popular definitions of innovation in the literature, three key defining elements of innovation can be identified. First is the type of innovative idea or invention. The Oslo Manual on collecting and interpreting innovation data (Organisation for Economic and Development, 2005) outlines four types of innovations: product, process, marketing and organisational. Second is novelty. The minimum entry level for an innovation is that it must be novel or “new to the firm” (Organisation for Economic and Development, 2005). Degree of novelty or “newness” can be defined as the extent of uncertainty associated with the implementation of the innovative idea within the context of its application (Shahbazpour, 2010). (Slaughter, 1998) divided the Novelty of the construction innovation in five different levels of Incremental, Modular, Architectural, System and Critical. Third is benefit or improvements in performance. In construction, traditionally performance has been measured in terms of cost, time, quality and safety (Bassioni, Price and Hassan, 2004). Recently environmental measures have also become an important performance indicator in construction projects (EPA, 2007).

Each of these elements (type, novelty, and benefit) can alter the significance and type of the impact that a given innovation has on productivity. In terms of type, whether the innovative ideas are a product, process or an organisational method results in different type of impact on productivity. For instance, process and organisational innovations are mainly concerned with the construction phase and thus will have a direct impact on the project’s productivity performance. On the other hand, product innovation may have much less significant impact on the production phase but much larger impact once the building or infrastructure is in operation. In terms of novelty, the degree of novelty determines the significance of the impact the given innovation may have on productivity. For instance an incremental change results in much less significant impact on performance than a more radical and disruptive change. Finally, different innovations would improve different set of performance indicators, thus having very different impacts on productivity.

in order to better determine the impact and nature of the relationship between given innovations and overall project productivity, types of innovation, novelty and the specific performance indicators being improved need to be determined. Determination of the innovations requires an innovation classification system, which can be used to better understand the relationship between the innovations implemented in a project and the subsequent improvements in productivity.

Innovation classification system

A multi-dimensional classification system has been developed by the authors, based on review of relevant construction and innovation management literature regarding the elements discussed previously. However, it was found that the most commonly accepted innovation classifications have mainly been developed by analysing innovation within the manufacturing and services context. As mentioned in the introduction, there are significant differences between construction and other industries. Consequently, in order to develop an appropriate innovation classification system for the

construction industry, modifications were made to these classification systems and where appropriate new categories were developed. This section will briefly outline each dimension and provide a definition for each classification category.

Innovation Type: The authors found it necessary to distinguish between development or utilisation of innovative construction materials or componentry and the development of innovative designs and features for buildings or infrastructures. Therefore, the product innovation category was limited to cover new materials or products used in the construction phase, and a new category was added, called Design, to account for the innovative design features introduced at the design phase of the project. Furthermore, guided by the construction technology classification system developed by (Tatum, 1988), the process innovation category was divided into two sub-categories of Tools and Function.

- **Product**: Product Innovation involves all new construction materials and products developed in the project or introduced to the project and used within the construction process.
- **Design**: Design Innovation is related to new and innovative plans, designs, sketches or concepts for the final building or infrastructure that is being developed in the project.
- **Tool**: The Tool Innovation involves the development or implementation of novel construction machinery equipment or tools in the construction project.
- **Function**: The Functional innovation refers to new tasks developed or introduced in the construction project and associated management processes.

After further consultation with industry experts two other categories were added where a combination of the previous sub-categories could exist:

- **Technology (Design + Product):** The new technology refers to the new design that is coupled with a new material or product.
- **Method (Tool + Function):** The Method innovation is the combination of the Tool and Function innovation that involve both a new tool or equipment and new tasks that are usually related to the new tool.

Innovation Novelty: Typically the innovation literature distinguishes between incremental and radical innovations. However, (Slaughter, 1998) provides a more detailed categorisation of novelty within construction innovation context. These categories are Incremental, Modular, Architectural, System and Critical.

- **Incremental**: Incremental innovation is a small change, based upon current knowledge and experience. It is often the result of continuous improvement initiatives and on-the-job problem solving.
- **Modular**: Modular innovation entails a significant level of novelty in one area of a system, but without impacting the other components of the system. Modular innovations may be developed within an organization and implemented without much negotiation with parties involved in the development or selection of other components.
- **Architectural**: Architectural innovation involves a small change within a component of a system, which results in major changes in the links to other components and systems. The distinction between modular and architectural innovations is made on the region of the change and, specifically, the degree of interaction with other components of the system.

- System: System innovations are identified through their integration of multiple independent innovations that must work together to perform new functions or improve the facility performance as a whole.

- Critical: Critical innovation is a breakthrough in science or technology that often changes the character and nature of an industry. While incremental innovations occur constantly, critical innovations are rare and unpredictable in their appearance and in their impacts.

Innovation Benefit: This dimension of the classification system deals with the type of performance improvement that is achieved through implementation of the new innovative ideas. As mentioned previously the following performance indicators will be used to distinguish between the types of benefits that is delivered by the given innovations.

- Cost: Direct cost savings or better utilisation of resources

- Time: Reduction in lead-times or increasing speed for the project or sub-tasks

- Safety: Improving safety and reduction of risks for the employees and public during and after the construction project.

- Environment: Reducing adverse impact of the construction processes as well as the final building or infrastructure on the natural environment.

- Community: Reducing adverse impact on communities affected by the construction project and improving communication with the stakeholders.

Case Study

SCIRT (The Stronger Christchurch Infrastructure Rebuild Team) is an organisation established under an alliance agreement and is responsible for rebuilding horizontal infrastructure in Christchurch following the earthquakes of 2010 and 2011. (SCIRT, 2011). Innovation was given a special consideration from the outset, when the SCIRT alliance was formed. In fact, members of the alliance were encouraged to innovate and report on their innovations on a monthly basis as one of their KPIs. As a result to date more than 500 innovations have been reported by SCIRT. This has provided a unique opportunity to analyse and better understand the relationship between construction innovation and productivity improvements. The authors were given full access to SCIRT's innovation database. For each reported innovation, the database contained a unique identification number, description of the innovative idea, its potential benefits and information regarding which member organisation had initiated the innovation. Some of the reported innovations were also accompanied by pictures or sketches to better describe the innovation. Each of the reported innovations were analysed and categorised based on the innovation classification system outlined in the previous section. The data was then analysed using pivot-table functionality of MS Excel, to better understand the types of innovations developed by SCIRT and identify any potential trends. The following section presents the summary of the results from this analysis.

Results

Figures 1-3 represent the spread of innovation categories in each dimension of the classification system: type, novelty and benefit. Most innovations in the SCIRT database seem to be made up of tools or functions in terms of innovation type and modular or architectural in terms of novelty. They also appear to deliver a wide-spread of performance benefits but mainly dominated by quality, time and cost.

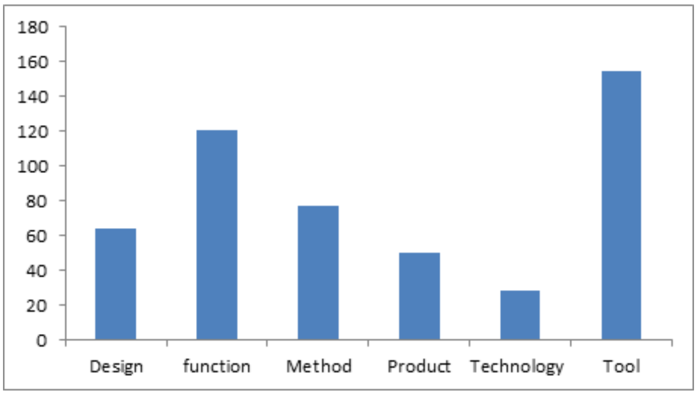

Figure 1. Innovation classification based on Type

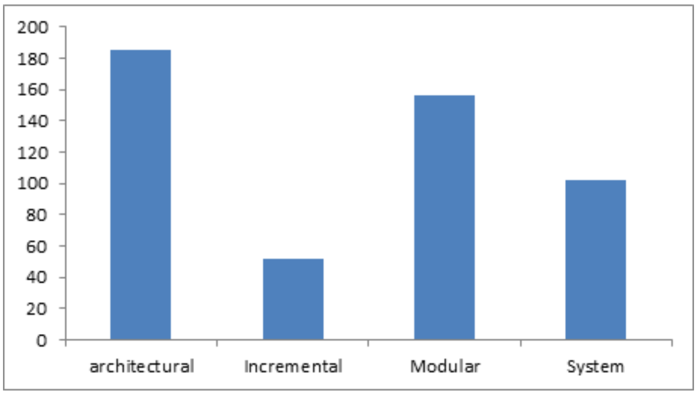

Figure 2. Innovation classification based on Novelty

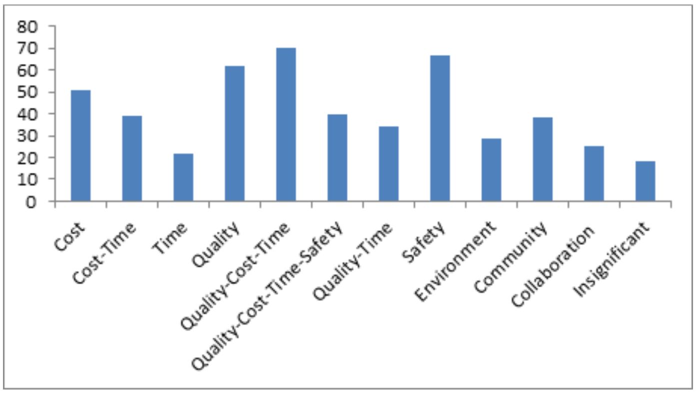

Figure 3. Innovation classification based on Benefit

The data was also analysed to identify emerging trends that would provide more insight in to the relationship between the three dimensions of the innovation classification system. When looking at

the spread of innovation based on a pair of two dimensions of benefit and novelty, an interesting trend emerged. As illustrated in Figure 4, it appears that architectural and modular categories of innovation are more focused on delivering a single benefit. On the other hand, system category of innovation seems to be the one that mostly delivers a combination of quality, time and cost benefits (see Figure 5). Modular innovation also appears to be the most prevalent category which focused on the indirect productivity improvements through safety, environment and community (see Figure 6).

When looking at the pair of innovation types and benefits similar trends appear. As illustrated in Figure 7, the majority of innovations are delivering a combination of quality, time and cost benefits were from the two categories of design and method. On the other hand function and tool categories seem to be more focused on delivering a single benefit (see Figure 8). Tools also appear to be the most prevalent type of innovation that delivers either safety, environment or community benefits (see Figure 9).

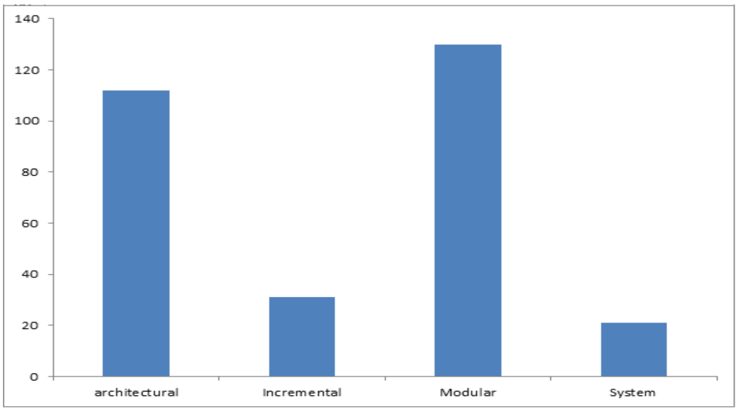

Figure 4. Innovation novelty categories that focused on delivering a single benefit

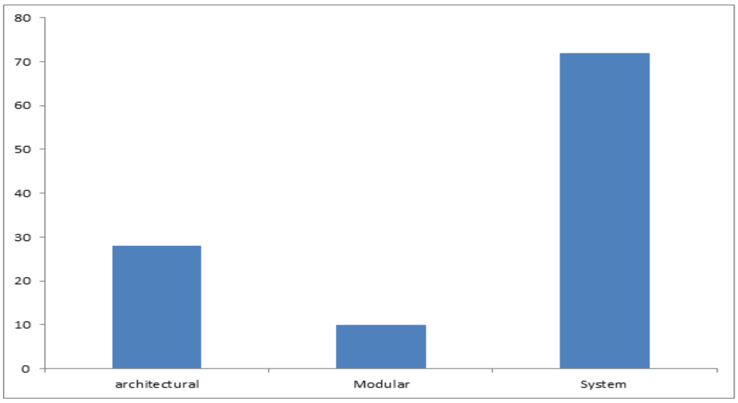

Figure 5. Innovation novelty categories that delivered a combination of quality-time-cost benefit

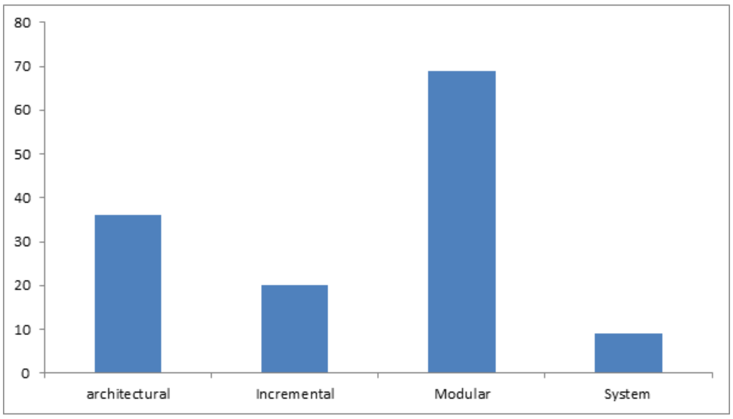

Figure 6. Innovation novelty categories that focused on either sustainability, safety or community

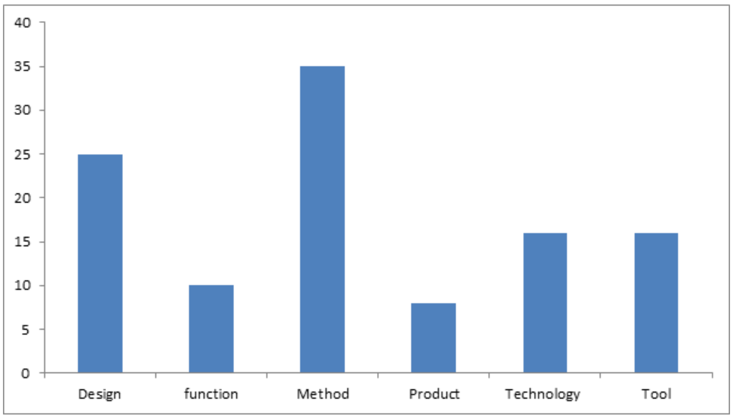

Figure 7. Innovation types that delivered a combination of quality-time-cost benefit

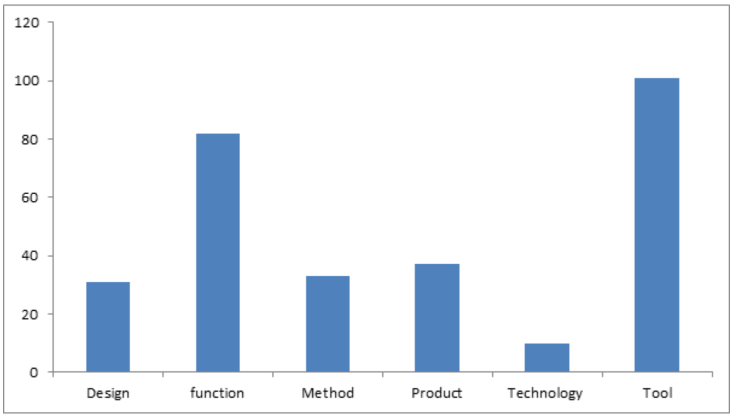

Figure 8. Innovation types that focused on delivering a single benefit

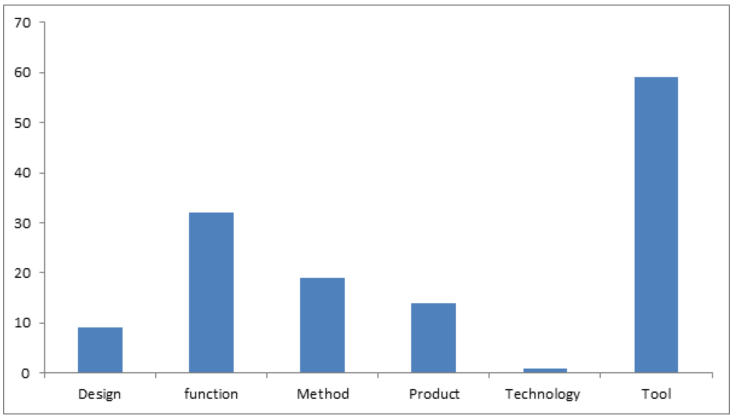

Figure 9. Innovation types that focused on either sustainability, safety or community

Analysis of the pair of type and novelty, also reveals some interesting trends. As illustrated in Figure 10, design innovation was dominated by architectural level of novelty, while product innovation was split between modular and architectural. Technology innovation (design + product) on the other hand was mainly dominated by system level of novelty. Modular and architectural innovations made up majority of the tools and functions, while those innovations classified as method, were mainly system or architectural innovations. Figure 11 also illustrates that the system level of novelty was mainly prevalent in methods, while modular innovations were mostly found under the tool and function categories. Architectural innovations spread amongst tools, designs, functions and methods. Also it was found that most incremental innovations were under the tools category.

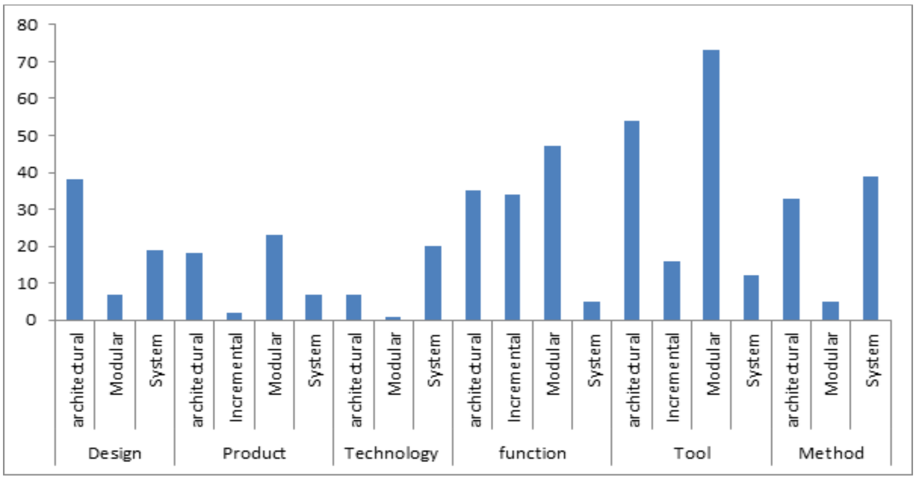

Figure 10. Degree of novelty of various types of innovation

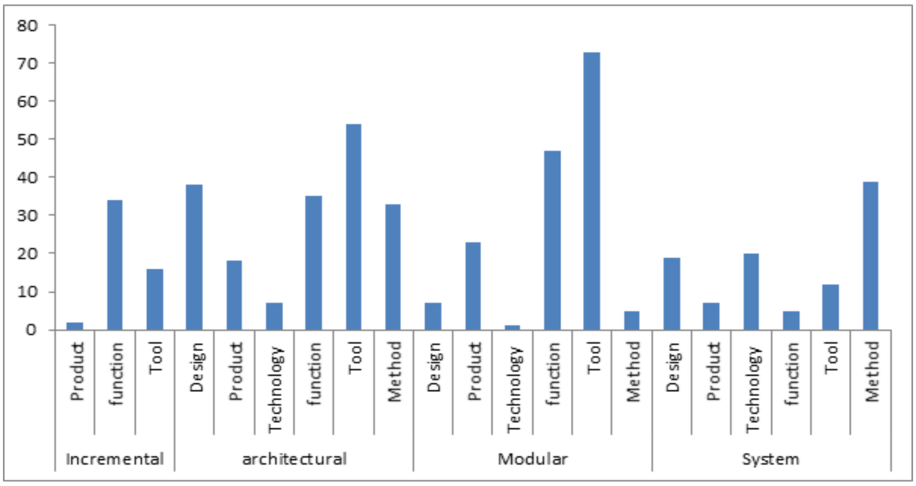

Figure 11. Spread of innovation types for each level of novelty

Discussion and Conclusions

The results of the analysis of 500 reported innovations by the alliance group, SCIRT, clearly demonstrates the diversity of types, degree of novelty and performance improvement benefits among construction innovations. The trends presented in the previous section have all emerged naturally based on the organisational dynamics and culture present among the member organisations as well as within the virtual alliance organisation. Given that innovation KPI reporting was linked to pay/reward system for the member organisations, there was motivation for all parties to look for opportunities to innovate. However, the data shows that most of the reported innovations were tools or functions that were developed to overcome immediate problems facing the operational teams. As a result most of these innovations were modular or architectural in terms of novelty. This indicates that most reported innovative solutions were developed to either solve localised problems or issues arising at the interface of operational sub-systems. The data also shows that when architectural and modular innovations were dominant, the reported innovations were mainly focused on a single aspect of performance improvement. In contrast the results show that when more sophisticated types of innovation such as technology and methods were developed, the impact was more widespread and significant, delivering benefits along multiple dimensions of performance such quality, time and cost.

Given that the reported innovations in the SCIRT database were developed without consideration given to the types of innovation, degrees of novelty or performance improvement benefits, they were all treated the same. The main reason for this equal treatment of the reported innovations is lack of in-depth understanding of innovation. As illustrated, there are large differences among various types of innovation, thus their impact on productivity and performance are of different levels of significance. The classification system developed in this study can be used by construction organisations and alliances in future to develop more detailed methods of calculating innovation KPIs, based on the innovation type, novelty and benefits factors. In such methods, different weightings can be given to each factor as a mechanism to encourage certain types of innovation,

with higher levels of novelty and focusing on specific combination of performance indicators that are tailored to the specific requirement of the construction project.

In conclusion the innovation classification system developed and demonstrated in this study provides a practical tool for researchers and practitioners in the field of construction management, to not only better understand the relationship between innovation and productivity, but to also put in place mechanisms to influence the types of innovation developed in their projects with the aim of maximising their productivity performance.

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IMPROVEMENT OF PRODUCTIVITY IN CONSTRUCTION PROJECTS USING A LEAN-DRIVEN SCHEDULING METHOD

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ABSTRACT

The building and construction sector accounts for more than 4% of New Zealand's Gross Domestic Product (GDP). However, the sector is plugged with problem in poor productivity level. One of the factors which largely affect productivity in construction is variability. This issue represents almost 80% of productivity reduction in repetitive construction projects. Variability causes instability and fluctuations in different performance measures such as cycle times, cost, and planning efficiency. Buffers are commonly used to protect production schedules against the variations by allowing a certain level of flexibility. Variability and buffer management are also key topics in the lean construction agenda as reduction in variability effects can decrease the non-value-adding components in production.

This paper discusses the use of a Lean-driven buffered schedule in improvement of productivity in construction. A systematically buffered schedule can improve the reliability of construction plans. The improvement is apparent where considerations are given to the probable non-alignment between the planned and the actual progresses. Consequently, waste in the form of waiting time or slow work can be minimised which addresses the Lean ideal requirements. It is shown that a systematic buffered construction schedule can decrease project delivery time by 31% to 41%, and increase productivity level up to 30% when combines with variation mitigation strategies such as "Last Planner System".

KEYWORDS:

Productivity; buffers; Lean Construction.

INTRODUCTION

The building and construction industry is the fifth largest sector in New Zealand. Its output contributes to 45% of all gross fixed capital formation of the country (Construction Inductry Council 2006; Productivity Partnership - Roadmap 2012; Building a Better New Zealand 2013). Nevertheless, the sector is plugged with a major problem in poor productivity level (Construction Inductry Council 2006; Pwc 2011; Productivity Partnership - Action Plan 2012; Building Research Association of New Zealand 2013). Figure 1 shows the changes in productivity level in construction sector over recent decades. The level remained almost static for the first 25 years. The constant level was followed by a decline during the past decade (Page 2010). Construction productivity in New Zealand is poor not only compared to other local industries, but also the international standards (Building Research Association of New Zealand 2013). Given the major contribution of this sector to the country's economy, the nation needs it to be more effective and productive.

Figure 1- Construction productivity in New Zealand over the past 35 years

In 2010, the Building and Construction Sector Productivity Partnership, a joint venture between industry and government was established in New Zealand (Building a Better New Zealand 2013). The partnership has a goal of leading a 20% lift in construction productivity by year 2020 (Productivity Partnership - Roadmap 2012). Improvements in the productivity in building and construction industry play a significant role in housing affordability (Building a Better New Zealand 2013). The intended objective by the Productivity Partnership mirrors the government's plan to build stronger growth and create jobs for all New Zealanders (Williamson 2012).

"Productivity" is normally defined as the volume of outputs from a process per unit of inputs (Page 2010). Maximization of productivity is referred to by "efficiency". Efficiency in an engineering sense means that a production process has achieved the maximum amount of output that is physically achievable given a fixed amount of inputs (Schreyer and Directorate 2001). The efficiency and performance of a production system are profoundly linked to the way in which the existing fluctuations in daily performance are managed (Alarcón and Ashley 1999; Tommelein et al. 1999; Ballard 2000; Thomas et al. 2002; Hopp and Spearman 2008; González and Alarcón 2010). The Productivity Partnership has conducted a research to acquire opinions of construction practitioners on methods to improve the productivity of the New Zealand construction industry. The research showed that "improvement of management" (such as implementing the Lean project management) is among the top six suggestions to increase current productivity levels (Building Research Association of New Zealand 2013). The role of management in stimulating improvement in construction productivity is supported by several international studies such as the published report on productivity improvement in the European industry (O'mahony and Van Ark 2003), the study by US National Research Council (National Research Council 1980), the report of the Construction Task Force on the scope for improving UK construction (Egan 1998), and the report on affecting construction factors in the Middle-East (Jarkas and Bitar 2011). Thomas et al. (2003) reported that 32% of the inefficient work hours in projects are because of deficiencies in the workforce management. They also showed that reducing this type of deficiencies can result in a higher level of reliability in the construction flow which can accordingly improve labour efficiency up to 51%.
A suitable management approach can be adopted on construction sites that involves two concurrent groups of strategies (Howell et al. 1993; Howell and Ballard 1994; Ballard and Howell 1998; Koskela et al. 2010). The first group of strategies should focus on control of variation through following up the operational activities and planning commitments (Howell 1999). Production planning and control methods such as the "Last Planner System (LSP)", the "Constructability Concept", and the "Rational Commitment Model (RCM)" can be applied for this purpose (Construction Industry Institute 1986; Ballard and Howell 1997; Ballard 2000; González and Alarcón 2010). However, it has been shown that this kind of variation control approaches only reduces variability to a certain extent (Conte 1998; Junior et al. 1998; Alarcón et al. 2005; Alsehaimi et al. 2009; Koskela et al. 2010). Therefore, a second group of strategies is required to manage the effects from the remaining variability over performance (Ballard and Howell 1995).

This paper discusses use of “Lean Construction” concept as a potential platform that can help to create a practical managerial framework to address the second group of management strategies. The idea conforms to the findings of “International Group for Lean Construction” (IGLC), a world leading non-profit research organisation which studies the development and application of Lean Production concepts and methods to the Architecture-Engineering-Construction (AEC) Industry.

A STRUCTURED APPROACH TO BOOST PRODUCTIVITY IN CONSTRUCTION

Identification of proper actions to improve the work efficiency starts with definition of a reliable index to quantify productivity. “Building Research Association of New Zealand” (BRANZ) suggested to measure the productivity level by a multi-factor productivity index (MFP) that comprises of labour and capital factors (Page 2010). It addresses a three-level industry structure proposed by Davis (2007, 2008). The structure comprises of “individual level” where on-site productivity is considered; “Firm level” in which the productivity is perceived in simultaneous groups of projects; and “industry level” that takes in productivity of the whole industry. This research fosters performance improvements at “individual level” in projects. In turn it enables managers to better allocate their available resources at “Firm level” and achieve a higher degree of efficiency. The outcome of improvement at the lower level may positively influence the productivity at the “industry level” for medium and long term periods. It becomes possible if a widespread adoption of the proposed planning method at construction projects and firms occur.

The importance of variability management in construction sites in improving performance at “individual level” is addressed in this paper. Variability is one of the factors which largely affects productivity in construction (Ballard and Howell 1994; Howell and Ballard 1994; Ballard and Howell 1995; Alarcón 1997; González et al. 2011). It is represented by the variations in daily production, time schedule, and cost control which appear in the form of deviation from the intended target (Alarcón 1997). The relationship between productivity and variability in practice is supported by the findings of the Catholic University of Chile based on the information collected from more than 1,000,000 square feet of building construction projects (Alarcón 1997). In fact, variability accounts for almost 80% of productivity reduction in repetitive construction projects (Ballard and Howell 1994).

VARIABILITY VERSUS PRODUCTIVITY

Variability has been identified as an inherent characteristic of production systems from the early 1920s by Shewhart (Garvin 1988; Koskela 2000). It causes instability in performance of construction processes by inducing fluctuations in the flow of work and information (Thomas et al. 2002). Figure 2 (a) demonstrates the negative impact of variability in a hypothetical construction project. The figure shows a part of a construction project that includes two processes which were planned to be done within 50 days. To analyse the variability effects, “velocity diagram” is applied which plots the cumulative progress of processes against time. Hence, the processes interdependencies can be observed.

In the presented case, outputs produced by the first process were prerequisites to the work performed by the second process. Tommelein et al. (1999) has suggested such a consecutive pattern in repetitive construction projects and term it as “Parade of Trades”. As the figure shows, variability has caused fluctuation in the performance of the first process. At the most extreme point (point A in Figure **2** (a)), the performance deviated by 8.1 days from the planned target. It conveys 121.5 units behind the schedule. This deviations in the first process caused three periods of waiting time in the second process (W1 to W3). During these periods the second process was idle to receive its requirements. The total waiting time in this case was 10.8 days. As a result, the production rate of the second process (number of produced units divided by time) ended up with 3 (units/day) slower than the planned rate. The slower production rate, caused 10 days delay in the final delivery date of this project. The variability affects not only the individual process but also other dependent processes. Figure 2 (b), shows how the problem can extend from a single case of two processes to a whole project. The figure illustrates a set of consecutive repetitive construction processes according to the

model suggested by Tommelein et al. (1999). The total planned time for this multi-process case was 90 days while due to variability, the finish time deviated by 10 days. Besides, the total waiting time in this case came to 32.2 days.

The strong connection between the degraded performance measures and variability has been addressed by several researchers (Ballard and Howell 1994; Alarcón 1997; Junior et al. 1998; González et al. 2004; Koskenvesa and Koskela 2005; Alsehaimi et al. 2012). It is argued that deviation from the planned date due to variability, roughly happens in one out of each three activities on construction sites (Ballard and Howell 1994). According to Hosseini et al. (2012), waiting time and delays account for up to 65% of total project time. Hence, the waiting time increases the portion of ineffective time within the project and accordingly represents lower work efficiency and a decreased productivity level.

ROLE OF BUFFERS IN VARIABILITY CONTROL

Given the role of variability in shrinking the work efficiency and its close connection to productivity, development of methods for variability management has been put in light (Ballard et al. 2005). Effective variability management can result in 30% to 49% lift in productivity (Howell and Ballard 1994; González et al. 2004; Alarcón et al. 2005). As stated before, to maintain a suitable management approach in construction it is suggested to focus on the “control” of flow variation by taking care of the operations and pushing the planning commitments onto activities (Howell 1999). Efforts should be put to mitigate variability through a set of controlling and corrective actions such as frequent checking and updates on the resource availability, shifting the attentions from local optimization toward the project optimality, spotting the potential obstacles and devise proper solutions for them. (Construction Industry Institute 1986; Ballard 2000; González et al. 2008). However, a second group of strategies is required to cope with the remaining part of variability (Ballard and Howell 1995).

Buffers have been commonly used to protect production schedules against the uncontrolled part of variation by maintaining a certain level of flexibility in the system (Howell 1999; González et al. 2011). A buffer isolates the production process from its environment as well as the processes depending on it (Hopp and Spearman 2008). Buffers can be implemented in the form of a delay between processes (time buffer), extra work capacity such as labours or machinery in each process (capacity buffer), or extra material in front of each process (inventory buffer). Thus, the processes can be shielded against the potential uncontrolled variation. According to Hopp and Spearman (2008), buffers can help to prevent loss of throughput, wasted capacity, and inflated cycle times in the production projects. Figure 3 (a), shows the role of buffer in improvement of project performance. It allows the comparison of the performance of the second process in two different cases: (1) a buffer is introduced to the system, and (2) a non-buffered situation. By introducing a buffer of 120 production units in supply or 10 days delay in its start time, the second process can be isolated against the variability in its upstream process. As the Figure 3 (a) shows buffers helped the second process to avoid the unnecessary waiting times to receive its requirements. This situation presents a better production rate and process efficiency. Accordingly, a higher level of productivity can be obtained. Similar improvements can be expected from the use of buffers in the illustrated multi-process case in Figure 3(b). A productivity improvement between 6% and 51% (depending on nature of work) has been reported when buffers were implemented in repetitive construction projects (Howell et al. 1993; González et al. 2009). A comparison between Figure 3 (b) and figure 2 (b) shows that the implementation of buffers not only reduces waiting times, improves production rates, efficiency of processes, and productivity, but it also can reduce the observed delay in the final delivery date of project. Accordingly, an improvement of 31% to 41% can be expected in project delivery time from the implementation of buffers in construction (Horman 2001; Koo et al. 2011). A general 30% lift in productivity is claimed to be achieved in construction projects through implementing the buffering techniques in combination with LPS as the strategy for variation mitigation (Ballard and Howell 1994).

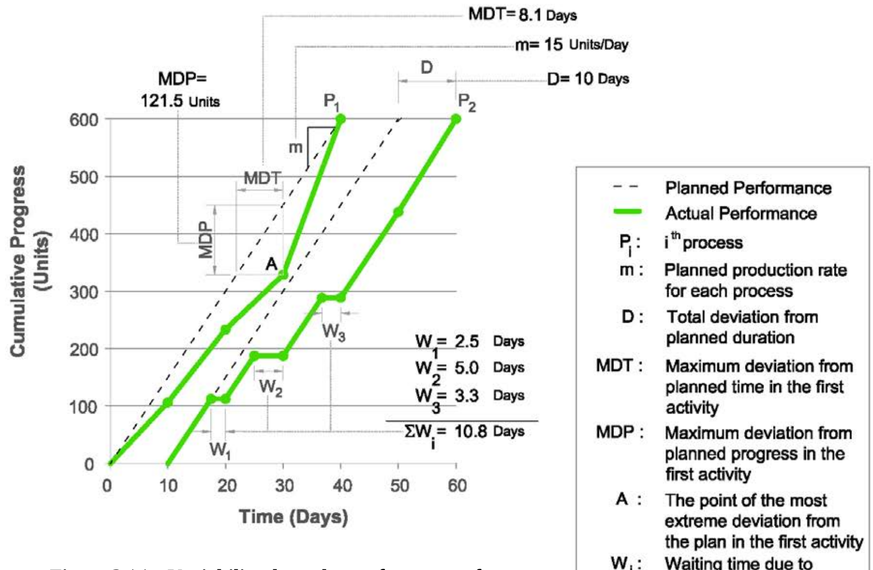

Figure 2 (a) - Variability degrades performance of a single set of processes

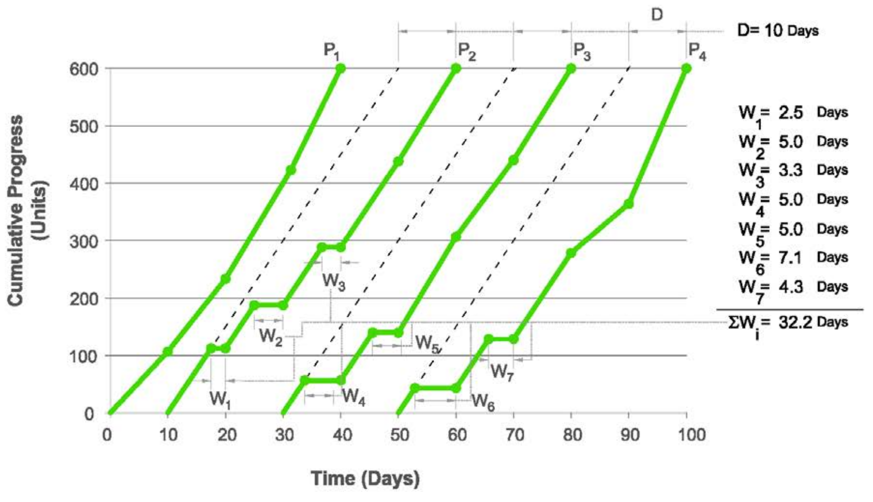

Figure 2 (b) - Degrading effect of variability on the whole project performance

Figure 2 – Variability effects on project performance

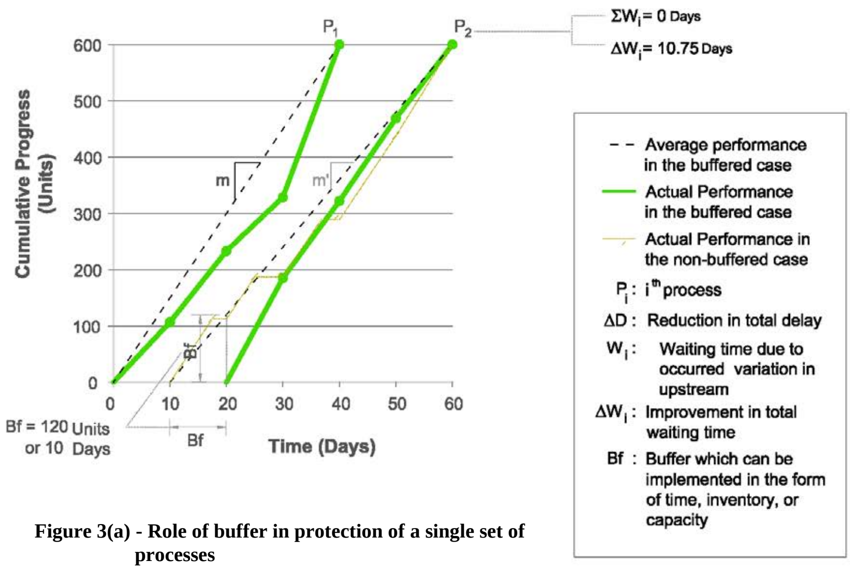

Figure 3(a) - Role of buffer in protection of a single set of processes

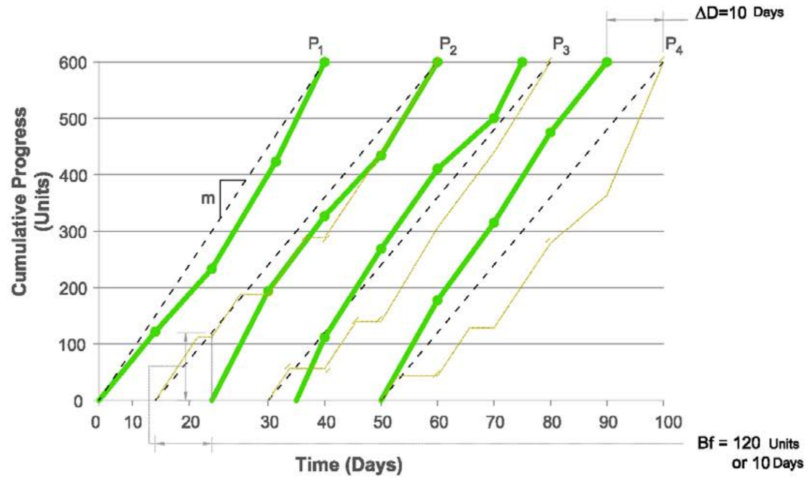

Figure 3 (b) - Role of buffer in a multi-process system

Figure 3- Role of buffer in improvement of project performance

Figure 3, also can show another advantage of using buffers in construction projects. It is able to help a crew of workers to spend less time on-site and finish their job faster by avoiding unnecessary waiting times/slow work. It increases efficiency of work at individual level that can reduce the total project duration. Page (2011) in 'BRANZ study report 259' has discussed that a quicker construction can be beneficial to both builders and owners. For builders, faster completion of each construction process may improve cash flow and it enables overheads to be spread over more projects, thereby increasing profit. For owners, quicker construction may result in a higher profitability and lower rental financial costs. In that report, Page (2011) focused on the effects of the project overall duration on profitability. This study argues additional potential savings exist from improvement in productivity and shorter duration for each individual construction process.

BUFFER MANAGEMENT TECHNIQUES

A wide range of production approaches and techniques have been developed to manage buffers. The techniques have evolved from inventory theory to the modern manufacturing techniques. They vary in terms of emphasis on decision rules, system status, and the type of used buffers (Hopp and Spearman 2008). Economic order quantity (EOQ), (Q, r) model, Base Stock model (BSM), Material requirement planning (MRP), Just-In-Time (JIT), Constant-Work-in-Process (CONWIP), Drum- Buffer- Rope (DBR), and Critical Chain project management (CCPM) are some of the existing buffer management approaches in manufacturing (Hopp and Spearman 2008). Similar strategies can be applied in construction to manage buffer as long as they are adapted to the peculiarities of its production environment (González et al. 2010). Production in construction is peculiar because it is associated with design and assembly of fixed-in-place objects, characterized by a site production, unique product, and temporary teams (Ballard and Howell 1998). A considerable effort has been invested to adapt the existing buffering methods in manufacturing to construction context. However, lack of practical buffering approaches is still apparent in construction practices (Park and Pena-Mora 2004; González et al. 2009). Introduction of "Lean construction" has provided a new ground to propagate an improved framework for addressing the buffer management issue in construction (González and Alarcón 2010).

BUFFER MANAGEMENT UNDER LEAN CONCEPT

Variability and buffer management are key topics in the Lean construction agenda (Ballard and Howell 1994; Ballard and Howell 1995; Koskela 2000; González and Alarcón 2010; Slack et al. 2010). "Lean Construction" is established on the basis of "Lean Production" which has introduced significant improvements to the manufacturing and automotive industry. In Lean, reduction of variability is considered as a means of decreasing non-value-adding components in production (Thomas et al. 2002; Womack and Jones 2003). "Value" represents customer satisfaction and non-value-adding elements characterise waste. Variability results in non-value-adding components (waste) in the flow of work and information in a production system (Thomas et al. 2002; Womack and Jones 2003). Lean Construction aims to reduce waste in production (Womack and Jones 1996). In this sense, reduction of waste increases efficiency in production system that accordingly decreases required time and cost to perform a task (Horman 2001; Thomas et al. 2002).

Figure 4, shows the current difference between average productivity in manufacturing and construction in New Zealand. These two industries are similar from operations management point of view, but manufacturing has a productivity level twice of construction (Page and Curtis 2011). It is expected that construction receives the same benefits as manufacturing by applying Lean concepts and methods in its production systems and projects. Alarcón et al. (2005) assessed the impacts of implementing Lean Construction on a number of projects and reported that the majority of project members noticed a significant improvement in productivity. Also, many of the interviewees addressed the importance of the Lean in avoiding waste of time and improvement in their project delivery. Similarly, Pacific Contracting of San Francisco reported a 20% lift in productivity and turnover by applying Lean concepts (Egan 1998). Existing evidences suggest significant opportunities to apply Lean in construction to prevent the negative productivity effects from variability.

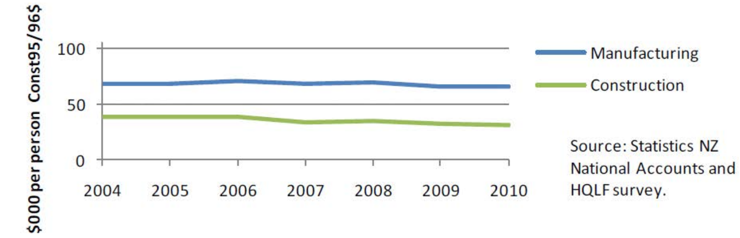

Figure 4- Comparison between productivity in manufacturing and construction in New Zealand (1995/96 dollars is used as the constant) (Page and Curtis 2011)

Lean ideal strives to avoid safety buffers because they represent waste (Womack and Jones 1996; Erdmann et al. 2012). Otherwise, in the absence of buffers, the system needs to control workflows strictly in order to be smooth and predictable. Hence, no buffer makes production systems vulnerable to disruptions and buffer-less system appears as a rare practice in ordinary construction projects (Hall 1983; González et al. 2009; Erdmann et al. 2012). The dichotomy between the Lean ideal and real practices connects with a "balance problem": A state of balance is required to be established between excessive size of buffer, that represents undesirable waste, and the no buffer scenario that stimulates vulnerability in the system and accordingly poor performance (Hopp et al. 1989; González and Alarcón 2010). The "balance problem" gives a valuable criterion to address the buffer allocation in construction schedules as an optimization problem.

The combination of buffer optimization and variability mitigation techniques can provide a hybrid framework that is able to introduce considerable improvements in project performance. Figure 5 presents some of the reported levels of improvement in productivity through application of hybrid strategies in construction activities. As shown, implementation of a systematic approach in variability management has resulted in an improvement between 6.4% and 51% depending on the nature of the construction work. The applied buffering methods in these experiments were segregated and locally adjusted to a restricted range of applications in their intended area of work. Therefor even more improvement can be expected in productivity in construction if a comprehensive and integrated buffer management approach is taken.

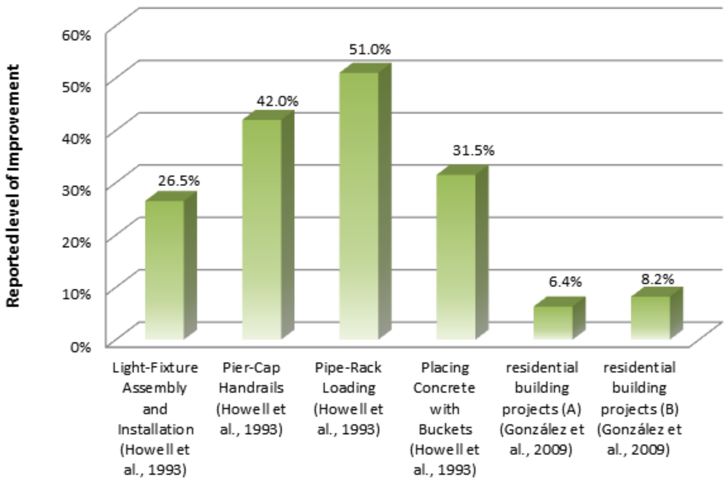

Figure 5- Reported improvements in construction productivity through implementing buffer management approaches

CONCLUSION

It was discussed that development of a buffering method based on the Lean construction concept can protect construction productivity against the negative effects of variability. Such a systematic buffering method can allow for generating reliable construction plans at the early stages of projects, by including the likely non-alignment between the planned and actual progress of processes. The improvement in planning reliability can bring significant performance improvements in construction projects. For instance, some studies have shown that 50% of improvement in the planning reliability can increase productivity up to 35.0% (González et al. 2010; González et al. 2013). The proposed method follows the Lean ideal to minimise waste in the form of waiting time or slow work which is mentioned by Page and Curtis (2012) as the main areas of waste in the New Zealand construction industry.

In summary, given the provided evidence a substantial boost can happen in construction productivity, by providing a hybrid variability management technique on construction sites.

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AIMING FOR A BETTER PUBLIC REALM: GAUGING THE EFFECTIVENESS OF DESIGN CONTROL METHODS IN WELLINGTON

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ABSTRACT

Design review aims to improve the quality of urban settings, principally by seeking to positively influence the design of individual buildings during the planning approval stages of development. Design review systems were first set up in New Zealand in the mid-1990s in Wellington and have been controversial from the outset. Criticism of design review, generally undertaken in conjunction with proactive design guidance, has come principally from the side of the development team. Designers and architects consider design review to be an affront to their professional judgement while land owners/developers tend to resist any attempt by local government to interfere with their assumed rights to dispose of their land as they see fit. The aims of design review are laudable; even if it is not set up to secure the best possible design outcome then at least the process should be able to prevent the worst outrages so as to ensure the visual quality of streetscapes.

The question that must be asked however is, "does design review really achieve what it sets out to do?" After outlining a brief lineage of design review practices leading up to establishment of the first such regime in New Zealand, the paper goes on to discuss the effectiveness of design review. Basing the discussion on literature sources as well as a recent case study looking at public perceptions of a Wellington street, the paper outlines the key positive attributes of design review as well as those issues seen to be problematic. The paper goes on to speculate over how design review could be made to work more effectively in Wellington.

KEYWORDS:

Design review; urban design guidelines; aesthetic control.

INTRODUCTION

It is never too difficult to find opinions critical of the appearance of buildings and cites. When discussing Sydney a decade ago, John Punter made the observation that the city had succumbed to "spectacularly ordinary commercial development" in the period after WWII and that this poor aesthetic quality is only excused by an otherwise discerning public because of Sydney's spectacular setting (Punter 2004 p406). When discussing New Zealand architecture, Layla Dawson of the *Architectural Review* recently expressed surprise that Auckland has the appearance of an unplanned jumble of high-rise blocks. Why, she asked, would the public put up with such poor architecture (Dawson 2010)? Making a more general observation, Bentley (1999) suggested that the public are united in their dislike of the ways cities have been transformed in recent times. Nevertheless, the question that must be asked is whether the appearance of the built environment really matters?

The appearance of the built environment can have tangible influence over property values, directly affecting the financial well-being of those who own property or conduct a business in an area. The choices people make every day usually include an aesthetic dimension. These may include deciding which city to live in, which house to buy and even which street to walk along (Madanipour 1996 p164). It seems that visually attractive places are more sought after by the public, helping to increase demand and therefore economic values. Increasingly, the built environment is being used as a tool in battles fought between cities for business investment, tourism and high-calibre workers (Carmona, Magalhaes et al. 2002, Cuthbert 2006). People regularly make choices around matters of aesthetics and it is clear that the visual attractiveness of cities affects the financial well-being of individuals as well as the wider community.

Like many cities around the world, Wellington has established an explicit design control regime s part of its regulatory planning system. Through its District Plan the Council seeks to "encourage positive growth that promotes the City's comparative advantages" and lists eight principles to guide development (Wellington City Council 2013). A key principle to influence design control activities acknowledges that the quality of the public realm is influenced by the buildings and structures that define it. The Central Area Urban Design Guide aims to achieve high quality buildings, places and spaces by ensuring developments are coherently designed, make a considered response to their setting and establish positive visual effects (Wellington City Council 2012).

WHAT IS DESIGN CONTROL HOW IS IT MANAGED?

Design control is generally administered as part of the wider regulatory planning system. Regulation of private development emerged in the wake of the Industrial Revolution as it became clear that the free market could not be relied on to consistently deliver appropriate results. Government regulation is essentially acting to ensure that the interests of society as a whole are served by any future changes to the urban environment. Design control is undertaken by local government on behalf of those who must live with the consequences but do not otherwise have a say in the nature of environmental change (Delafons 1994, Ellin 2006). Depending on the planning context, regulation is nothing more than a backstop to help ensure that individual projects are built in a manner that does not create untoward environmental effects. This, coupled with reliance on the private sector to initiate changes, means that planning regulation tends to be reactive, rather than proactive, about managing the built environment.

A number of methods for regulating and controlling the aesthetic outcomes of urban development have been developed and successfully operate in different parts of the world. Punter (2007) advises that design review practices can be either regulatory or discretionary. Regulatory (also referred to as administrative) systems are an add-on to zoning controls, where design outcomes are controlled by rules and objective measures. Examples of this are maximum height limits, prescriptions for location of buildings in relation to boundaries, and floor area ratios. These systems provide high levels of certainty to all parties and regulation can be conducted largely through administrative functions, reducing demand on local authority resources. However, they are also criticised for being coarse in nature with a tendency toward monotonous environments because new projects within an area are all built to the same prescribed limits (Delafons 1994; Madanipour 1996).

Discretionary systems are more 'pragmatic' as they allow regulation to refer to the immediate setting and other variable factors that cannot be accounted for in most rules based regimes. The more successful discretionary systems, in terms of meeting the needs of different stakeholders, are informed by design guidelines or briefs that provide both a target for designers and a reference for those assessing the proposal (Nasar and Grannis 1999). While discretionary systems often allow local conditions to be taken into account they are often criticised by the development industry and designers for their arbitrariness (Scheer 1994).

Over the past 30 years there has been a tendency for regulatory design control to become more discretionary to create scope for development design quality to be scrutinised more closely. Likewise, design guidance informing discretionary systems has become more prescriptive in response to calls for more certainty around the process for applicants. In short, design control systems appear to be converging as they are modified to include both discretionary and regulatory characteristics (Punter 2007).

The literature outlines a number of challenges for design review. Scheer (1994) notes that design review is time consuming and expensive, that it is easy to manipulate through persuasion and pretty pictures, and that it is administered by overworked and inexperienced staff. However, she also suggests that these matters are easy to solve, mainly with additional financial or human resources, through education and by ensuring the process is adequately audited for political involvement. Presenting more substantial challenges for design review are issues relating to power, freedom, justice and aesthetics. These issues

exist as tensions between competing social, political or legal forces. The *power* issue raises questions around who makes the key decisions. Arguing from a design professional's perspective, Scheer makes the observation that design review is the only field in which lay people (or those not specifically trained in design) can be left to rule over professionals directly in their areas of expertise.

Freedom of expression in the built environment is another matter that troubles design review. Concerns about freedom are triggered by societal values aligned with property ownership, particularly in the 'new world' countries. This concern is most pronounced in the United States although the courts there have consistently upheld the rights of government to control design outcomes (Lai 1994). *Justice* is another matter of concern, where the reviewer is seen to hold the power, which may limit the extent to which a 'fair hearing' is possible. This issue is minimised where written guidelines underpin the planning process. Finally, the murky area of *aesthetic preference* questions whose values should be referenced. She rightly notes that in many cases guidance remains unhelpfully abstract and projects tend toward soft solutions and mimicry in order to navigate the review process.

Traversing legal issues raised by design review, George & Campbell (2000) identify the various interests that are active in it. Their work addresses the subject in an American context, so freedom of expression is a consistent theme. They highlight the need for variety in the built environment from a physiological perspective. As human wellbeing is affected by the environment, the case for regulation suggests that new designs should avoid inducing unnecessary stress, anxiety or fear in people. However, people also learn and develop senses through experience of their environment and so it is important that they are challenged. More complex settings, which arise through unfettered design decisions, create such opportunities. It is on this basis that the authors challenge control methods that require no excessive differences from the current setting. In addition, pushing the current boundaries of design creates opportunities for development of new theories, new methods and general advancement of the field, which they argue can be a benefit to all of society. To properly acknowledge and balance the various interests George and Campbell (2000, p171-173) describe four criteria that a sound design review process must address:

1. A clearly articulated and demonstrable public interest
2. Demonstrable links to the stated intent
3. Application early in the design or decision process
4. Encouraging a variety of acceptable decisions.

Punter (2007) incorporates these criteria into a comprehensive framework for design review and development management (Table 1). The twelve principles are grouped under four headings; community vision, design planning and zoning, substantive design principles and due process. The principles under the first heading aim to capture the views of the community as a step in generating a comprehensive view to guide development and control. The community vision becomes the reference for all decisions. Secondly, three principles inform development of a suitable process that includes incentives as well as requirements necessary to regulate for high quality design outcomes. The next three principles address the nature of the relationship between the comprehensive plan and the development industry charged with its implementation. Punter argues that the relationship should be pluralistic and not overbearing in order to allow creative solutions to emerge. Under the final heading four principles address issues of fairness in administering the design control regime.

Table 1: Principles for Progressive Design Review

Source: Punter (2007)

Community vision
1. Committing to a comprehensive and coordinated vision of environmental beauty and design
2. Developing and monitoring an urban design plan with community and development industry support and periodic review

Design Planning and Zoning
3. Harnessing the broadest range of actors and instruments (tax subsidies, land acquisition) to promote better design
4. Mitigating the exclusionary effects of control strategies and urban design regulation
5. Integrating zoning into planning and addressing the limitations of zoning

Broad, Substantive Design Principles

6. Maintaining a commitment to urban design that goes well beyond elevations and aesthetics to embrace amenity, accessibility, community, vitality and sustainability
7. Basing guidelines on generic design principles and contextual analysis and articulating desired and mandatory outcomes.
8. Not attempting to control all aspects of community design but accommodating organic spontaneity, vitality, innovation, pluralism: not being over-prescriptive.

Due Process

9. Identifying clear a priori roles for urban design intervention
10. Establishing proper administrative procedures with written opinions to manage administrative discretion, and with appropriate appeal mechanisms.
11. Implementing an efficient, constructive and effective permitting process
12. Providing appropriate design skills and expertise to support the review process.

DOES DESIGN CONTROL HELP ACHIEVE WELL-LIKED STREETSCAPES?

Given the concerns raised by the authors cited in the introduction to this paper, along with similar reactions outlined in the popular media, questions around the effectiveness of design control processes can be raised. A 2003 study discussed the effect two of the character area design guides have had on development (McIndoe 2003). The report reviews the process leading to resource consent and through to completion as well as the architectural merit of the completed project. Based on a review of 16 individual projects, the report concludes that, in essence, the District Plan rules and associated design guidelines have been effective in achieving desired character outcomes. However, all is not ideal. The research also suggests a strong positive correlation between the involvement of an architect and a successful outcome. This is significant given that the two suburbs of Thorndon and Mt. Victoria fall under the guidance of the most prescriptive design guides in the District Plan. The report suggests a similar correlation between the absence of a skilled professional and a poor quality result. What chance at achieving high or even passable outcomes do projects have when designed by non-architects in those areas where the guidance is less explicit?

A year later Rae (2004) reviewed completed projects in the Central Area including the Courtenay and Cuba Character Areas in a similar, subjective review of 20 completed projects. The study concluded that the guidelines are not effective when used in conjunction with controlled activity status under the District Plan. Controlled activity status is where the proposed building or activity essentially cannot be refused, regardless of the aesthetic qualities of the built form. While the earlier study found pre-application consultation to be widespread and beneficial to project outcomes, the second study found early consultations to be ineffective for a variety of reasons. The architects Rae consulted noted that the advice given by Council officers in the early stages was inconsistent and conservative. He also found that when it is undertaken, consultation does not occur at the critical stage of site-specific analysis, commencing instead once preliminary design proposals have been formed. As a consequence Council urban design input has little effect in prompting significant changes, should they be necessary, to improve outcomes. Finally, the research suggested that the discipline specific approach to evaluating projects could have a detrimental effect on projects when compared to assessment of proposals in a more holistic manner. Rae cited changes in project particulars to satisfy singular and conflicting advice from heritage, traffic wind and urban design advisers leading to have diminished design outcomes.

While interesting, both of these earlier studies relied on the expertise of the authors to evaluate the design outcomes. While Scheer argues that design review should be the exclusive domain of experts trained in the visual arts, and in particular to be architects, there is little to suggest that such experts speak on behalf of the wider population. Indeed, what little research that has been done to compare the aesthetic preferences of lay people and professionals suggests that there are differences in perception (Groat 1994). So, despite the pleadings of Scheer and others that design review, if it is undertaken at all, should be left to the experts, a different and more populist view is that designs should be evaluated in a manner that represents the views of the wider population. This paper reports on the findings of research designed to do just that.

College Street case study

A survey of 75 respondents sought to understand people's visual perceptions of the buildings lining both sides of College Street in Wellington. People's preferences for the designs of individual building, the relationships formed between adjacent buildings and for the overall streetscape were collected. Initial analysis of the survey results identified a number of streetscape issues that were teased out with participants in two focus group discussions. One focus group was made up of trained professionals working in the fields of planning, architecture and urban design. The other group comprised only un-trained lay members of the public. By separating the groups in this manner it was anticipated that the discussions would run more freely, unhampered by a need to consider the views of the other group. The aim of the research has been to identify characteristics in the design of individual buildings and their relationships with others that are valued by the public as well as those that are not perceived positively in urban streetscapes. If those that are highly valued can be encouraged through design review and those that diminish aesthetic experience can be avoided then there is a chance the control of design can have a positive affect on the visual qualities of cities.

Preferences for two individual buildings stood out. The first (fig 2) can be seen to typify the changing context of this part of the city in that it has been converted from a light industrial activity to a primarily residential use but, contrary to most other residential developments, is of a reasonably small scale. The second favourite building is that occupied by a well-known food market, Moore Wilson (fig 1). Established in the area for more than 20 years, the building has recently been renewed and expanded. The key reasons given by survey respondents for their preferences for these two buildings are the façade details and their overall shapes. Through the focus groups it was understood that these factors help both buildings create a positive relationship with the street space and that fenestration helps people relate to the activities taking place inside. The two focus groups were in agreement that because of this they were able to forge positive associational meanings for these two buildings.

Figure 1: Detail from the street facade of the Moore Wilson retail outlet, judged as one of the two best buildings in College Street by the public.

Figure 2: Residential building in College Street. This building has the highest preference rating among the public.

Although several buildings, like the two discussed above, were perceived positively, nearly half the buildings along the street are not liked by the public. The two most disliked buildings are a small, dark coloured structure between the two found to have the greatest appeal (fig 4) and a multistorey commercial building at the eastern end of College Street. Both are considered impersonal buildings. In the case of the smaller structure, the mirrored glass and dark colour contribute to this feeling. The larger building is large in relation to the street width, has very flat surfaces and finishes and at street level does not forge a relationship with the street because of its blank walls and driveway. Participants in the focus groups identified all these as reasons for the negative evaluation. Both buildings predate the current design control processes, would have been built under an administrative regime, where height was main influence on design.

There are several positive relationships between adjoining buildings along College Street. The relationship between two buildings at the western end of the street were established decades ago, when

the street was being developed around light industrial and commercial activities. Known in the survey as buildings A & B, this harmonious relationship is enhanced not only by similarities in height but also by similarities in colour and design expression. It can be seen that fenestration patterns, façade detailing and alignment between floor levels help create links between the two sites. Not far behind in this urban design category is the relationship between Moore Wilson and building ‘R’. This is an interesting result as the two are at opposite ends of the spectrum for being liked by the public. Factors that made this relationship more likable include similarity in building heights, colour and rhythm of façade articulations. These links help overcome differences created by the design approaches taken by the respective designers.

Figure 3: Building 'B', which forms a well-liked relationship with Building 'A' to its right.

Figure 4: The least liked building in College Street is also considered to have a positive relationship with the Moore Wilson building to its left.

The least liked inter-building relationship is considered to be representative of the tensions that arise as the built environment changes to accommodate the growing popularity of an area. The Trinity Apartments building was constructed in 2005 for residential purposes, riding the wave of popularity of living close to the city centre. The project amalgamated several titles and was built to 4 metres above the allowable height limit for the zone, which is 27 metres above ground. The relationship established with the single storey, vividly coloured metal workshop on the adjacent site was poorly received by respondents. Interestingly, the data suggest that the principal ‘fault’ in the poor relationship was attributed to the building that was there first. Discussions with the focus groups confirm that the poor relationship can mainly be attributed to differences in height and that differences between the building fabric of bother buildings and that the workshop activity is no longer suitable to the area also contribute to the responses.

The final scale at which perceptions of the College Street environment was examined was at the overall street. Respondents were asked to evaluate the collections of buildings along each side according to relationships between building heights, the three dimensional alignment between facades and the surface designs of the facades. Definition of these three levels or scales is based on the environmental psychology literature (Nasar 1988, Stamps 2000). The research confirms that people are generally dissatisfied with strong variations in building height within a single street. In the case of College Street, the southern side exhibits greater variation and was rated more poorly than the north. Survey respondents and focus group participants were fairly united in their views. Variations in height were suggested to be evidence of poor relationships between buildings and disruptive to aesthetic coherence. Despite – or perhaps because – the southern side of the street has witnessed more extensive redevelopment than the northern side of the street, it is perceived negatively at each of the three spatial scales.

Discussions around the merits of the Trinity Apartments (fig 5) deserve special mention, as the design of this residential building raises a number of concerns with the public. Those trained in design and planning appear to be ambivalent about the building but the survey responses suggest that the lay public is slightly positive about the design. However, in the meeting of the lay focus group, all participants made their displeasure with this building known and the issues raised became the agenda for the rest of

the session. The key issues are the overall height of the building, the poor relationship formed with the adjoin structure, the large blank side walls, projecting private balconies and large areas of glass on the street façade. Interestingly, while people consider fenestration an important contributor to the design, it was generally agreed that the areas of glass are too large for the residential activity in this setting. People are both empathetic to the way glazing can restrict privacy for the buildings' residents as well as cause their dwellings to heat during the day. While they could appreciate the need to address both concerns by drawing blinds during the day, people thought more could be done by the designers to avoid the need for this.

Figure 5: The Trinity Apartments building, in the middle, establishes a poorly regarded relationship with its neighbours. The public also dislike the large blank side wall and the private balconies projecting beyond the site and into the public street space.

DISCUSSION

Building height came out as key factor influencing people's perceptions of urban streetscapes. Surveys went some way toward identifying this and it was teased out during the two focus groups. Where height had a negative influence it was either because this led to an overbearing presence in the street, essentially creating a sense of claustrophobia amongst the respondents or that excessive variations in height often mean large, blank side walls are seen. Pronounced differences in height, usually created by the more recent intervention, were considered to be visually awkward and to suggest overdevelopment.

More than any other characteristic, height leads to tensions in development and change processes. Height tends to be controlled by area-wide prescriptions. In the urban context, height is where the landowner stands to improve profitability of the redevelopment project. The design guides do not stress the importance of height relationships between buildings or height in relation to street dimensions. Accordingly new development is prone to push to the limit. Many projects push through the limit by putting forward an argument that the additional effects of the extra height are minimal.

Bergen, Norway provides an example of how building height could be addressed in the planning/design review process to avoid such negative outcomes. The Bergen *Regulerings Plan* (Bergen Kommune

2010) allows for site-specific height controls. Allowable heights are set out in the plan and the prevailing maximum is 27 metres. However, there is also an overarching requirement for new buildings to fit closely with the context which allows planner to limit new buildings to be no more than 3 storeys above the neighbouring structure, irrespective of the stated maximum. Another restriction limiting height is the requirement for façades to have a relationship with the street width of no more than 1.1 to 1. Clearly the emphasis is on the public space surrounding the site rather than giving certainty over development potential. While the vision of the plan is a denser, more compact city, the approach seeks to maintain existing building scale relationships while encouraging incremental change.

Wellington has similar blanket allowances for building height, varying from 27 metres in Te Aro to 65 metres in the central area. The only additional factor restricting height appears to be the effect the proposed structure would have on wind patterns at street level. In most circumstances these are mitigated against though design.

Visual interest in the façade composition is a key success factor. Where the street façade is flat and visually uninteresting the public tend to evaluate the building negatively. Linking in with the matter of building height, when new developments are markedly higher than their neighbours the side walls become strongly visible to those using the street. Side walls are often kept blank for practical, economic and fire protection reasons. While the design guides seek to avoid uninteresting boundary walls the recommendations tend to focus on surface treatment and small scale modelling. Fundamentally these remain blank because of a lack of fenestration. It seems the design guides have been unable to limit creation of new, visually uninteresting side walls in College Street.

The design guides appear to be particularly effective at fostering interesting principal façade treatments. The Moore Wilson redevelopment is a case in point, as the aesthetics of the warehouse retail typology are generally not viewed positively.

Encroachment into public space by private development. Seen to be negative in spatial terms as well as to send negative messages about the building. The layperson's focus group was particularly concerned about these two factors in their evaluations of the private open spaces situated in the public street air space. When it was pointed out that other buildings, such as the one judged to be favourite amongst all of those in College Street, also have balcony projections into public space, their views did not change. The difference, as it was pointed out, is the number and extent of the encroachments. On the other hand, the professionals' focus group did not express negative reactions to the balcony extensions. The design guide is supportive of the contribution that balconies and other façade articulation can make to design outcome but does not specifically address the matter of location in relation to boundary. Encroachments are an opportunity for landowners to locate parts of their development on public land if there is a good reason why it can't be fully contained within their site or to accommodate some form of public amenity provided by the landowner, such as the verandah. Approval of encroachments is dealt with outside the statutory planning process. Interestingly, where a design outcome relies on articulations extending across into public space there is always a risk the design detail would not be allowed by the encroachments evaluation process. To avoid potentially negative outcomes there should be clear policy around why encroachments are to be allowed and linked more closely to planning regulation.

The literature reminds us that people attach meanings to buildings and other parts of the built and natural environment when forming an aesthetic response. This research confirms this, particularly through the focus group discussions where participants provided examples of positive and negative associational meanings when discussing their building preferences. Controlling or guiding design for the meanings people will attach to new developments could be fraught, given that meanings are personal, linking to a person's experience as well as to wider cultural or social constructs. Meanings also attach over time and can change over time. While links between certain design attributes and the meanings people relate to them are known the design control literature is largely silent on this issue. It may be appropriate then to undertake the necessary research to enable better understanding of how, if at all, design control could be improved by accounting for this dimension of environmental aesthetics.

CONCLUSION

This paper has discussed regulatory design control from the perspective of the public opinion. After establishing the relevance of the appearance of the public realm to the lives of individuals and to society, the paper proceeded to discuss how local government can control the design of new development proposals. Although design control has been applied in circumstances dating far back in history, it is only n the past half century that its use has become widespread. Design control is not unproblematic and several of the tensions that arise have been identified. These include tensions around freedom of expression and whose opinions are best to guide decisions around aesthetics.

The question arises: is design control an effective means by which to ensure well-liked urban streetscapes? Two studies of limited scope have been conducted around that very question. A shortcoming, if the aim of design review is to make a better built environment for all, of the studies is that neither engaged with the public. The research reported in this paper did consult with the public in an effort to gauge their opinions on the design quality of individual buildings, of relationships between building and of entire collections or streetscapes. Key factors affecting environmental aesthetic judgement include building height, visual interest and façade composition, the extent to which parts of a development encroach into public space and the meanings people associate with buildings and their details. Addressing the matter of height, it was noted that height is usually prescribed over wide areas with little regard for how this might affect individual relationships between buildings. Land value is clearly tied up with its development potential and allowable height is one of the key factors affecting value. Planning in the city of Bergen, Norway was cited to provide an alternative means for controlling building height. Finally, it was suggested that new research is necessary to understand how associational meanings can be referenced in design control processes, if at all.

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ENERGY END-USES IN NEW ZEALAND'S NON-RESIDENTIAL BUILDINGS

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ABSTRACT

The Building Energy End-use Study (BEES) was a 6-year project investigating energy and water use in non-residential (predominantly office and retail) buildings in New Zealand. This was the first time a comprehensive nationwide study focussing on these areas had been undertaken in New Zealand.

Premises were randomly selected and included a variety of sizes and activity types, from small corner dairies to large corporate offices. Likewise the buildings these premises were within were of various construction forms, sizes and age. The data collected within the study was multi-faceted and multi-disciplinary: a telephone survey was undertaken which collected energy revenue and building data simultaneously. More than one-hundred of these premises were monitored at an appliance, end-use and premise level.

One key finding was the need to classify the premises by activity type beyond simply office and retail, in order to make sense of the monitored results. This included classifications such as food-retail and general-retail, among others.

For premises with office activities, the energy was generally split into thirds: lighting, space conditioning and plug loads - which partially confirmed previous New Zealand research from the 1980s on energy use in office buildings.

It was also found that lighting electricity was particularly important for general-retail activities. Lighting electricity ranged between 10% and 55% of total premise electricity, and varied considerably in the combinations of lamp types encountered. Very similar findings were also identified for the heating and cooling systems.

The electricity attributed to commercial refrigeration was also of great significance. Commercial refrigeration was predominantly found in food-retail premises, such as supermarkets, and was 40% of the total premise electricity monitored, on average.

These results provide key baseline information for New Zealand's non-residential buildings into the future and enable businesses to identify where they are best to focus efforts for reducing energy use.

KEYWORDS:

Energy; End-Uses; Non-Residential; Commercial; Office; Retail.

1. INTRODUCTION

Understanding how energy resources are used in non-residential buildings is key to improving the energy efficiency of New Zealand's building stock. More efficient buildings will help reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) has taken the first step towards this by establishing where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

The BEES research began in 2007 and ran for six years, gathering information on energy and water use through surveying and monitoring non-residential buildings. By analysing the information it has been

possible to answer key research questions about resource use in buildings including baseline estimates on the number of buildings, the total energy-use in New Zealand, average energy use intensity and water consumption for the Auckland region.

The study employed two main methods of data collection – a high level survey of buildings and premises, and intensive monitoring of individual premises.

The high level survey initially collected data about a large number of buildings. From this, a smaller survey of premises within buildings was completed using a telephone survey, and collecting records of energy and water use and data on floor areas. The information has enabled a picture to be constructed of the total and average energy and water use in non-residential buildings, the intensity of this use and resources used by different categories of building use.

The monitoring was the most intensive data collection process used in BEES, with both energy and environmental monitoring taking place in the premises for a two-to-four week period. Occupant questionnaires and audits (including appliance, lighting, building, hot water, space conditioning and other energy sources) were also undertaken.

BEES provided a unique opportunity to explore the uses for which energy is used through the data collected by on-site monitoring. The aim of this paper is to provide an understanding of key end-uses with New Zealand's commercial retail and office buildings. It also investigates the relationship between the energy use, particularly electricity, and the activities within buildings.

2. MONITORING ELECTRICITY END-USES

Extensive monitoring of end-uses to obtain electricity data was carried out on 84 of the 843 premises that participated in the BEES study. Also, as part of the premise audits, a detailed inventory was created of the plug loads (appliances), lighting, building systems, hot water and space conditioning. This work provided data on the presence (or absence) of certain types of appliances and technologies.

The breakdown into end-uses was achieved by selecting separate circuits from the various distribution boards within each of the premises. It was found that as different premises were wired in different ways, only a broad categorisation of end-uses were possible. This meant the plug load end-use included some mixed-use circuits which, for example, may include such equipment as portable electric heaters, refrigeration and cooking units. Had this equipment been on a separate circuit they would have been assigned to a specific end-use group. The end-use category, components and descriptions are provided in Table 1.

Only 10% of the monitored premises had dedicated refrigeration circuits present while cooking circuits were present in twice as many premises. All of the monitored premises had lighting and plug load circuits, with around three-quarters having circuits for space conditioning. Water heating (64%) and miscellaneous (51%) circuits where found in more than half of the premises.

Table 1: End-Use Groupings and Example Components.

End-Use	Example Components	Description/Rule
Lighting	Lights.	Lighting.
Plug Load	Plug loads, appliance groups.	Anything that plugs into a power socket or is part of a combined fixed-wired circuit. This includes some appliances which would have been assigned to another category had they be able to be isolated. Examples of this would be plug-in refrigeration and portable electric heaters not on dedicated circuits.
Water Heating	Water Heating.	Fixed hot water units e.g. instant hot water, hot water cylinders.
Space Conditioning	HVAC, air-conditioning, air-handling unit, heat pump, heating, boiler, air-curtain, reheat.	Anything used to intentionally/directly alter the thermal environment of a space. Systems may or may not be ducted
Cooking	Cooking, stove, bakery oven, oven, pie-warmer.	Anything used to transform food through heat.
Refrigeration	Refrigeration board total, refrigeration, chiller, fridge, food cabinet.	Any commercial refrigerator or chiller which is separately hard-wired. Plug-in refrigerators/chillers will be in the "plug load" group.
Miscellaneous	PABX, server room, garage, central services, lift, UPS, ATM, timer, other.	Residual category.
Process	Screen printing dryer, x-ray, fan, mechanical, tools, compressor, industrial, pump.	Anything process or industrial oriented.

The Electricity Performance Indicator ($EnPI_{elec}$) by end-uses for each premise is shown in the Figure 1. Each premise is shown as a single circle. A random 'jitter' has been added to the horizontal position of each point so that overlapping points can be better distinguished. The end-uses are arranged in decreasing mean $EnPI_{elec}$ for each end-use which are shown by a horizontal red line. The median for each end-use is consistently less than the mean and is shown with a green line. The lighting and plug load end-uses have higher average $EnPI_{elec}$ than the other end-uses, while the $EnPI_{elec}$ for the remaining end-uses tend to reduce as the proportion of premises with that end-use reduces.

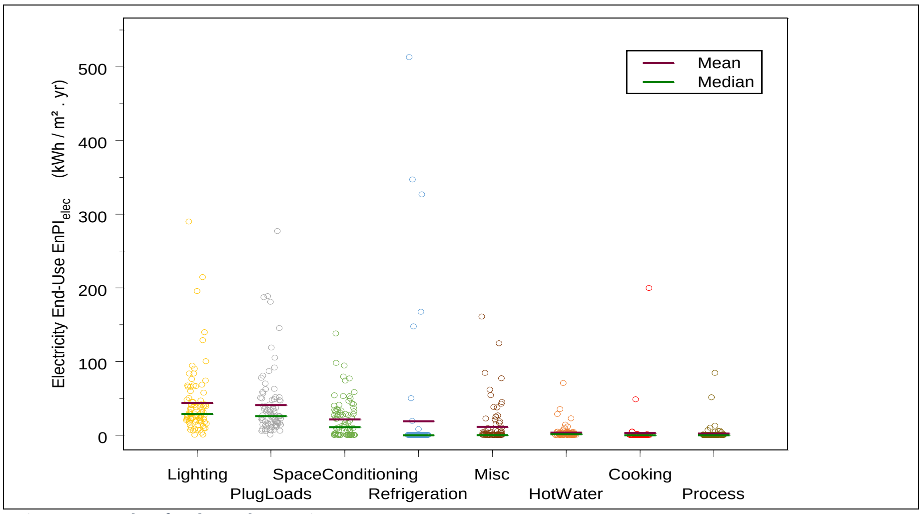

Figure 1: Dot-plot of End-Uses by Premise.

The high number of zeros for the end-uses that are not usually present, such as the refrigeration and miscellaneous end-uses, strongly effects the mean $EnPI_{elec}$ for those groups. Table 2 gives some summary statistics where only end-uses that are present are considered. The refrigeration end-use, when present, can be seen to be very large in comparison to the other end-uses.

Table 2: Summary Statistics for the End-Use Groups when Present.

End-use	Count	$EnPI_{elec}$ (kWh/m^2.yr)						
		Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum	Standard Deviation
Lighting	84	0.13	19.7	28.9	43.8	48.2	289.5	46.3
Plug Load	84	0.25	14.8	26.0	40.9	47.5	276.6	46.8
Space Conditioning	62	0.09	8.0	26.7	28.9	38.7	137.6	27.3
Refrigeration	8	7.91	42.0	157.1	197.0	331.4	512.8	181.8
Miscellaneous	43	0.01	1.6	5.0	22.3	25.6	160.5	34.5
Water Heating	54	0.11	1.5	2.5	5.5	3.8	70.3	11.1
Cooking	18	0.01	0.1	0.1	14.5	1.2	199.3	47.5
Process	20	0.00	0.1	0.8	9.2	5.6	84.1	20.9

The large differences between the means and medians for the end-uses suggest the distribution of the end-uses may be skewed. Histograms of the non-zero $EnPI_{elec}$ for each of the end-uses show that this is indeed true. The distributions had a long tail to the right indicating that a few premises have end-uses that use energy considerably more intensively and in excess of typical (median) or average (mean) usage.

3. KEY END-USES

Through the monitoring, the standard three end-uses in office buildings were confirmed as being the key energy uses. These are plug loads, lighting and space conditioning. They have notably and consistently higher $EnPI_{elec}$ and proportions, as well as a higher presence in the monitored premises.

3.1. Plug Loads

An audit list of 77 individual appliances was used to identify appliance numbers and types during a premise audit. This audit recorded everything plugged into a wall socket as an individual appliance. It excluded ducted space conditioning, large circuit-wired end-uses, domestic hot water, lighting and other central services, which were all picked up at a circuit level.

Plug loads on average, ranged between 21% and 56% of the total estimated annual electricity use indicating the dependence of activity to the amount of energy used. The more operation specific appliances, such as commercial dishwashers or food handling equipment, were less likely to be present in the premises.

The three appliances that appear in at least 90% of the audited premises were hot water, computers and space conditioning that was not wired directly to a circuit. Premises had a very high presence of desktop (85%) and laptop (52%) computers, printers (61%) and copiers (78%) and other computer related equipment. Most had limited kitchen facilities for staff use, typically with a refrigerator (88%), microwave (87%), electric jug (65%) and/or boiling water unit (64%).

Of the appliances providing plug-in heating and cooling functions, fans and heat pumps had a high presence with 63% and 61% of premises having at least one fan or heat pump. This was followed by portable electric heaters (55%). Fixed electric heaters had a low presence (16%), and were typically being replaced by heat pumps. It is interesting to note many of the older distribution boards still had labelling for fixed electric heaters, complete with timers and control gear but often these circuits were used for newly installed heat pumps, with the timers and control bypassed.

Over 220 individual appliances were monitored for a two-to-four week period. These measurements were undertaken at one-minute time intervals to allow the characteristics of fast switching to be examined in detail. Below is a dot-plot of the annual electricity use for 31 types of monitored appliances. The vertical scale is broken at 2,500 kWh/yr to show the detail of the majority of appliances while still including the four plug-in commercial refrigerator units that were using in excess of 3,000 kWh/yr.

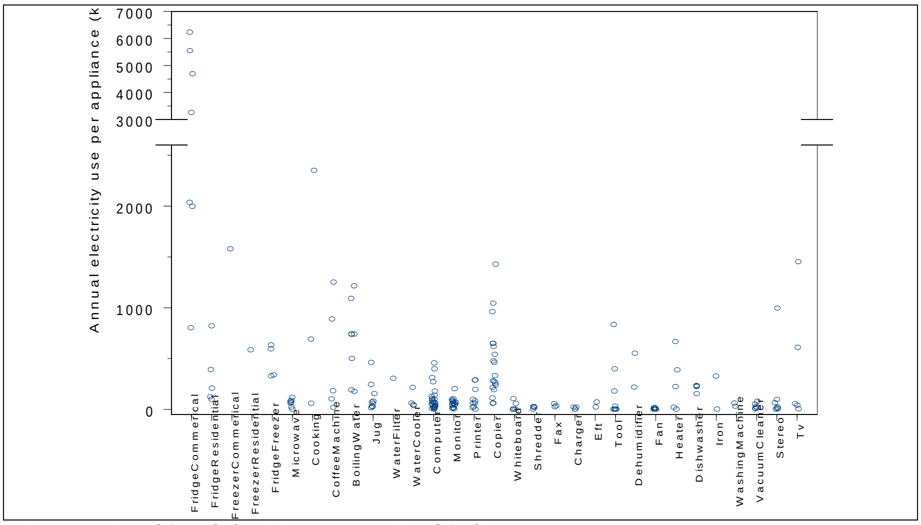

Figure 2: Estimated Annual Electricity Use per Monitored Appliance.

While many types only had a few individual appliances recorded, some had multiple recorded – office equipment in particular (computer, copier, monitor and printer). The distribution of the appliance types, like the distribution of the end-uses, shows a skewed distribution with many values significantly higher than the median.

As an example of the variability, the highest energy using computer used more than forty times the energy than the lowest energy using computer. The top three of these computers were left on outside of business hours and can be seen distinct from the rest of the computers.

3.2. Lighting

The lighting audits involved a walkthrough audit taking an inventory of all installed and operable lamps and luminaires. Information was also collected on the installed capacity, as well as the physical lighting information and monitored interior illuminance levels over the two-to-four week period. Lighting electricity ranged between 10% and 55% of the total estimated annual use.

Fluorescent lamps were dominant, found within 98% of all audited premises and an average of 227 lamps per premise. Fluorescent lamps were generally not the only lamp type found in each premise – up to six different lamp types were recorded in individual premises.

Table 3: Estimation of Lamp Stock per Premise.

Lamp Type		Premises with Lamp Type	Presence	Percent of Total Count	Average Count	Average Count per 1,000 m²	
						All Premises	Lamp Type present
F	Fluorescent	99	98%	30%	227	308.00	310.00
CFL	Compact Fluorescent	60	59%	18%	30	24.60	36.40
H	Halogen	59	58%	18%	49	39.80	53.50
I	Incandescent	52	51%	16%	6	4.23	8.93
IR	Incandescent Reflector	24	24%	7%	12	3.96	18.00
MH	Metal Halide	14	14%	4%	28	5.37	20.40
O	Other	13	13%	4%	15	2.79	15.10
IP	Incandescent PAR	4	4%	1%	12	0.41	5.74
LED	Light Emitting Diode	2	2%	1%	27	0.74	17.10

The drivers of lighting energy use are complicated with interconnected relationships between lighting electricity use and other factors including hours of use, average illuminance levels, lighting capacity and the coverage (building floor area. The importance of the relationship between these factors was examined and displayed in the table of graphs below.

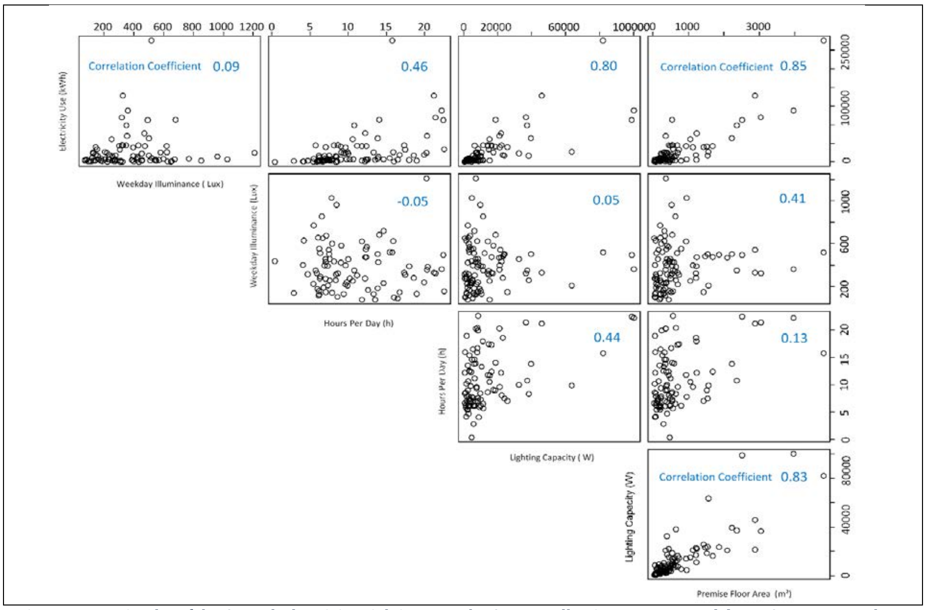

Figure 3: Matrix Plot of the Annual Electricity Lighting Use, the Average Illuminance over Weekdays 10 am – 4 pm, the estimated hours of use, the Installed Lighting Capacity, and Size of the Premise.

The strongest relationships involving the lighting energy use are the premise floor area (r = 0.85) and the total installed capacity of the lighting (r = 0.80). Including both of these variables in a linear model increases the multiple r^2 for the model from 0.74 for just the floor area to 0.76. This very small increase in predictive value shows that little is added when the lighting capacity is considered. It can be seen in Figure 3 that the total installed lighting capacity is strongly correlated with the floor area suggesting that much of the correlation of lighting energy use with lighting capacity is due to the fact that lighting capacity itself is correlated to premise floor area. Furthermore, the lighting $EnPI_{elec}$ and the lighting power density (W/m²) were less correlated with one another (r = 0.32) than the the total lighting electricity use and the lighting capacity (r = 0.85).

3.3. Space Conditioning

Not circuit-wired space conditioning appears in 90% of the monitored premises, in some cases as the primary means of heating and cooling, but is also found in premises with ducted space conditioning systems. Fans and portable heaters could be viewed as "personal" comfort appliances, and might be used either if there was no other heating or cooling system or if the main heating and/or cooling system was inadequate. Anecdotally, the presence of fans or portable heaters in a fully space conditioned building could be an indicator of comfort issues – they were often found in rooms where the occupants informally expressed their dissatisfaction.

Unsurprisingly, centralised space conditioning systems were most common in the largest buildings, with all but one of the stratum 5 buildings using this. As building size reduced, the prevalent source of heating (and often cooling) was electric heat pumps, down to the smallest buildings.

One of the most interesting results is the distribution of supplemental electric heaters and fans, which was effectively independent of building size. The maximum number of heating types was five (central space conditioning, fixed electric, portable electric, portable electric fans and portable gas heaters), found in a stratum 2 building in a small rural town. Although the proportion of premises with only a single heater system is similar across the five size strata, there is a small, but steady increase in the number of heating systems as the strata size increases, with an average of 2.15 heating systems being used across all strata.

4. NEW ZEALAND'S NON-RESIDENTIAL BUILDINGS

The New Zealand non-residential building stock is extremely diverse. Buildings were stratified by size (5 strata) and building use (3 strata), as shown in Table 4.

Overall, it is estimated that there are 41,154 BEES buildings in New Zealand. With a total floor area of 39.93 million square metres and an average floor area per building of 970 m^2.

Table 4: BEES Estimate of Count and Area of Commercial Office and Commercial Retail Buildings by Size Strata.

Size Stratum	Commercial Office		Commercial Retail		Other BEES*		TOTAL	
	Area (10^6 m^2)	Count	Area (10^6 m^2)	Count	Area (10^6 m^2)	Count	Area (10^6 m^2)	Count
S1: 0 – 649 m^2	1.31	4,022	4.31	15,300	2.61	8,287	8.23	27,609
S2: 650 – 1,499 m^2	1.35	1,404	2.52	2,668	3.79	3,936	7.65	8,007
S3: 1,500 – 3,499 m^2	1.75	790	2.32	1,035	3.72	1,719	7.79	3,544
S4: 3,500 – 8,999 m^2	1.85	339	1.71	339	4.19	817	7.76	1,496
S5: 9,000 m^2 +	2.34	137	2.04	111	4.10	250	8.49	499
Total	**8.61**	**6,692**	**12.91**	**19,453**	**18.42**	**15,009**	**39.93**	**41,154**

**Comprises Industrial Service, Industrial Warehouse and Commercial Mixed Buildings Valuation Codes.*

Of the 6,692 commercial office buildings, the average commercial office building has a gross floor area of 1,287 m^2. It is estimated sixty percent (4,022) of the office buildings have a floor area less than 650m^2 while 137 have a floor area greater than 9,000m^2.

Across all BEES buildings, the total electricity use was estimated to be 6,370 GWh/yr. Total gas use was estimated to be 1,130 GWh/yr. Figure 4 and Figure 5 indicate the BEES sample showed an increasing $EnPI_{elec}$ with increasing floor area. It is expected this increase is due to the increased level of services provided as building size increases. However, the pattern raises some interesting questions for future research.

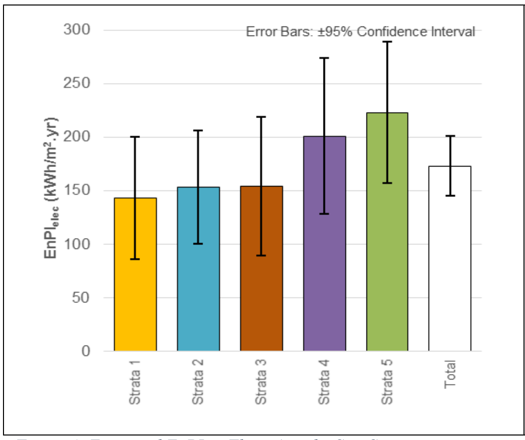

Figure 4: Estimated EnPI$_{elec}$ Floor Area by Size Strata.

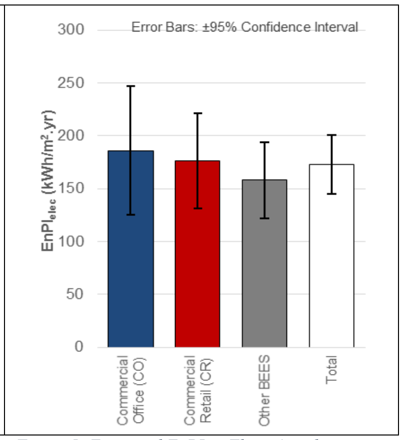

Figure 5: Estimated EnPI$_{elec}$ Floor Area by Building Use Strata.

Figure 4 and Figure 5 provide the breakdown for electricity use (EnPI$_{elec}$) by both the building size strata and building use strata. It shows a likely increase in EnPI$_{elec}$ as the building size increases, however the error bars show the large variability. This means the perceived trend is non-confirmatory. There is even less distinction between the building use strata.

As the energy monitoring was undertaken at a premise level only, Figure 6 and Figure 7 use individual premise electricity data, by building use strata and building size strata for their containing buildings.

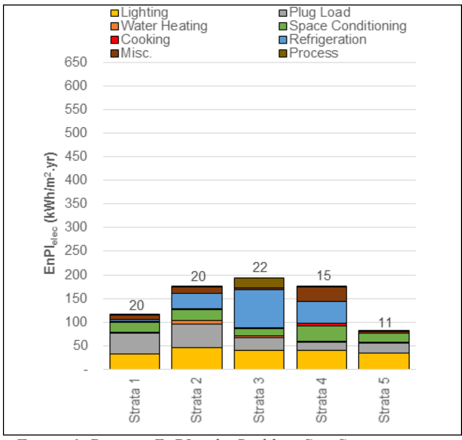

Figure 6: Premise EnPI$_{elec}$ by Building Size Strata.

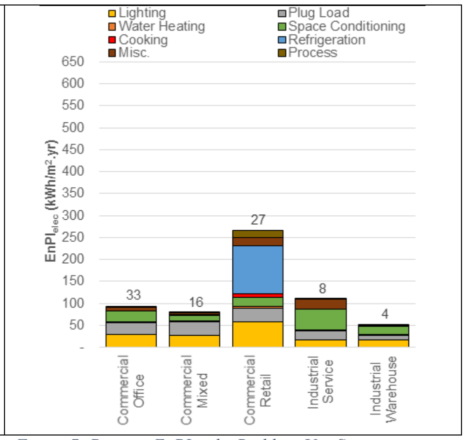

Figure 7: Premise EnPI$_{elec}$ by Building Use Strata.

Interestingly, the majority of refrigeration loads fall within premises in Commercial Retail buildings, with a very small amount also in Commercial Mixed buildings. The premises within the Commercial Office category seem to follow the one-third rule.

Figure 6 and Figure 7 show a wide spread of end-uses across all size strata. Premises within the smaller and larger building size strata appear to be using less electricity per unit area, primarily due to the absence of refrigeration.

It is clear that the building use strata and building size strata are inadequate as a basis for understanding energy consumption – information is also required on the activities being carried out within the premises.

5. PREMISES WITHIN NON-RESIDENTIAL BUILDINGS

The premises within these BEES buildings added another level of complexity. With not all premises within a building being of the same occupied use, e.g. a commercial office building may contain one or more retail premises. The premises were therefore via analysed a number of methods to aid in determining any natural activity groupings. Analysis of different premise activity classifications demonstrated that floor area is not as useful as classifications that discriminate electricity end-uses and activities, such as the Classification of Premise Activity, described below.

Table 5: Classification of Premise Activity Description

Code	Activity	Activity Description	Key Energy Uses
OFF	Office	General office activities with designated workstations and sedentary work.	Office equipment, lighting, space conditioning.
MIX	Multiple	Multiple premise activities.	Unable to be separated.
GEN	General Retail	Retail pre-made products ready for sale (no processing).	Focussed/display lighting, space conditioning.
BOX	Big Box Retail	As per GEN but more warehouse base.	Flood lighting.
HOT	Food Preparation & Cooking	Typically heats, cooks or bakes food.	Cooking, lighting.
ICE	Food Storage	Typically stores food without any major HOT activities.	Refrigeration, lighting.
CSV	Commercial Service	Generally provides commercial services.	Process, lighting, space conditioning.
ISV	Industrial Service	Garage/warehouse type service, intensive processing/manufacturing.	Process, lighting.

Of the BEES participant premises within buildings categorised as Commercial Office buildings, their premise activities were predominantly Offices (83%), using the classification of premise activities system. The remaining were split between Commercial Service, General Retail, Food Preparation & Cooking, Big Box Retail and Food Storage. This however, does not take into account those premises not participating in the BEES programme. This clearly shows the difficulty of labelling buildings with a typology such as office building when the activities carried out within often drive the energy usage and intensity through end-uses.

Figure 8 and Figure 9 provide a comparison of the monitored electricity by end-use against the premise activity classifications. Figure 8 provides an $EnPI_{elec}$ comparison while Figure 9 gives the proportions of electricity consumption for each end-use. The numeric values at the top of each column represent the number of monitored premises falling into that categorisation. In a few cases this is a very small number.

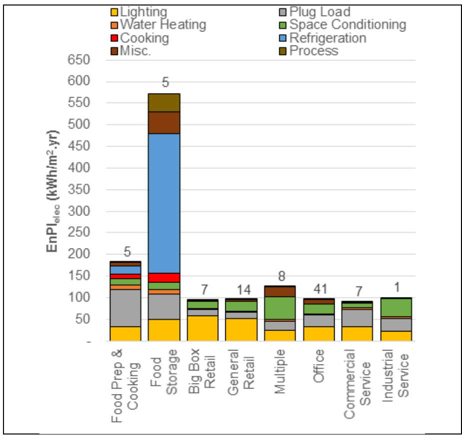

Figure 8: Premise EnPI$_{elec}$ by Classification of Premise Activity.

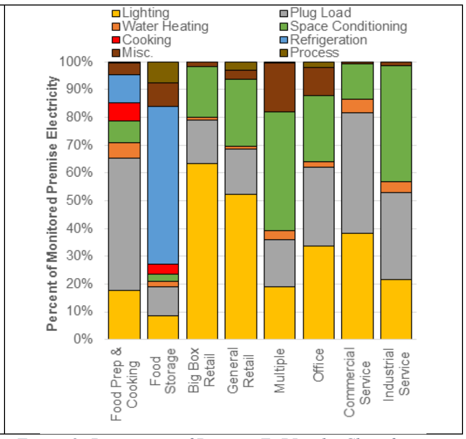

Figure 9: Percentage of Premise EnPI$_{elec}$ by Classification of Premise Activity.

Of interest is the large difference in overall electricity consumption and the proportion of refrigeration load in the Food Storage category compared to the other activities. The Food Preparation & Cooking category also has a noticeable refrigeration EnPI$_{elec}$.

Figure 8 and Figure 9 show that the one-thirds rule is somewhat appropriate in non-food premises (further analysis shows that those with a very small premise floor area do not present the same findings). However, in the Food Preparation & Cooking and Food Storage premises the presence of refrigeration and cooking end-uses significantly impact on the overall electricity usage per square metre, demonstrating the need for these two categories to be considered independently for patterns of electricity, and/or individual end-use consumption.

The Food Preparation & Cooking and Food Storage premises appear to have a high proportion of plug loads, as opposed to cooking. This may be due to the number of cooking end-uses which are not circuit-wired (i.e. temporarily plugged in through a wall socket), and therefore would fall into the plug load end-use. The plug loads in the Big Box Retail and General Retail premises do not appear to be large and generally would only include a small number of components. The Commercial Service, Multiple Uses and Office premises appear to have a higher plug load, all having it account for approximately one-third of the electricity use.

Lighting appears to be very important in the General Retail and Big Box Retail premises, which display a higher proportion of lighting. Within the Food Preparation & Cooking and Food Storage premises, lighting seems somewhat unimportant as a focal point for improving resource efficiency. In the remaining Office and Multiple Use premises, lighting is approximately one-third of the monitored electricity consumption. Further lighting investigation is shown below.

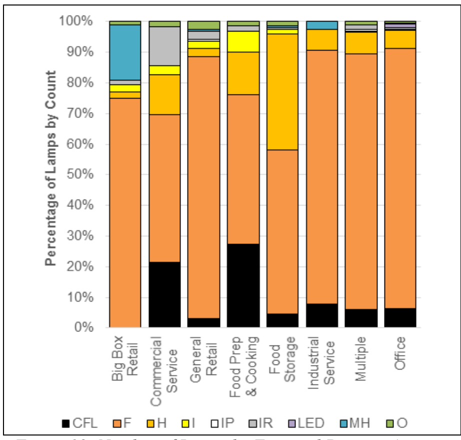

Figure 10: Number of Lamps by Type and Premise Activity.

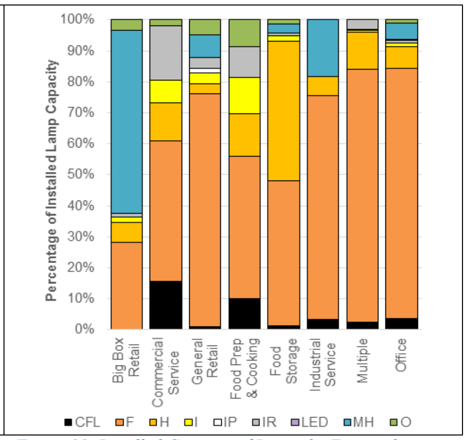

Figure 11: Installed Capacity of Lamps by Type and Premise Activity.

This shows by in large that fluorescent lamp types are dominant, both by count and by installed capacity, across all premise activities. What is interesting is the contrast between the count and the installed capacity in the Big Box Retail and Industrial Service premises, with metal halide lamps demonstrating a more significant electricity impact, and CFL having a less significant electricity impact. Most other activities appear more similar to one another.

Premise level space conditioning appears to be the most prevalent in the Office and Multiple Use premises and a smaller portion in the General Retail premises, and the $EnPI_{elec}$ does not necessarily increase with premise or building floor area. Based on the monitoring results space conditioning is largely absent from the Food Preparation & Cooking and Food Storage premises. A possible reason for this may be that a portion of the space conditioning end-use was included on the refrigeration circuits.

Three of the monitored Food Storage premises are supermarkets, displaying very intense refrigeration use, and fall within large or medium size buildings. Refrigeration does not appear in any other premise activity, other than in Food Preparation & Cooking premises. Cooking end-use is also a distinguishing factor in these categories, which only appears in the Food Preparation & Cooking and Food Storage premises. It is noted that refrigeration and cooking end-uses may be present in most premises, but are only used for employee's personal use as opposed to business operational purposes.

The miscellaneous and process end-uses are quite widely spread over all activities, while water heating is generally very consistent, but is very small in contrast to the other end-uses. This however, may be due to some building's reticulation systems having central water heating plant, which may not necessarily be identified within the premise level monitoring and walkthrough audits.

The different premise activities demonstrate that analysis based solely on floor area is not as useful as classifications that discriminate electricity end-uses and specific premise activities.

6. CONCLUSION

Early New Zealand research into energy use in non-residential buildings suggested that the end-use energy profile was equally split between space conditioning, lighting and computing appliances (Baird & Newsam, 1986). BEES both confirms the importance of that trio of end-uses, but also found that in many premises, and consequently in many buildings, different end-use patterns exist.

There was a significant variation in energy end-uses across buildings. This strongly impacted the buildings overall energy use, which was influenced by the nature of the activities within the buildings.

A clear message found throughout the BEES research was the need to investigate by premise as opposed to building use, to determine homogenous groups, particularly in the commercial retail and mixed use categories.

It is able to be concluded that lighting is very important across most activities, but especially in retail. Refrigeration dominates the electricity end-use in the Food Storage premise, and to an extent in the Food Preparation & Cooking premises, while it is evident in a few of the premises.

High commercial refrigeration means a large portion of energy use and is therefore more energy dependent. It is not significantly important for most buildings, but for those that do have it refrigeration is very important.

The results of the BEES programme offer a new insight into the stock, operation and management of New Zealand's non-residential buildings. If one word could be used to describe the new knowledge from this research it would be 'diverse'. This diversity has made BEES a far more complex research programme than was envisaged at its start in 2007. The lessons learnt from this will provide a strong base for future policy, energy management, standards, design tools and research around New Zealand's non-residential building stock.

ACKNOWLEDGEMENTS

The work here was jointly funded by BRANZ from the Building Research Levy, the Ministry of Business Innovation and Employment (MBIE) from the Public Good Science Fund and Infrastructure and Market Resources, and the Energy Efficiency and Conservation Authority (EECA).

There have been numerous people who have provided support throughout the project. Their advice, time and contribution have much been appreciated and have strengthened the research and results created.

The BEES work has also been supported by a formal research collaboration agreement between BRANZ, the Centre for Building Performance Research at Victoria University of Wellington and The Bartlett Faculty of the Built Environment at University College London.

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BRANZ HOUSE CONDITION SURVEY

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ABSTRACT

The BRANZ House Condition Surveys have been carried out every five years since 1994 and provide snapshots of New Zealand's housing stock at different points in time. Previous surveys were centred on the three main centres in Auckland, Wellington and Christchurch. The 2010 House Condition Survey (HCS) was the first nationwide survey, and also the first to include a representative selection of rentals properties, which make up approximately 33% of the New Zealand's total housing stock. The next BRANZ House Condition Survey is scheduled to begin in early 2015.

Approximately 500 standalone, townhouse or terraced houses / units were inspected throughout New Zealand, and interviews were completed with each occupant concerning their family circumstances and maintenance practices. BRANZ has recently carried out an in-depth analysis of the results to study any differences in condition between rental and owner occupied houses in the survey.

A subjective overall condition assessment was made for each dwelling by assessors, and was based on a three point scale. Assessors gave more importance to critical components that may have more serious long-term effects, such as a leaking roof, than components which will not have detrimental effects to the structure if left as they are; for example a broken kitchen bench.

The survey found that generally rental houses were in worse condition overall than owner-occupied houses, and had a higher incidence of components in poor or serious condition.

KEYWORDS:

Building Condition; Rental Stock; Maintenance.

INTRODUCTION

The BRANZ House Condition Surveys (HCS) provide "snapshots" of New Zealand's housing stock at different points in time. This has been done by investigating a group of houses and their occupants that broadly represent the underlying range of designs, ages and varying conditions of New Zealand houses. As more surveys are completed, and trends and problems identified, a reliable information base is established on which to make comparisons.

Previous surveys were carried out in 1994, 1999 and 2005 and were carried out on predominantly owner-occupied houses in Auckland, Wellington and Christchurch. The 2010 HCS was the first that was nationwide and included rental properties.

Four hundred and ninety one houses were inspected and occupant interviews were completed concerning their family circumstances and maintenance practices. This 'matched' sample, where the property had been inspected and the occupants interviewed, included one hundred and eight rented houses. All properties in the HCS were standalone houses or units. For the purposes of the survey, the term 'house', includes townhouses and terrace houses, and excludes apartments and flats. As such, 'houses' had a maximum of two common walls, allowing the inclusion of terrace housing, but in the most part **exclude** flats and apartments. It was required that each property had no units above or

below it, and that there was fire separation from other units if adjoined, thereby constituting an independent dwelling.

Telephone surveying

As for past HCS potential participants were called by a telephone research company, and asked to answer a short questionnaire on the maintenance of their home and if they would allow BRANZ to complete a physical inspection of their property. The survey was altered slightly for the rental houses to acknowledge the responsibility of the landlord rather than the tenant for the maintenance of the house.

From the samples returned from telephone surveying, approximately 540 householders agreed at the time to both participate in the telephone survey and allow the physical inspection of their house.

PROPERTY SELECTION PROTOCOL

Owner Occupied Properties

The owner occupied properties were sourced from two groups. The five main centres (Auckland, Wellington, Christchurch, Hamilton and Dunedin) were the first group, stratified by city, and could be surveyed with a simple random sample in each stratum. The rest of the country was put into another group, to be surveyed using a cluster sample based on area unit.

Cities

For the cities, properties were randomly selected, for example 35 properties were to be in Manukau City. The area unit, physical/postal address, owner name and age of each property were obtained for each property in each city. Then for each of the chosen properties, six more properties within the same area unit and property age were selected to be available as substitutes in case of refusals.

Clusters

Sixty-nine area units were randomly selected. Four properties for each area unit were then randomly selected. Again six substitute properties for each property were also sourced.

The locations of the clusters are shown in Figure 1.

Figure 1: Intended survey locations – selected cities in orange, clusters in yellow

The occupants of each these property were sent a letter requesting their cooperation with the HCS study. Local papers were also given a press release to coincide with the mail-out.

Rental properties

A modification to the sampling method was necessary for rentals, as approximately 2% of the houses recruited under the initial methods were rentals – far lower than could be expected. With the discovery of the bias toward owner occupation, analysis was performed to find out what was required to rebalance the sample. Subsequent analysis has shown that the one hundred and eight rented houses surveyed is an adequate number to incorporate rentals within a 95% confidence interval.

Rented households were recruited by telephone survey through the random selection of phone numbers in required area units and strata. This was for a number of reasons including statistical integrity and simplicity of recruitment. Due to the random selection and cold-calling, there was no longer a requirement for landlords and property agents to be involved. However, tenants were not provided with any information on the condition of the houses, and where a serious problem was found, a call was made directly to the landlord.

Canterbury Earthquakes

Difficulty in maintaining the statistical integrity of the sample after the Canterbury earthquakes led to the removal of Christchurch houses. Surveyors were working in Christchurch on 4th September, and moved onto other areas in the South Island. The second, more destructive earthquake on 22nd February meant it would not be possible to collect data from the required number of houses. The data from the 15 houses surveyed prior to the earthquakes was not used in the analysis. The sample was adjusted to enable a similar accuracy to the original design to be achieved (Jowett, 2011).

SURVEYOR TRAINING

This was the first HCS where a standardised training programme was undertaken by all surveyors involved in the physical surveying of the recruited houses. In previous surveys qualified assessors were contracted to do the inspections and fill out the standardised form according to their own experience and knowledge. By training assessors as a group, the programme aimed to achieve higher consistency between the surveyors, particularly as more surveyor were involved.

The experienced surveyors were responsible for implementing a training programme for additional surveyors. This initially involved six surveyors, and three of the six were selected to proceed with the surveys. Along with physical inspection techniques, surveyors were trained to use digital pen technology, which allowed forms to be sent back in digital format while surveyors were still in the field. Surveyors were also trained in the use of geotagging digital cameras, which tagged photos to the location where they were taken.

FINDINGS

Overall Condition

A subjective overall condition assessment was made for each dwelling by assessors, and was based on a three point scale. Assessors may give more importance to critical components that may have more serious long-term effects, such as a leaking roof, than components which will not have detrimental effects to the structure if left as they are; for example a broken kitchen bench.

The assessed condition of owner occupied houses was higher than that of rented houses. As seen in Figure 2, owner occupied houses were nearly twice as likely to be in good condition as rented houses. Nearly twice as many rented houses than owner occupied houses were in poor condition.

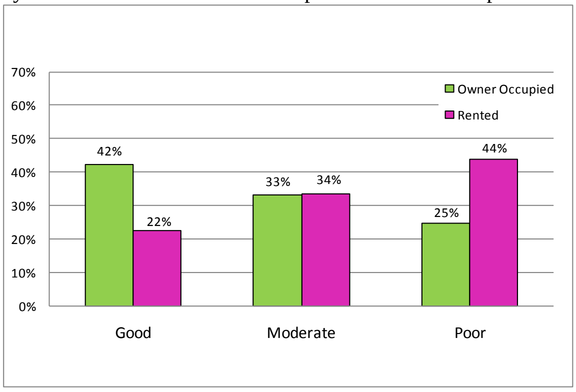

Figure 2: The assessed overall condition of houses in the 2010 HCS by tenure

Occupant Perceived Condition

There is a disparity between the actual condition of the house, and the occupant-perceived condition, as shown in Figure . For both the rental and owner-occupied properties, the householder perceived the condition of the property to be significantly better than the BRANZ assessors.

Owner-occupiers tend to be overly optimistic about the condition of their homes – over 70% believe that their home is in good or excellent condition when BRANZ assessors put only 42% into this category. This disparity between perception and assessment may be influenced by a primary focus on cosmetic appearance, which aligns with the condition of the interior tending to be slightly higher than the exterior, with less visible things considered to be of lower importance or not considered at all

In the case of the rental properties, approximately 80% of the occupants considered the property to be in good condition and only 2% believing their home to be in poor condition. This is a remarkable contrast to the assessments made by the BRANZ surveyors, who considered that only 22% of rental properties were in good condition and 44% in poor condition. This suggests that renting households:

- Are more optimistic about the condition of the home they are residing in
- Have lower expectations surrounding the condition of the home
- Are less critical about the state of the home than owner-occupiers, potentially because the upkeep of the home is not the tenant’s responsibility.
- Have higher tolerance for poor conditions, or accept lesser conditions as ‘the norm’

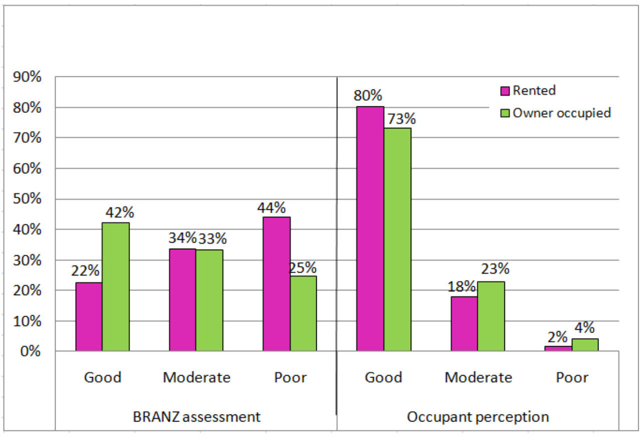

Figure 3: Occupant perceived condition versus BRANZ assessed condition

Condition Ratings

This condition ratings section is based on ratings for components, rather than the broad dwelling assessment presented above. These ratings are based on a five point scale, as shown below in Table 1.

Table 1: HCS condition rating scale

CONDITION	Description	Rating
SERIOUS	Health & safety implications, needs immediate attention.	1
POOR	Needs attentions shortly - within the next three months	2
MODERATE	Will need attention within the next two years	3
GOOD	Very few defects - near new condition	4
EXCELLENT	No defects - as new condition	5

Exterior Components Needing Immediate Attention

More rentals had exterior and envelope components that needed immediate attention than owner occupied houses. Gutters, windows and floor were far more likely to require immediate attention in rentals than in owner occupied houses.

However, owner occupied houses were more than twice as likely to have blocked subfloor vents needing immediate attention than rentals. This is probably a result of more extensive planting and site development for owner occupied properties.

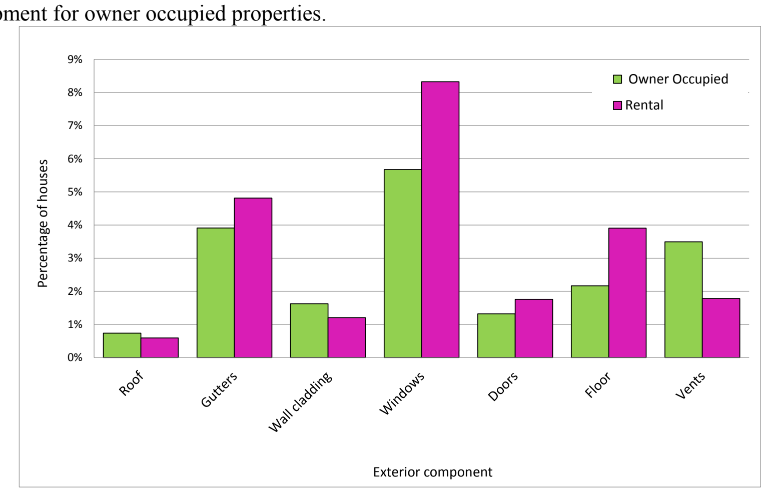

Figure 4: Exterior and envelope components in serious condition

Exterior Components Needing Attention Shortly

Unsurprisingly, properties of both tenures had a higher incidence of components needing attention in the short term, rather than immediately. Roofs, windows and doors of rental properties were more likely to be in need of repair in the near future than in owner occupied houses.

As before, owner occupied houses were more likely to have blocked subfloor vents needing attention than rentals.

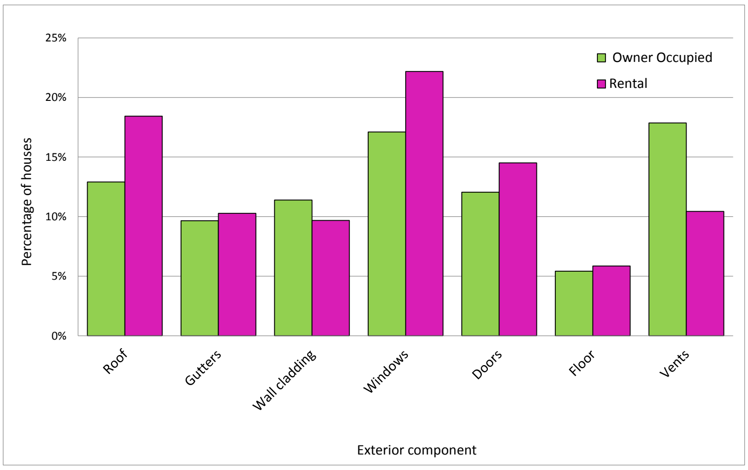

Figure 5: Exterior and envelope components in poor condition

Interior Components Needing Immediate Attention

More rentals had linings that needed immediate attention than owner occupied houses. Internal doors were also far more likely to require immediate attention in rentals than in owner occupied homes.

However, owner occupied houses were more likely to have kitchen fittings and linings in need of immediate repair. That said, the survey implies that there are a significant number of cookers in rental properties needing immediate attention. The survey also showed that cookers were more likely to be dangerously sited in rental properties.

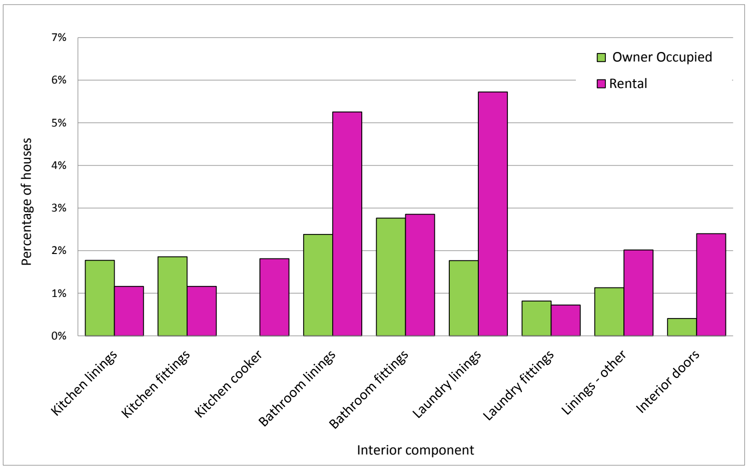

Figure 6: Interior components in serious condition

Interior Components Needing Attention Shortly

Predictably, properties of both tenures had a higher incidence of interior components needing attention in the short term, rather than immediately. Rental properties had far more interior components in poor condition as demonstrated in Figure 7.

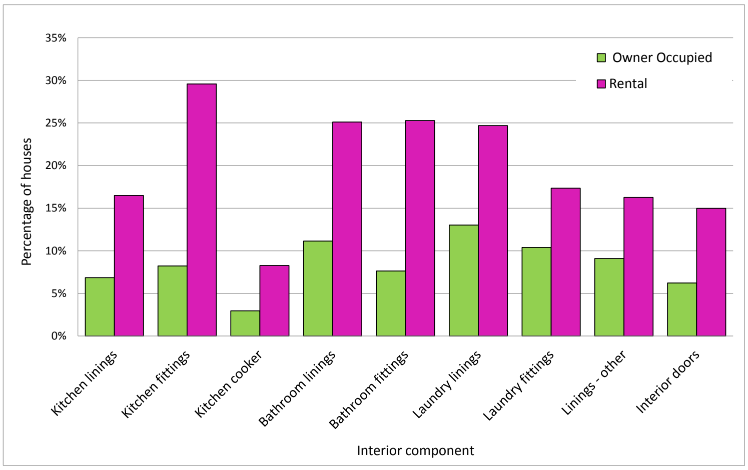

Figure 7: Interior components in poor condition

CONCLUSION

A clear disparity between the actual condition of the house and the occupant-perceived condition was found during the BRANZ House Condition Survey (see Figure 3). For both rental and owner-occupied properties, the householder perceived the condition of the property to be significantly better than the BRANZ assessors did.

Owner-occupiers tend to be overly optimistic about the condition of their homes. Over 70% believe their home is in good or excellent condition while BRANZ assessors put 42% into this category. This disparity may be influenced by a focus on cosmetic appearance, which aligns with the overall survey finding that the condition of the interior of owned properties tended to be slightly higher than the exterior – less visible areas are considered to be less important.

In rental properties, approximately 80% of occupants considered the property to be in good condition, and only 2% believed their home to be in poor condition. This is a remarkable contrast to the BRANZ surveyors, who considered that only 22% of rental properties were in good condition and 44% in poor condition. This suggests renting households are more optimistic about the condition of the home they are in and have lower expectations of the condition of the home, particularly as the upkeep of the home is usually not the tenant's responsibility.

Meanwhile, the analysis completed here suggests that there are few gross differences between the condition of the exteriors of owned and rented properties. However, this analysis does highlight that rented properties are much more likely to have interior areas in need of maintenance, a fact that it appears most tenants are willing to ignore.

The BRANZ House Condition Survey series demonstrates that the New Zealand housing stock requires a significant amount of maintenance to return properties to average condition. This paper exemplifies that this lack of maintenance is likely to be the result of occupants being overly optimistic about the condition of their homes. The analysis completed here shows that this optimism is not dulled by the more obvious interior areas, particularly those of rental properties, being in poor condition. Overall, it appears that occupants are not able to realistically assess the condition of their properties and so fail to ensure that their dwellings are adequately maintained. It will be interesting to see if this trend continues into the next BRANZ House Condition Survey, scheduled to begin in early 2015.

ACKNOWLEDGEMENTS

This work was jointly funded by the Building Research Levy and the Ministry of Business, Innovation and Employment (MBIE). The Centre for Research Evaluation and Social Assessment (CRESA) undertook the social survey of homeowners on BRANZ Ltd's behalf, and John Jowett provided statistical analysis for the project. The work of the Brendan White, Sheng Huei Huang, Desiree Pickering, and the surveyors who worked on the project is gratefully acknowledged.
BRANZ Ltd is very grateful to the many homeowners who allowed access to inspect their houses. Without their assistance this survey would not have been possible.

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A PRODUCTION MODEL FOR CONSTRUCTION: A THEORETICAL FRAMEWORK

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ABSTRACT

The building construction industry faces challenges as increasingly more complex projects, declining project backlogs, economic uncertainty, and increasing competition. Furthermore, the construction industry has no history of application of mathematical approaches to model and manage production. In essence, the sector relies on practices based on intuition and experience lacking the required level of attention to handle uncertainty and complexity. Mathematical models have enabled a comprehensive understanding of production mechanisms. For example, manufacturing industry has a track record of success in developing and using robust mathematical models to manage production. However, manufacturing modeling approaches cannot be applied directly into the construction. Steady state conditions, nonterminating events, long production runs, minimum levels of uncertainty, and permanent production facilities characterize production in manufacturing. In contrast, production in construction takes place under unsteady state conditions, with terminating events, short production runs, and different levels of uncertainty, all conducted in temporary production facilities. There has been little research in construction to understand the fundamental mechanisms of its production. This research develops an in-depth literature review to examine the existing knowledge about production models and their characteristics in order to establish a foundation for the production model in construction. As a result, a theoretical framework is proposed which will be instrumental in the further development of mathematical production model aimed to predict the performance and production behavior of construction projects.

KEYWORDS:

Production model; system model; lean construction; process control; building construction;

INTRODUCTION

The building construction industry faces challenges such as increasingly more complex projects, declining project backlogs, economic uncertainty, and increasing competition. Additionally, building construction often occupies the bottom of industrial productivity rank reports worldwide, even showing negative productivity rates. In fact, the building construction industry has no history of application of mathematical approaches to model and manage production. The sector relies on practices based on intuition and experience lacking the required level of attention to handle uncertainty and complexity. In its best, the building construction industry utilizes ordinary project management practices and frameworks limited on assess the consequences of deviations rather than the causes inside the production system. Ultimately, construction demands a mathematical explanation of its production system. Mathematical models have enabled a comprehensive understanding of production mechanisms. For instance, manufacturing has a track record of success in developing and using robust mathematical models towards productivity increase, system comprehension and event forecasts. Nevertheless, the manufacturing model does not directly apply to construction. Steady state conditions, nonterminating events, long production runs, medium to low levels of uncertainty, and permanent production facilities characterize production in manufacturing. In contrast, production in construction takes place under unsteady state conditions, with terminating events, short production runs, and high levels of uncertainty, all conducted in temporary production facilities. However, both manufacturing and construction may share similar characteristics that deserve further investigation.

Since the introduction of Toyota Production System (TPM), production paradigms shifted in the manufacturing industry. High variety product in a small quantity, a restricted market demand inflicted by the results of World War II pushed the Japanese industry to reevaluate the use of resources and production methods. Based on observations of Taiichi Ohno and Shigeo Shingo and driven by the goal of catch up with American automotive industry, the production philosophy called Just In Time (JIT) jointly with automatization, established the foundations of TPM. Constituted in 1945, TPM only

received significant exposure in the autumn of 1973, when the improvements brought by the relentless elimination of waste helped Toyota across the Japanese economic crises (Ohno, 1988).

In an attempt to reproduce the success achieved by Toyota, the industry understood, generalized, and adopted TPM, translating it into a manufacturing philosophy, later entitled "Lean Manufacturing" (Womack et al., 1991). While lean principles were extrapolating the boundaries of manufacturing, permeating production and even reaching business models (Womack and Jones, 2003), mathematical explanations of manufacturing production emerged. Studies about queueing systems (Duenyas and Hopp, 1990), lead time reduction (Hopp et al., 1990), machine maintenance (Hopp and Wu, 1990), Kanban (Spearman et al., 1990), inventories (Simon and Hopp, 1991) and finally an overall mathematical explanation to the science of manufacturing (Hopp and Spearman, 1996) quantitatively defined the behavior of production practices.

While construction industry was understanding and adapting the lean principles, waste eradication, flow, value, value-stream and zero-defect representing JIT, their implementation was problematic. Excessive consumption of raw material, disconnection of activities unable to create a minimum flow, focus on costs over the value, inefficient measurement system, and high levels of rework due to production errors and specification changes commonly composed the construction industry environment. Not to mention construction seems to left behind one pillar of TPM. Moreover, machine automation is barely implemented, restricted to isolated activities, and mostly used as an information tool in the design phase while completely forgetting the human-automation element (Koskela, 1992, 2000).

Despite the actual production model barriers, construction slowly progresses towards the achievements of the benefits of the incorporation of TPM practices (Koskela, 1992). As a matter of fact, mathematical approaches toward the explanation of production phenomena in construction, similarly to the accomplishments of manufacturing (refer to Factory Physics Foundation of Manufacturing Management by Hopp and Spearman, 1996) successfully have comprehend of effects of variability and the influence of buffers on sequencing tasks or trades (Alarcon and Ashley, 1999, Tommelein et al., 1999). Albeit, researchers consistently advance on the design and management of work-in-progress buffers, the results still are theoretical and restrictedly applied (Gonzalez et al., 2013).

A number of studies have been carried out on the understanding of the fundamental mechanisms of production in projects, mostly in the building construction industry. Notwithstanding, the current knowledge is at a rudimentary stage to describe the foundations for a production model in projects. Projects are known for features as uniqueness, temporality, uncertainty, and complexity, as a result characteristics that create barriers to modeling approaches. Therefore, projects hold similar attributes and constraints that can be explored. The challenge is to produce mathematical expressions to explain and quantitatively compare different projects.

There has been little research in construction to understand the fundamental mechanisms of its production. This research develops an in-depth literature review to examine the existing knowledge about production models and their characteristics in order to establish a foundation for the production model in construction. As a result, a theoretical framework is proposed which may serve as a basis to further development of mathematical production model aimed to predict the performance and production behavior of projects.

A BRIEF UNDERSTANDING OF CONSTRUCTION

The definition of construction extrapolates technical characteristics. It is not only civil engineering abstracting to a broader understanding of building, putting up, setting up, establishment and assembly. Construction is the materialization of a concept through design into the project product utilizing specialized labor. Furthermore, this approach excludes prototyping as the final product. Because prototype objectives to test a process or concept on real situations providing information about what works and what needs improvement to a future final product. The project product is final and definitive, meant to usability in its first build attempt as designed, in contrast of prototypes. Therefore, project's scope may include prototyping, as in design phase. Finally, this research identifies as building construction products: roads, bridges, tunnels, house building, oil-well construction and so

forth, in summary project deliverables with technical backlog related to architecture and civil engineering despite field of application.

Figure 1 displays the organization of several project driven approaches in four compiled stages and key characteristics. The initial stage consists of a group of process to identify feasible solutions to achieve sponsor's strategic business goal (Feasibility). After, the project and technical team dismembers the solution in design specifications and plans related to how made the project product (Design). The next step is following the instructions from the previous stage to build the product (Construction). Final step is handling the completed product to operation user that collects the benefits of business goal (Operation). Possible categories of inputs on the construction system are material, tools, equipment, labor, management, time, and conditions; product, material, management may be part of the output (Bernold, 1989).

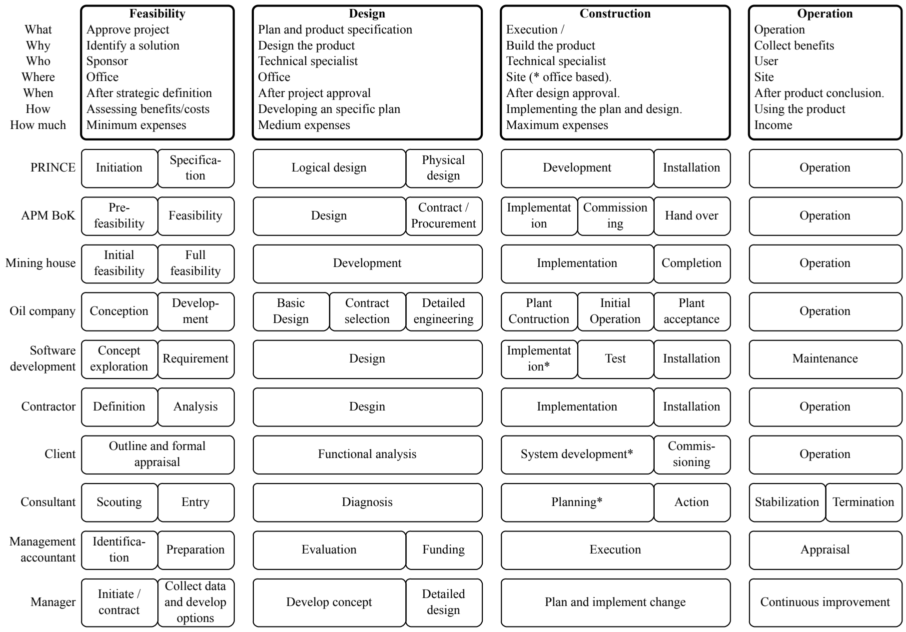

Figure 1 - Characteristics of project stages (project stages on various approaches adapted from Smith et al., 2006, p.16, originally from S. McGetrick The Project Life Cycle, PROJECT, June 1996)

PRODUCTION FACILITIES

Project takes place in different locations, frequently related to where are the main phase stakeholder. Originating from a strategic demand, feasibility studies take place where the sponsor locates. Product design requires a forte technical knowledge usually not sponsor's metier. Henceforth, include a third party company may be necessary to collect all requirements, plan and design a product to execution. The design stage tends to move to third party offices with regular interaction with the sponsor. Similar reasoning is valid for the construction stage, except the location. The place where construction takes place is distinctively important because this stage gathers nearly all resources and labor needed for building the project product as designed and planned. This resource convergence is responsible for the most part of expenditure in the project and unfolds any faults and inaccuracy of foregoing project stages. Once the artifact had been completed it is delivered to the customer, and then subsequently handled to the final user.

Construction's on-site production implicates on problematic logistics. Different from manufacturing, where the choice of factory location fulfills strategical logistic goals of product distribution and supplier connection construction solely depends on where the user needs the finished product to be. "The delivery is to a temporary location, without permanent facilities for handling material" (Koskela,

2000, p.192). The provisional feature complicates the employment of optimal delivery routes and connection to preferred suppliers, moreover hindering the formation of an efficient supply chain.

Spacial location may severely interfere on the supply chain. Depending on the construction site localization, several non technical restrictions may apply. For instance, building a skyscraper in the city centre may request obeying to municipal timetable restrictions for load moving, material delivering and dispatching, also stand in need of additional safety procedures due to population proximity (Borg et al., 2003). While isolated site locations endure to transport material in and out because of long distance from suppliers, improper and even inexistent routes (Wyrik and Eschenbach, 1989). A long distance from preferred suppliers often rises costs to a level where the chain becomes unfeasible, forcing executioners to work with alternatives sources. New parties are most likely to experience a slower project learning curve than usual partners, in the event that previous involvements support the creation of both product and process know-how via lessons learned.

On building construction industry, the supply chain is critical due the excessive amount of raw material required to product assembling. Expressively at construction phase, the raw material needs to arrive on site in correct amount and sequence, once there is minimal warehouse installed on site incapable of handling massive amount of material. Arriving and queueing coordination is essential to neither overload warehouse nor starve production line. Material surplus may impact how material flow to the production line because overstocks may delay picking activities, furthermore reducing the space necessary to cargo handling inside the warehouse. Starving production line is more critical, once it may switch off the production line, or part of it.

PRODUCTION RUN

Construction production is a project with defined constraints of scope, budget and schedule. By definition, short run is the window frame when steady factors drive production, consequently addition of capital is not possible so increase output requires more labor (Baye, 2010). In fact, on short production run the cost and the total amount of units to produce is clear from the beginning, as well as the deadline, budget and project scope (unfortunately not always realistic). In contrast, long production run is unclear about both production end and total units to produce, thus relying on forecasts. For instance, upstream oil production rig expects to extract a set number of oil barrels in a set time, but it will keep extracting until reservoir extinction. Average cost (cost/units) on short production runs are more accurate than on the long run because the units to produce can be considered constant. Initially, long run forecasted units have a higher potential risk than short run exact units, for the same total cost. Although, long run production may overwhelm the forecast unit creating a more favorable cost/units relation (McGuigan et al., 2011). Moreover, short run production aggregate higher costs per unit than long run production because the number of units to produce is much less than on long run productions making short run production more sensitive to risk in case of unit variation. In conclusion, short run production demand has a lower potential risk, but demands more accuracy because value concentrates in each unit to produce. So, small variations on labor may affect production and overall cost.

EVENT TERMINATION

Projects by definition are a finite terminating endeavor (Office of Government Commerce, 2009, Project Management Institute, 2013). Although there are some divergences about when project starts, the termination is clear. The handover to the user is the final milestone of the product construction so any activities later on relate to project documentation and formal closure. Then, if the project start is similar to an acceleration from a standing position, similarly termination represents a slowdown till stop. Even deeper, if considered every set up, activity startup and ending, the system receives several and sequential on and off switches causing work fragmentation (Thomas et al., 1990). This fragmentation implies on a numerous transient states, i.e., a timeframe in which the system is either adapting to an on/off change or responding to a disturbance, consequently affecting the state condition.

STATE CONDITION

The system is in a steady state when several properties are invariant over time. Project endeavor, with distinctive outcome or low level of previous technical knowledge from the executioner team, involves learning curves, therefore altering output/input relation over time, in summary a characteristic of

unsteady state system (Walsh et al., 2007). In steady state average work output is strictly less than average capacity, as claimed by Law (Capacity) in manufacturing (Hopp and Spearman, 1996). Construction might assume steady or unsteady depending on process repetitiveness and system balance, besides an extensive range of other sources for operation breaks and delays (Bernold, 1989).

COMPLEXITY

The only consensus among complexity is that there is no agreement about the general definition of complexity (Vidal et al., 2007). Vastly present in the literature, the word "complex" seems to stand for a supernatural being supposedly responsible for physical disturbances, a scary ghost haunting projects, for short. Although, a characterization about what is complex seems possible. The structure is complex; if composed by several interconnected pieces (Baccarini, 1996), in that they are dynamic networks of interactions, and their relationships are not aggregations of the individual static entities (Mitchell, 2009). Furthermore, a theory towards complexity emerges; originated from chaos theory, the "complexity theory states that critically interacting components self-organize to from potentially evolving structures exhibiting a hierarchy of emergent system properties" (Curlee and Gordon, 2011, p.31).

Projects are complex. A timed vehicle of state change involving several interrelated stakeholders, activities, and uncertainties may fit the description of complex. Methods to assess projects, classify and measure project complexity have been discussed in the literature. However, most methods are restricted computations on scheduling and activity relationship (for example, models created by Kaimann, 1974, Temperley, 1981, Nassar and Hegab, 2006). Such models provide a relative complexity comparison of similar projects on a same industry but fail on a comprehensive scenario. A more open and simple approach relies on the use of Analytical Hierarchy Process (AHP) (Saaty, 1990) to assess project criteria and on a variety of projects providing a calculated numerical grade from zero to one for complexity (Vidal et al., 2011). Despite it is possible to use this method to congregate projects into clusters, such survey does not exist yet. As a consequence, no explicit information comparing complexity of projects in building construction with other industries could be traced.

UNCERTAINTY

Similarly to complexity, uncertainty is an unintelligible expression without a straightforward description. Keynes was the first economist to incorporate uncertainty as a theory pillar, adding the distrust factor to economic science. How to be rational in an uncertain world, in what degree and how to specify it (refer to Mello, 2011 about Keyne's life and work). Further, the nature and effect of uncertainty on the probability: "Human decisions affecting the future, whether personal or political or economic, cannot depend on strict mathematical expectation, since the basis for making such calculations does not exist" (Keynes, 1936). In the final analysis uncertain is beyond any prediction, forecast, calculation or measurement specially considering human behavior (Association for Project Management, 2006). Stakeholders value the business outcome, the main reason projects exist, (Kezner, 2001, Association for Project Management, 2006, International Project Management Association, 2006, Office of Government Commerce, 2009). Value is relative. Therefore, internal and external, direct and indirect customers may have a different perception of the achieved project business outcome depending on their vantage point and individual background (Womack et al., 1991, European Commission, 1995, Aguirre, 2013, Weiss, 2013), according to Keynes a fertile soil for uncertainty.

Risk

Uncertainty differs from risk. In addition, the viewpoint on uncertainty and risk vary from different disciplines (Perminova et al., 2008). While uncertainty is a potential, unpredictable, unmeasurable (Knight, 1921, Crouhy et al., 2005), and uncontrollable outcome; risk is a consequence of action taken over uncertainty. As an illustration, two men about to skydive from an airplane, but there is only one parachute onboard. At this point, the level of uncertainty experienced by the men is equal, in this case whether or not the parachute will open. At the moment that a man chose jumping, despite the uncertainty is the same to both he bears all the risk. The uncertainty ceases with the parachute opening during the skydiving, through time passing, event, and action. Nevertheless, there is still the risk on a safe landing even after uncertainty come to an end (example from Mun, 2006).

Projects are risky. The action to conduct an endeavor upon uncertainty is the intrinsic nature of risk. Hence, deal with risk is crucial in project management to achieve successfulness business results. Control uncertainty is impossible, therefore, it is possible to identify, measure, and formulate plans to transfer, provoke, mitigate, avoid or embrace the impact of risk. Risk management's objective is to assure uncertainty does not deviate the project from business goals. In detail, risk manager succeeds maximizing opportunities, minimizing threads and hedging against the risk of a contingent, uncertain loss. The primary maneuvering instrument upon uncertainty is the risk contingent, which determination counts on the summation of expected value, which consists of the probability of risk occurring multiplied by the financial impact if it occurs of (AACE International, 2012) plus an amount judged sufficient to handle unforeseen risks. Additionally of the average risk value, calculated its variability of an aleatory variable is relevant, in particular spreading over time. Value-at-Risk (VaR) "describes the quantile of the projected distribution of gains and losses over the target horizon" (Jorion, 2007, p.21).

Variability

How close or spread out a data set is clustered. Variability is a measurement of variation, difference between results, moreover "potential scenarios of outcomes" (Mun, 2006, p.36). Risk affects variability as more risk causes a broader span of possible results. The impact of variability in construction production processes is known and proven: decrease of productivity (Tommelein et al., 1999), as well the consequences to the project: scheduled delays and cost overrun (Alarcon and Ashley, 1999). Construction conditioned by short run production demonstrates extreme sensitiveness to variability in labor. Considering that at steady factors manipulation of production output requires administration of labor as an input. Hence the understanding of the relation between labor and productivity potentially enables the control of production. However, As the variability is a result of risk and uncertainty, mathematically correlate variability to labor is challenging. In statistics, productivity of labor in building construction does not fit on a normal distribution, provided that the variance is undefined, curvature is leptokurtic (Radosavljević and Horner, 2002). Leptokurtosis may influence productivity of labor analysis in the event that estimations made using normal distribution overestimate at low levels of significance and largely underestimate at high levels of significance. The wider end of leptokurtic distribution means risk is coming from outlier events and extreme observations are much more likely to occur.

Cone of uncertainty

Uncertainty not only decreases over time passing but also diminishes its impact by risk management, specifically by decision making. In other words, the impact of uncertainty strongly depends on the decision of the risks taken. Researches findings indicate that the project estimation builds on foreseen quantities of uncertain events distributed at several stages resulting of the process of resolving decisions (McConnell, 2006). Figure 2 shows a decrease on variability and consequently increase on accuracy of estimates over project progression. Still, the cone does not form itself naturally. It is a product of various decisions taken as project progresses concerning plan and product. Narrowing the cone implies on removing variability sources sooner. On the contrary, a wider cone results from later decisions (McConnell, 2006). Figure 3 presents a parallel analysis illustrating the impact of decisions made on early stages than late on possible cost reduction in construction projects. Hence to protect subsequent events from variability, and the effects of it, decisions should be in early stages that are higher sources of variability.

Experience from the past may support correct decision making. Commonly called "lessons learned" by project literature and practitioner, the term defines the practice of learning from successful and unsuccessful passed events. Consequently, assess captured outstanding project events on post project reviews to re-use in future endeavors despite having a remarkable potential to reduce variability the process frequently ends in capturing (Atkinson et al., 2006). The likely re-use of lessons learned depends on their applicability on future projects, moreover the similarity between projects, in other words project receptiveness.

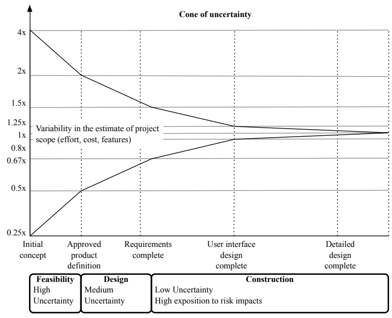

Figure 2 - The Cone of Uncertainty for sequential project development (adapted from McConnell, 2006, p. 27)

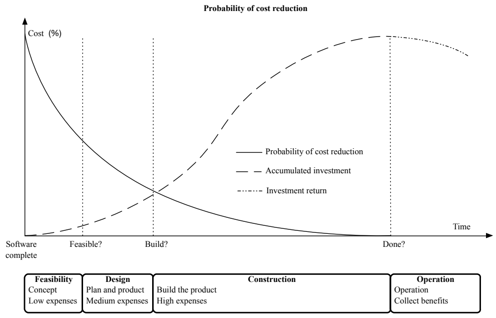

Figure 3 - Graph of percentage cost over time demonstrating how early correct decisions may impact cost reduction (adapted from Smith et al., 2006, p.80)

REPETITIVENESS

"Repetitive manufacturing is the production of discrete units in a high volume concentration of available capacity using fixed routings. Products may be standard or be assembled from standard modules. Production management is usually based on the production rate" (Spencer and Cox, 1995, p. 1276). Construction production run is short and easily countable considering the final project product, nonetheless the sub products might be broken in several units creating an artificial repeatability. Construction produces multiple products in low volume coupled with process structured in the midway of batch (Matching major stages of product and process life cycles from Hayes and Wheelwright, 1979).

Repetitiveness supplies the opportunity of more use of lessons learned, inevitably proportionating improvement in processes and products. High level of repetitiveness may propitiate continuous enhancements due to the likeness, easiness of measurement and comparison between construction cycles. Formed by four basic sequential activities, Plan-Do-Check-Act (PDCA), Shewhart's cycle founded an unceasing circle of quality enhancement. Likewise, Six Sigma, a set of techniques and tools for process improvement, aims to defects riddance and variability minimization. At Six Sigma levels, processes in a state of statistical control expects no more than 3.4 defects per million opportunities and short-term process capability index (C_{pk}) equals two, numbers representing a stable process almost variability free. In summary, repetitiveness may create a chain of effects resulting in improvement and variability reduction, or in terms of system description. It creates a feedback connection on activities or process. Furthermore defining a close loop system where passed deviations might be used to correct current and future production.

CONSTRUCTION SYSTEM

Several elements found in this literature review connect construction to characteristics a dynamic system. Furthermore, revealing a high similarity between the resulting theoretical framework and the concept of the feedback loop to control the dynamic behavior of the system as shown in Figure 4. Interconnectivity is explicit between project stages, in the event that subsequent phases rely on the accomplishment and performance of previous ones. In summary an activity or stage may impair or favor a successive action depending on the level of correlation and dependence. This dependent connection remains valid to a divided *n*-substages or *n*-activities, although the level of influence for sequential, parallels or overleaping relationships have not been investigated at this point. Block diagram representation is common for control systems, where a system output may determine an input of the following system or the output a later system affect the output of previous systems in the chain (Ogata, 2010). For example, the manager in charge eventual corrective actions when an activity deviates from defined tolerances of the plan, management by exception (Office of Government Commerce, 2009). Control loops in the process control industry work in the same way. Once defined a set-point, three tasks occur: measurement comparison and adjustment. If feedback and an inner controller (characterized by the interaction of the operational manager for example) are added to the activity C_n, the system now, structured by two closely linked process and encapsulated feedback,

constitutes a cascade control system. Secondly, the interdependence of activities forms a conduit to propagation of unsure events. Potential risks captured through all project life may impact project execution if not properly treated resulting in variability. Equivalently, control systems may transmit unfiltered noise across connections affecting vulnerable components causing disturbances and unpredicted behavior.

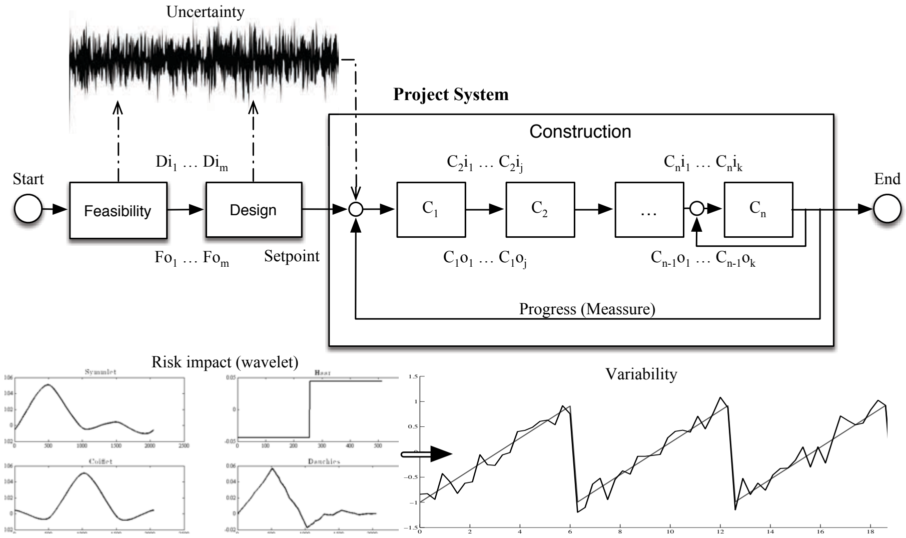

Figure 4 - The project construction system — a theoretical framework

The understanding of how risk transforms into variability and especially how variability affects networked activities propitiates opportunities to construction develop methods to avoid and mitigate (filter) the propagation of risk (noise). Regarding the materialization of risks in variability different variability outcomes build on how much concentrated or distributed the risk impact was. This scenario requires a function capable of scale variation and energy (impact) conservation when calculating the functional energy. Evolved from Fourier transformation, wavelet network[1] may be used as universal function approximator[2] to estimate unknown nonlinear functions, hence as to attain the required control performance. Despite a new concept in the control area, wavelets have been successfully used in several applications such as physics, signal processing and statistics where small complicated details matters (Xu and Tan, 2003, p.130). Operating on possible same characteristics of wave theory: linear/non-linear; deterministic/stochastic; time-domain/frequency domain; direct/inverse problems; discrete/continuous models (Dager and Zuazua, 2006); control theory may create a bridge theory to explain the effects of variability in construction by extending elements of the dynamic systems to the construction.

CONCLUSION

This literature review conducted a search for elements in all project life that possibility influence project performance, mostly affecting the behavior in construction. Also, several comparisons were made between project and manufacturing aiming to identify key components that could serve as pivot to application of successfully proven methods and theories from manufacturing into construction. The outcome is a theoretical framework in a system shape connecting stages and activities, as well as proposing a flow to uncertainty, risk and variability. The construction system provides a mean to

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[1] "Wavelet network is a type of building blocks for approximation of unknown functions based on the concept of the multi-resolution approximation. The building block is formed by shifting and dilating the basis functions, the mother wavelet and father wavelet" (Xu and Tan, 2003, p.130).

[2] A universal function approximator is a system that, given a set of predictor variables, can output an accurate estimate of some predicted variable.

analyze the effects of cascade elements in a micro and macro view providing to the building construction industry ways to measure and predict performance. Although this study was comprehensive, the list of unmentioned influencing points is still endless. Fortunately, additional inputs, outputs or loops may be later added or either subtracted from the system without disrupting the theory. Furthermore, not only to mechanical or machinery automation, the use of control theory and process control opens a horizon for human task automation and implementation of productivity control in construction.

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DEVELOPING A TECHNIQUE FOR CALCULATING MOISTURE REMOVAL EFFECTIVENESS IN NEW ZEALAND HOMES

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ABSTRACT

Most homes in New Zealand rely on the natural ventilation through open windows as described in the New Zealand Building Code. However, a recent survey showed that insufficient ventilation is a common problem during the cooler months. This research investigates strategies for home ventilation from the perspective of managing indoor moisture in a temperate/marine climate. Two approaches to ventilation were studied, an infiltration-only case; and a supply-only mechanical system that delivered air from the roofspace into the lounge and bedrooms. An experimental building was constructed that allows the airtightness of the building envelope to be selected anywhere in the range of 1-9 ach@50Pa. The indoor climate was computer-controlled, with humidifiers and heaters to simulate occupancy. Two tracer gases were used to study the ventilation rates between indoor zones in real time. A series of experiments investigating contaminant removal effectiveness revealed that the mean age of CO_2 depended on the ventilation rate as expected, with a large change observed between the infiltration-only and supply-only ventilation cases. However, the mean age of water vapour was found to be less sensitive to ventilation, and influenced by sorption in the building materials. A computer model was developed to model the movement of moisture within the building by sorption into materials and by air transport between rooms. The model was shown to agree reasonably well with experiments.

KEYWORDS:

Moisture; Ventilation; Airtightness

INTRODUCTION

Moisture is the key contaminant in New Zealand homes, and is usually linked with poor ventilation, inadequate heating and lack of source control. Excess indoor moisture, when coupled with low indoor temperatures contributes to health issues (Howden-Chapman, 2007) and this situation is not unique to New Zealand (WHO, 2009). Previous work at BRANZ (McNeil, 2012; Bassett, 1986) has shown that houses in New Zealand continue to be built to a higher level of airtightness than previously, despite any Building Code (DBH, 2005) requirement to do so. The trend towards more airtight houses is thought to be due to progressive changes in construction techniques e.g. the widespread move from strip flooring to sheet flooring in the 1960s and the adoption of aluminium joinery over timber joinery. In recent years there has also been a strong trend to slab-on-ground construction. The most recent work (McNeil, 2012) also measured in-service ventilation rates and compared them with an estimated background infiltration rate based on the airtightness of the building envelope. The results showed that about two-thirds of all new homes are likely to need supplementary ventilation on top of background infiltration to achieve acceptable levels of indoor air quality (0.3-0.5 air changes per hour (ach)), but this only occurs in half of these tighter houses. In terms of natural ventilation, the New Zealand Building Code relies heavily on having an adequate area of openable windows, but these results suggest it may not be sound to assume the windows are opened in practice.

In recent years there has been a large growth in the adoption of mechanical ventilation systems, which are often marketed as a solution to indoor moisture problems. The majority of ventilation systems being installed in New Zealand are relatively simple supply-only fans, which take air from the

roofspace into the living area. Often these ventilation systems are controlled only by a simple differential temperature measurement between the living space and roof space.

It is estimated that existing building stock will make up two-thirds of buildings in 2050 (Saville-Smith, 2009). Therefore any ventilation solutions that are adopted need to be effective over a wide range of building airtightness levels. Consequently it is important to know how different ventilation systems perform in terms of providing adequate levels of ventilation and dealing with moisture, and how this may be affected by the airtightness of the building envelope.

The aim of this study is to measure the ventilation rate and moisture removal effectiveness in a test building with a controllable level of airtightness, and to then develop a numerical model that simulates this behaviour so that the results can be generalised to the rest of the country. The goal is to enable homeowners to make informed choices about the 'why' and 'how' of ventilating the spaces they live in and to enable ventilation system manufacturers to provide the most systems.

This paper describes the results from two-tracer measurements for the infiltration-only case and the supply-only ventilation case and compares these results with a preliminary version of the numerical model.

The theory of tracer gas measurement of ventilation rates is well developed (Sherman, 1998; Rudd, 2009), as is the measurement of contaminant removal effectiveness for ducted ventilation systems (Persily, 1994; Sherman, 2008). For a naturally-ventilated building, there is no extract duct, only the adventitious openings in the envelope, which are usually numerous and nearly impossible to fully quantify. This is also the case with the supply-only ventilators that are popular in New Zealand. (Sandberg, 1983; Haghighat, 1990) began work in the area of mean age of air and ventilation efficiency in naturally-ventilated buildings, defining a term for relative contaminant removal effectiveness relating mean age of air and mean age of a contaminant. Their work has been used further (Bassett, 2000; NT VVS 118; NT VVS 019), and is used in this study as a basis for calculating the local mean age of CO_2 and moisture in the test building. CO_2 is used in this study as a proxy for the air.

Numerical models of room air and surface absorption have been developed over the years (Plathner, 2001; Rode, 2001). These models differ in approach, but appear to agree well with corresponding experiments. This work recreates the model used by (Rode, 2001) and compares the model with experimental data.

EXPERIMENTAL PROCEDURE

Experimental Building

An existing single-storey building, Figure 1, was relocated to the BRANZ campus, just north of Wellington. The building has a floor area of 91 m^2 and internal volume of 206 m^3.

Figure 1: Experimental building.

The building sits on timber piles and is of typical timber construction, with trussed roof framing, and particle board flooring. The cladding is fibre cement weatherboards fixed directly over a flexible synthetic underlay, the roof is clad in corrugated iron over a bitumen-impregnated underlay. The interior lining is plasterboard, painted with an acrylic paint, and the particle board flooring is sealed with polyurethane. Windows and doors are single-glazed aluminium joinery. The walls, floor and ceiling are insulated with fibreglass insulation to the requirements of the Building Code (DBH, 2005).

To enable the airtightness of the building to be varied, the building was initially made as airtight as practically possible using the "Canadian Airtight Drywall" (Lstiburek, 1984) approach. Ports were then installed around the interior of the building, which can be opened to simulate houses of lower airtightness. The range of airtightness that can be achieved is from 0.9 ach@50Pa to 9 ach@50Pa.

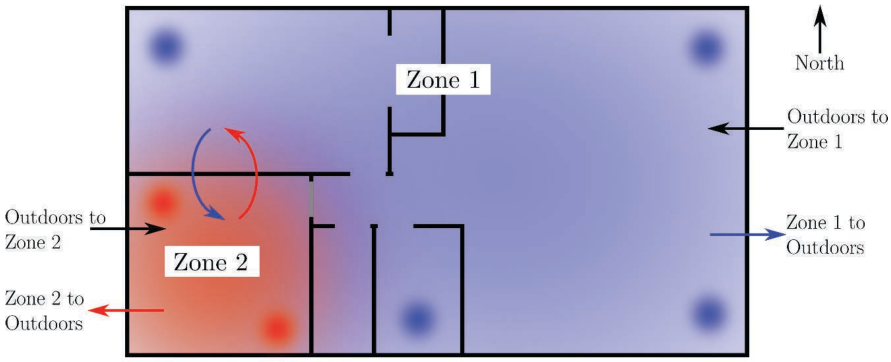

Figure 2: Floor plan of test building.

A floor plan of the test building is shown in Figure 2. For the experiments described in this paper, the building is divided into two zones, the smaller of the two bedrooms (Zone 2) and the rest of the house (Zone 1). Zone volumes are $22m^3$ and $184m^3$ respectively. The doors to all rooms were left wide open, apart from the door separating Zone 2 from Zone 1.

Instrumentation

The conditions within the test building were controlled and monitored by a central computer system, a schematic of which is shown in Figure 3.

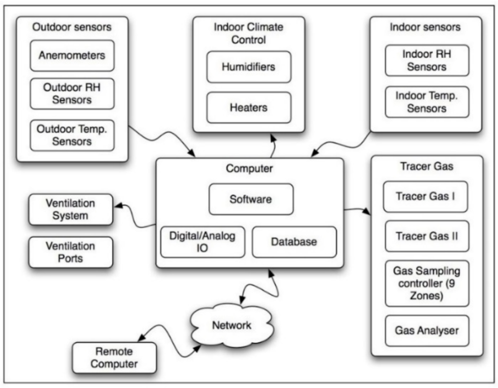

Figure 3: Instrumentation scheme used in the house.

The main tracer gas experiment utilises an Innova 1412 Photo Acoustic Gas analyser which was connected to a pair of manifolds containing a set of solenoid valves that allowed for a choice in sampling location. The computer system also controlled the indoor climate via heaters and humidifiers. At the current time there is no extra cooling or dehumidification.

The tracer injection rate was adjustable over a range spanning a few millilitres to hundreds of millilitres per minute via a manual controller. To minimise flow rate drift, the flow controllers were kept a few ˚C above ambient temperature. Bubble flow meters were used to measure the flow rate on a regular basis.

Ventilation Configurations

Two ventilation configurations were studied in this work, the background infiltration case, and forced ventilation driven by a simple supply-only ventilator. The schematic of a supply-only ventilator is shown in Figure 4. The supply-only system ducts roofspace air into the living space. Both configurations were studied at building airtightness levels of 1, 3, 5 and 9 ach@50Pa.

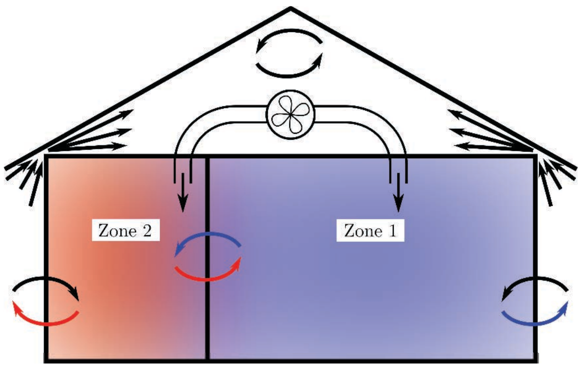

Figure 4: Supply-only ventilation system.

The ventilation system had three diffusers in total, two in Zone 1 and one in Zone 2. The default settings were used on the controller supplied with the unit. The controller used a measurement of the temperature difference between the living area and roof space to adjust air flows. The ventilator also provided a background level of ventilation overnight and once the roofspace had cooled below the temperature of the living area, even though it was adding cooler air to the living area..

Measurement of Ventilation Rates - Tracer Gases and Sampling Locations

Tracer gas sampling locations were distributed around the building in a volume-weighted manner. Zone 1 had eight dosing and sampling locations, and Zone 2 had two. Air samples were returned to the same zone they were sampled from via the manifolds at the gas analyser.

In order to measure ventilation rates, two tracer gases were used, Sulphur Hexafluoride (SF_6) and Carbon Dioxide (CO_2). These were dosed into Zone 1 and Zone 2 respectively in accordance with the constant emission method (Sherman, 1998). The experiments took place at the end of autumn, leading into early winter. Both tracer gases were introduced at an accelerated rate to get to an estimated equilibrium concentration, then the dosing rates were dropped to a rate adequate to maintain concentrations in the detectable range throughout the experimental period. Concentrations of all gases in each zone were measured every ten minutes by the gas analyser.

Once the building was dosed with tracer gas, the differences between measured concentrations at different locations in the same zone were negligible, suggesting the air in each zone was well mixed.

Multizone Mass Balance Equation

Inter-zonal ventilation rates were calculated using a standard mass balance equation, and well developed existing theory (Sherman, 1998; Rudd, 2009)

$$V\frac{dC_{(t)}}{dt} = Q\left[C_e - C_{(t)}\right] + F \quad (1)$$

Where,
V = enclosure volume [m^3]
Q = airflow through enclosure [m^3/s]
C_e = external tracer concentration [kg/m^3]
$C_{(t)}$ = internal tracer concentration at time t [kg/m^3]
F = tracer dosing rate [kg/s]

The following data from the measurements were required to solve the system of equations:

- Concentrations of both tracer gases in their respective zone
- Temperature of the air in each zone
- Dosing rate of each tracer

The results were then averaged to give inter-zonal flows on an hourly basis.

Mean Age of Contaminants

Measurements were made of the mean age of air (using CO_2 as a tracer) and moisture, treating the water vapour as a gaseous contaminant.

Moisture was introduced continuously into Zone 2 using a humidifier. A dosing rate similar to two sleeping adults (Plathner, 2001) was chosen, as it represented a reasonable in-use moisture load. As the humidifier output (approximately one kg/hour) was more than two sleeping adults would generate it was pulsed on for one minute intervals every five minutes to give an effective moisture introduction of 0.16 kg/hr over the dosing period, for a total of 1.28 kg. Each dosing period ran for a total of eight hours, beginning at 10pm, finishing at 6am.

The local mean age of CO_2 and of water was calculated for Zone 2. This can be difficult when there are no exhaust vents, but (Sandberg, 1983; Haghighat, 1990; Bassett, 2000; NT VVS 118; NT VVS 019) have shown how the two results can be expressed as a relative contaminant removal effectiveness by taking a ratio of the two measurements.

The mean ages (τ_p) of CO_2 and moisture were calculated using Eq. (2) (NT VVS 118):

$$\tau_p = \frac{C_p}{(F/V)} \quad (2)$$

In summary, the mean age of CO_2 and moisture were calculated from a set of dosing experiments. The resulting changes in humidity were observed, and the data from the temperature and humidity probes were used to calculate the density of water vapour in the zone air.

SIMULATION METHOD

A model was developed to simulate the dosing experiments, with the long-term aim of extending these results to a wider range of building design and climate zone in New Zealand. The model required

hourly-averaged ventilation data and the amount of introduced moisture. Results were then compared with the calculated values based on the vapour density of the air in the room.

The air and walls of Zone 2 were modelled taking the same approach as that developed by (Rode, 2001). The transport equations are based on the humidity ratio (absolute moisture content) of the air. The basic form of the model is shown in Eq. (3):

$$V.\rho_{air}\frac{x^{new}-x^{old}}{\Delta t} = \sum G \quad (3)$$

Where,
V = the volume of the room [m^3]
ρ = air density [kg/m^3]
x = humidity ratio of the air [kg/kg]
G= a source term [kg/s]

The source term was summed over the various sources available, different source terms can be written for different source types, see Eq. (4), Eq. (5).

The source term for ventilation air is:

$$G = n_{vent}V\rho(x_{vent} - x_{air}) \quad (4)$$

Where,
n_{vent} = the number of airchanges per unit time [h^{-1}]
x_{vent} = the humidity ratio of the source air [kg/kg]
x_{air} = the humidity ratio of the air in the zone [kg/kg]

The source term for emission from an absorptive surfaces is:

$$G = A_{surf}\beta(p_{surf} - p_{air}) \quad (5)$$

Where,
A_{surf} = the available surface area in the room [m^2]
β = the surface transfer coefficient of the surface [kg/(m^{2}sPa)]
p_{surf},p_{air} = the partial pressures of water vapour on the surface and room air respectively [Pa]

Once the sum of the sources was found using Eq. (4) and Eq. (5) the new humidity ratio was calculated by re-arranging Eq. (3). The moisture-dosing experiments were carried out simultaneously with the ventilation measurement work so that hourly mean ventilation rates were available to the model.

Humidity ratios were first calculated for each sensor location, and the ventilation rates used were taken from the hourly data sets (see 'Ventilation Measurements' below). The surface area of Zone 2 was taken as 47m^2, with a typical surface transfer coefficient of 2x10^{-10} kg/(m^{2}sPa), surface temperature and humidity were taken as the measured values inside the wall just behind the lining.

RESULTS

Ventilation Measurements – Infiltration-Only Case

Figure 5 shows the amount of airflow between zones in the infiltration only case for the range of airtightness levels of the test building (1, 3, 5 and 9 ach@50Pa). Each flow is averaged over several days of measurements and the standard deviations of each data set are represented by the error bars of the hourly averages.

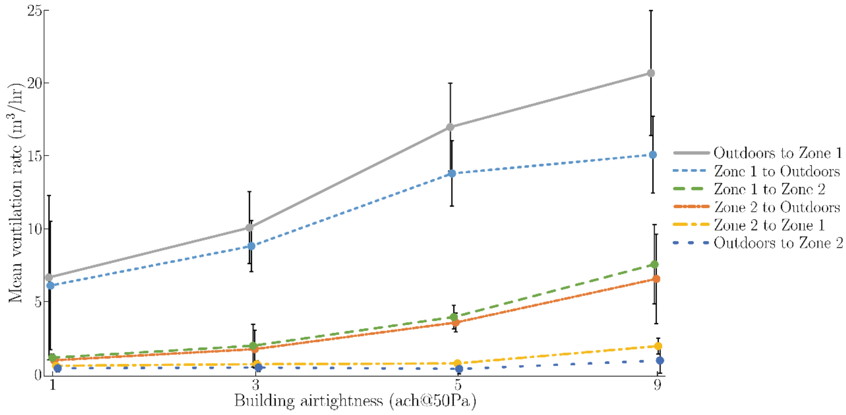

Figure 5: Mean flow rates between zones vs airtightness – infiltration only.

The air flows in Figure 5 are plotted in Figure 6 as net ventilation rates in 6 with error bars representing the standard deviations of the hour averages. As expected there is a steady trend to lower flows as the airtightness (ach @50Pa) increases. This is in contrast to the flows measured with the supply-only ventilation as shown in Figure 7.

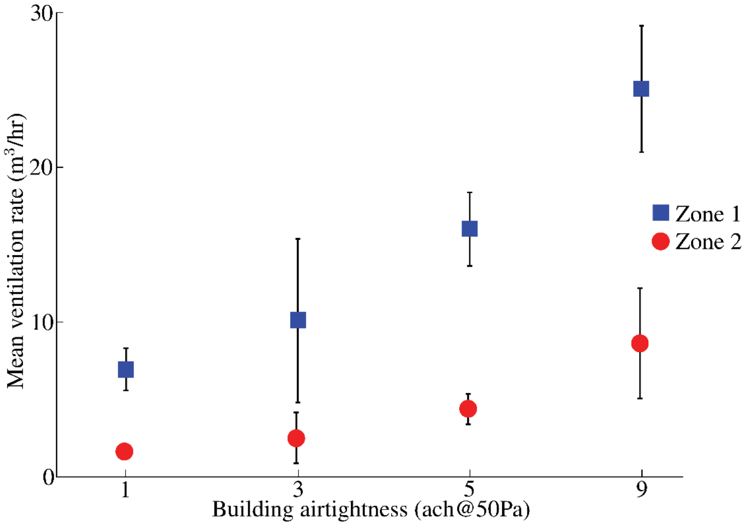

Figure 6: Mean total ventilation rates for each zone vs airtightness – infiltration only.

Ventilation Measurement – Supply-Only Ventilation

The supply-only ventilation system was switched on and the diffusers uncovered in late May 2012 and the averaged measured ventilation rates plotted in Figure 7 for each of the zones and airtightness level. As expected, average flows for each zone are substantially higher than the infiltration case, but there was also no obvious dependency on the building airtightness. The ventilation rate was certainly influenced by climate variability as reflected in the error bars, but wind speeds during measurements at

5 and 9 ach @50 Pa were lower and therefore less influential than normal over these limited measurement periods. Unlike the infiltration-only case, air flows between Zones 1 and 2 were

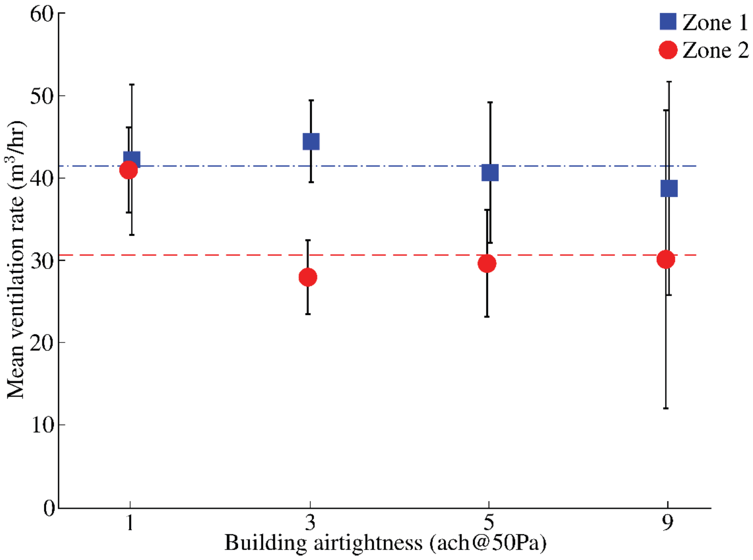

Figure 7: Mean ventilation rates for each zone vs airtightness – supply only ventilation.

balanced

MOISTURE INTRODUCTION AND MEAN AGE OF CONTAMINANTS

The effectiveness with which moisture is removed from Zone 2 can now be expressed in terms of the mean age of moisture for the infiltration and supply ventilation cases. Average values of the mean age for two-day periods are given in Table 1 for the four building airtightness settings. These results can then be compared with the mean age of air (CO_2) measured in Zone 2 expressed as a relative contaminant removal effectiveness for the period.

Table 1: Mean age of CO_2 and moisture in Zone 2.

Ventilation configuration	Airtightness [ach@50 Pa]	Mean age CO_2[hours]	Mean age moisture[hours]	Relative contaminant removal effectiveness[-]
Infiltration-only	9	3.1	11.4	0.27
Infiltration-only	5	3.9	11.6	0.33
Infiltration-only	3	5.1	11.8	0.43
Infiltration-only	1	14.1	12.2	1.16
Supply-only	9	1.0	8.9	0.11
Supply-only	5	1.0	8.4	0.12
Supply-only	3	0.9	9.3	0.10
Supply-only	1	1.2	7.7	0.16

MODELLING OF MOISTURE-DOSING

A comparison between measured and calculated humidity ratio in Zone 2 is given in Figures 8 and 9 for the infiltration and mechanical ventilation cases respectively. The data extends over a two-day period with the onset of moisture release indicated by the vertical line. There is reasonable agreement between measurement and prediction. However. there is some buffering of the dosed moisture by condensation accumulating on the window that is not captured by the model. This is shown as shaded areas on the plots indicating sorption and desorption processes not accounted for in the model. It is clear that an additional source/sink needs to be added to account for the formation and evaporation of condensation.

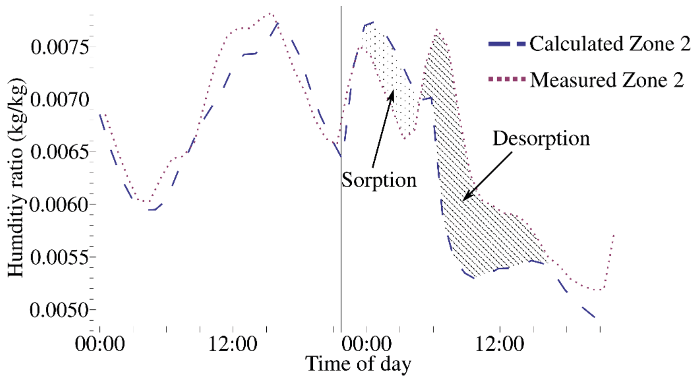

Figure 8: Measured and modelled humidity ratio, 1 ach@50Pa, infiltration-only.

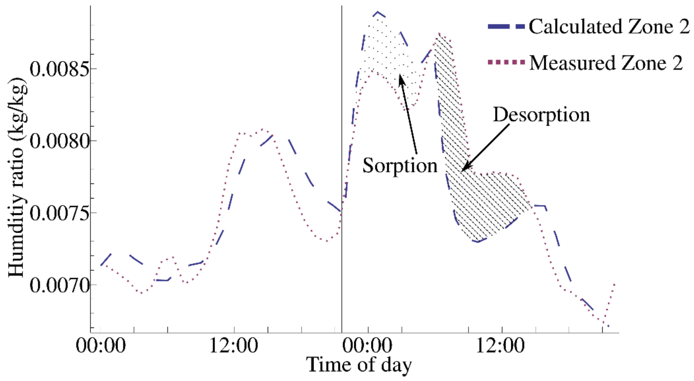

Figure 9: Measured and modelled humidity ratio, 3 ach@50Pa, supply-only ventilation.

DISCUSSION

Ventilation Measurements

Ventilation rates measured for the infiltration-only cases were often inadequate for air quality and moisture control. Even with the building at 9 ach@50Pa, the mean ventilation rate for Zones 1 and 2 were 25 m^3/h (equivalent to 0.13 ach) and 8.7 m^3/h (0.39 ach) respectively. In the case of Zone 2, most

of the air came from Zone 1 rather than from outdoors, and this will have a bearing on the capacity of this air to control moisture in Zone 2 if there are moisture sources elsewhere in the building. The reason for this air flow imbalance during the measurement period was due to the external walls of Zone 2 being on the lee side of the building and at a negative pressure relative to indoors. This could well be a factor in the relative contaminant removal effectiveness of natural ventilation in bathrooms on the lee-side of a building.

The ventilation rates delivered by the supply-only ventilation system are were higher on average than the infiltration case. The mean ventilation rate in Zone 1 was 41.6 m^3/h (0.23 ach) and in Zone 2 was 32.2 m^3/h (0.68 ach). The ventilation rate was found to be less dependent on the airtightness of the building than expected and this has been explained in terms of lower-than-normal wind speeds during measurements with the building at 5 and 9 ach@50Pa. The influence of infiltration is still evident in the standard deviation of hour average ventilation rates in Figure 7 which is shown to increase increases as the building becomes less airtight.

Research work in the experimental building has since moved on to examine the moisture removal effectiveness of passive stack ventilators. These stack vents penetrate the roof and therefore the air flows should be less dependent on wind direction than air flows through infiltration paths. These vents can also be easily modified so they are fan-assisted to cope with high moisture loads and when the natural driving forces are insufficient. There are good prospects that stack and hybrid stack ventilation systems might be cost effective in homes where supplementary ventilation is necessary.

Mean Age of Air and Moisture Calculations

The results above are mirrored in the mean age of air (using CO2 as a proxy). In the infiltration case, the increase in ventilation as the building becomes less airtight results is a steady decrease in the mean age of air. When the ventilation system is active, the mean age of air appears more steady as mentioned above, though there is the expectation that the mean age of air could be lower in the 5 and 9 ach configurations due to the lower wind speeds experienced during the experiment.

Though there is a very clear difference between the mean age of air when comparing the infiltration and supply ventilation cases, the same cannot be said for the mean age of moisture, as the difference is much less marked The mean age of for air for the infiltration and supply ventilation cases (6.5 and 1.0 hours) had relatively little influence over the mean age of moisture (11.7 and 8.6 hours respectively). This is a result of sorption in building materials buffering the moisture in the air, limiting the rate at which moisture moves from one room to another.

A second factor limiting the application of mean age calculations to moisture is that, incoming air is also likely to be a source of moisture. The modelling phase demonstrates that this buffering by materials is still a significant component, and this will be looked at in more depth later in the programme.

Modelling of Moisture Movement and Comparison to Measurements

The reported measurements were carried out over too short a period to fully characterise the relative performance of these two ventilation approaches. Instead, the data is being used to develop a numerical model to generalise results over longer periods. Beyond this, mean age differences could still be a useful metric when considering condensation and mould risk, particularly when comparing different patterns of moisture emission.

Modelled and measured humidity data ratios have been shown to agree reasonably well in Figures 8 but there are times when the two results diverge, such as early in the first day of the mechanically-ventilated case where a secondary peak is evident in the measured data that the model does not reflect. This peak coincides with switching on the heating in the room, and is thought to originate from

condensation evaporating from the window and adding to the moisture in the air. An additional term might usefully be added to the model to account for condensation on glass, as there is a large glazed area in Zone 2.

When the area under the curves in Figures 8 and 9 are compared, the differences are quite small (3.2% for the infiltration-only case, and 0.03% for the supply-only ventilation case). In both instances the modelled data is slightly underestimated. The agreement between the total areas under the curves indicates that the differences observed in the plots, (shaded areas) are an artefact that can be attributed to sorption/buffering in the room.

CONCLUSIONS

This study set out to establish a method for measuring the moisture removal effectiveness of residential ventilation systems. Two common approaches to home ventilation in New Zealand are infiltration alone and infiltration supplemented with a supply-only ventilator. These were examined in an experimental building partitioned into two zones where one of the zones contained a moisture source. Ventilation rates and moisture removal effectiveness results were measured over several days with the building at airtightness levels between 1 and 9 ach @ 50 Pa with the following conclusions:

- Average ventilation rates in the building were much higher with a combination of air infiltration and a roof-space mounted, supply-only ventilator than the case with infiltration alone.
- The mean age of moisture in Zone 2 was much higher than the mean age of air due to sorption of moisture in building materials and was only weakly influenced by higher ventilation rates.
- The humidity ratio for air in Zone 2 was calculated using simple mass balance equations accounting for air-carried moisture and sorption. While reasonable agreement between this calculated value and that measured was achieved, it was clear that condensation will also have to be modelled.
- Methods for measuring contaminant and moisture removal effectiveness have been used here to examine the scope for optimising home ventilation in temperate climates for moisture control. At this stage more work will be necessary to interpret these results more generally in terms of condensation and mould risk.

ACKNOWLEDGMENTS

This work was funded by the New Zealand Building Research Levy and the New Zealand Ministry of Business, Innovation and Employment.

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EFFECTS OF SOLAR COLLECTORS ON INDOOR AIR QUALITY IN JUNIOR CLASSROOMS IN WINTER 2013

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ABSTRACT

Indoor air quality (IAQ) is typically poor in New Zealand (NZ) schools (Bassett and Gibson, 1999; Cutler-Welsh, 2006; Mclntosh, 2011), especially during winter weather. Naturally ventilated classrooms are frequently under ventilated (Canha *et al.*, 2013). Mechanical ventilation can improve the IAQ but at the expense of energy consumption (Cutler-Welsh, 2006; Xifeng *et al.*, 2012). As the hours of school occupancy are closely aligned with hours of solar radiation (NIWA, National Climate Database), a solar collector unit that warms ventilation air appears to be a good solution to achieve acceptable IAQ in classrooms. This study explored the effects of solar collectors on IAQ in six occupied junior classrooms situated in three Palmerston North schools in winter 2013. The temperature, relative humidity (RH) and carbon dioxide (CO_2) levels in each classroom were monitored during school hours (9am-3pm) from July 27 to September 29 (NZ school term 3). Usages of the existing heaters were also monitored. In each school, adjacent classrooms were either assigned to a control group (solar collector disabled) or a treatment group (solar collector activated). Results show that although mean concentrations of CO_2 were lower in treatment classrooms than in control classrooms, this difference was not significant ($P_{value} = 0.86$). In 2 out of 3 treatment classrooms, exposure to CO_2 level below 1000ppm (recommended guideline) was more than 50% school day. All classrooms were within the range of RH recommendation (40%-60%) for more than 63% of school day. All classrooms were exposure to world health organization (WHO) recommended temperature guideline (18ºC-24ºC) for at least 67% of the day. The temperature exposure to 18ºC-24ºC in treatment classrooms was as similar as in the adjacent control classrooms. However it was at the expense of energy consumption. The heater usage in the three control classrooms was 1.4, 3.8 and 2.9 times higher respectively than in adjacent treatment classrooms. Thus the solar collector unit played a positive role on improving IAQ in classrooms and reducing heaters usage.

KEYWORDS:

Temperature, relative humidity, carbon dioxide; exposure; solar collector unit.

INTRODUCTION

The IAQ in junior classrooms has received some research attention in recent years (Smedje, 2000; Fromme *et al.*, 2007). Poor IAQ affects children's health (Smedje *et al.*, 1997; Mendell and Heath, 2005). There was a significant association between the RH in the classroom and respiratory disease among children (Mendell and Heath, 2005). A low classroom temperature can aggravate asthma symptoms among asthmatic children. Several studies found high concentration of CO_2, high level of RH, and low level temperature in NZ junior classrooms in winter (Bassett and Gibson, 1999; Cutler-Welsh, 2006; Mclntosh, 2011). As poor IAQ was found in NZ junior classrooms in winter, there is an urgent need to improve it.

This poor IAQ in classrooms in winter could be improved by increasing the mechanical ventilation rate (Heudorf, 2007; Canha *et al.*, 2013), but this comes at the expense of energy consumption

(Cutler-Welsh, 2006; Xifeng *et al.*, 2012). As the school hours are closely aligned with the optimum solar radiation (NIWA, National Climate Database), the solar energy seems to be an effective solution to increase ventilation rate and temperature. Thermal solar collectors that warm the incoming air in a box and push the warmed air with a photovoltaic powered fan was investigated as an effective solution to generate both electricity and heat (Zogou and Stapountzis, 2011). It was found that solar collectors could generate sufficient airflow to improve the ventilation rate (Tonui and Tripanagnostopoulos, 2007) and bring warm air into a house through a duct. However, there has been no research on the application of solar collector in NZ classrooms in winter. This paper gives the preliminary results of a study investigating the effects of solar collector unit on the IAQ in NZ junior classrooms in winter.

METHODS

The study involved 3 primary schools (6 classrooms) in Palmerston North. To reduce the variability in the sample, very similar classrooms were selected (heating, building characteristics and population characteristics). Treatment (solar collector activated) and control (solar collector disabled) classrooms from the same school were located side by side to minimise variability and were matched for construction type. This study was conducted in winter 2013 during school term 3 (9 week period). To protect the privacy, these classrooms were named 1C, 1T, 2C, 2T, 3C, 3T (1, 2 and 3 represent the school, C stands for Control, T stands for Treatment). Teachers were able to operate heaters as needed for thermal comfort.

Figure 1: The custom made support structure with the monitoring equipment

Environmental measurements (temperature, RH and CO_2) were collected in each classroom at 2-min intervals, 24/7. This paper presents the data from 9am to 3pm (school hours). These three parameters were measured by either Gas Probe IAQ sensors (BW Technologies Ltd, Calgary, Canada) or IAQ-Calc Meter Model 7545 (TSI Incorporated, Shoreview, USA). The device was placed in a custom made support structure (Figure 1) to prevent tampering by occupants and to keep the probe at the 1.1 meters high from the floor (average height when students are seated). The support structures were located in the best available location for average classroom environment.

The use of heaters was recorded by a type K thermocouple connected to a microvolt logger (Branz Ltd), positioned in front of each heater. All the devices were checked and calibrated before commencing fieldwork. Statistical software R was used to analyse the data (R Development Core Team, 2014).

RESULT AND DISCUSSION

Carbon dioxide

Based on the recommendation from the NZ standard "ventilation rate for acceptable IAQ" (NZS, 1990), the concentration of CO_2 should be below 1000 parts per million (ppm). A concentration of CO_2 above 1000ppm indicates an inadequate ventilation rate in the classroom (Moffat, 1997).

Table 1 shows the results of CO_2 in the 6 classrooms from 9am to 3pm. Although mean concentrations of CO_2 were lower in treatment classrooms than in control classrooms, this difference was not statistically significant ($P_{value} = 0.86$). The averaged CO_2 concentration in 4 out 6 classrooms was above 1000ppm during school hours. This result is similar to another NZ school study, which found 4 out of 5 classrooms with CO_2 level above 1000ppm (Cutler-Welsh, 2006). However Bassett and Gibson (1999) showed only one third of the Wellington (NZ) classrooms with CO_2 level above 1000ppm. Table 1 shows standard deviation (SD) for treatment classrooms lower than in the control classrooms in each school. This indicates lesser variation of the sample in treatment classrooms than in control classrooms.

Table 1: CO_2 level in the 6 classrooms from 9am to 3pm

Classrooms	Mean (95% CI)	SD	Range
CO_2 (ppm)			
1 C	1299	526	390 -- 3476
1 T	1362	507	448 -- 3376
2 C	1340	530	386 -- 3666
2 T	1045	417	403 -- 2892
3 C	955	427	390 -- 2698
3 T	870	383	400 -- 2248

School 1 showed some unexpected results with a CO_2 level in the control classroom (1C) lower than in the treatment classroom (1T). This level (1362ppm) was lower than the mean CO_2 levels found in other studies (Cutler-Welsh, 2006; Fromme *et al.*, 2007). There may be several factors contributing to a high level of CO_2 in classroom 1T, including doors and windows of classroom 1T assumed being kept closed for the majority of the school hours when doors and windows were open in the adjoining control classroom (observation during data downloading). However the number of occupants in classroom 1T was lower than classroom 1C.

In School 2 and School 3, the solar collector unit played a positive role in reducing the concentration of CO_2 in treatment classrooms. However in School 2, CO_2 levels in both classrooms were above 1000ppm (recommended guideline). School 3 showed CO_2 levels well below 1000ppm. Several factors may have contributed to this lower level. Firstly, the volume of classrooms in School 3 is bigger than in other schools. Then the monitoring device was located close to the exterior door, which would have introduced a flow of fresh air every time the door was opened. But the sensors were located in the best available location in these classrooms.

Figure 2 shows exposure to CO_2 in the 6 classrooms during school hours.

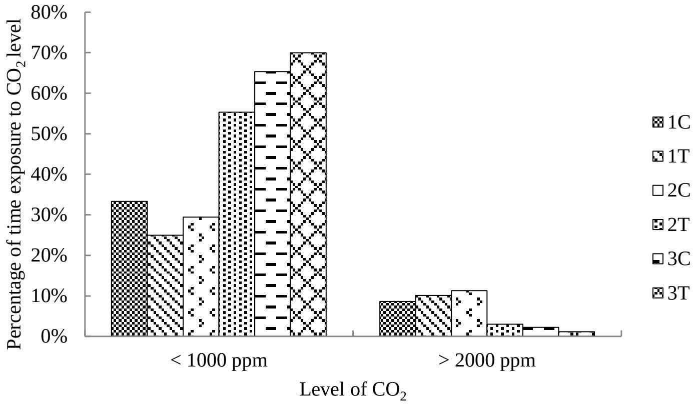

Figure 2: Percentage of time exposure for each level of CO_2 in the 6 classrooms from 9am to 3pm

Exposure to CO_2 below 1000ppm was very similar in School 1 and School 3 for both treatment and control classrooms. However in School 2 exposure to CO_2 below 1000ppm in treatment classroom was two times higher than in control classroom, indicating a positive impact of the solar collector unit. This result is consistent with the largest CO_2 level difference (300ppm) found in Table 2. Mclntosh (2011) found 13 out of 35 classrooms with the CO_2 level below 1000pmm for more than 50% of the school day, but there were 3 out of 6 classrooms with the CO_2 level below 1000pmm for more than 50% of the school day in this research. Similar results were found for exposure to CO_2 above 2000ppm for School 1 and School 3. Again the solar collector unit shows a positive result in School 2 with the exposure three times lower in treatment classroom than in control classroom for CO_2 level above 2000ppm.

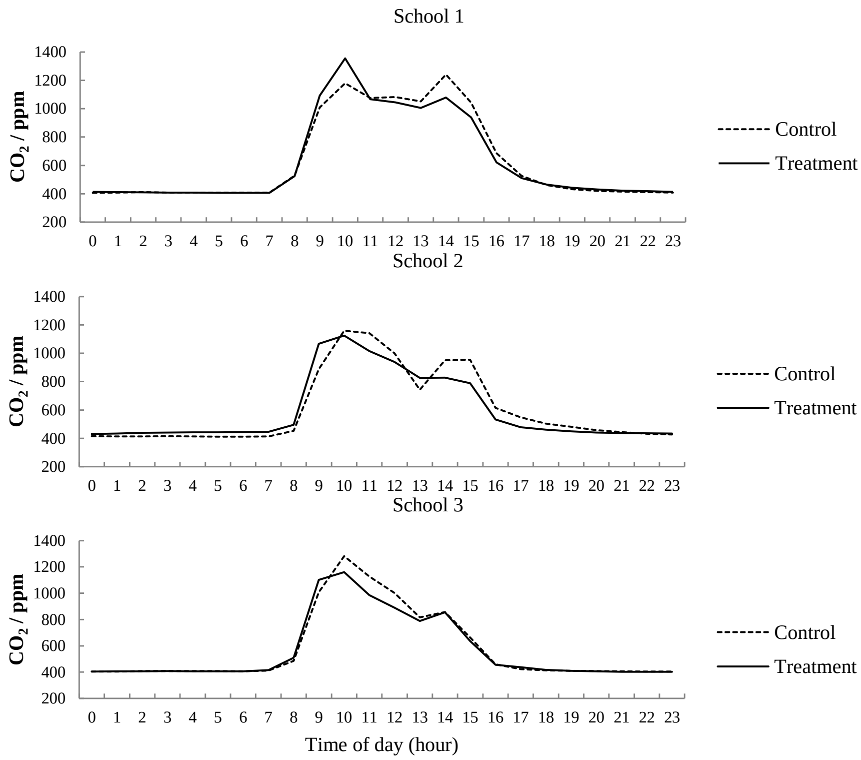

Figure 3: Relationship between CO_2 level and time of a day for each school

Figure 3 shows averaged hourly level of CO_2 during a week period (26th Aug. - 30th Aug.). The level of CO_2 was stable at 400ppm from 8pm to 7am in all classrooms (similar to the ambient level). There was no internal source of CO_2 during this period. With teachers and students coming to the classroom, the level of CO_2 increased from 8am and peaked at around 10.30am. Following the peak, there was a decrease until 13.30 (lunch time). There are two reasons to explain this decrease. Firstly, the windows and doors could be open as the outside temperature rose. Secondly, there were outdoor activities during this period on school schedule (observation during data downloading). The CO_2 concentration gradually decreased to 400ppm after the rebound between 13.30 and 15.30. This rebound was due to the assembling in classroom before home time.

Temperature and heater usage

The NZ Ministry of Education recommends an indoor classroom temperature of 18ºC (Ministry of Education, 2003). The WHO has suggested temperature between 18ºC and 24ºC (WHO, 1987). The risk of respiratory infection will increase for temperature below 16ºC, and the risk of cardiovascular strain will increase for temperature below 11ºC (Pierse *et al.*, 2011).

Table 2 shows in all classrooms the averaged temperature level fell within the WHO recommendation. Whereas Mclntosh (2011) reported the mean temperature in 8 out of 35 (23%) Wellington junior classrooms were below 18ºC during school day. In School 1 (1C, 1T) and School 3 (3C, 3T), despite higher usage of heater in control classrooms, the temperature in treatment classrooms were higher than in control classrooms. However due to a heater usage almost 4 times higher in control classroom than in treatment classroom in School 2, the solar collector unit was not power enough to create higher temperature. Higher SD in all treatment classrooms shows more fluctuation due to strong link with weather change, when compared to purchased energy in control classrooms.

Table 2: Temperature and heater usage in classrooms from 9am to 3pm

	Temperature			Heater usage	
Classrooms	**Mean (95% CI)**	**SD**	**Range**	**Total heater usage (hours)**	**Ratio of heater usage (C/T)**
1 C	20.6	1.88	13.6--25.8	90	1.4
1 T	21.5	1.90	13.9--26.8	63	
2 C	21.3	1.72	14.2--25.0	91	3.8
2 T	20.6	1.74	12.3--24.6	24	
3 C	22.3	1.65	16.8--26.5	62	2.9
3 T	22.5	2.40	14.6--29.5	21	

Figure 4 shows the temperature exposure to below 16ºC (respiratory infection increase), to WHO recommendation (18ºC-24ºC) and to excess temperature (>25ºC). Temperature in classrooms should be maintained in the range of 18ºC to 24ºC (recommended range).

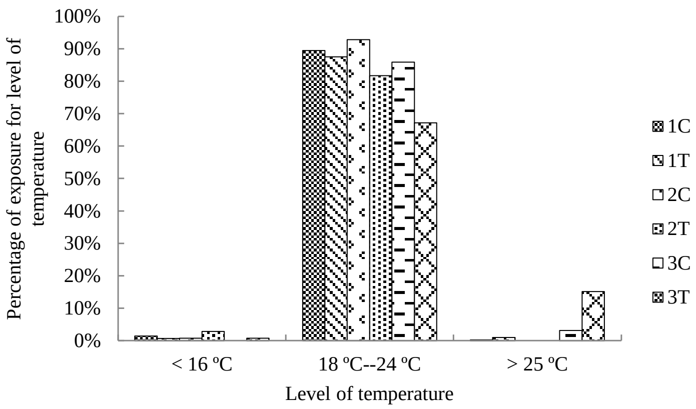

Figure 4 Percentage of exposure for each level of temperature in classrooms from 9am to 3pm

Figure 4 shows very similar result (with 80% of time in the recommended temperature range) in all classrooms but classroom 3T. Data shows 15% exposure to temperature above 25ºC (over heating) in classroom 3T. This overheating exposure was probably due to a high thermostat set point on the solar collector unit. Mclntosh (2011) reported that 9 out of 35 (26%) Wellington junior classrooms experienced a low temperature (< 18ºC) for half of the day and thirty out of these classrooms with

lower temperature (<16ºC) during school hours, whereas in our study only some 3% of school hours for classroom 2T were below 16ºC.

Relative humidity

American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE) has suggested an acceptable range for RH between 40% and 60% (ASHRAE, 2007) in the 20ºC-22ºC temperature range. Lower RH is bad for respiratory infections (Mendell and Heath, 2005), but RH above 70% benefits the survival and growth of airborne bacteria and fungi (Sterling *et al.*, 1985; Koep *et al.*, 2013).

Table 3 shows the average RH in all classrooms from 9am to 3pm.

Table 3: RH level in the 6 classrooms from 9am to 3pm

Classrooms	Mean (95% CI)	SD	Range
RH			
1 C	56.3	6.3	40.0 -- 78.0
1 T	54.4	7.9	34.0 -- 80.0
2 C	57.5	6.8	36.0 -- 79.0
2 T	57.1	6.8	38.5 -- 73.0
3 C	51.4	6.9	33.0 -- 73.0
3 T	48.6	9.6	26.0 -- 82.0

The minimum RH in all control and treatment classrooms was under 40% and the maximum was above 60%. However the mean RH for each classroom fell within the ASHRAE guideline. Mclntosh (2011) showed an averaged RH level in 11 out of 35 NZ classrooms exceeded 60%, whereas in our study we found all the classrooms within the ASHRAE recommended RH range (40%-60%). The mean RH was lower in treatment classrooms than in control classrooms (from 0.4% to 2.8%). SD of RH distribution in treatment classrooms was higher than in control classrooms in School 1 and School 3 and similar for School 2. It indicates more variation of the sample in treatment classrooms than in control classrooms. This is due to the connection with outside variable climate.

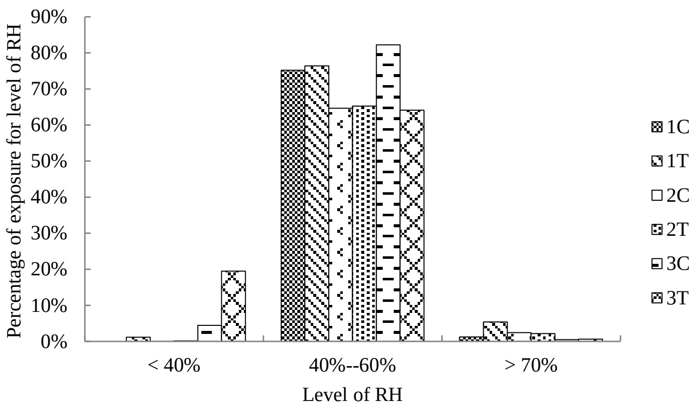

Figure 5: Percentage of exposure for each level of RH in classrooms from 9am to 3pm

Figure 5 shows a very similar RH exposure level to the recommended range (40%-60%) for School 1 (75%) and School 2 (65%). For School 3, data show 15% exposure to RH below 40%, this result is closely related to the finding in Figure 4, with higher temperature in the same time in classroom 3T.

Smedje (2000) suggested that there is positive relationship between the levels of CO_2 and RH. Our results are consistent with these finding for School 2 and School 3.

CONCLUSION

Our study on the effectiveness of the solar collector on IAQ showed:

(1) Mean concentrations of CO_2 were lower in treatment classrooms than in control classrooms, but this difference was not statistically significant (P_{value} = 0.86). Exposure to CO_2 level below 1000ppm was more than 50% school day in 2 out of 3 treatment classrooms.
(2) All classrooms were within the range of ASHRAE recommended RH guideline (40%-60%) for more than 63% of school day.
(3) All classrooms were exposure to WHO recommended temperature guideline for at least 67% of the day. The exposure to recommended temperature in control classroom was higher than in the adjacent treatment classrooms but at the expense of energy consumption.
(4) The heater usage in the three control classrooms was 1.4, 3.8 and 2.9 times higher respectively than in adjacent treatment classrooms.

Thus the solar collectors played a positive role on improving IAQ in classrooms and reducing heater usages.

ACKNOWLEDGEMENTS

This study was funded by the Health Research Council of New Zealand, the New Zealand Lottery Grants Board, the Building Research Association of New Zealand, Massey University and Otago University.

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BUILD BACK SMARTER: CASE STUDIES OF HOUSE PERFORMANCE RETROFITS AT THE TIME OF EARTHQUAKE REPAIRS

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ABSTRACT

Beacon Pathway has been researching ways in which improved house performance upgrade measures can be included alongside repairs of residential houses damaged during the Canterbury earthquakes. Because of the nature of residential renovation behaviours, combined with the large number of houses requiring repair (as many as 100,000) the rebuild represents the most significant opportunity to improve the performance of residential dwellings in Christchurch for the next 20-30 years.

The kind of damage sustained in the earthquakes – broken chimneys, damaged roofs, ceilings or walls, broken or poorly fitting windows and frames, cracked or damaged floors or foundations – is the kind of measure which combines very well with home performance improvement. In particular improvements such as installing insulation (particularly in walls), efficient heating and hot water systems would ideally be undertaken alongside earthquake repairs. Getting earthquake repairs underway is a complex process and, even though improving home performance is commonsense, there are considerable barriers to including these improvements.

In order to trial undertaking house performance upgrades at the time of repair, and to develop and demonstrate a robust approach to including home performance upgrades into "standard" repairs, six case study houses were looked at. A range of performance improvements were undertaken in the case studies including: ceiling, wall and underfloor insulation; double glazing retrofits; hot water system upgrades; heating upgrades; water efficiency measures; and ventilation improvements.

The case study evaluation found that the implementation of this approach was practical and cost effective and that scale up at a city wide level was possible.

KEYWORDS:

Retrofit; earthquake repairs; case studies

INTRODUCTION

The Canterbury earthquakes (Sept-09, Feb-10 and Jun-10) had a massive impact on the region's housing stock with 15-17,000 houses demolished, 100,000 homes with Earthquake Commission repairs under $100,000 in value and 15,000 homes needing major repair with a value of more than $100,000 (EQC 10 June 2013, IAG 9 April 2013, Southern Response 9 April 2013). This compares to the 3,300 renovations estimated to normally occur annually in Christhchurch**.**

Alongside the numbers of homes needing the repair, the nature of the damage : broken chimneys, damaged roofs, ceilings or walls, broken or poorly fitting windows and frames, cracked or damaged floors or foundations provided a unique opportunity to upgrade the thermal envelope of many houses, something not regularly undertaken in the life of a 'typical' NZ home. For example it is estimated wall linings are replace about every 30 years (estimate from Winstone Wallboards).

Beacon proposed that performance upgrades could 'slipstream' the earthquake repair process and result in warmer drier homes for Canterbury residents. Given the repair process would be disruptive to residents it made sense to intervene and improve performance while builders, plumbers, electricians and other tradespeople were already working on Canterbury homes. Beacon promoted this as an

efficient way to upgrade the housing stock in a region and could provide New Zealand, and perhaps the world, with a proven process to recover from a natural disaster.

A wide range of barriers to such a process were identified by government, insurers, the Earthquake Commission and stakeholder groups. In order to trial undertaking house performance upgrades at the time of repair, and to develop and demonstrate a robust approach to including home performance upgrades into "standard" repairs ten case study homes were identified and trialled with the "upgrade at the time of repair" – or Build Back Smarter approach. Of these 6 houses were upgraded and repaired during the two year life of the evaluation. These case studies and the implications for the Canterbury rebuild as well as future disaster recovery in New Zealand are discussed.

METHODS

Selection of Case Study Houses

Proposed Sample Frame

A project plan was developed in conjunction with key stakeholders and a sample frame for selection of case study homes was developed. A number of parameters were examined in relation to this, but ultimately only housing typology and the type of damage were determined to be critical factors.

Typology

In order to retain simplicity in the project only detached dwellings (which don't rely on adjacent properties for structural/fire safety aspects) were included in the initial sample frame.
Because retrofitting wall insulation was expected to be a key intervention, it was decided that only light timber framed buildings would be included in the project – ie houses with concrete walls in the main living area for example (where wall insulation retrofit is trickier) wouldn't be included.

Houses built in the 1990s in particular have also been identified (Ryan et al, 2008) as less suitable and easy to retrofit. Houses built post 2007 should have been built with current Building Code standard insulation, which is significantly greater than the pre-2007 standard (DBH 2007). More modern houses could also be expected to have relatively new hot water systems and better heating than older homes. For this reason houses built prior to 1990 were also preferred.

Type of damage

In order to be able to test the range of interventions proposed a minimum level of damage for participant houses was considered necessary. As wall insulation is seen as a key component, only include houses with damage to external cladding or internal linings in at least the living areas, but preferably also the bedrooms were included in the sample frame.

Timeframe for Repair

The project was intended as a three year project, from July 2010 to June 2013, allowing for full repair and evaluation of outcomes. In order to meet these timeframes, only houses where houses were planned to commence before the end of 2010 were intended to be included in the project.

Source of Homes

When commencing the project, the focus was on houses with substantial damage – where the greatest opportunity for upgrade was anticipated. Houses with damage of less than $100,000 value were being dealt with through the Earthquake Commission (EQC) repair process, while those with damage greater than $100,000 in value being repaired by their insurer. Accordingly the two largest insurance companies represented in Canterbury – IAG and AMI Insurance (subsequently bought out by the Government and renamed Southern Response) were recruited as partners to the project with the case study homes to be provided from their pool of 6500 major house repairs. These companies' project management staff were briefed on the project criteria, and asked to refer homes that appeared to meet these criteria to the Build Back Smarter team, so that they could be evaluated in detailed for suitability, with the homeowners then being invited to participate.

Actual Case Study Home Selection
While the sample frame was developed with the intention that house selection would commence in July 2010 and that repairs and upgrades would commence in case study homes shortly after than, in actuality no house was referred by the insurance companies for consideration by the project until February 2012. This is because no repairs were being undertaken by the insurance companies while legal issues around the apportionment of repair costs between the insurance companies and the EQC were being resolved. As time progressed, a pragmatic decision was made that the project would accept any homes as case studies on a "first come first serve" basis – as long as they met most of the sample frame criteria.

As a result the houses included as case studies were amongst the first repaired in Christchurch – with Huntsbury 2 being one of the first 6 repaired by the IAG insurance company – with repairs completed in October 2012 – a full three years after the first earthquake.

Case Study Homes
Table 1 sets out the case study homes included within the project. As can be seen from the table only 5 of the homes were actually repaired by June 2014 – with detailed insurance investigations leading to 3 being demolished /rebuilt, one being under repair for nearly 12 months and a further 3 still awaiting repair to commence – nearly 5 years after the first earthquake.

Table 1: Build Back Smarter Case Study Houses

House	Household	Typology	Location	Insurer/ PMO	Repair Status
Huntsbury 2	Retired couple	1950s Mass Housing+ 1980s addition	Port Hills	IAG/ Hawkins	Repair complete Oct 2012
Huntsbury 1	Family: couple and two children	1950s Mass Housing+ 1980s addition	Port Hills	Arrow/ Southern Response	Still awaiting repair June 2014
Woolston 1	Couple and disabled son, major health issues	1950s Mass Housing	On the flat	IAG/ Hawkins	Demolished
Cashmere 1	Couple	Villa + 2000s extension	Port Hills	Arrow/ Southern Response	Still awaiting repair June 2014
Mt Pleasant 1	Couple	Villa + 2000s extension]	Port Hills	IAG/ Hawkins	Repair complete December 2013
Spreydon 1	Couple	1930s bungalow [Lath and plaster linings]	On the flat	IAG/ Hawkins	Repair complete September 2013
St Martins 1	Single retired	1970s concrete floor, low pitch roof	On the flat	Arrow/ Southern Response	Still awaiting repair June 2014

House	Household	Typology	Location	Insurer/ PMO	Repair Status
Redcliffs 1	Rental.	1960s mass housing with more recent additions	Port Hills	Hawkins/ IAG	Repair commenced, then decision to demolish
Somerfield 1	Couple with 2 kids	Transitional bungalow [Lath and plaster linings]	On the flat	Arrow/ Southern Response	Repair complete September 2013
Halswell 1	Couple	1960s mass housing	On the flat	Hawkins/ IAG	Repair complete May 2013
Papanui 1	Extended family 3 gens	1950s mass housing	On the flat	Hawkins/ IAG	Work started 21 August 2013 - repair still underway as of June 2014
New Brighton 1	Couple	1950s art deco	On the flat	Hawkins/ IAG	Decision to demolish

Assessment of Upgrade Opportunities

Once the insurance companies referred homes into the project, and homeowners had agreed to participate, Community Energy Action, a Christchurch based home energy efficiency trust, assessed the homes using the Beacon Home Assessment and Plan Prioritisation (HAPP) tool. This tool had been developed during a national home retrofit project in 2009 and trialled in 600 houses (Easton and Saville-Smith, 2011**).** The tool was slightly modified to include assessment of opportunities for retrofit created by earthquake damage. The output of the assessment is an Upgrade Plan for homeowners, identifying the retrofit priorities for the specific dwelling. Table 2 outlines the types of retrofit opportunities identified through the house assessments of earthquake damaged homes.

Table 2: Retrofit Opportunities in Earthquake Damaged Homes

Damage to be repaired	Retrofits that can be included
Roof damage	Ceiling insulation – particularly in low cavity roof spaces and skillion roofs Install heat transfer systems in low cavity roof spaces
Ceiling damage	Removal of downlights Install efficient lighting Install externally vented bathroom / kitchen ventilation Install heat transfer systems
Cladding damage	Wall insulation combined with building paper
Wall lining damage	Wall insulation
Floor or foundation damage	Under-floor insulation Ground vapour barrier
Twisted or raked window frames	Double glazing/high performance glass Improved thermal frames Reduce window area on south side
Chimney damage	Replace older fires with efficient clean heating option
Hot water cylinder damage	Replace with solar, heat pump or wetback water heating

	Cylinder wraps and seismic restraint Upgrade and lag piping
Plumbing damage	Water efficient fittings Rainwater tanks

Implementation of Upgrades

The implementation of upgrades was undertaken at the same time as earthquake repairs, either by the building team assigned to the repairs by the insurance company, or by subcontractors identified by Beacon who worked under the insurance company appointed builder. The use of the insurance company builder was intended to ensure that the retrofits had a minimum impact on the pace of repair – something that had been identified as a significant concern for insurers and their project management offices. The insurer appointed builder is also responsible for health and safety on the repair site, and therefore needs to have a high degree of co-ordination and control of repairs. Subcontractors identified by Beacon were used in the installation of features where the builder team did not have the expertise – most notably insulation, where IOANZ accredited installers were required, double glazing, solar hot water and heat pump hot water system installation.

A Beacon project manager worked with the insurance company appointed builder to ensure co-ordination with these subcontractors – and that quality assurance standards were met. He also met frequently with homeowners to ensure they were engaged in the process.

Funding of the retrofits was provided by the project, however some homeowners also funded upgrade work at the time of repair, and this was also undertaken by the insurance appointed builders.

The overall project management of the site and repair (including homeowner funded improvements) was undertaken by the relevant project management office for the insurer – Arrow in the case of Southern Response insured homes, and Hawkins for IAG insured homes.

Evaluation Methods

The evaluation of the case studies focussed on the process of upgrades and ease of including these. This is because past research has well proven the performance benefits (Grimes et al, 2011; Burgess et al, 2010; Pollard, 2009; Burgess et al, 2009**)** and health outcomes (Telfar-Barnard et al, 2011; Howden-Chapman et al, 2008) of retrofitting houses. The focus of this project was how to undertake retrofits at the time of earthquake repair in a way that could be scaled up to large numbers of houses.

The case study evaluation involved structured interviews undertaken post repair with:

- Insurer's project manager
- Builder
- Homeowner

The process of repair was also carefully monitored and documented by the Beacon project manager who undertook a post repair assessment of the house.

The houses were also assessed pre and post repair using the Homestar™ online assessment tool, by a qualified Homecoach.

RESULTS

Inclusion of Retrofit at the Time of Repair

In all the case study homes, inclusion of the retrofit measures at the time of repair appeared to have no impact on the pace or difficulty of the repair process for the case study household, project management office, builder or insurer. The installation of the wall insulation at the time of repair was a measure which all parties (homeowner, builder, project manager) felt was a particularly worthwhile

measure to be undertaken at the time of repair. Where this was being done alongside the replacement of external cladding, good communication and co-ordination between the builder and the insulation subcontractor was required, however this did not create any delays in the repair process. In addition the extent of potential wall insulation installation was often greater than initially anticipated. This is because in some instances the cost in labour and time of wallpaper stripping and repairs to damaged plasterboard is often greater than complete replacement of the plasterboard.

In all cases the repairs spanned many months – and in some instances more than a year, with the retrofit work being a relatively minor component of the overall project.

In terms of the quality of installation however, generally the retrofits were relatively poorly installed by many of the insurer appointed building team, with quality work most often being achieved by the Beacon appointed subcontractors.

In 4 of the case studies where ventilation improvements were included (bathroom and kitchen extract ventilation and heat transfer systems) these were poorly installed to incorrect specifications. Most commonly the extract ventilation was not ducted externally, and in some of the cases was also incorrectly located. In 2 case studies the heat transfer systems were installed incorrectly – with inlets, outlets and thermostats installed in incorrect locations.

In all of the case studies where low flow plumbing fittings were specified as part of the retrofits, these were not installed as required by the insurer's contractors.

Where insulation was installed in the ceilings and underfloors as part of the retrofits by Beacon appointed subcontractors, problems with the builders, plumbers and electricians disturbing or damaging the insulation was also common.

Performance Improvement

While no performance monitoring was undertaken, the homes were assessed prior to and after the repairs. In the 5 completed repairs, the houses were all assessed as a 2 star Homestar™ rating prior to repair, and a 5 star Homestar™ rating post repair and retrofit. Homeowners all reported that they experienced improvements in warmth and comfort in the homes post repair and retrofit, with most attributing the greatest benefits from the improvements in insulation.

Ease of Scale Up

Homeowners, project managers and builders all saw the benefits of the Build Back Smarter approach to retrofitting at the time of repair, and there was a strong willingness to move from a case study/pilot to a wider pan Christchurch retrofit project.

Homeowners and project managers identified that there were two major factors that they saw were needed in any scale up of the service.

1. The whole house assessment and identification of priorities for retrofit. While there are many generic tools out there, homeowners indicated that the professional in home assessment and discussion of priorities with the assessor, was a critical factor in helping them to understand for their home, where expenditure was best directed.
2. The project management and communication role of the Beacon project manager. House retrofits were a small proportion of the total repair project. And homeowners identified that they already felt overwhelmed by the earthquakes, post earthquake assessment process for repairs, and long timeframe for action to occur. This has created substantial stress for homeowners and retrofit at the time of repair was seen by many as "too hard" without the help of an external facilitator/communicator to liaise between the insurer's project manager, the insurer's builder and the homeowner.

Cost of retrofits

In all the case study houses the homeowners took the opportunity to include additional improvements to their homes, beyond the earthquake repairs. This ranged from kitchen upgrades, to house extensions, as well as performance improvements such as double-glazing and improved heating systems. The value of these additional improvements ranged from $20,000 to over $60,000. In terms of willingness to pay for performance retrofits, all the households indicated that they would have been prepared to pay for some aspect of the retrofit if they had not been part of the project.

In terms of the costings for the retrofits funded by the project, it was identified that substantial additional costs were being incurred by including them as part of the repair works being undertaken by the builders. An additional margin of between 15-22% was added by the builder to the cost of materials and all labour being undertaken by subcontractors. This added considerably to the price of retrofits, and meant some measures were not undertaken for cost reasons. The actual prices of materials were also identified as being inflated in the Christchurch market when compared to the rest of New Zealand. For example, in house where the hot water cylinder was being replaced as part of the retrofit, the homeowner (who paid the cost for the cylinder as her contribution) bought a new hot water cylinder online and had it freighted from Auckland, in order to save an estimated $600 when compared to the price being charged for a comparable hot water cylinder in Christchurch. Other products such as rainwater tanks, were also identified as being much more expensive to supply from Christchurch, than other parts of the country

DISCUSSION

The Build Back Smarter pilot project was undertaken initially to determine whether retrofits at the time of earthquake repair could be achieved, and how easy it would be to develop a methodology whereby the scale up to a pan Canterbury programme was possible. At the start of the project it was anticipated that there would be a range of technical and logistic barriers that would need to be worked through in order to achieve a seamless process. There was a major concern that retrofits at the time of repair would result in delays and/or health and safety issues during the repair process.

In practice, neither of these issues came through as problems to the process. This is more fully documented in the Beacon report on the project (Easton, 2013). However the repair of homes in Christchurch has been dogged by extensive delays. It was 18 months from the commencement of the project until the first house was referred to the project team. And the repair of this first house was not completed until 3 years after the first earthquake. The other case study houses in the project were all "early" repairs –and as of June 2014 there remain thousands of houses in Christchurch with substantial damage that are experiencing their fourth winter in an unrepaired house.

The project found that the biggest barrier to homeowners upgrading homes at the time of repair is the help they need to make choices and prioritise action (the independent assessment) and the assistance – often moral as much as technical, to work through the process with their insurer, their project manager and their builder to incorporate retrofits into the repair process. The earthquakes have taken a significant mental and physical toll on homeowners and households in Christchurch. The extended timeframe, multiple assessments and processes undertaken by the EQC, it's project managers EQR and the insurers and their project managers has also exhausted the capacity of many Canterbury citizens.

In addition the project has identified capacity and capability issues within the building sector in Christchurch, which are barriers to retrofits at the time of repair. There has been an explosion of building activity in Christchurch and prices have increased substantially for both materials and labour. It may be that many contractors see this as a once in a lifetime opportunity to make a significant financial gain. In the same way it is a once in a lifetime opportunity to deliver better housing outcomes for Christchurch citizens. However the former, rather than the latter outcome seems likely. For the last 12 months the Canterbury Sustainable Homes Working Party – a pan government, NGO

and interest organisation, has been trying to facilitate a scale up of the Build Back Smarter approach across Canterbury.

While it is clear that key organisations are committed to upgrade at the point o repair, as evidenced by their investment in investigation and public statements, a joint solution has proved elusive to date. This intervention needs a new business model; it needs action from central government (across multiple agencies), local government, industry and the NGO sector. The business model needs clarity from each of the players as to their role; this has been institutionally and economically complex.

CONCLUSION

There is widespread support across central and local Government, insurers, builders, project managers and homeowners for a cross-Christchurch scale up of a Build Back Smarter service. There are an estimated 15,000 houses where substantial repairs are yet to be commenced who could benefit from such a service. The Christchurch rebuild represents a once-in-a-generation opportunity to see a substantial improvement in many Christchurch homes. At this stage however it appears unlikely that this outcome will be achieved. There are lessons here for other natural disasters.

ACKNOWLEDGEMENTS

I would like to thank the Beacon Project Manager, Bill King for his many hours spent working with homeowners, builders, project managers and insurers undertaking the pilot project. The project was funded by the Ministry of Business Innovation and Employment, the Energy Efficiency and Conservation Authority and Fletcher Building.

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HOW COULD NEW ZEALANDERS BUILD RESOURCES & CAPABILITY FOR THE ON-GOING CARE OF THEIR HERITAGE HOUSING?

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ABSTRACT

In 2014, Victorian and Edwardian villas, built around the turn of the 20th Century, have come of age. The classically referenced designs were crafted from the heart of native trees and have endured over a century of life. Their timber framed structures have been resilient to earthquake forces. The property values of inner suburbs have ensured they were retained, their decorative exteriors protected by layers of paint. The interiors are less intact, ravished by changing occupation and fashions. Recent surveys have found that attempts at restoration were thwarted by the lack of design and technical resources. Common renovations, to increase day-lighting, open-plan kitchens to dining and to connect living spaces to the exterior were foreign concepts to the villa typology. Results were sometimes sympathetic but more often destructive. A survey of heritage advisers, architects and tradespersons found an urgent need for guidelines. This paper sets out a blueprint for researching and disseminating resources for the restoration and renovation of heritage housing in New Zealand. It considers the mandate and responsibilities of public sector organizations including Heritage New Zealand, Department of Building & Housing, local governments, and the Building Research Authority of New Zealand (BRANZ). It proposes facilitating a Heritage Housing Network for information sharing between heritage researchers, designers, building contractors, craftspeople and home owners to build national capability and cultural pride in regenerating heritage housing.

KEYWORDS:

housing regeneration; heritage design; building craft.

INTRODUCTION

Victorian and Edwardian timber villas populate the inner city suburbs of New Zealand cities and towns. Constructed in timber frame and of native timbers, they have endured a century of occupation. Recent research has confirmed that there is not sufficient publicly accessible design and construction resources and capability to preserve or restore their character and sensitively integrate modern expectations for comfort, convenience and higher building standards. This paper sets out to investigate how the required research and education could be undertaken. Firstly, the background of the New Zealand villa is presented and the evidence for the need for resources and increased capability is summarized. In order to understand who might collaborate in this initiative, current public and private stakeholders involved in heritage housing are identified and their current roles are discussed. Stakeholders extend from Government ministries, departments, agencies, the building industry, design professionals, researchers, universities, heritage organizations, house owners and the general public. Findings are brought together in a discussion and finally a proposal to bring key stakeholders together to set the initiative in motion is presented.

BACKGROUND

In 2008, it was estimated that 86,000 villas existed throughout the country (Page & Fung, 2008). The New Zealand villa (1890-1914) is a unique hybridisation of Gothic Revival features, classical Italianate architecture and the presentation of Victorian social concern. Originally, the term ‘villa’ had referred to a stand-alone country house owned by the wealthy; a housing type which flourished during the Georgian era in Britain (1715-1830). However, as architect Bill Toomath argued, the New Zealand

style owed as much to the American suburban adaptations of the style as it did to British origins (Toomath, 1996). By the time it had reached this country (in the late 19th century), it had adopted a looser description as a comfortable house with more than four or five rooms. Essentially, anything that was larger than a cottage became a villa by proxy.

Basic four-roomed settlers' cottages were typically developed by pushing out a front room into the verandah space to form a gabled bay, breaking the symmetric facade. In its simplest form, the villa became the basic building block of turn of the century New Zealand towns. Comprised of largely standardised, manufactured elements, more elaborate forms and complex geometric and spatial arrangements displayed financial and social success of the occupants. Enterprising carpenter-architects, adapting plans from pattern books and sourcing a veritable range of house products from local timber companies, created a housing stock that proved remarkably resilient and adaptable. Similar floor plans were adopted on a variety of sites, including the hilly terrain of Wellington where their topographic navigations were reminiscent of San Francisco.

While the external Italianate style was American inspired, the internal spatial layout was indicative of the social beliefs held by the Victorians. As Toomath explained; 'The elaborately ornamented, bay-windowed, high wooden villas gave expression to Victorian society's pride in property... which appealed to the self-made man' (Toomath, 1996). Privacy was important, with the verandah acting as a demarcation of public and private space. Front rooms (often the drawing room and master bedroom) were the most decorative to indicate the affluence and good taste of the occupants. Every surface became an opportunity for decoration, with wallpaper, elaborate materials and carpets, timber panelling, pressed metal, decorative glass and plaster all commonly used. Utilitarian spaces, beyond the hallway arch, were far more restricted in their interior finishes, with bathrooms (if there was one) and kitchens basically furnished.

Figure 2. Century old timber villas on the hillside of Aro Valley, an inner city suburb of Wellington.

In 2014, villas, particularly in central city suburbs, are prime real estate. Gentrification of some areas has pushed house prices high, but the typology similarly remains a domain of students, young professionals and families. For much of the 20th century villas had been viewed with derision, as urban populations pushed out in the suburbs in search of space and a contemporary housing aesthetic. They found revived appreciation in the 1970s, when a new generation enthusiastically recognised its potential for renovation, restoration and adaption as family homes. Simple, straightforward organisation of villas makes them well suited to adaptation. However, a lack of understanding of the architectural style combined with modern requirements (open-plan living, contemporary kitchens and bathrooms, garages), results in too many renovations using inappropriate proportions, features and materials. In 2002, Di Stewart noted that 'the desirable nature of these houses and areas are causing their occupants to expect more from their living conditions, putting the building's integrity under strain as it deals with multiple renovations' (Stewart, 2002). These can compromise the integrity of the bay villa form and detract from its cultural heritage.

THE NEED FOR RESOURCES AND INCREASED CAPABILITY

Currently there is little guidance for the owner of a traditional residential building in planning repairs or modifications, if it is not listed by a local authority or registered by the New Zealand Historic Places Trust (NZHPT). There were several key books, dating back some 25 years, produced by conservation professionals: *Restoring a New Zealand House* (Cochran, 1980), *Restoring with Style: Preserving the Character of New Zealand Houses* (Hill, 1985), *Old New Zealand Houses* (Salmond, 1986), *The New Villa: Past and Present* (Stewart, 1992 & 2002) and *The New Zealand Period House: A Conservation Guide* (Arden & Bowman, 2004). These books are available in public libraries but many are out of print. Other recent publications, *Built in New Zealand: The Houses we live in* (Toomath, 1996) and *Villa: From Heritage to Contemporary* (Hansen & Salmond, 2009) investigate the pedigree of the villas and celebrate villa living today. One of the larger local authorities provides a booklet which is aimed at private home owners (NSCC, 2003) but practical information to inform villa restoration and renovation decision making is generally not readily available.
In 2009, the Building Research Association of New Zealand (BRANZ) research report 'Determining the industry need for a Retrofit and Renovation information resource' (Hindley & Pringle, 2009) reported on a survey of architects and designers and found a significant gap in appropriate details and solutions; difficulty finding and making like for like substitution replacement; fitting new elements into existing structures; working out original building details; finding style and period information. Subsequently, BRANZ published a technical resource on villa renovation, *'Renovate Villa'* (Pringle, 2010) and a website, *Renovate – a technical resource for industry* (BRANZ, 2014). These publications illustrate typical original house construction and finishes and identify common issues requiring repair. Alternative compliance paths for renovation work are explained but example solutions are not offered. New Zealand has a performance-based building code. For the detailed construction in new timber framed buildings, a compliance document with Acceptable Solutions is available. Additions and alterations to heritage housing require building consent and any new construction is required to meet the NZ Building Code. Most original timber framed construction is not code compliant; for reasons including inadequate sub-floor heights, lack of insulation and double-glazing and a drained cavity or building papers behind weatherboards. The integration of such requirements into the villa typology raises common issues, yet common acceptable solutions are not publicly accessible or even agreed by the Territorial Authorities. Conservation architects may have an in-house library of such details but inexperienced architects and builders are forced to design from first principles or limited experience. Furthermore, the incorporation of historically authentic design principles in interior and exterior detailing is difficult and demands a high level of knowledge and design skill. The resulting cost of the complex design and building consent approval processes are a factor in dissuading home-owners from any restoration or renovation work except for basic maintenance. Poor productivity within the wider New Zealand building industry was confirmed in an industry report (CENZ, 2010) citing poor education and skills and lack of information sharing as contributing factors. In 2014, BRANZ launched a website, of down-loadable technical details (BRANZ, 2014). While the details address weather-proofing no reference to historical design styles is made. The initiative does signal the potential of internet information transfer.

In 2010, Victoria University of Wellington with funding support from BRANZ, undertook detailed case studies tracking the alteration of sixteen timber villas in Wellington. An analysis of the case studies revealed an apparent lack of information on original design features and the need for further research and publicly accessible design resources (Mackay, 2010). A 2011 study, partially funded by Wellington City Council, *Scoping Resources for the Restoration and Renovation of Wellington Villas* (Hughes & Mackay, 2011), reported on interviews with home owners, design professionals, trades-people, builders and heritage advisors involved with villa restoration and renovation. The survey confirmed the need for the following information: strategies for restoration and renovation, guides on sympathetic additions and alterations, source books on historical detailing (including timber mouldings and joinery details), advice on upgrading thermal performance and day-lighting, design and construction guides for the restoration of typical villa features (including verandahs and balconies), information on traditional exterior and interior finishes and maintenance (both short and long term) schedules.

Two recent initiatives were focused on sharing knowledge and building networks. In March 2010, in Auckland, heritage & conservation architects Salmond Reed (Salmond Reed, 2012) held their first one day workshop; on lime materials. In 2011, a second workshop for 30 participants was held on 'architectural paint sampling and analysis'. A following workshop focused on 'roofing'. A Salmond Reed participant survey identified topics for future workshops: timber conservation, building materials technology, masonry and concrete repair technology, Canterbury earthquake feedback, decorative metalwork, NZ building stones, NZ building timbers including overview of changes in prevalent species as stocks are exhausted, history of glass for buildings in New Zealand, the conservation/heritage argument for sustainability/ESD/Greenstar, conservation plan & policy writing (particularly those for management of building and landscapes) and roofing materials (shingles, lead and metalwork) (Salmond Reed, 2011). In November 2010, in Wellington, Conservation Architect Paul Cummack set up a grass-roots organization Contechi to provide seminars and networking for designers and advisers involved in architecture heritage conservation (Cummack, 2012). While these activities are successful in exchanging knowledge locally, they do not meet the need of national information resources. Also, opportunities for professional heritage and trades education and training in Australia and New Zealand were recently reviewed on behalf of the Heritage Chairs and Officials of Australia and New Zealand (HCOANZ). The report identified 'looming skills shortages' for heritage professionals and specialist heritage trades (HCOANZ, 2010).

In 2011, George Farrant, Principal Heritage Advisor, Auckland City Council considered that there was 'not only a need', but rather 'it's a dire need' for resources for restoration and renovation of villas. (Hughes & Mackay, 2011) However, many questions remain. 'How could these be provided? Who should to lead such an initiative? Who could and should fund the research, the dissemination of findings and the net-working? In order to answer these questions, the following section investigates the current stakeholders.

STAKEHOLDERS AND POTENTIAL COLLABORATORS

Stakeholders involved in the on-going care of heritage housing extend from Government ministries, departments and their agencies, the building industry, design and building professionals, educators to house owners and occupiers.

The Department of Building and Housing (DBH), now part of Ministry of Building Innovation and Employment, was set up in 2004 to 'improve building quality and housing availability in New Zealand' (DBH, 2014). The department is responsible for building and housing policy making, regulation and dispute resolution. Their 'Statement of Intent 11/14' does not specifically identify the regeneration of existing housing stock or acknowledge the value of heritage housing design in society. DBH administers a wide range of legislation and regulations on housing design, building construction and services, consent processes and resolution services as well as for the licensing of engineers, architects, project managers and tradespeople. Principal documents are the Building Act and the New Zealand Building Code. DBH communicates information to the public via their ConsumerBuild web-site (DBH, 2014) which aims to provide 'independent advice on buying, renovating and maintaining homes'. The content, aimed at the general public, is brief, basic and generic and not of practical use in understanding the complexities of old houses. It recommends seeking design services from to building designers and advises to 'take care to renovate to the existing style of the house and neighbourhood' only to facilitate on-sale. DBH does not acknowledge the social and cultural value of heritage housing design and craft or provide any support for its conservation or maintenance. It appears that only the amenity value of housing is supported.

The Ministry for the Environment (MFE) states its mission as 'environmental stewardship for a prosperous New Zealand' (MFE, 2014). The Ministry provides information to the public on the Resource Management Act (RMA), the legislation behind District Plans. District Plans can include heritage areas where changes to the external envelope of heritage houses are strictly controlled. In 2007, the Ministry held workshops on the scope of heritage management under the RMA for practitioners. (MFE, 2012).

Local Government Territorial Authorities (TA), are required to implement planning and building regulations, principally the RMA with regards to urban planning and the Building Act with regards to building. Local Government New Zealand (LGNZ), a membership organisation, aims to be the national voice of local government and the champion of best practice in the sector of almost 80 local authorities. The LGNZ mission is - "Effective local governance across New Zealand" and it is interested in working to achieve objectives including ensuring services are provided to the community in the best way possible, taking a collective approach to community needs and creating a sense of local identity and place. Local government focuses on providing for the well-being of communities and has a key role to play in securing these outcomes for communities. The organisation concentrates on issues which impact on the local government sector and it plays the role of a cohesive voice for the large number of local authorities in New Zealand. This is an important role as the LGNZ can interface with government departments and ministries on behalf of its members, and is well regarded in government circles. With regard to heritage issues LGNZ has recently facilitated discussion and meetings between representatives of local authorities and relevant government ministries in the proposed review and rewrite of Historic places legislation. It has provided the forum for discussion for Local Authorities which may not otherwise have had the time or resources to make their voices heard.

The New Zealand Historic Places Trust (NZHPT) is an autonomous Crown Entity and an agency of the Ministry for Culture & Heritage. It is established under its own Act of Parliament – the Historic Places Act. It is governed by a Board of nine members, who are appointed by the Minister for Arts, Culture and Heritage on the basis of their skills, knowledge or cultural background relating to historic heritage. The Historic Places Act 1993 also established the Maori Heritage Council to advise on the identification and protection of Maori heritage. The Trust's core activities include identifying New Zealand's significant heritage places, which is an important first step in managing and conserving this finite resource. The Register is only an identification tool; it does not give any protection to places that are included on the Register. The NZHPT cares for 48 nationally significant heritage properties. There is also a membership arm of the Trust, to which members of the general public can belong. Membership numbers are static due to a range of factors, not least of all the current recessionary economy. The role of the Trust is often not clear to the average citizen, there is a perception that the Trust protects heritage places, but this is not the case. Protection is provided by local authorities of which there are 74 in New Zealand. As each local authority has its own policies and rules, this means that there is a great deal of variability in what and how heritage places are managed and/or protected. This causes confusion for the public and does not provide the best environment for heritage protection.

The Energy Efficiency & Conservation Authority (EECA) is a crown entity which promotes energy efficiency and the use of renewable energy. The Energy wise provides basic principles to improve energy efficiency for during house renovations. The web-site does not provide comprehensive results of evidence based research or detailed design solutions for the unique issues related to insulating an original timber villa. (EECA, 2012)

Building Research Association of New Zealand (BRANZ) is an independent and impartial research, testing, consulting and information company providing resources for, and owned by, the building construction industry in New Zealand BRANZ, 2012). Under the Building Research Levy Act 1969, it is funded by levying building contractors at the point of building consent applications. Indirectly, this cost is passed on to building owners. Their services include testing and research, education product appraisal and technical advice. BRANZ is wholly owned by Building Research, an independent organization owned by the building construction industry in New Zealand.

Architects and architectural designers are required to be registered by the New Zealand Registered Architects Board (NZRAB) or licenced under the Building Act Licenced Building Practitioner (LBP) scheme in order to sign off building consent applications for significant house alterations. Mandatory continuing professional development (CPD) applies to both groups. Maintenance work or alterations not affecting the building envelope, structure or plumbing system are not regulated. In 2012, the New Zealand Institute of Architects (NZIA) had around 3000 members. Approximately fifty percent are

registered architects working in New Zealand. Although the NZIA prime focus is to promote ‘excellence in architecture’ the objects of the institute also include ‘the acquisition and dissemination of knowledge relating to architecture’ and ‘to improve and elevate the technical and general knowledge of persons engaged in architectural practice’ and to undertake initiatives ‘in conjunction with any other professional body or bodies, institutes or institutions’ (NZIA, 2012a). NZIA promote the NZ ICOMOS Charter and provide Heritage & Conservation Guidelines (NZIA, 2012b) to members. Guidelines ‘support research and education into the conservation of cultural heritage and the built environment. NZIA Awards include a ‘heritage’ category, although public architecture gained the 2012 heritage awards. NZIA manage continuing professional development courses necessary for on-going registration. This facility, including an e-learning platform could be useful in disseminating information. In October 2011, NZHPT listed twenty four New Zealand architectural practices specializing in conservation work. Architectural Designers New Zealand (ADNZ) is a professional body of over 350 architectural designers and architects (ADNZ, 2012). Members must hold recognised professional qualifications or relevant experience and undertake compulsory CPD. Designers Institute of New Zealand (DINZ) have ‘spatial design’ members but these designers do not advertise interior heritage design services. The Institute of Professional Engineers of New Zealand (IPENZ) include a heritage division but its focus is on engineered structures and machinery rather than buildings (IPENZ, 2014). All architectural associations provide opportunities for further on-going education. Compulsory CPD provides an effective dissemination route for information.

Builders and carpenters are required to be licensed under the LBP scheme in order to undertake consented work on housing. Licensed building practitioners require a recognized qualification usually provided by Industry Training Organizations (ITO’s) and/or sufficient experience on site. CPD is mandatory for licence renewal. Practitioners can become members of the Registered Master Builders Federation Association or the Certified Builders Association of NZ. RMBF is committed to recognizing heritage work through an award for the ‘renovation of the year’ (RMBF, 2012). Joiners do not require to be licensed but can apply to be a member of the Registered Master Joiners Association.
Tertiary education institutions are governed by the Education Act (1989) which requires that ‘research and teaching are closely interdependent’, institutions ‘are a repository of knowledge and expertise’ and that they ‘accept a role as critic and conscience of society’ (UNZ, 2012). All Schools of Architecture: University of Auckland, UNITEC and Victoria University of Wellington (VUW) offer Masters degrees in Architecture. Some design studios will engage with the design of existing buildings but only VUW offers undergraduate courses in conservation architecture; Building Heritage Conservation and Interior Heritage Conservation (VUW, 2012). Masters qualifications can include practice-based design research theses, which are potential vehicles for building knowledge on regeneration of heritage housing. No dedicated qualifications in conservation architecture are offered in New Zealand, although the Museum & Heritage Studies at Victoria University include the study of the conservation of material culture. Around the country, nine tertiary institutes offer courses on traditional Maori crafts (HCOANZ, 2010). In 2012, UNITEC is hosting a two week course in Italy for students and practitioners. In August 2014, HNZPT is hosting a week-long workshop led by Australian conservation expert, David Young for 25 participants. (HNZPT, 2014)

Australasian Housing Researchers’ (AHR) conferences together bring researchers mainly involved in policy, economics and social housing. In recent years design and heritage have not been a focus of conference calls. Beacon Pathway Inc is an incorporated society with aims to facilitate research to improve the performance of poor performing existing housing and new housing (Beacon Pathway, 2012). Centre for Housing Research Aotearoa New Zealand (CHRANZ), established by Housing New Zealand Corporation (HNZC) in 2003, sets ‘housing research priorities for the total housing market and invests in independent research’ (CHRANZ, 2014). HNZC manage state houses (built after 1940) and tenancies. Housing Research for New Zealand is ‘a collaborative project that aims to improve access to current information about all aspects of housing’ (HRNZ, 2014). The internet portal, seeks to address the 21st C issue of locating information and links to over 6,000 files. In the architectural history field, at VUW, Senior Lecturer, Nigel Issacs researches history of building technology and Christine McCarthy, facilitates annual seminars on New Zealand architectural history.

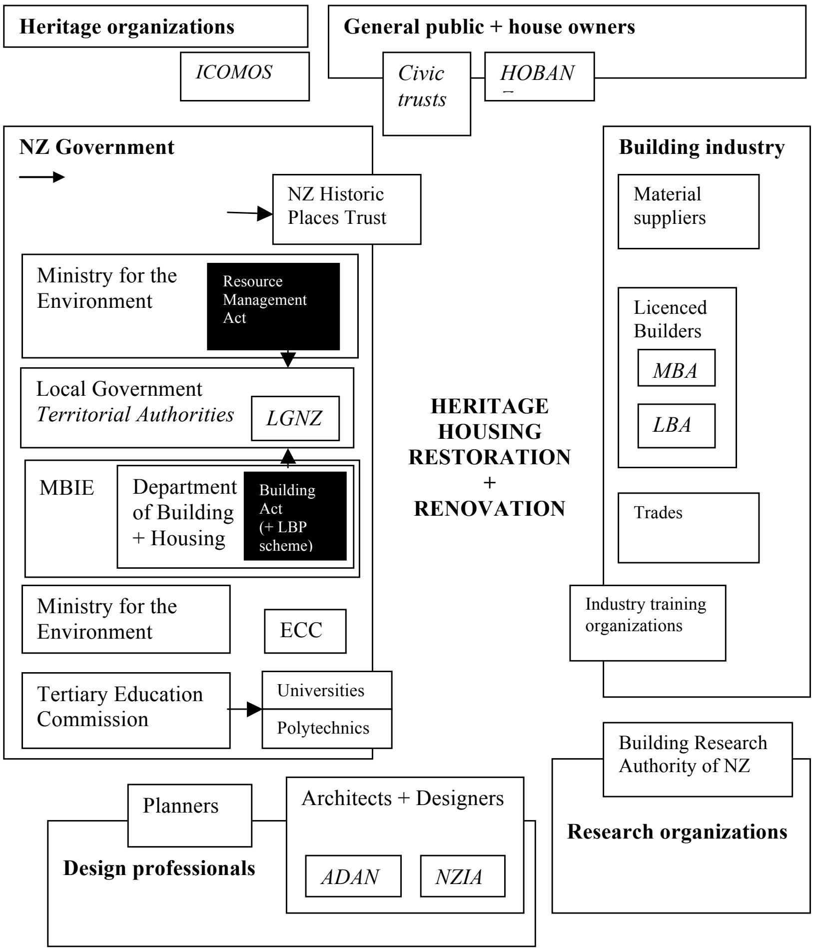

Figure 2: Diagram of stakeholders in heritage housing in New Zealand. Key Acts are highlighted. Professional organizations are noted in italics.

ICOMOS, the International Council on Monuments and Sites, is an international non-government organization of heritage professionals engaged in the conservation of places of cultural heritage value and dedicated to the conservation of the world's monuments and sites. ICOMOS NZ, established in 1987, designed the New Zealand Charter, and promotes education programmes, seminars and workshops in heritage conservation. Although 'adaption' is recognised in the NZ Charter, policies strongly favour conservation.

The general public are stakeholders both individually and communally. At the home owner level, New Zealand has a do-it-yourself culture which in 2007 was valued at NZ$1 billion (Mackay, 2007). The industry is supported by major material and product suppliers who provide instruction sheets for basic construction. Throughout New Zealand, many cities have Civic Trusts. These non-profit organizations

of citizens promote good urban design and city development as well as ‘the preservation of heritage, in all its aspects’ (ACT, 2014).
The relative positions of many stakeholders involved with heritage housing in New Zealand are summarized in Figure 2. The following discussion and plan proposes how more resources and education could be achieved.

DISCUSSION

The need for comprehensive resources for the on-going care of traditional housing is clear, but it begs the question as to why they do not already exist. Unlike the design and construction of new housing, the nature of caring the heritage housing is complex; demanding an understanding of cultural heritage, historical design and construction as well as a century of life-style changes and new technologies, building practices, regulations, codes and approval processes. Presently, in New Zealand, this comprehensive specialist knowledge is confined to the small number of conservation architectural practices and specialized trades in New Zealand. Annually, thousands of other architectural designers, engineers, builders and joiners and homeowners are carrying out work on heritage housing. While the few reference books provide good back-ground information, alterations appear to be designed in isolation and from grass-roots experience. The design of these solutions is not critiqued or the construction tested over time.

In 2010, when the villas were over 100 years old, BRANZ first recognised the need for renovation resources, but as BRANZ is a building industry funded body the information is technically focused in building practice of the 21st Century. It identified the complex compliance processes necessary for building consent approval. However, exemplar design solutions for the evolution of the villa design typology and detailed design and construction ‘alternative solutions’ for restored or new building elements (to comply with building codes) are not publicly available and are urgently required. Such resources would be welcomed by Local Government heritage advisors (in their role of promoting and approving alterations and additions to housing in heritage areas), house owners (in understanding the villa typology and planning the care their houses), architectural designers and builders (in enabling efficient design work and fabrication in a housing renovation industry that is notorious for slim profits) and by students of architecture (as no New Zealand comprehensive reference texts on traditional or renovation exist).

At a Government level, facilitation of such resources seems difficult. In one ‘tower’, the crown entity HNZPT supported by Ministry for Culture & Heritage and their agency NZHPT promote architectural conservation of listed houses only and in another ‘tower’, the Department of Building & Housing regulates building construction. Neither organization take responsibility for providing public comprehensive information and educational resources for heritage housing. In other countries, this is not the case. Historic Scotland (HS, 2014) support building craft and conservation architecture, with research funding, education courses and technical publications to the industry and the general public. The New Zealand Institute of Architects pledge support for research and education in conservation architecture, however on the surface the provision of publicly accessible resources might be seen as undermining the profession. The counter-argument is that well researched and certified design details, could make design and documentation more efficient enabling architects to undertake more projects and educating more architects on the principles of heritage conservation. The selective publication of design elements from past projects undertaken in office could raise issues of copyright and liability. Would firms be prepared to release such information pro bono? Alternatively firms could undertake research as part on the research collaboration funded from outside, but who would pay?

In 2014, in New Zealand, public funding for architectural research has other priorities: the design and re-building the Christchurch as a result of recent earthquakes, the remedial design and repair of buildings caught in the leaky building crisis and the upgrading of poor performing housing. The nature of the house restoration and renovation industry does not suggest an obvious industry research sponsor within the private sector. For example, material suppliers seek to sell bulk product but restoration and

renovation use less material and a higher degree of craft. Design and trade firms working on heritage housing are typically small scale and dispersed, with little resources for sponsorship.

A HERITAGE HOUSING NETWORK?

The rising awareness of the need for more information and education among heritage advisers, conservation architects, architectural heritage organizations and academia suggests that a group could come together to form the core of a network with the aim of 'developing information resources and design and building craft capability for the on-going care of heritage housing'. (This paper set out to propose a public plan to facilitate the on-going care of century old timber villas, but the initiative could extend to other historical housing in New Zealand, including the Bungalow, Art Deco and State House styles). BRANZ, EECA and Beacon Pathway have undertaken considerable research and provide advice on the upgrade of the thermal performance and energy efficiency of existing housing. However, the future of heritage housing requires a wider perspective of identifying best practice architectural design, maintenance, restoration and/or renovation design strategies and detailed construction. Heritage housing specialist builders and trades have recognised expertise so the inclusion of this group is vital for the effective sharing of information and increasing the capability and pride within the heritage housing sector.

The *Heritage Housing Network (HHN)* proposed could have a limited term (i.e. 5 years) with objectives to gather and format existing knowledge, identify areas requiring further research, facilitate and seek funding for research projects, facilitate effective and efficient dissemination of best practice, facilitate net-working, information sharing and a continuing professional development platform for the heritage housing sector. The mandatory CPD requirement for both housing design and building practitioners has created platforms for information dissemination as well as paying clients. Although, in the short term, significant funding from Government, local authorities and building industry appears unlikely, the initiative would meet many objectives and is likely to be supported in principle. Professional associations for architectural design and construction, have greater incentives to provide support, including funding. The aims of a *Heritage Housing Network* have the potential to improve quality, efficiency, productivity and pride in a sector which has been seen as second rate to new, innovative home design and construction. Tertiary institutions and ITO's could have various roles. Schools of Architecture could provide research capability via undergraduate and post-graduate courses or academic research as well as facilities for seminars, symposia and specialist courses. Heritage housing is an excellent focus for practice-based research, where students work within an architectural practice under university supervision. Specialist work placement schemes within carpentry apprenticeships may also be a possibility. The *HHN* could focus on architectural design from conservation to renovation. This would complement the technical guides on renovation produced by BRANZ. BRANZ could also have a role in critiquing and approving Alternative Solutions. Although the timing of the *HHN* is overdue, only the recent advances in digital drawing and documentation, the Internet, video communication and social net-working provide the communication and education platforms to effectively connect the many stakeholders across the country.

An analysis of the stakeholders suggests the composition of a steering group; heritage advisers supported by LGNZ, conservation architects supported by ICOMOS and/or NZIA, licenced builders supported by FMBA, academics supported by their Universities and representatives from HNZPT, HPA, DBH and BRANZ. It is proposed that their first initiative be a one day Symposium where invited guests from stakeholder institutions present their vision for improving the care of heritage housing in New Zealand. All the many public and private stakeholders involved would be invited. This event would confirm support for a *Heritage Housing Network* and clear the ground for its foundation.

CONCLUSION

In conclusion, this research confirmed a need for the creation and dissemination of knowledge and skills to enable better on-going care for heritage housing in New Zealand. Government mandate for

this provision appears to be lost in the gulf between the Ministry of Culture and Heritage and the Department of Building & Housing. It is not a 'function' of HNZPT under the Act. The value of historic housing is not recognised by DBH and BRANZ, whose policies advocate amenity only. A diverse range of other stakeholders, who value historic design and craft, are dispersed throughout the country in multiple organizations and institutions. The paper proposes bringing stakeholders together at an initial symposium to understand this issue and to work together in forming a *Heritage Housing Network* facilitate research, design and building craft education and resources for the on-going future care of heritage housing in New Zealand.

ACKNOWLEDGEMENTS

This paper has extended previous research under-taken in collaboration with Vivian Rickard, Wellington City Council and Nigel Hughes (Mackay et al, 2012). The author acknowledges their contribution with thanks.

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Note: All web-sites were accessed 29 February 2012

YIMFY: A CENTRE FOR APPROPRIATE BUILDING TECHNOLOGY IN NEW ZEALAND

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ABSTRACT

Our built environment creates large demands on both energy and material resources. Building codes protect people's health and safety, but in doing so there is an inadvertent impact on the wider environment, resulting in the destruction of ecosystems that support us all. We need to actively explore and encourage different and better ways of natural building so that the well being of both the environment and people are not harmed.

Appropriate technology is an important part of this strategy and is suited to time, place, culture, and environment. It uses local materials to do useful work in ways that do the least possible harm, while remaining very aware of the impacts of its use.

Technologies are required that are not harmful to have close by -indeed we are proud to show them off. Hence the term YIMFY – Yes! In My Front Yard.

Exploratory and experimental building is difficult to carry out under current NZ building regulations that do not encourage appropriate ecological design. Such work conducted in an Appropriate Technology Development (YIMFY) Centre would feed working technologies suitable for NZ conditions into the New Zealand built environment, with the aim of helping produce new, or retrofitted, buildings that are environmentally restorative. It would encourage affordable, assisted, owner building.

A YIMFY Centre set up to be run by suitably experienced professionals will have a large positive economic impact locally. It will help reduce our dependency on fossil fuels as we head into post peak-oil energy descent scenarios. Its work will add positively to the New Zealand economy as a whole and help establish New Zealand as a leader in earth stewardship.

It will show by example. The key items are exemplary design elements to capture the public imagination, combined with key personnel, and a good business model.

KEYWORDS:

Sustainable; Appropriate technology; Built environment; Building materials; Embodied energy

INTRODUCTION

The importance of the built environment in making human occupation of the Earth possible is indisputable. The process of creating that built environment is also important. In New Zealand, as in many other countries, the building and construction industries make a significant contribution to our economy and prosperity. But all this activity, first building and then operating the structures that support our existence, is stressing the Earth's environment beyond its ability to regenerate.

Globally, the construction industry places large demands on both energy and material resources and is responsible for 40% of annual natural resource consumption, 30% of energy consumption and 30% of greenhouse gas emissions[1]. This is not sustainable and it is vital that we learn to build and repair buildings in ways that not only minimise damage to global ecosystems, but which also promote their regeneration. We need to actively explore and encourage different and better ways of building so that

the well-being of both the environment and the people who occupy it are not harmed. *Appropriate building technology* is an important part of this strategy.

Appropriate technology means technology that is suited to time, place, culture and environment, using local materials to do useful work in ways that do the least possible harm. Appropriate building technology includes *natural building* or *alternative building*, and generally refers to materials and systems that are minimally processed, readily available, renewable, recyclable or are recycled.

To date the focus for addressing issues of sustainability has been on energy efficiency, water efficiency and minimisation of waste. Important progress has been made on all these fronts resulting in increased insulation levels, increased air tightness, and more efficient appliances and services. Less emphasis has been placed on the materials and construction systems being used, or on their embodied energy.

David Eisenberg, director of the Development Centre for Appropriate Technology (DCAT) in Tucson, Arizona puts it thus:

> ".. it was the energy efficiency folks who dismissed the importance of embodied energy continually until the last few years, not those of us involved in greening the built environment. Their argument was that if you compared operating and embodied energy, you would see that embodied energy was insignificant. My argument was that we were talking about a significant number dwarfed by a huge number, but the size of the embodied energy did not mean that the embodied energy was not important, just that it was made to look insignificant by the size of the operating energy. They often used percentages to compare the two and I would say, okay using that method, what is the percentage of embodied energy when operating energy is zero? And how much have you increased the embodied energy in order to get to net-zero? My view is that that is the bigger issue...we're typically using much higher embodied energy materials and systems in most of these buildings to get to low operating energy performance - which amplifies the problem. And the global warming potential also typically goes way up.
>
> The other aspect of this is the assumption that we will have the affordable and available energy to continue to build energy intensive buildings the way we've been doing it. A tenuous assumption at best. Regardless, it would be great to have more research and better documentation for the spectrum of natural building materials and systems."[2]

In New Zealand operating energy in houses is much less than in other parts of the developed world largely because we use less for space heating and cooling. We are much closer to the position that Eisenberg alludes to than many other developed countries. In his 2010 paper "Materials Matter More" [3]Andrew Alcorn asserts that hot water heating is the largest emitter of CO_2-e followed by "non- bio-based materials" in New Zealand. He concludes by suggesting efforts to reduce our carbon footprint are best focused on renewable hot water heating systems and maximising the use of bio-based building materials.

The most common bio-based building material in New Zealand is timber. There are major industries supporting it, research is well funded and there are many building regulations pertaining to its use. Other bio-based or appropriate building materials like earth, straw bale, and hemp are not so well supported and, apart from earth wall building systems, they are not regulated. This makes their use problematic and often impossible, hence the need for research and development. The Building Research Association of New Zealand (BRANZ) research programme does not cater for this area of research.

Exploratory and experimental building is difficult to carry out under current New Zealand building regulations that do not encourage appropriate ecological design. Such work conducted in an Appropriate Building Technology Development Centre would feed working technologies suitable for our conditions into the New Zealand built environment, with the aim of helping produce new, or

retrofitted, buildings that are environmentally restorative. It would also encourage affordable, assisted, owner building.

YIMFY BACKGROUND AND VISION

The concept of creating a New Zealand Centre for Appropriate Building Technology has been a long held dream for Graeme North. Over an architectural career spanning forty years, he has been at the forefront of the renaissance in earth building in New Zealand, chairing the Standards New Zealand (SNZ) committee that formulated the 1998 Earth Building Standards[4], and being a founding member of the Earth Building Association of New Zealand, EBANZ. In 2010 North was the recipient of a Winston Churchill Fellowship and made a study trip to Europe to investigate existing Appropriate Technology Centres. His findings are recorded in the 2011 report that followed that trip, “Appropriate Building Technology, YIMBY – Yes In My Back Yard,”[5] which will be discussed in more detail later in this paper. The paper concludes by putting forward the case for establishing an Appropriate Building Technology Centre in New Zealand.

In 2012, Robin Allison, founding member of Earthsong Eco-Neighbourhood (Earthsong)[6] in Ranui, West Auckland, approached North with the idea that the front-of-house site at Earthsong, owned by Walk to Work Ltd (W2W), be considered as a possible site for a Centre for Appropriate Building Technology. W2W is a company, set up by Earthsong residents and friends, with the aim of developing a commercial enterprise on the Swanson Rd site that would be compatible with the ethics of Earthsong: a complementary development. Allison and North invited three others to join them and in November 2012 ‘YIMFY - Yes In My Front Yard‘ was born. The steering group of North, Allison, Alan Drayton, Amanda Garland and Min Hall has substantial theoretical and practical expertise in sustainable architecture and building, community involvement, and successful project development.

YIMFY is the opposite of NIMBY – Not In My Back Yard, where any negative consequences of technology choices are inflicted on others, somewhere else. With YIMFY, the technologies being developed and demonstrated are not harmful to have close by, they are worthy of being placed in the front yard for all to see. Early discussions with W2W and Earthsong indicated a promising fit with other future eco-businesses on the W2W site. This would locate the YIMFY Centre within reach by public transport of over 1.5 million Auckland residents as well as overseas visitors.

At the end of 2012 a vision document was sent out to potentially interested parties:

> “Our vision is to develop a centre that supports and promotes the use of environmentally restorative building materials and systems.
>
> The YIMFY Centre will have two main areas of focus:
>
> - a centre for coordination of research, advice, and advocacy;
> - a destination site, built using successful natural building methods employing appropriate technology, for demonstration, display, and education of groups and individuals.”[7]

CURRENT SITUATION IN NEW ZEALAND

Although the Building Act 2004 includes many purposes intended to support sustainability and despite building controls being performance based rather than prescriptive, experimental building is difficult to carry out in this country. Building consent applications require fully worked out solutions to be submitted before a consent can be issued. There is a case for allowing experimental building to take place under the control of suitably qualified people such as registered architects or chartered engineers to ensure safety, while allowing freedom from more formal controls to encourage innovation. There are two mechanisms within the current regulatory system that can allow this to happen.

Territorial Authorities (TA) can establish a zone for experimental or demonstration buildings. This would require district plan changes made under the Resource Management Act 1991. Within the Building Act there is also provision for TAs to grant a building consent subject to a waiver or modification of the New Zealand Building Code (NZBC). The current legal position is that a waiver is the key mechanism for exemption in respect to building legislation, or TAs can permit sustainable and experimental demonstration buildings through the resource consent process. In reality such moves require the full support of the relevant TA to succeed.

Despite the regulatory issues, the development of appropriate building technologies is already happening at individual sites throughout New Zealand, but there is no single organisation that connects them or acts as a repository of knowledge about the systems being used.

In 2010 EBANZ[8] widened its scope to include 'Natural Building' as a core area of interest. Its by-line now reads "promoting the art and science of earth and natural building". Initially it was solely associated with earth building techniques but over time became involved in other building systems and methods including straw bale. EBANZ members have been consulted by TAs, BRANZ and the Ministry of Business, Innovation and Employment (MBIE), with regard to consents, guidelines and determinations for buildings using earth, straw and other materials. The committee that formulated the 1998 Earth Building Standards was made up largely of EBANZ members. These standards are a major success of the performance based Building Act and have been cited as acceptable solutions to the NZBC. This makes building consent applications for earth buildings no more difficult than timber or concrete block buildings. However all the work undertaken by EBANZ has been done by committed individuals for little or no remuneration. It is not sustainable.

Hands-on workshops using earthen materials, straw bale and other natural materials are run from time to time in different locations but there is very little in the way of formal training available. Aoraki Polytechnic in Timaru runs an on-line Certificate in Natural Building and a limited amount of earth building research has been carried out at the University of Auckland and Victoria University of Wellington where researchers have also investigated straw bale. TA Eco Advisors can direct people to individual designers, builders and manufacturers if they know about them. The website, Ecobob, is an online forum and repository of information about 'eco living' mainly by way of subscriber listings for products and services, some of which are related to appropriate building technology.

Environmental rating systems, Greenstar NZ[9] and the Living Building Challenge (LBC)[10] encourage the use of building materials with low embodied energy. However in the absence of a mechanism to rate them, appropriate building materials have not featured strongly in Greenstar rated buildings. The LBC takes a stronger position on materials in terms of the toxicity of their ingredients and the distance from material source to building site. Research and experimentation undertaken by an Appropriate Building Technology Centre could support LBC initiatives.

Overseas web based sites offer a huge range of material about appropriate building technology and these are being accessed by many New Zealanders. The material being accessed is not always appropriate to New Zealand and this is where a New Zealand based centre could play a crucial role in helping transfer overseas based information into the local environment.

Many natural building techniques are quite labour intensive, even if material costs might be low. This makes the use of such techniques of interest to owner builders who are keen to create affordable houses for themselves and their families. Having access to good and relevant information is of great importance to these people. A YIMFY centre has the potential to assist owner builders and thereby make a significant contribution to affordable housing in New Zealand.

INTERNATIONAL APPROPRIATE BUILDING TECHNOLOGY CENTRES

Examples of Appropriate Building Technology Centres overseas are useful to study when considering setting one up in New Zealand. In 2010 North visited some of these as part of the WCF study trip. Those that have particular relevance to the proposed YIMFY Centre are: CAT in Wales, the Eden

Project in Cornwall, and FEB Building Research Centre in Kassel, Germany. The other author of this paper, Min Hall, visited the BRE Centre for Innovative Construction Materials at the University of Bath and the Genesis Centre in Somerset in 2013, both of which have relevance for YIMFY. Two further web-based centres, the Development Centre of Appropriate Technology (DCAT) in Tucson, Arizona and the Ecological Building Network based in California are also discussed.

There are some key factors to consider in the structure and function of these centres which are primarily either:

- A living/working site
- An educational site
- A demonstration site
- An experimental site
- Or a mixed site.

The Centre for Alternative Technology (CAT)[11]

CAT in Wales is arguably Europe's flagship eco-demonstration centre. It was founded in 1973 by Gerard Morgan-Grenville on the site of an abandoned slate quarry near Machynlleth. Morgan-Grenville, conceived it as an intentional community, a place to experiment with sustainable living and to be a 'test bed' for new ideas and technologies. As CAT grew it attracted more volunteers keen to experience the social and environmental benefits offered by such a place. Almost immediately there was conflict between living and demonstration sites, which was partially resolved when the Visitors' Centre opened to the public in 1975. There is still a residential community on the CAT estate, but it is no longer a part of the general visitor circuit. Ninety permanent and volunteer staff operate CAT all year round, with an additional sixty people helping during the summer months. With around 60,000 visitors per year, there are large economic spin-offs for the local economy.

What started off as a living situation set up to 'show,' has turned into a demonstration site dominated by visitors. CAT survives economically by offering and administering tertiary educational courses. Its research activities, bookshop and information services produce a range of very useful materials. It provides free information to around 200,000 people and tertiary courses to around 500 students per year. The relatively new, 2010, Wales Institute of Sustainable Education (WISE) building, designed by Pat Borer and David Lee, features seven metre high curved rammed earth walls and is attracting even more visitors.

CAT's primary role, therefore, is a mixed one: educational, demonstration and experimental.

The Eden Project[12]

The Eden Project, in what was a disused quarry in Cornwall, is an internationally renowned centre for environmental education with a large emphasis on plants and ecosystems. Its enormous bio domes, designed by Sir Nicholas Grimshaw, enable artificial tropical and temperate environments to exist in the English countryside and attract 1.2 million visitors annually. Tim Smit conceived of the Eden Project in 1995 and took advantage of the Conservative Government's millennium projects scheme to realise his dream. The gates opened in 2000 while construction was still in process: the process of building such a unique place was just as interesting and educational as the completed project. In 2005 an educational and interpretation centre including classrooms was completed.

The Eden Project is primarily a demonstration site, delivering an environmental message more or less informally, with a lesser formal educational role. It is designed and maintained to a very high standard and gate takings and proceeds from the shop account for a majority of the income.

Forschungslabor für Experimentelles Bauen (FEB)

Professor Gernot Minke, author of key technical texts on appropriate building materials and construction methods[13], lead FEB, the Building Research Institute at the University of Kassel for thirty five years. Materials were analysed and tested both in the laboratory and the open field, also on the campus, over that period. Many experimental buildings were built but sadly both these and the

laboratory have been dismantled since North's 2010 visit. However the way FEB was structured has relevance for the YIMFY centre. Although the University supported FEB on an operational level, funding for projects came from government grants, EU grants, and from overseas agencies involved with humanitarian projects in third world countries. FEB's primary roles were educational and experimental.

BRE Centre for Innovative Construction Materials (CICM)[14]

The Building Research Establishment (BRE) Centre for Innovative Construction Materials (CICM) established in 2006 at the University of Bath has similarities to FEB. Experimental work with a range of materials including straw bale, earth and hemp is carried out both in the laboratory and in the field under the leadership of Professor Pete Walker. Funding comes from government grants , EU grants and from industry. Current projects include Balehaus using prefabricated straw panels and Hempsec using prefabricated hempcrete wall panels. CICM's primary roles are educational and experimental. Of particular relevance to the YIMFY centre is the notion of partnerships with research centres and industry.

The Genesis Project[15]

The Genesis Project at Somerset College near Taunton was established to provide education in sustainable construction. Its bespoke Genesis Centre, designed by Architype, incorporates many appropriate building materials and systems and provides teaching facilities and display spaces for sustainable building materials and services. The project is self funding via partnerships with industry and the educational programmes it offers. It serves as an information repository for sustainable construction and gives the public the opportunity to see many products and systems both in the fabric of the Genesis Centre or displayed within. Its key audiences are primary and secondary schools, tertiary students, and professionals from the construction industry as well as people involved in restoration and owner builders. Suppliers, manufacturers, trades people and professionals subscribe to a database which is available to the public and administered by the Genesis Project. Both Project and Centre are a combination of being a demonstration site and an educational one.

Development Centre for Appropriate Technology (DCAT)[16]

DCAT run by David Eisenberg, in Tucson, Arizona, is a non-profit organization that supports the development and use of sustainable technology through education, research, and projects. An important part of DCAT's work has been working with code officials in revising building codes to include sustainable issues and most recently in getting Appendix R Strawbale Construction accepted as part of the International Residential Code that covers the entire USA. DCAT's website offers links and resources but also includes the following in its vision and mission statements:

> "We value the potential to evolve sustainable, life-enhancing human systems and built environments that are fully integrated with nature. Technology is the application of ideas, energy and resources to solve problems and create change. Appropriate technology is that which strives to minimize negative consequences to all life, and connects people with each other and the Earth. We value elegant solutions that enhance community self-sufficiency, build local economies, and draw on cultural wisdom. Like a spider web, our relationships are made strong through their interconnecting strands. Sharing collective knowledge, the whole is more resilient."

Funding is largely from sales of books and donations The spider web analogy is an important one for YIMFY as it sets up a network of interconnected people, sites and information.

The Ecological Building Network (EBNet)[17]

EBNet was set up by Bruce King in California in 1999. Since then it has been developing and promoting green building technology. From the EBNet website, the network is:

> "an open, collaborative group of builders, scientists, architects and engineers sharing the best knowledge we can find for everyone's benefit. Here you will find practical technical guidance by for designing and constructing better buildings, wherever you are. Whether you are building a straw bale home in Argentina, a low-income village with shipping containers in Shanghai, or a concrete office structure in Sacramento, we have information you can use."

The on-line Build Well Library is becoming a major depository for appropriate technology providing links to conference and research papers, standards, and books. EBNet is funded largely from sales of books and donations. The on-line presence and international links are of particular relevance to the YIMFY project.

LEARNING FROM INTERNATIONAL EXAMPLES

Observation and analysis of international examples reveals the quite different demands and sometimes conflicting requirements between the needs of an appropriate working/living arrangement, a demonstration space, a research place, and an educational space. The invisible structures for each are quite different, yet because they are invisible they remain hard to discern, but crucial to the running of any operation.

On demonstration sites, the standard of presentation becomes critical. It is what people see, touch, smell, and hear directly that is important. A demonstration site or centre is mostly set up for short-term visitors. It requires external relationships that are quite different from a live-in arrangement or intentional community where internal relationships are more important. The proposed YIMFY Ranui site is a discreet but easily accessible location adjacent to a sympathetic and well functioning co-housing development, Earthsong Eco-Neighbourhood.

With educational sites and experimental sites, invisible structures and external relationships can become more important than those which are visible. If there are links to other agencies such as a universities, government departments, funding bodies, and industry then some control of on-site activity can be lost as most funding comes with strings attached.

A thriving centre can generate large localised spin-offs, not only as a driver for the local economy from its own activity, but also from visitors. Overseas examples such as CAT and the Eden Project show that an attractive Appropriate Technology Centre set within a local culture is not only immensely fascinating and educational for visitors, but can also stimulate a whole range of associated activity . CAT has generated hospitality businesses catering for visitors and students and has stimulated the formation of around 50 other local business.

Any Appropriate Technology Centre must be integrated with adjacent or satellite areas where it is possible to innovate, research and experiment freely out of the public eye. The FEB experimental field on the university campus is an example of such a place. Conversely a successful centre must have the facilities to demonstrate and pass on what it discovers by way of open days, workshops, or more extended formalised teaching.

An important aspect of CAT and even more so of the Eden Project, is the integration of permaculture gardens with the built environment. For a demonstration site these gardens are a major drawcard and reflect the underlying holistic nature of the concept of appropriate technology.

A key role for most of the centres cited is that of a repository of essential knowledge and skills that will facilitate the on-going integration of appropriate building technology into the built environment.

It is clear that a web-based knowledge and information base is vital to the success of any 21st Century Appropriate Technology Centre.

REQUIREMENTS FOR YIMFY: A CENTRE FOR APPROPRIATE TECHNOLOGY

A YIMFY Centre requires a synthesis of many parts including:

- a vision and a visionary team
- a suitable site(s) close to, or having ready access to existing settlements with local natural resources and access to natural building materials
- an inspirational design on a human scale where human activities are harmlessly integrated into the natural world and is supportive of healthy human development
- a sound business plan
- good personnel and visitor management
- good publicity
- adherence to local rules and regulations
- elements of living/working arrangements if required
- integration of productive permaculture gardens
- areas for research and experimentation, demonstration, and education, both informally and formally

Design must allow for the different requirements for those living/working on site (if any), the needs of formal education, and the needs of an experimental site, the needs of demonstration displays, and the needs of visitors. Adequate funding stream(s) are essential.

The key elements are: exemplary design elements to capture the public imagination, key personnel, and a sound business model.

YIMFY PROGRESS

In its Vision Document the steering committee identified areas of work that YIMFY might undertake:

- Design and build a display centre using appropriate building technologies.
- Act as a demonstration centre where individuals and groups can experience and learn about appropriate localised natural materials and resources.
- Host talks, workshops, and hands-on training programmes in appropriate building technology.
- Link, coordinate and generate research in appropriate building methods throughout New Zealand, and make that information available.
- Support the development of affordable, effective and culturally appropriate methods to improve existing buildings.
- Provide expertise to support both owner-builders and construction professionals.
- Work to get appropriate systems accepted for NZ Building Code compliance.
- Coordinate and cooperate with overseas centres doing similar work.

The Vision Document has been circulated using existing networks such as Permaculture in New Zealand (PiNZ) and EBANZ and a database of over 130 interested people has been established.

A workshop was held with W2W and Earthsong to find common ground and establish how the parties can cooperate. At the workshop a brief was developed for a studio design project with Unitec

Architecture students which took place at the end of 2013. This was a useful exercise in getting an idea of how the Ranui site might work as a YIMFY Centre. A practical workshop on earth building techniques has also been held on the site and contacts with other organisations have been established.

A charitable trust is being set up to establish a legal structure to operate under. Once legal status is confirmed it is proposed to carry out a feasibility study which will include preparing a business model, prioritising activities, exploring funding options, and considering occupation arrangements of the W2W site in Ranui.

Future goals include:

- Seeking funding for various activities
- Establishing and running a co-ordinating office
- Setting up and maintaining a website and data bases - domain names have been secured
- Seeking partnerships and relationships with allied organisations and individuals, both locally and internationally – these include EBANZ annual conferences and the forthcoming International Straw Builders' Conference (ISBC) in Methven in 2016
- Look at implementing a design and then running a YIMFY Centre

CONCLUSION

An Appropriate Building Technology Centre would fill an obvious gap in building research being undertaken in New Zealand. Exploratory and experimental building is difficult to carry out under current building regulations which means that to research and use many appropriate building materials and techniques for new and retrofitted buildings that are environmentally restorative is at best difficult and more often impossible. Individuals and organisations around the country are working with appropriate building technologies but there is no single organisation that connects them.

YIMFY: A Centre for Appropriate Building Technology in New Zealand would act as a centre for the current decentralised system: a hub to connect, support and grow the work being done by individuals. It would provide a crucial missing element in New Zealand's built environment research programme, contribute towards more affordable housing by assisting owner builders, and enable wider use of appropriate building technologies within the existing regulatory system.

ACKNOWLEDGEMENTS

The authors acknowledge the support and input from the other members of the YIMFY steering committee: Robin Allison, Alan Drayton and Amanda Garland.

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Towards an agreed minimum housing performance standard for rentals: Results from New Zealand's first warrant of fitness pre-test

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8. Tauranga Council

Abstract

Housing is one of the key material determinants of health and well-being; shelter is a fundamental human need. New Zealand housing is of a lower quality than most OECD countries and several national surveys and research studies have shown that private rental housing is in poorer condition than either social housing, or houses that are owner occupied. Living in substandard housing is seriously damaging the health of New Zealanders with children from low-income families, Māori and Pacific peoples disproportionately affected. Over 70% of all children who are in poverty live in rental accommodation (20% in Housing New Zealand housing and 50% in private rentals).

The current regulatory arrangements for rental housing have not been amended since 1947. Today these guidelines are seen by many as inadequate including the Children's Commission's Expert Working Group on Solutions to Child Poverty; the group has recommended the introduction of a Rental Housing Warrant of Fitness (WOF), as a means to addressing the health and safety of a large proportion of children living in poor quality private rental housing.

Councils are interested in developing a WOF tool that will assist in improving the quality of the rental housing stock, which would result in improved health outcomes and a reduction in injuries occurring in the home. A WOF for housing would provide a minimum standard for rental dwellings and would provide an information tool for tenants and landlords to understand the performance and safety of a dwelling.

This paper explores the results from New Zealand's first field test of a housing WOF method that includes houses from five regions throughout New Zealand involving 144 homes. It also includes a consideration of the particulars included in the assessment methodology.

Keywords

Minimum housing standard, WOF, housing, health, safety, energy efficiency, injury.

Introduction

Housing is one of the key material determinants of health and well-being; shelter is a fundamental human need. New Zealand housing is of a lower quality than most OECD countries and several national surveys and research studies have shown that private rental housing is in poorer condition than either social housing, or houses that are owner occupied. Living in substandard housing is seriously damaging the health of New Zealanders with children from low-income families, Māori and Pacific peoples disproportionately affected. Over 70% of all children who are in poverty live in rental accommodation (20% in Housing New Zealand housing and 50% in private rentals).

The current regulations for rental housing quality have not been amended since 1947. Today these guidelines are seen by many as inadequate including the Children's Commission's Expert Working Group on Solutions to Child Poverty; the group has recommended the introduction of a Rental Housing Warrant of Fitness (WOF), as a means to addressing the health and safety of a large proportion of children living in poor quality private rental housing.

Council and ACC interest

Councils are interested in developing a WOF tool that will assist in improving the quality of the rental housing stock, which would result in improved health and housing performance outcomes and a reduction in household injuries. A WOF for housing would provide a minimum standard for rental dwellings and can also be an information tool for tenants and landlords to understand the performance of a dwelling.

Councils identified an interest in investigating the feasibility of a WOF approach that would result in a pass or fail for houses. Councils considered they needed more information not only about the feasibility and acceptability of a WOF, but also how the WOF could be implemented.

The Accident Compensation Corporation (ACC) became involved because it is interested in developing a tool that would assist in mitigating hazards in the home to reduce the number of injury causing accidents. Injuries in the home are a major source of ACC claims.

Collaboration

In June 2013 Auckland council facilitated a meeting of interested groups, including groups with relevant technical skills, local government and central government agencies, to investigate establishing a Rental Housing Warrant of Fitness (WOF). The June meeting was followed by a smaller, technical workshop in Wellington in July whereby Auckland, Dunedin and Wellington councils together with EECA, ACC, NZ Green Building Council (NZGBC), University of Otago, Wellington (UoOW) and BRANZ discussed what the key elements of a WOF assessment might include.

After the July workshop, the NZGBC and the UoOW decided to work jointly to develop a WOF, which includes assessment criteria, an assessment checklist and an assessment guide for using the checklist.

In October 2013, Auckland, Dunedin, Christchurch and Wellington councils met in collaboration with ACC, the NZGBC, UoOW and other interested parties. The NZGBC and the UoOW presented their work on the WOF and received feedback from the various stakeholders. The stakeholder group, along with the inclusion of Tauranga city council agreed on doing a pre-test of the WOF tool whereby the councils would drive the pre-test on a local level and the UoOW and the NZGBC would provide a finalised version of the draft WOF criteria, checklist and accompanying guide.

Subsequently, the councils and research teams presented the idea of the WOF and the plan for the pre-test in a number of public fora, with landlords, students, to MBIE and the media.

Results

Demographics

Five regions took part in the rental housing WOF pre-test, Auckland building assessors inspected 34 houses, Tauranga assessors inspected 25, Wellington inspected 39, Christchurch inspected 22 and Dunedin assessed 24 houses, giving us a total sample size of 144 houses.

The houses ranged in ages from those built in 1880 to those built in 2013. The average year the houses were built was 1968. The sample of houses in Tauranga was significantly newer than the other regions. House sizes ranged from $30m^2$ to $220m^2$ with an average house size of $91m^2$. The average size of a house in New Zealand is $149m^2$(QV data).

The inspections on the houses took from 15 minutes to three and a half hours (200 minutes), with the average length of time being 51 minutes. There were no significant differences between the length of time to conduct the inspections and the different regions.

Table 1. Demographics

Region	Number of houses	House age mean (range) years	House size Mean (range)m^2	Length of time to conduct assessment
Auckland	34	1973 (1950-2013)	77 (30- 150)	41 minutes (15-95)
Christchurch	22	1967 (1930-1993)	71 (40-200)	43 minutes (15-200)
Dunedin	24	1959 (1880-2009)	109 (50-200)	60 minutes (25-130)
Tauranga	25	1992 (1960-2013)	109 (35-200)	59 minutes (25-160)
Wellington	39	1957 (1900-1998)	93 (40-220)	52 minutes (15-100)
Total sample	144	1968 (1880- 2013)	91 (30- 220)	51 minutes (15-200)

In each housing sample, councils aimed to include a mixture of construction ages to ensure the sample was representative of the style and age of houses within their region of New Zealand. Overall most houses in the sample were built between 1950 and 1979, or from 1980 onwards. The sample was short on houses built before 1920 and between 1920-to-1979. A representative sample of construction eras[1] needed to include 20 houses built before 1920, and 30 houses built between 1920 and 1949 (See Table 2).

Table 2. Age of houses by region

	Number of houses				
Region	Sample size	pre-1920s	(1920-1949)	(1950-1979)	(1980+)
Auckland	34	0	0	28	6
Christchurch	18	0	4	9	5
Dunedin	23	3	5	8	7
Tauranga	17	0	0	4	13
Wellington	34	4	0	29	1
Total sample	126[2]	7	9	78	32

Most (78%) houses were single storied, but the sample also included two (018%) and three (2%) storied dwellings. The majority of houses (46%) were standalone dwellings (detached); 35% were duplex, 10% were terraced and 9% were apartments.

[1]Sample calculations prepared by Dr Lucy Telfar-Barnard, University of Otago, Wellington.

Councils were asked to try and obtain samples that included at least 15 standalone dwellings (detached) and at least 10 semi-detached houses, town-houses or apartments, in order to make the sample representative of house styles in New Zealand. Dunedin reached this target with 15 standalone houses sampled. Auckland, Tauranga and Wellington almost reached this target with 13 standalone houses. Christchurch sampled seven standalone houses.

Table 3. Type of dwellings sampled

Region	Number of houses	Detached	Duplex	Terraced	Apartment
Auckland	34	38%	24%	35%	3%
Christchurch	22	32%	59%	-	9%
Dunedin	24	63%	25%	-	13%
Tauranga	24	54%	46%	-	-
Wellington	29	45%	31%	3%	21%
Total sample	133	46%	35%	10%	9%

All councils aimed to include in their rental housing samples ten council houses and 15 private rentals. Dunedin almost made this target with recruiting nine private rentals. All other regions were able to achieve this target. The total sample achieved the sampling target with 65% of houses privately owned rentals and 45% of houses owned by the councils.

Table 4. Private or social ownership of rental housing

Region	Number of houses	Number of private rentals	Private housing	Social housing
Auckland	34	26	76%	24%
Christchurch	22	12	55%	45%
Dunedin	24	9	38%	63%
Tauranga	25	15	60%	40%
Wellington	38	30	79%	21%
Total sample	143	93	65%	45%

Most houses in the sample had one bedroom (31%). However, 27% of the sample had three-bedrooms and one-fifth (20%) had two bedrooms (See Table 5).

Table 5. Number of bedrooms in dwellings sampled

Region	Number of houses	Number of bedrooms					
		1	2	3	4	5	6+
Auckland	34	41%	15%	35%	9%	-	-
Christchurch	21	43%	24%	19%	5%	10%	-
Dunedin	24	21%	25%	8%	13%	17%	17%
Tauranga	25	32%	8%	44%	16%	-	-
Wellington	39	21%	26%	26%	18%	5%	5%
Total	143	31%	20%	27%	13%	6%	4%

Items that passed or failed the rental housing WOF pre-test

Of the 144 houses that were assessed in this rental housing WOF pre-test, eight houses passed (6%) and 136 houses (94%) failed. To pass the WOF a house had to meet 31 criteria. These 31 criteria were divided into 94 possible checklist items. For example the ceiling insulation criteria were assessed using five checklist items. Not all houses were required to pass all of these items, as some items were not applicable to the house. Of these 94 possible items, the average number of items failed on the list was five, with some houses passing all required items and some houses failing up to 27 items. The results below are sorted by components assessed in the kitchen, then the bathroom, living room and bedrooms. Insulation and general items assessed during the inspection follow.

Kitchen

One of the most common reasons for a house to fail was because the house had water that was too hot or cold, 40% of houses failed the kitchen water temperature check. Of the houses that failed the WOF (136 houses) 4% did so solely because the water was too hot or too cold. The average temperature of hot water in the houses was 54°C, which was within the passable range of 55±5°C with a range from zero (those houses without power) to 70°C.

All houses passed had intact walls and ceiling linings with intact floors in the kitchen area; and all houses had a potable water supply. Almost all houses were clear of mould in the kitchen (99%), had a functioning stove and oven (96%), and had adequate food preparation and storage areas (99%). Likewise almost all houses had working lighting (99%), appropriate waste water drainage with a sound connection (99%), visibly safe power outlets and light switches (99%) and secure storage (98%). The large majority of houses had effective ventilation to the outside (92%) (See Table 6).

Table 6. Components assessed in the kitchen

Component assessed	Number of houses (144)	Fail	Pass
Wall and ceiling linings, and floor intact	142	0%	100%
Surfaces clear of mould	144	1%	99%
Functioning stove and oven	140	4%	96%
Effective ventilation to the outside	144	8%	92%
Adequate food preparation and storage	144	1%	99%
Working artificial lighting	139	1%	99%
Potable water supply	144	0%	100%
Hot water temperature at tap (55°C ±5°C)	135	40%	60%
Waste water drainage with sound connection	144	1%	99%
Visibly safe power outlets and light switches	144	2%	98%
Secure storage (1.2 m high or child-safe lock)	144	2%	98%

Table 7. Water temperatures taken from the kitchen tap

Region	Number of houses	Temperature hot water ^{0}C
Auckland	32	54 (42-69)
Tauranga	21	54 (43-65)
Wellington	30	56 (44-65)
Christchurch	19	58 (45-70)
Dunedin	19	47 (0-63)
All regions (144)	121	54 (0-70)

Bathroom

All houses had functional sewerage disposal and all houses had working lighting in the bathroom. Almost all houses had intact wall, ceiling and floors (99%) and in the bathroom had an operational toilet (99%), and a functioning bath or shower (99%). Likewise almost every house had effective waste water drainage (99%) and visibly safe power and light switches (98%). Most (92%) bathrooms had surfaces clear of mould and effective ventilation to the outside (93%) (See Table 8).

Table 8. Components assessed in the bathroom

Component assessed	Number of houses (144)	Fail	Pass
Wall and ceiling linings, and floor intact	144	1%	99%
Surfaces clear of mould	144	8%	92%
Operational toilet	144	1%	99%
Sewage connection functional	144	-	100%
Functioning bath or shower	144	1%	99%
Effective ventilation to the outside	144	7%	93%
Waste water drain connected	144	1%	99%
Working artificial lighting	140	-	100%
Visibly safe power outlets and light switches	139	2%	98%

Living areas

In the living areas almost all houses (99%) had intact wall and ceiling linings and the floor was undamaged. Almost all houses (99%) also had living areas that were clear of mould, had visibly safe power outlets and light switches (99%), and had opening windows with secure latches (97%). All houses (100%) had working lights in the living area, while 96% of hallways had functioning lights, 84% of houses had functioning lights in stairwells. Suitable curtains or drapes were present in the living areas of almost all homes (94%). Fixed heating was present in two-thirds of the houses (63%), which meant that approximately one-third of homes (37%) did not have fixed heating. While 62% of houses had security stays, 38% of houses failed for not having security-stays where required in the living area (See Table 9).

Six percent (6%) or 8 houses out of the houses that failed the rental housing WOF pre-test (136 houses) did so because they had inadequate fixed heating. Less than 1% of houses that failed the housing WOF did so solely through having inadequate security stays in the living room.

Table 9. Components assessed in the living areas

Component assessed	Number of houses (144)	Fail	Pass
Wall and ceiling linings, and floor intact	144	<1%	99%
Surfaces clear of mould	144	<1%	99%
Working artificial lighting:			
• Living, lounge, dining	136	-	100%
• Hallway	104	4%	96%
• Stairs (switch at each end)	32	16%	84%
• Other	15	-	100%
Visibly safe power outlets and light switches	136	1%	99%
Heating, fixed, effective and safe	143	37%	63%
Opening window (each area) with secure latch	143	3%	97%
Window security stays (where required)	125	38%	62%
Curtains/drapes present	144	6%	94%

Bedrooms

Almost all houses had bedrooms that had opening windows with latches to shut them, the walls and ceilings were intact, surfaces were clear of mould, the bedrooms had working artificial lights and safe power and light switches. Almost all bedrooms also had suitable curtains present (See Table 10).

Fifty-seven percent (57%) of homes had window stays on their bedroom windows however, 43% of houses had at least one bedroom window without a window stay on it when required. Working smoke alarms were required in approximately 30% of the bedrooms (See Table 10).

Table 10. Components assessed in the bedrooms

Component assessed	Bedroom 1			Bedroom 2			Bedroom 3			Bedroom 4		
	N	Fail	Pass	N	Fail	Pass	N	Fail	Pass	N	Fail	Pass
Opening window, with latch	141	2%	98%	99	3%	97%	70	0%	100%	32	3%	97%
Window stays (if required)	125	38%	62%	90	44%	56%	64	45%	55%	29	52%	48%
Wall/ceiling linings intact	134	<1%	99%	103	1%	99%	72	0%	100%	32	0%	100%
Surfaces clear of mould	135	7%	93%	102	4%	96%	72	7%	93%	32	0%	100%
Working artificial light	133	0%	100%	100	0%	100%	71	3%	97%	32	3%	97%
Safe power & light switches	135	0%	100%	102	0%	100%	72	1%	99%	32	0%	100%
Smoke alarm within 3m	135	27%	63%	102	35%	65%	70	26%	74%	31	29%	71%
Curtains/drapes present	132	6%	94%	101	8%	92%	70	7%	93%	32	6%	94%

House entrance

All houses assessed had securely locking doors. Eighty-six percent (86%) of houses had their address clearly labelled and the house was easily identifiable. Eighty-seven percent (87%) of houses had working outdoor lighting at their front doors (See Table 11).

Table 11. Components assessed at the entrance of the houses

Component assessed	Number of houses (N=144)	Fail	Pass
Address clearly labelled and identifiable	140	14%	86%
Securely locking door(s)	143	0%	100%
Working light	135	13%	87%

Insulation

Fourteen percent (14%) of houses failed at least one component of the ceiling insulation inspection. The most common reasons for failing the ceiling insulation requirements were not having insulation to the 120mm requirements (29%) or for having gaps, tucks or folds in the insulation (22%) (See Table 12).

Table 12. Ceiling insulation components assessed

Component assessed	Number of houses (N=144)	Fail	Pass
Insulation to requirements (120 mm)	123	29%	71%
No gaps, tucks, or folds	113	22%	78%
No dampness in insulation	113	2%	98%
Clearance from lights, ducts and roof	114	10%	90%
Thermoplastic insulated cabling	115	4%	95%

Twenty-two percent (22%) of houses failed one or more components that were assessed during the underfloor insulation aspect of the inspection. The most common cause of failing the underfloor insulation requirements was due to a lack of a ground vapour barrier (61%) in those houses that required one (61 houses out of the 144 sample). See Table 13.

Table 13. Underfloor insulation components assessed

Component assessed	Number of houses	Fail	Pass
Insulation to requirements	79	28%	72%
Dry underfloor	74	7%	93%
Ground vapour barrier	61	61%	39%
No ponding	71	3%	97%

General housing requirements

The general state of repair of the sample of house was excellent with almost all houses considered to be weather-tight (99%) and structurally sound (99%). In addition almost all houses (98%) had no cracks or holes in their roofs, 95% had no cracks or holes in the external cladding, 99% had no cracks, holes or missing windows and 93% had spouting and storm-water functioning and not leaking. Ninety-four (94%) of houses had two effective methods of egress and 93% of houses had visibility strips on glass doors and 99% of houses had paths, decks and surfaces that were not slippery and were free from moss. All houses that required their non-potable water to be labelled complied with this. Handrails and balustrades were required to comply with the code; however 31% of houses inspected did not have suitable handrails and balustrades.

Table 14. General components assessed

Component assessed	N	Fail	Pass
Envelope in reasonable repair and weather tight	143	1%	99%
No cracks, holes in roof	136	2%	98%
No cracks, holes in external cladding	141	5%	95%
No cracks, holes or missing panes in windows	144	<1%	99%
Spouting and storm-water functioning and not leaking	135	7%	93%
Two effective methods of egress	139	6%	94%
Structurally sound	141	1%	99%
Glass doors include visibility strips	108	7%	93%
Handrails and balustrades to code	101	31%	69%
Non-potable water labelled	59	0%	100%
Paths, decks and surfaces non-slippery/free from moss	141	1%	99%

Conclusion

The results from this pre-test have informed the checklist. Some items that were found to be difficult to assess are being considered for dropping from the inspection, such as security stays. For example these items may no longer be required to pass a rental housing WOF but could instead be an advisory item. Other items have had further refining as to what is required to pass the WOF.

The top five items that did not pass were: unsafe water temperature; lack of security stays; no smoke alarms near bedrooms; handrails or balustrades not up to the recent Building Code Standards; or not having a fixed efficient form of heating. Alongside the refinements mentioned above it is expected that more houses would pass this WOF checklist as despite a high fail rate, if houses in this rental housing WOF pre-test fixed low-cost items that include the correct installation of smoke alarms, security stays on the windows, and hot-water at a safe range, 44 extra houses would have passed the housing WOF assessment, which would have given a pass rate of 36%.

The next steps from developing the final assessment tool are still being considered. There are a number of potential pathways to be considered. The outcome from Central Government's own work on a housing WOF for Government owned housing stock is also being monitored.

The field test demonstrates that defining a minimum performance standard for New Zealand homes is certainly possible. Furthermore results from the engagement surveys with landlords and tenants as well as assessors demonstrated high levels of engagement with the assessment while 83 percent of landlords indicated they would be taking action to improve their rental property as a result of participating in the trial.

Councils, the NZGBC, ACC and UoOW are currently determining where they are best placed to put their future efforts and the level of associated resourcing required to take a housing WOF scheme for private rental housing forward.

Acknowledgements

We would like to thank all the landlords who volunteered their rental properties for an inspection and also the tenants.

FIRE SAFETY IN NEW ZEALAND TRANSIENT ACCOMMODATION BUILDINGS

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ABSTRACT

Ideally fire safety codes should be rigorously based to mitigate risk to reasonably similar levels over the range of buildings and their usage. Reliable and consistent data on past fire incidents, their consequences and the overall building stock is therefore necessary. Unusually New Zealand has had a national Fire Incident Reporting System (FIRS) since 1975 with more consistent and complete data than other countries. The authors also accessed coronial reports on fire fatalities since 2000 for all fatal fires in New Zealand except for single dwellings to compare fatality rates from fires in different types of transient accommodation (hotels, motels, boarding houses etc). As details of rooms and bedspaces in different types of transient accommodation was not readily available, a list was accessed via an accommodation booking website and approximately one quarter of these were used to assess their size, type of accommodation and quality as reflected by star ratings. The presence of sprinklers was assessed by inspecting interior photographs of rooms where available, and locating externally mounted sprinkler inlets using Google streetview. Allowing for size, the presence of sprinklers was strongly a function of the quality (star rating) of the facility. Although most facilities are not sprinklered, about half the bedspaces are sprinklered. Overall the rate of casualties for all transient accommodation is almost double that for residential and for non-sprinklered accommodation almost four times that of residential. Of particular concern are large low quality facilities such as backpacker accommodation which may have poor fire separations and limited fire safety features. It is recommended that the requirements for fire sprinkler protection within the New Zealand Building Code are increased and a requirement for retrospective upgrading of older buildings, where most accommodation fires occur.

KEYWORDS:

Fire Safety; Transient accommodation; Fatalities; Building Codes; Sprinklers.

INTRODUCTION

The majority of fire fatalities in New Zealand are in residential accommodation that is permanent dwellings. This is consistent with sleeping occupancies being higher risk than other occupancies, as occupants will not be aware of a fire unless woken by a fire alarm or other external means. It is not physically possible to smell while asleep, so unlike wake individuals a fire will not be identified by the smell of burning. The other types of sleeping accommodation are sleeping under care or detention, that is rest homes, hospitals, prisons and so on, and *transient accommodation*. *Transient accommodation*, as defined by the Residential Tenancies Act (NZ Govt 1986), is "accommodation that is ordinarily provided for periods of less than 28 days at a time." It has a similar meaning in the Building Act (NZ Govt 2004) and the New Zealand Building Code (NZ Govt 1991). Buildings used for sleeping under care or detention now have a high level of fire safety, after changes to fire safety requirements after several multiple fatality fires. Although the number of fatalities is lower in transient than residential accommodation, more people spend more time at home, rather than in hotels and motels and other transient accommodation, so in terms of risk, transient systems, may be worse. The worst fires in New Zealand, in terms of fatalities have been in transient accommodation, since the Sprott House, a rest home fire in 1969 that resulted in the loss of seven lives (McLean, 1992). Transient accommodation overall has a higher level of fire safety systems such as automatic smoke detection and sprinklers, however in both older residential and transient accommodation automatic fire detection may not be present. Surprisingly, very little data exists on fire sprinkler rates of transient

accommodation buildings in New Zealand. A report published in 1976 by H.E. G. Henderson gives an overview of hotel fires and fatalities between 1958 and 1975, but since that time, the data has not been updated or further research undertaken, despite two significant changes to the New Zealand Building Code. This project provides a contemporary analysis of transient accommodation in relation to fire fatalities in New Zealand. It is based on the collecting of two data sets: accommodation and fire fatalities. In this project, a random sample of accommodation buildings in New Zealand was taken and analysed for the presence of fire sprinklers.

Transient accommodation fatality Fires
As the number of fire fatalities in transient accommodation buildings is relatively small, Table 1 below summarises all fatal fires since 1986. Following this table is a qualitative description of the three worst transient accommodation fires.

Date of fire	Description of fire
24 April 1987	Andersons Bay Road, Dunedin One person dies in a motel fire.
18 October 1987	Te Roopu Rapu Hostel One person dies in a hostel fire
27 December 1987	Taneatua Hotel Three children die in a hotel fire.
17 June 1989	Masonic Hotel One person dies in a hotel fire.
13 March 1991	Anzac Parade, Wanganui Two people die in a motel fire.
20 November 1992	Ferry Road Hostel Seven die in a shed used for sleeping accommodation at a hostel after bedding caught alight.
19 February 1993	Seaview Hotel Two men die in a hotel fire.
4 February 1995	New Empire Hotel Six die when a fire is deliberately lit in the lobby of the hotel. Fire doors were propped open causing the fire to rapidly spread to all three floors of the building.
21 February 1995	Wellington Street, Nelson One person dies in a backpacker fire.
16 December 2000	Quay West Hotel A 24 year old male dies after his grass skirt costume is deliberately set alight in the 5th floor toilets of a 4.5 star hotel.
5 August 2005	Unicorn Motel A 63 year old male dies after petrol vapour explodes in a motel room. It could not be ruled out that the fire was not deliberate.
6 May 2007	Timbertops Motor Park A 35 year old male dies after his bed catches fire in a holiday park cabin.

Table 1: Description of fatal fires in transient accommodation since 1986

Taneatua Hotel – 1987
Luke Hessey (6), David Hessey (4), and Heath Flutey (10) died in a hotel fire during the early hours of 27 December 1987. The three were sleeping in an upstairs bedroom and were rescued by volunteer firemen, but died soon after due to smoke inhalation. The building did not contain any smoke detectors (Graham, 1987).

Ferry Road Hostel – 1992
A shed at the rear of the Ferry Road Hostel in Christchurch was being used for sleeping by a group of young people on the night of 20 November 1992. The shed was not licensed for residential use and therefore did not meet minimum requirements under the Building Code or contain fire detection or suppression. A fire developed in the early hours of the morning, starting in a mattress most probably

by discarded smoking materials. The fire resulted in the deaths of all 7 occupants, 6 of whom were found to have significant levels of solvents and alcohol in their blood (Miller, 2008).

New Empire Hotel – 1995
On 4 February 1995, Alan Lory, a previous resident of the hotel (Figure 1), deliberately started a fire around 3.30am which quickly spread through the entrance lobby, stairwell, and third floor of the hotel. There were 35 occupants within the hotel at the time, with 8 on level one, 16 on level two, and 11 on the third level. Occupants Keith Lazenby (64), Terrence Holland (74), William Ward (70), Murray Jackson (59), and Kathleen Ellis (34) died in the blaze, and Bret Jones (18) died from jumping out of a third floor window to avoid the fire. Lory was charged with 6 counts of manslaughter and 1 charge of arson and was sentenced to life imprisonment. Investigators found a significant cause of the loss of life was fire doors that were left open, allowing the fire to quickly spread. The hotel was originally built in 1914 as a boarding house and was extensively renovated in 1974, although the buildings use, providing low cost accommodation, did not change (Miller, 2008).

Figure 1: New Empire Hotel c 1975. Hamilton City Libraries. (c1975). New Empire Hotel [Photograph]. Retrieved from: http://hamiltonlibraries.contentdm.oclc.org/cdm/ref/collection/p16653coll13/id/16

None of these buildings contained sprinkler systems and there is no information that states that automatic detection was present, and in many cases the records state that automatic smoke detection and/or fire alarms were not present.

ACCOMMODATION SURVEY

Aggregated data on transient accommodation establishments is collected and published by Statistics New Zealand in a monthly accommodation survey, it does not account for all transient accommodation types, nor does it contain information about fire protection (Statistics NZ, 2012a). The Department of Building and Housing also does not hold any relevant data. An analysis of a random sample of accommodation buildings was therefore undertaken to provide the required data.

The comprehensive accommodation website, the New Zealand Tourism Guide, was used to produce a list of transient accommodation providers (Tourism NZ, 2013). This list contained 9000 providers, including hotels, motels, backpackers, bed and breakfasts, holiday parks, holiday houses, lodges, and apartments. For this study, due to building similarity across several of the accommodation types, a reduced number of accommodation categories could be used. Definitions were taken from Tourism New Zealand. In this study, the definition of backpackers was expanded to incorporate rural hotels, particularly if they contained shared bunk-type accommodation, to better align with data provided by the New Zealand Fire Service. Similarly, the definition for bed and breakfasts was expanded to include farmstays, homestays, and luxury lodges and retreats due to their similar nature of hosted

accommodation in a residential house-type dwelling. The definitions for apartments, holiday parks, holiday homes, hotels (with the exception of rural hotels), and motels remained as described by Tourism New Zealand.

Each accommodation establishment from the list was assigned a random number from 1 to 9000 in an excel spread sheet, these were sorted into numerical order and the first 500 with sufficient information for analysis were used to produce the sample. Some establishments (20%) were no longer operating or did not provide sufficient online information about their accommodation and were therefore excluded from the sample.

Each accommodation provider was analysed to obtain the number of accommodation units, type of accommodation, Qualmark star rating (if rated), the number of floors, and whether the building was fire sprinkler protected. This information was sourced online via the accommodation provider's website and multiple accommodation review websites such as agoda.com, booking.com, expedia.co.nz, wotif.co.nz, holidayhouses.co.nz, jasons.co.nz, and tripadvisor.com. Although the vast majority of information was recorded for use by the tourism industry, by utilising multiple sources, enough information could be gathered for this study. The presence of fire sprinklers was particularly difficult to assess and was determined by inspecting interior photographs of rooms where available, locating sprinkler inlets on the outside of buildings using Google Street View, and searching for user reviews of accommodation for mention of fire sprinklers. Although many of the 'higher-end' providers would digitally remove fire sprinklers from their official photography, often user uploaded reviews, comments, and photographs would determine the presence of sprinklers. The sample of 500 included a breakdown of accommodation types as shown in Figure 2.

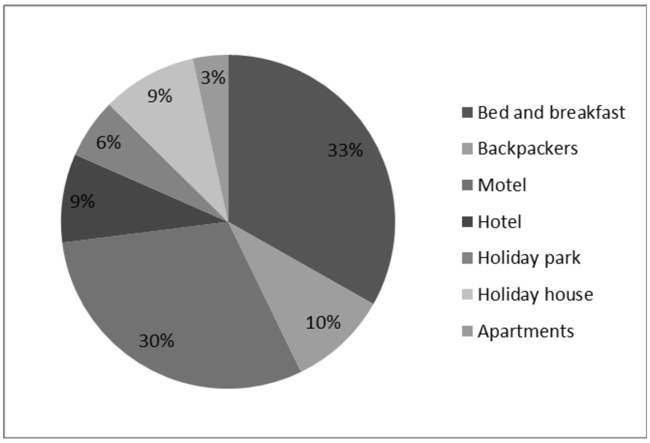

Figure 2: Percentage of accommodation types included in sample.

The sample is one twelfth of the overall accommodation in New Zealand and can be considered an accurate representation.

FIRE FATALITIES

The majority of fire fatalities are recorded by the New Zealand Fire Service in the Fire Incident Reporting System (FIRS). The data in FIRS dates back to 1975 with the establishment of the National Fire Service (NZFS 2011). While data exists previous to 1975, its reliability is uncertain. A list was taken from FIRS of all accommodation fire fatalities in New Zealand. 40 fatalities were recorded since 1975. If the search is extended back to 1950, 56 fatalities are recorded. Not all fatalities are recorded in FIRS data, with several fatalities not recorded between 1968 and 1973. Media searches, using the

newspaper indexes Index New Zealand, the New Zealand Index database, and the Auckland Libraries New Zealand Card Index, were used to obtain media reports of fire fatalities in accommodation buildings. An additional 9 fatalities were found, all during the period of 1968 to 1973. A summary of number of fatalities per year is given in Table 2.

Year	Number of fatalities	Year	Number of fatalities	Year	Number of fatalities
2007	1	1987	5	1972	2
2005	1	1986	3	1971	5
2000	1	1984	2	1968	1
1995	7	1981	1	1962	7
1993	2	1979	4	1961	3
1992	7	1977	1	1960	1
1991	2	1976	2	1959	1
1989	1	1973	1	1956	4

Table 2: Number of fire fatalities in transient accommodation buildings in New Zealand

FIRE SPRINKLERS IN TRANSIENT ACCOMMODATION

Seven percent of accommodation establishments contain fire sprinklers compared to 93% without sprinklers. However, 43% of accommodation units contain fire sprinklers compared to 57% of units not containing sprinklers, based on the average number of units per establishment. This analysis, due to the variability and difficulty in obtaining the number of bed spaces, will be based on the number of units.

Occupancy rates vary by accommodation type, with a range within the 2012 year from 56% occupancy for hotels to 15% for holiday parks (Statistics NZ, 2012b). Occupancy rates tend to be higher in the accommodation types that are more likely to be fire sprinkler protected. On average, it can be expected that 47% of occupied units contain fire sprinklers as opposed to 53% of occupied units without sprinklers. Although most establishments are not sprinklered, just less than one-half of the occupied units are sprinkler protected.

Factors Influencing Presence of Fire Sprinklers

Hotels are most likely to be sprinklered, with 51% of hotel establishments containing fire sprinklers. Apartments and backpackers are the next likely to be sprinklered, with 24% and 10% of establishment~~s~~ types respectively. Only one motel and one bed and breakfast contained sprinklers within the sample. No holiday houses or holiday parks in the sample are sprinklered.

The greater the number of units, the more likely it is for the establishment to be fire sprinklered. All establishments with more than 151 units were sprinklered, as were 60% of establishments between 101 and 150 units, 18% of establishments between 21 and 100 units, and about 1% of establishments between 4 and 20 units. No establishments of three or fewer units were spinklered. The number of units also relates to the overall building size of the establishment, as more units require a greater floor plate and/or building height. Less than 1% of buildings with one floor were sprinklered. This rate increases to 3% of buildings with two floors, and 19% of buildings with three to five floors. 95% of buildings with 6 or more floors were sprinklered, with all buildings over 7 floors containing fire sprinklers. The greater the number of units and floors, the more likely a building is to be sprinklered which is consistent with the requirements of the New Zealand Building Code.

Qualmark is the primary rating system used to assess accommodation standards in New Zealand. Only 119 of the 500 (24%) accommodation providers in the accommodation sample had a voluntary Qualmark rating. Lower quality establishments are less likely to have a Qualmark rating (Statistics NZ, 2012b, & Qualmark 2013). There is a higher percentage of sprinklers in Qualmark rated

establishments. Of those establishments rated 3 stars and above, 17.6% contained sprinklers as compared to 3.2% non-rated establishments. For hotels, motels, and backpackers, of those rated 3 stars or higher, 23.5% contain fire sprinklers compared to 5.1% for non-rated accommodation. A trend is evident in the Qualmark ratings of hotels, motels, and backpackers whereby a higher rating corresponds to an increased likelihood of the building containing fire sprinklers. Additionally, as with all accommodation types, those hotels, motels, and backpackers that are Qualmark rated are more likely to contain fire sprinklers than those that are not rated.

The majority of accommodation establishments contain between 4 and 20 units and are not Qualmark rated. There are very few establishments with 3 or fewer units or greater than 100 units. As a comparison, Statistics New Zealand records the average number of units per establishment for the year ending 2012 as 56.6 units per hotel, 16.1 units per motel, and 61.4 units per backpackers, with a combined average of 31.4 units per establishment. Figure 3 shows the number of buildings containing fire sprinklers for accommodation sizes and Qualmark rating,

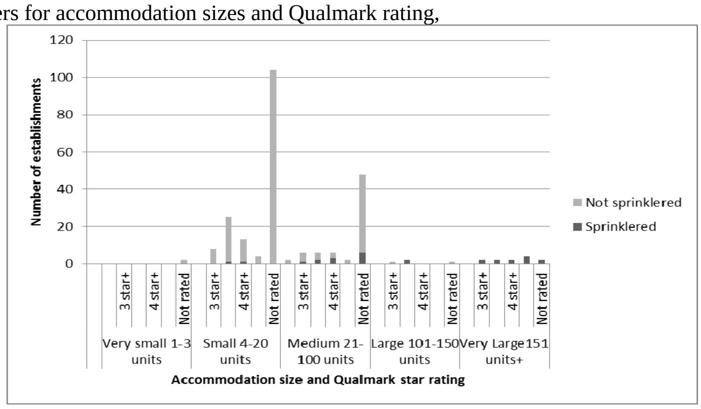

Figure 3: Presence of fire sprinklers by accommodation size and Qualmark rating in establishments

The majority of establishments that are likely to be fire sprinklered are any with more than 151 units, regardless of Qualmark rating. Overall, the data shows a correlation between Qualmark rating, number of units in an establishment, and the presence of fire sprinklers. The correlation between size and rating is most probably due to the facilities (such as swimming pools and restaurants) that must be provided to obtain a higher star rating. In most cases, it may only be profitable for the larger establishments to provide the required facilities for higher quality ratings.

FIRE FATALITIES IN ACCOMMODATION BUILDINGS COMPARED WITH DOMESTIC DWELLINGS

Between the period of 1975 and 2011, the New Zealand Fire Service records a total of 970 residential fire fatalities (NZFS 2011). Within these 37 years, the average fatality rate is 26.22 fatalities per year. Within the Fire Incident Statistics, residential fires include those in houses, flats, home units, apartments, boarding houses, half-way houses, dormitories, hotels, motels, lodges, and residential outbuildings such as garages, garden sheds, and glasshouses. As such, there is no distinction between transient and permanent accommodation and different building types, which is required to compare fire fatality data with information on the number of buildings in New Zealand. While separate residential categories of fire fatalities are recorded for most years, there is a period during the 1990s that only contains aggregated data. Of the years where information is separately categorised, an average of 93% of fatalities occur within buildings used for permanent residences, including houses, flats, and apartments. This percentage can be used to approximate the number of fatalities in

permanent residences for those years where data is aggregated. Figure 4 compares the number of fatalities in permanent residences to the number of fatalities in transient accommodation per year.

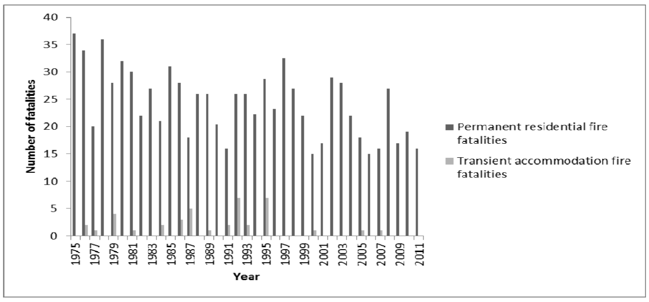

Figure 4: Comparison of fire fatalities in permanent residences and transient accommodation per year

While there are a lower number of fatalities in transient accommodation, it does not mean there is a lower level of risk than in permanent residences. A comparison can be made by measuring the fatality rate per 100,000 dwellings. Data from the New Zealand Census, the accommodation surveys undertaken by Statistics New Zealand, and the data gained from the accommodation sample within this project can be used to determine the number of these buildings in New Zealand. A combination of sources is required in which to appropriate the number of buildings, as no definitive source can state how many single units houses there are in New Zealand, let alone how many bed spaces exist in multi-storey apartment buildings. Table 3 shows an approximate count of the number of buildings in New Zealand.

Permanent residences	
Separate House	1,193,358
Two or more flats/units/townhouses/apartments/houses joined together	266,751
Total occupied dwellings	**1,460,109**
Transient accommodation	
Hotels	557
Motels	1798
Backpackers	442
Holiday parks	417
Bed and breakfasts	1992
Holiday homes	504
Apartments	204
Total all accommodation	**5914**

Table 3: Number of permanent residences and transient accommodation in New Zealand (Statistics NZ 2012b, 2013)

Since 1975, there have been a total of 899 fire fatalities in permanent residences with an average of 24.3 fatalities per year. Likewise, since 1975 there have been a total of 40 fire fatalities in transient accommodation with an average of about 1.08 fatalities per year. Based on this data, there are about 1.6 fire fatalities per 100,000 permanent residences per year compared to around 18 fire fatalities per 100,000 transient accommodation establishments per year. If the total number of fire fatalities for each residential type since 1975 is considered, there has been a rate of around 62 fatalities per 100,000 permanent residence compared to around 676 fatalities per 100,000 transient accommodation establishments. As such, there is a factor of risk 11 times greater in transient accommodation in comparison to permanent residences.

The results change when the number of residential bedrooms and accommodation units are compared instead of the number of establishments. There are an average of 3.10 bedrooms per private occupied dwelling in the 2013 census (Statistics NZ, 2013). The sample of transient accommodation taken in this project averaged 19.1 units per establishment. In this case, there can be assumed to be approximately 4,526,000 bedrooms in permanent residences and 113,000 units in transient accommodation in New Zealand. This results in a rate around 0.5 for fatalities per 100,000 permanent residential bedrooms per year and around 1 fatality per 100,000 transient accommodation units per year. If the total number of fatalities since 1975 is used, the rate is about 20 fatalities per 100,000 permanent residential units and about 35 fatalities per 100,000 transient accommodation units. As such, there is a factor of risk almost 2 times greater in transient accommodation units in comparison to bedrooms in a permanent residence.

As discussed earlier within the paper, only 43% of accommodation units are fire sprinkler protected. This percentage means that approximately 64,500 accommodation units are unsprinklered within New Zealand. Assuming the rate of fire fatalities in sprinklered accommodation is zero, the rate per 100,000 unsprinklered units is 1.7 fire fatalities per year. This rate in unsprinklered units is just over three times the risk posed by bedrooms in permanent residences.

Types of accommodation where fire fatalities occur

Most fatalities tend to occur in small to medium sized buildings with facilities similar to those of lower star ratings and without fire sprinkler protection. While FIRS data extends back to 1975, the amount of qualitative data collected with each incident varies. Fatalities since 1986 record significantly more information that those prior to 1986, where only the number of fatalities per year is recorded. Additionally, not all fatalities were able to be sourced in media reports. The analysis includes number of fatal fires and fire fatalities per year and the number of fatalities per fire (figure 5). The accommodation type, age of accommodation building, and presence of fire sprinklers is also recorded.

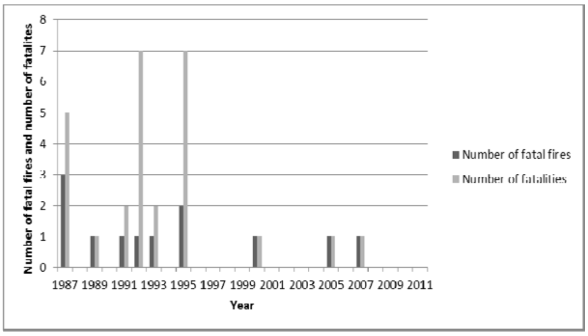

Figure 5: Number of fatal fire and fire fatalities in transient accommodation buildings per year

Over half of the number of fatal fires resulted in only one fatality, but single fatality fires only comprise 26% of fatalities so fatal fires in transient accommodation are likely to result in multiple fatalities.

The majority of fatalities occurred in hotel and backpacker accommodation (Figure 6). The hotels in which fatalities occurred tended to be similar to those with low star ratings and in some cases have greater similarities to backpackers than to 4 or 5 star hotels. While this issue is discussed later in the paper, it is of note that there is only one fatality in a large, fire sprinklered hotel. Additionally, there is only one fatality in a holiday park but the number of fatalities relates to accommodation buildings

provided onsite and does not include any fire fatalities that occurred in caravans or tents within holiday parks. There are a similar number of fatal fires between hotels, motels, and backpackers, although hotels and backpackers are more likely to result in multiple fatalities.

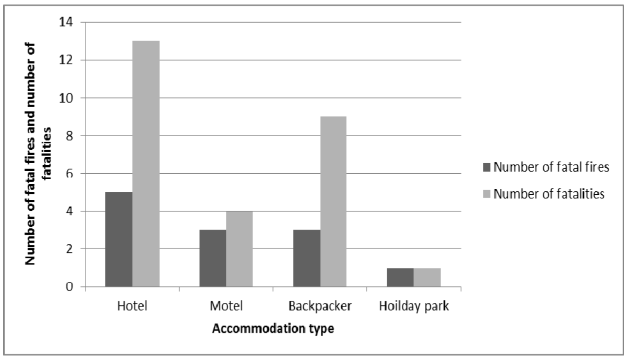

Figure 6: Number of fatal fire and number of fatalities by accommodation type

The decade in which the building was constructed is important in relating building code requirements to buildings where fatalities have occurred. In New Zealand, changes to the building codes only apply to new buildings or buildings that undergo significant renovation. Two buildings within the sample in the graph above were extensively renovated and are recorded by date of renovation, rather than date of construction. The majority of fires occur in buildings constructed or renovated between the 1940s and 1970s, well before automatic smoke detection became mandatory in sleeping areas (Figure 7). Overall, the trend is that fatal fires and the majority of fatalities occur in older buildings, with only one fatality recorded following the 1992 change in building code and no fatalities recorded in buildings following the 2004 building code changes.

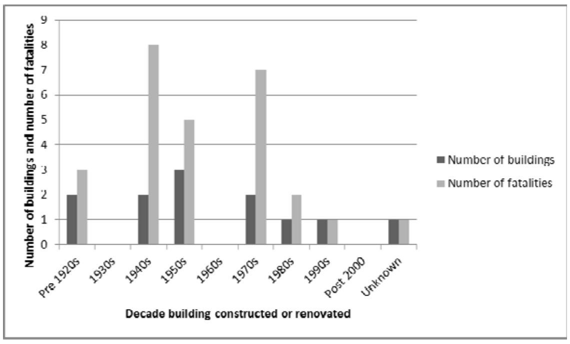

Figure 7: Number of buildings with fatal fires per decade constructed or renovated and number of fatalities per decade which the building was constructed or renovated

Only one fire, resulting in a single fatality, contained fire sprinklers, however as the individual concerned had his clothes set alight it is highly unlikely sprinkles would have had an effect on the outcome of this fire (Corbett, 2001). Nearly all of the fatal fires and fatalities occurred in non-sprinklered buildings and all of the multiple fatality fires occurred in non-sprinklered buildings. From this, it can be observed that fire sprinklers in transient accommodation have a significant correlation to preventing fire fatalities.

Overall, the results indicate that fire fatalities occur in older unsprinklered transient accommodation buildings. Multiple fatalities are also more likely to occur in hotel and backpacker accommodation with facilities similar to those with lower star ratings.

RECOMMENDATIONS

Requirements for fire sprinkler protection within the New Zealand Building Code should be more rigorous, particularly by reducing the height and size requirements for sprinkler protection in transient accommodation buildings. As the majority of fire fatalities occur in older accommodation establishments, without automatic smoke detection, it is recommended that the building code is made retro-active for transient accommodation buildings, so that all buildings are brought up to current code requirements for automatic smoke detection in sleeping areas.

CONCLUSION

This paper has discussed the difficulty in accessing data on fire sprinkler rates in transient accommodation buildings in New Zealand. A sample was undertaken of 500 accommodation establishments to fill the gap in data and was used to determine the rates of fire sprinkler protection in transient accommodation buildings. While only 7% of accommodation establishments contained fire sprinklers, 43% of units in transient accommodation were sprinkler protected due to the larger size of sprinklered accommodation. Building size, including the number of units in an establishment and the number of floors, and Qualmark star ratings had an impact on whether an establishment was sprinkler protected. Large, multi-storey, high quality accommodation was more likely to be sprinkler protected as compared to small to medium, low-rise, low quality accommodation.

Fire fatalities in transient accommodation since 1986 have practically all occurred in unsprinklered establishments. The rate per 100,000 units in transient accommodation is approximately 1, which is around twice the risk of bedrooms in permanent residential dwellings per year. If fatalities are assumed to only occur in unsprinklered accommodation, the rate increases to 1.7 per 100,000 units in unsprinklered transient accommodation per year. Multiple fatalities were also common in transient accommodation, with low quality hotels and backpackers presenting a higher risk. Low quality, unsprinklered hotel and backpacker accommodation are of particular concern as they provide the highest fire fatality risk.

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MATERIALS PERFORMANCE TESTING METHODOLOGIES

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ABSTRACT

Materials and construction methods continue to evolve. The empirical knowledge derived from traditional building practice is often insufficient for predicting durability problems with emerging materials and construction techniques. Consequently the capability for robust durability assessment of new products and techniques is an essential platform for supporting an innovative, dynamic building industry.

The New Zealand Building Code (NZBC) is primarily performance-based: only for a few classes of materials, such as timber and concrete, do prescriptive 'deemed-to-satisfy' solutions exist. For other situations, the Code offers only the advice that suitable durability performance may be demonstrated through either laboratory testing, a documented history of use, or by analogy with the behaviour of similar building components. Little further guidance is provided concerning how these criteria might be satisfied in practice.

In response, this paper describes the development of durability verification test techniques that will be used to avoid future issues resulting from changes to materials and construction methods. It is hoped that the methods developed will also serve to alleviate suspicion of 'new' products by developing appropriate, reliable and practical tests to assess them.

KEYWORDS:

Durability; Test Methods; Accelerated Weathering.

INTRODUCTION

Ensuring that buildings have an appropriate durability has always been an important aspect of building regulations. This is emphasised by the current NZBC, which includes the functional requirement that: "*Building materials, components and construction methods shall be sufficiently durable to ensure that the building, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the building*" (MBIE, 2014).

The NZBC is a performance-based, rather than prescriptive code, intended to permit innovative solutions and minimise the constraints placed on building design or choice of materials and techniques, providing the mandated minimum performance levels are achieved. The Code's B2 Durability clause is the single exception to this philosophy, setting default lifetimes for building elements depending on their criticality of function and ease of replacement (Table 1). These durability provisions apply to any part of the building which is fulfilling another Code requirement (e.g. structural stability or fire performance).

Table 1. A summary of the performance requirements for building elements specified by the NZBC B2 Durability clause. Note that the mandated service life allows for routine maintenance, but not reconstruction or major renovation.

	Nature of Building Element	*Required Service Life*	*Typical Examples*
(i)	Provides structural stability, *or*	50 years	▪ Load-bearing walls
(ii)	Difficult to replace, *or*		▪ Buried electrical wiring
(iii)	Failure undetectable thorough normal maintenance regimes		▪ Building wraps behind masonry veneer walls
(i)	Moderately difficult to replace, *or*	15 years	▪ Building envelope cladding
(ii)	Failure undetectable during everyday occupancy of building		▪ Sealants and flashings
(i)	Easily replaced, *and*	5 years	▪ Architectural coatings
(ii)	Failure readily apparent		▪ External gutters

The reason for retaining this prescriptive aspect in an otherwise performance-based code is essentially one of consumer protection: it was considered inappropriate to allow the service life of buildings to be effectively set by market forces, particularly given that a significant proportion of owners would have little expertise in evaluating the relative benefit of construction styles and materials (Bennett, 1998). Note that despite this prescription, the choice of materials for producing building elements of the required durability is left unregulated.

Industry reaction

Specifying durability in terms of building element service life has a number of drawbacks. These include the issues of perception involved in judging difficulty of replacement and the potential mismatch between Code requirements and the expectation of owners who, for example, are often surprised to discover the roof of their house only needs to last 15 years. Chown and Oleszkiewicz (Chown, 1997) offer some of the most telling criticism of this approach, noting that it may only be truly practical where the building element in question is essentially inaccessible (so that service life is independent of maintenance) and the rate of deterioration under the in-service environment is known. Otherwise, building designers, certifiers and owners assume a significant burden in determining and documenting material and component service life in various environments, based on an assumed level of maintenance. Often the information necessary to do this rigorously is not readily available.

This contention is supported by the most recent 2012 BRANZ Industry Needs Survey (TNS, 2012). As shown in Fig. 1, 73% of respondents cited ‘materials durability’ as the area most in need of new information over the next 5 to 10 years.

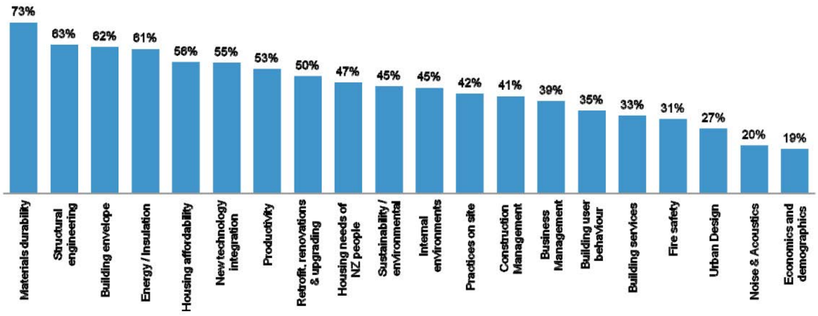

Figure 1. Importance Evaluation of Information for the next 5-10 Years (% rating need as 'High') (TNS, 2012)

Perhaps the perception of an absence of reliable information is unsurprising, given that the same respondents identified 'manufacturers' trade literature' and 'company websites' among the most valued sources of information (Fig. 2).

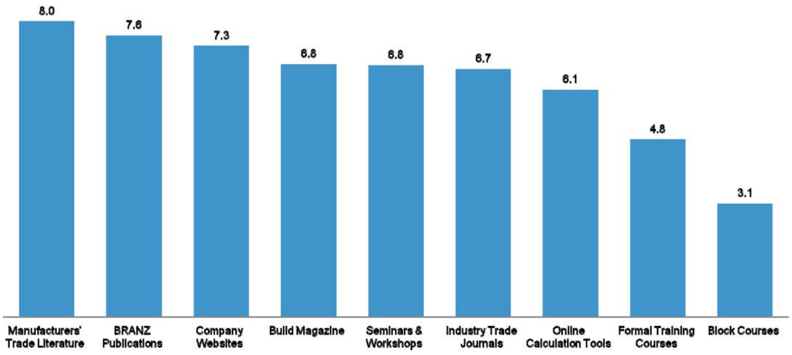

Figure 2. Value of Various Sources of Information: Mean scores out of 10. (TNS, 2012)

It is surprising that Standards and building code documents don't feature as sources of information, although it is possible that these were not included as possible responses.

Establishing compliance

Part of this difficulty arises because, despite the unquestioned importance of the subject, there is no broadly applicable methodology available to verify that building materials, components and construction methods will meet the performance requirements of the NZBC B2 Durability clause. Manufacturers and, especially, the statutory bodies responsible for certifying buildings as compliant with the Code, frequently wish to rapidly assess the expected service life of a new material, or even a conventional one in a new environment. The absence of a list of specific test methods that will generate a 5, 15 or 50 year durability rating is consequently a source of frustration.

For a restricted range of building materials and techniques, the NZBC incorporates the concept of 'Acceptable Solutions'; prescriptive construction methodologies that, followed to the letter, will

ensure Code compliance. Acceptable Solutions primarily exist for time-honoured construction methods (e.g. timber-framed or concrete construction, earth buildings) that draw on a background of many years' actual service history and development under New Zealand conditions. Even where an Acceptable Solution ordinarily covers durability compliance, the situation becomes complex when new materials with uncertain capability and interactions are introduced.

In cases where an explicit durability evaluation is required, the NZBC documents an approved verification methodology, known as B2/VM1. Unfortunately B2/VM1 offers only the generic guidance that proof of performance should be demonstrated by in-service history, laboratory testing, or analogy with similar products/situations. Anyone involved with materials testing will appreciate that this advice is both valid and a profound over-simplification of the process required.

TEST METHOD DEVELOPMENT

In practice, there is no shortage of test methods for a vast variety of materials and potential applications. However, a considerable amount of skill is necessary to collate and synthesise this information in a reliable and appropriate test that allows the assessment of a material's durability.

Examples of the need for expert judgement include: considering whether the degradation methods in accelerated tests (heat, moisture cycling, freeze-thaw, UV exposure etc) are appropriately matched to real-world causes of deterioration; assigning quantitative service life predictions on the basis of qualitative rankings of observed durability; and assessing likely variation in performance due the different macro- and micro-climates, materials interactions, intensity of use and maintenance that come with a specific instance of use on a particular building.

Although considerable research has been carried out into the durability and service life of buildings, materials and components by both BRANZ (Lee, 2008, Marston 2011) and overseas researchers, such as NIST and BRE, there is still a substantial absence of knowledge and information available.

As already mentioned, this means that New Zealand Standards and Building Code documents cannot provide reliable and quantified methods to determine the likely service life of materials. The result of this manifest in the NZ building stock, and the five-yearly BRANZ House Condition Surveys regularly highlight the poor state of New Zealand homes. The last, 2010, survey also showed that about 5% of houses less than 10 years in age had a major element in serious condition (Buckett, 2011). The elements would need immediate remediation, but would likely need replacement based upon the assessment system used in the survey.

In the past, BRANZ has developed and published accelerated methods such as the Evaluation Methods EM4, EM5 and EM6. These define test procedures for coating and jointing systems for flush finished fibre cement sheet cladding (EM4), adhesives and seam tapes (EM5) and window / door support systems (EM6). These methods are published on the BRANZ website and are referenced in NZBC E2/AS1.

The work described here aims to develop practical NZ assessment methodologies to evaluate the performance of priority materials and building components. To achieve this, the key environmental factors affecting the durable life of these building components will be identified, contributions of installation will be examined and accelerated and reliable tests will be developed to assess these priority building materials / components.

An example of this approach, detailing learning from past materials testing, and laying out how this research will be extended to provide a reliable and appropriate test for exposed polymeric materials is given in the following sections.

NATURAL AND ACCELERATED WEATHERING OF PVC

Past testing of natural exposed polymeric materials across New Zealand indicated that there was a clear and reliable correlation between the property loss of clear unstabilised polypropylene (PP) and polyethylene (PE) and solar exposure (Marston, 2008). Samples were exposed across the length of the country at sites in Kaitaia, Paraparaumu, at the BRANZ site in Judgeford and in Invercargill.

Trends for mechanical property change for more UV stable polymers during natural exposures, such as white polyvinylchloride (PVC) and black PE, were less clear cut. This is demonstrated in Figure 3, which shows the tensile strength of PVC samples exposed at Judgeford for up to seven years as a function of the UV radiation dose that is known to critically affect PVC mechanical properties (Andrady 1997).

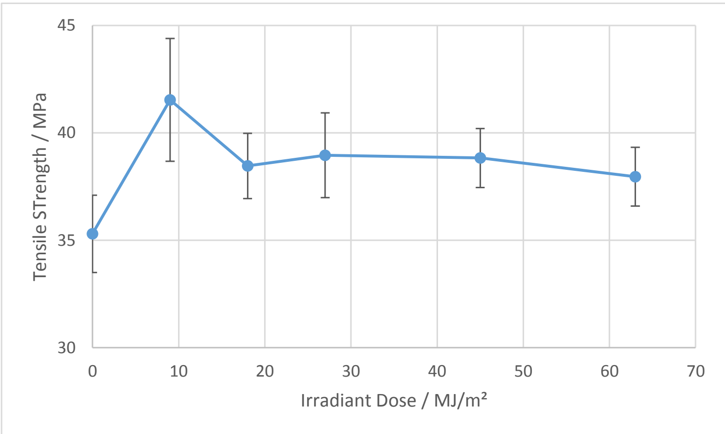

Figure 3. PVC tensile strength retention during natural exposure at Judgeford as a function of cumulative harmful radiation dose

The results perhaps imply that outdoor exposure of the samples is allowing the samples to relax internal stresses from the sheet manufacturing process and as a result the samples are gaining strength with time (Marston, 2008). Effectively the samples have been annealed during the exposure. This effect has been reported by other workers for the tensile strength of PVC following three years of natural exposure (Tsurue 1981). It is believed that eventually UV damage will cause the samples to lose strength, but this effect had not occurred by the end of the seven year exposure used in the study. This is not surprising as correctly formulated white PVC would be expected to perform acceptably for ~15 years outdoors in New Zealand.

The same PVC material was exposed to accelerated weathering using both xenon arc lamp and QUV fluorescent accelerated weathering chambers. The xenon arc chamber was set to the following cycle:

- 9 hours Light: 0.35 W/m² irradiance at 340 nm, Black panel temperature of 60°C
- 3 hours dark and spray: Black panel temperature of 40°C

The QUV used QUV-A 340 fluorescent tubes and the cycle was:

- 8 hours Light: 0.68 W/m² irradiance at 340 nm, Black panel temperature of 60°C
- 4 hours dark and condensation: Black panel temperature of 50°C

Samples were exposed for increments of 1000 total hours in each of the accelerated weatherometers. Tensile strength results for the samples that underwent accelerated weathering are shown in Figure 4. As before, results are presented as a function of the critical UV radiation dose received by the samples (Andrady 1997). Results for the samples that underwent natural exposure at Judgeford are also shown.

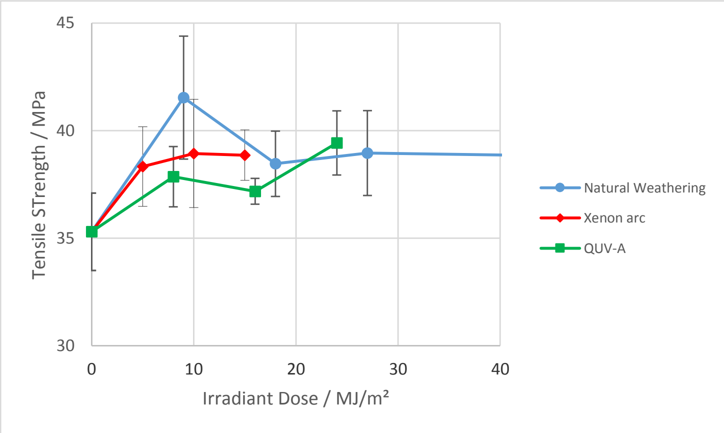

Figure 4. PVC tensile strength retention during natural and accelerated weathering as a function of cumulative harmful radiation dose

Figure 4 shows that the tensile strength trends for the PVC samples that underwent accelerated weathering generally replicate the natural weathering results: the samples initially gained strength during exposure. The exposure times for the accelerated samples, up to 3000 hours exposure in the weatherometers, were not long enough to initiate PVC tensile property loses. This is not surprising as the European standard for PVC windows, EN12608, indicates that about 6000 hours of light exposure in a xenon arc accelerated weathering apparatus mimics 5 years in southern European climates such as Spain or Italy (EN 2003).

Clearly, extended accelerated exposures will be necessary to begin to replicate the effects of natural weathering on the mechanical properties of more UV durable plastic materials. For this reason on-going research will focus upon evaluating the property changes of the less durable clear PP and PE that have already been studied during natural exposures (Marston, 2008).

ACCELERATED WEATHERING TEST METHOD DEVELOPMENT

The PP and PE materials used in the natural weathering study will be exposed for periods of time in both the Q-Panel Q-Sun xenon arc and Q-Panel QUV-A weatherometers. To align with the previous natural weathering project (Marston, 2008), the longest exposures will be targeted at a 50% loss of sheet tensile strength. Shorter exposures will be employed to further divide this irradiance dose into quarters.

UV Durable Materials

White PVC and black PE will be incorporated into later experiments to assess the ability of the accelerated tests to mimic the colour and gloss changes found during natural exposure of these materials (Marston, 2008).

Further Acceleration

Initial tests will utilise the accelerated weatherometer set-point conditions used by BRANZ for the last decade. Later tests will examine the reliability of increasing both the set point UV irradiance and cabinet temperature to attempt to further accelerate the exposures. This will reduce the time samples will need to be in the cabinets and as a result will reduce the cost of the testing.

CONCLUSION

New Zealand has had a mandatory requirement for durability in its national Building Code since 1992. In theory this should have stimulated industry awareness of the issues behind achieving appropriate service life of building materials and foster an active interest in the development of standards and test methodologies that could facilitate good durability design.

In practice, the transition from prescriptive to performance-based solutions has not been without its difficulties and the potential innovative and economic benefits have yet to be fully realised. New Zealand is a small country and there are few independent organisations with the technical resources and breadth of expertise to carry out rigorous assessments of materials durability. This is particularly evident when new, or composite, building systems are introduced to the market.

While based on sound scientific and engineering precepts, durability assessment remains as much art as science. Past BRANZ research has been successful in developing material test methods that have been integrated into the NZBC for the benefit of the industry. This work will build upon existing research understanding to improve the reliability of accelerated test methods, for example accelerated weathering of polymers, to provide defined test methodologies for adoption by the regulator, Standards NZ, specifiers, product distributors and product manufacturers. After each test method has been quantified and proved they will be published within BRANZ reports and in the literature, as appropriate.

ACKNOWLEDGEMENTS

The work described is supported by the New Zealand Building Research Levy.

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BUILDING BETTER APARTMENTS - DESIGN CONSIDERATIONS FOR NEW ZEALAND

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SUMMARY

Design requirements for residential living in New Zealand are currently undergoing change as the country's population grows and its demographic make-up evolves.

Many people now prefer apartment living close to the city centre, placing a premium on dwellings in this locale. Due to a lack of available space however, developments need to be medium-to-high density.

To ensure that the well-being and safety of residents are not compromised it is crucial that correct design decisions are made from the outset.

Appropriate space dimensions, effective noise control, fire safety and earthquake protection, along with durable construction materials are key to successful apartment design. This paper offers a summary of these considerations.

HOME – AN INTERPRETATION

Home is the most important place for the majority of people. It is 'our place', where we can relax and unwind. We associate the word 'home' with positive attributes such as health and wellbeing, recreation, socialising, inspiration, shelter, protection, safety and comfort - to name but a few.

If our home is in an apartment building, there are some specific design challenges that must be met to ensure it remains 'our place', and has the capacity to adapt to our own and our family's changing needs.

Apartment living is becoming increasingly important in New Zealand, especially in the more densely populated cities of Auckland, Wellington and Christchurch. Reasons for this include increased immigration and land constraints, but also that New Zealanders' lifestyles are changing.

There are more households comprising couples and singles, more people renting because they cannot afford to buy, and more city dwellers moving in from the suburbs because they enjoy the proximity to work, shops and nightlife. There are also increasing numbers of retirees who want the convenience of apartment living and who require less space after their children have left home.

As a country New Zealand is still relatively inexperienced when it comes to apartment design. Copying international practice isn't always the answer: what works for someone in New York or Berlin may not necessarily keep a Kiwi happy.

New Zealanders value their connection to the outdoors, they like to drive, and have bulky possessions needing storage such as tools and sporting gear. As well as providing extra

room, New Zealand designers have the added challenge of tackling earthquake protection within the structural design.

Traditionally New Zealand homes are about 250 m^2 for a typical family of four or five. However, intensification means making more use out of less space, hence Kiwi homes in future will be smaller than they are currently, yet living quality must not be compromised.

The New Zealand Building Code (NZBC) could offer space recommendations for apartments to guarantee a decent living standard. For instance, the absolute minimum size for a family home for four would be at least 90 m^2, with a reasonably sized outside deck plus underground storage.

In addition, it is important to offer a mix of dwelling types to suit people's different lifestyles as well as ensuring a vibrant atmosphere in apartment developments. A townhouse or two level apartment can be a good option for a larger family that would like to live in town. A penthouse is ideal for more affluent residents who enjoy entertaining, while a loft apartment may also appeal.

For aesthetic reasons it is important to mix units, and to create buildings where people can easily identify their home. With a variation of set out, cut backs, balconies and bay windows it is relatively simple to create visual interest while avoiding monotony.

A survey initiated by Wellington City Council (2009) identified some key likes and dislikes about apartment living.

Top five likes:

1.	Lifestyle and city living	(23%)
2.	Proximity to work	(20%)
3.	Proximity to shops and cafes	(11%)
4.	Low maintenance	(11%)
5.	Better safety and security	(7%)

Top five dislikes:

1.	City noise and noise from neighbours	(27%)
2.	Lack of outdoor space	(17%)
3.	Living too close to neighbours	(9%)
4.	Apartment size and lack of storage space	(8%)
5.	Parking issues	(7%)

SOUND PERFORMANCE

Noise in cities is derived from a number of sources, including traffic, road works, groups of people and from neighbours, whether they are simply talking, listening to music or partying.

The acceptable noise level within a bedroom for permanent noise is 30 dB and 35 dB for peak noises. Someone singing in the room next door would generate a noise level of about 75 dB. Painful noise begins at a level of 90 dB. Hence the sound attenuation capability of a partition should be at least 55 dB to reduce 90 dB to 35 dB.

The NZBC Clause G6 Airborne and Impact Sound/Acceptable Solution 1 (G6/AS1) expresses sound attenuation properties in Sound Transmission Classes (STC). An STC of 55 dB is the minimum required for apartment partitions.

The conventional guide for reducing airborne sound transmission is the mass law. This assumes that the heavier the structure, the less sound it will transmit (i.e. the more attenuation for airborne sound and sound at low frequencies). R'w is the weighted apparent sound reduction index.

Concrete options that achieve the weighted apparent sound reduction index (R'w) required to comply with G6/AS1 for walls, floors and ceilings between occupancies are as follows.

Denser concrete structures can also help to reduce the transfer of *low* frequency sounds.

- STC 55 - 150 mm concrete wall - 52 dB R'w
- STC 55 - 200 mm concrete masonry - 55 dB R'w
- STC 55 - 150 mm concrete slab - 52 dB R'w

Impact sound is the term used for sound waves that are generated on a partition, and are caused by such things as footsteps on the floor, hammering onto a wall, slamming doors and windows, or vibrating plant equipment. The most common impact sound in apartments is caused by people walking on the floor above a unit.

Impact sound is measured in LnwdB, which is the sound level transmitted below a floor from impact applied to the floor from above. The lower the LnwdB figure, the better the sound attenuation.

The impact sound attenuating performance of a material or system is described by its Impact Insulation Class (IIC). IIC indicates the amount of impact noise isolation provided by a floor/ceiling assembly. The NZBC requires the IIC of floors to be no less than 55.

Impact sound can only be minimised by uncoupling the building elements. Therefore, to reduce the noise from people walking in the apartment above, it is necessary to separate the stepped-on surface from the structure.

The IIC 55 minimum required by the NZBC for impact sound insulation can be achieved by a 150 mm concrete slab with underlay and carpet.

Further sound comfort can be achieved through the use of a floating screed, which is standard in some European countries. The screed is separated from the structural slab via a rigid but soft, light and airy material. This can include boards made of rubber or cork granulate, or mineral wool and polystyrene of between 5 mm and 30 mm. This insulation prevents sound transfer via the structural slab, while using 5 mm side strips minimises flanking sound to the walls.

FIRE SAFETY

In densely populated developments fire is a serious threat to property and to lives.

The Great Fire of London in 1666 devastated the city, much of it built from wood, and left an estimated 70,000 of its inhabitants homeless.

According to the NZBC Clause C Protection from Fire/Acceptable Solution 2 (C/AS2) apartment buildings must be able to withstand a fire without losing their structural stability and integrity for 60 minutes. If a sprinkler system plus smoke and alarm detection are incorporated the 60 minute requirement can be reduced to just 30 minutes.

However, an over reliance on a sprinkler system has potential drawbacks. Sprinkler systems are generally not fed by an independent water supply, but by the main water reservoir. These are fitted with auto shut valves that cut water supply during a seismic event. In this instance the sprinkler system may not be supplied with water, and therefore fail to extinguish any fire that occurred post-earthquake.

While steel structures can be coated with intumescent paint to achieve a degree of fire resistance, health protection gear has to be considered for the painters. Steel structures, along with timber, can also be clad with non-combustible materials such as gypsum boards. However, the structure may not be protected if an impact or earthquake damages the fire-protection layer before the minimum time required for fire resistance has elapsed.

When compared to other countries the 60 minutes to collapse provision is relatively short. For instance, in Germany 90 minutes is required.

A basic 100 mm concrete wall or slab provides a Fire Resistance Rating (FRR) of 90 minutes. Concrete is a simple and economic solution to achieve the highest fire safety:

- 1 hour - 75 mm (60 min as per NZBC C AS/2)
- 1.5 hours - 95 mm
- 2 hours - 110 mm
- 3 hours - 140 mm (180 min as per NZBC C/AS6, warehouses, bulk retail, etc.)
- 4 hours - 165 mm

STORAGE SPACE

One of the biggest challenges with apartment design is to provide sufficient storage space. Kiwis love the outdoors, and have equipment and bulky items to store. Cars, bicycles and prams also pose challenges in terms of storage. It is fortunate however, that these items can generally be stored in underground facilities.

While underground construction is relatively expensive, the convenience it offers renders it a worthwhile investment. There are also innovative solutions for car parks, such as circular lift towers, which negate the need for ramps and drive through passages. Similar systems are available for bicycles.

In terms of underground construction, retaining walls have to take up high lateral earth forces and at times hydraulic pressure from ground water. While concrete offers resilience in wet environments, as a porous material, and one that is prone to cracking, concrete is vulnerable to water ingress. The results can be potential freeze damage and the corrosion of the steel reinforcement.

As highlighted by Hooker (August 2012) however, concrete can achieve a degree of waterproofing through the use of Permeability-Reducing Admixtures (PRAs). The most commonly used PRAs consist of hydrophobic, or water-repellent, chemicals derived from soaps or fatty acids, vegetable oils, and petroleum. The materials coat the concrete surface, but leave the pores open.

Another type of PRAs is finely divided solids - either inert or chemically active fillers such as talc, clay, siliceous powders, hydrocarbon resins, and coal-tar pitches. These materials provide a barrier to reduce the movement of water through the pores.

The third type consists of crystalline products - proprietary chemicals in a carrier of cement and sand. These are hydrophilic materials that increase concrete's density to block concrete pores and resist water penetration.

Using concrete plus PRAs will help achieve underground construction that is long lasting, low-maintenance and will keep stored items safe and dry.

EARTHQUAKE RESISTANCE

Resulting from New Zealand's geographical location on the Pacific and Australian fault line, the country's buildings require sound structural designs that can withstand strong seismic forces. The Napier earthquake in 1931 and the recent Canterbury earthquakes are stark reminders of the importance of earthquake-sensitive structural design.

Given our earthquake-prone location, it is un-surprising that two of the most common and successful seismic design solutions have New Zealand origins. Under the umbrella term "damage resistant design" their objective is two-fold, preserve life and minimise damage.

These solutions are briefly described below, and should be incorporated into any structural design for new apartment buildings.

Base Isolation

New Zealander Dr Bill Robinson developed the lead-rubber base isolation system, which was first used in Wellington in 1982 and is now used worldwide in earthquake-prone areas. The system proved its worth in the February 2011 Canterbury aftershock when the base-isolated Christchurch Women's Hospital escaped relatively undamaged.

The base isolation system uses isolators to separate the building from the ground, buffering the structure from significant movement during an earthquake. Ideally the building itself should be of rigid construction so that any movement will be carried by the entire structure, and not concentrated at specific points.

A building's stairs should also be constructed of a rigid material. Rigid stairs will be able to slide on extended bearings at the landings and so be prevented from moving out of place and potentially collapsing.

PRESSS

The PREcast Seismic Structural System, known as PRESSS, was developed in the 1990's during a ten year joint U.S./Japanese programme at San Diego State University. The programme initiator and head was New Zealander Dr Nigel Priestley. PRESSS buildings are simple to construct and compare favourably in terms of cost with conventional reinforced concrete structures.

In the PRESSS system concrete precast walls, beams and columns are jointed in a ductile manner. Mild steel cables hold the structural elements together when the building shakes. Energy dissipaters dampen the impact of the seismic forces, while post-tensioned cables placed in the centre of the structural members enable the building elements to snap back into their original position once the shaking stops.

An important PRESSS building in Christchurch is the Southern Cross Endoscopy Building. Completed in 2010 this 5-storey medical facility verified the theoretical principles of PRESSS

during the September 2010 and February 2011 Canterbury earthquakes by emerging structurally unscathed and available for immediate reoccupation.

DURABLE MATERIAL

It is essential for the longevity of any apartment building that structural materials and materials exposed to the elements are durable. As apartment buildings are subject to more intense wear-and-tear than typical residential developments durability is a crucial design consideration.

For highly trafficked areas, such as corridors and stairwells, it is important that construction materials are able to withstand impact. The use of plasterboard walls brings with it many drawbacks in terms of impact resistance, the implications of which are potentially serious if used on a fire wall for instance.

In terms of outdoor spaces such as courtyards, picnic areas, hard-standings as well as various types of outdoor furniture, the requirement for durability is equally important. Not only are these spaces and equipment for common use, but they are subject to the harsh effects of wind, rain, ultra-violet light and temperature swings.

It is common for apartment developments to be surrounded, in part at least, by some form of paved 'shared space' – an area used by motor vehicles, bicycles and pedestrians. There are many successful examples of concrete paved outdoor areas, many of which go beyond traditional concrete block paving and flagstone paving. Permeable paving and pervious concrete are gaining traction with designers, while concrete's ability to be coloured provides visual appeal along with practical applications such as identifying parking areas without the need for raised kerbing.

The fallout from the 'leaky homes' continues, and places an even great premium on robust, low maintenance and durable construction materials within an overall design that is suitable for the local climate, incorporates appropriate detailing and is brought to life by skilled trades professionals.

The consequences of any shortcuts in terms of quality materials, design or practice will be magnified by the scale of an apartment development. This will impact dramatically on the cost and pace of any remedial work.

CONCLUSION

The size and composition of New Zealand's population is currently undergoing considerable change. One outcome of this overarching demographic shift is the need for more medium-to-high density residential apartment complexes in the heart of New Zealand's major cities.

However, to ensure that the short, medium and long term needs of the residents are not compromised appropriate design decisions must be made from the outset, particularly in the areas of adequate living space, sound performance, fire safety, storage facilities, earthquake resistance and the selection of durable materials.

As evidenced by international experience and other construction applications in New Zealand, concrete offers a range of advantages that will see it make a significant contribution to future residential developments.

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SECURITY OF PAYMENTS FOR SUBCONTRACTORS IN THE NEW ZEALAND CONSTRUCTION INDUSTRY: STAKEHOLDER VIEWS ON THE KEY ISSUES AND IMPROVEMENT MEASURES

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ABSTRACT

Subcontractors play a major role in the construction industry with responsibility for 80-90% of the project work. However they face security of payment issues, which affect their cash flow, productivity and performance, with cascading effect on the rest of the industry supply chain. These problems persist in spite of the improvement expected from existing legislations and bylaws. To date, there is little research on subcontractors' security of payment issues and mitigation measures in the NZ construction industry. This study contributes to filling the knowledge gap in this area by investigating the issues and providing evidence-based solutions. Through pilot interviews and questionnaire surveys, industry stakeholders' perceptions were collected and analysed by means of content analysis and the descriptive statistics and the Spearman's Rank Correlation test. Results showed that key factors undermining subcontractors' security of payment in New Zealand included main contractor 'going-bust', poor record keeping, lack of supporting evidence during claim preparations, late or no-payment, and delayed release of certified amounts and retentions. The full paper reports on some identified mitigation measures; these comprised having partnering agreement between all parties at the start of the project with focus on win-win outcomes for all, and having a review of the Payment Schedule - section 21(3) of the Construction Contracts Act 2002 - to prohibit self-serving basis for calculating scheduled amount and withholding or refusing payment. Overall, collaborative working arrangement such as partnering is recommended as the most appropriate and fundamental solution that could help to resolve wider issues. This approach also resonates well with the key values of trust, relationship and reputation which define the way business is conducted in the New Zealand construction industry.

KEYWORDS:

Cash flow, construction industry, retention, security of payment, subcontractor.

INTRODUCTION

Fair Work Building and Construction (FWBC, 2012) defines 'Security of payment' as "a general term used to describe the entitlement of contractors, subcontractors, consultants or suppliers in the contractual chain, to receive payments due to them" (p.1). Security of payment issues still exist in the industry in spite of existing legislations and bylaws aimed at resolving the issues (Hughes, Hillebrandt, & Murdoch, 2000; Steelman, 2013).

The recent global financial crisis (GFC) affected, and is still affecting, many sectors of the local and global economies. It has left in its wake, painful financial crunches that are still crippling businesses. The bitter lessons learnt have elevated financial and contractual risk awareness and response to all-time highs. The construction industry is known as one of the most risky sectors of the economy (Cormican, 2014). King (2010) observes that companies in the construction industry now operate in a high risk environment that is dominated by cutbacks and austerity. The industry has transformed, metaphorically speaking, to a 'jungle' where the fittest thrive and pass on risks and responsibilities without commensurate reward to the weakest. Subcontractors, being the 'weakest' by their position in the lowest rung of the supply chain, now have to pick up the largest proportion of risks,

responsibilities and losses passed down from the top through self-serving contractual clauses. The most critical aspects of the risks relate to ‘security of payment’ issues. These issues arise when payment for duly completed work is fraught with risks such as non-payment, incomplete payment or delayed payment.

Security of payment issues are the root causes of cash flow problems in the construction industry. Lord Denning’s – Master of the Roll’s – rightly observed that cashflow is the lifeblood of the construction industry (Bates and Wray, 2011). Security of payment issues are conduits for draining the very lifeblood of the service provider’s business through constrictions on cash inflows. King (2010) observes that companies are more likely to fail due to the lack of cash than reductions in turnover or squeezed margins. Therefore security of payment issues are responsible for increasing rate of bankruptcy and liquidation of businesses in the construction industry. This is supported by Collerton’s (2014) remark that, without cash, it is easy for companies to go out of business, notwithstanding how profitable the company is or how many assets it has.

King (2010) observes that withheld retentions often represent the profit for the project, adding that “unless you chase for unpaid retentions, it is unlikely that they will be paid” (p.1). FWBC (2012) notes that some principals and contractors do hold up or reduce payments owed to subcontractors, in order to inflate their own positive cash flow. In New Zealand, Ninness (2013) notes that “while retentions have a legitimate purpose, their complicated structure allows many building firms to use the resource as working capital at their subcontractors' expense, thereby creating widespread problems for the construction industry” (p.1).

Subcontractors’ own faults

Subcontractors themselves do cause some of the security of payment issues they face. For instance Collerton (2014) notes a frequent problem of invoicing not done on time. This usually happens when the subcontractor is too busy pushing the work as fast as possible, and in the process forget other important administrative work that affects payment and cashflow. Even when the invoice was provided on time, it might be fraught with a lot of issues that provide grounds for dispute and partial payment. Some of the issues include over-estimating future work to end of the claim period, not providing supporting documents such as site photos, carrying on variation work without prior agreement on the associated cost and extension of time, and not keeping proper site diaries (Mbachu, 2012). Collerton (2014) further notes that when the scope of work is not mutually agreed to before work starts; it is easy for the edges to get blurred because of extra work that may be ordered during the implementation phase. Producing a surprise invoice that is above the original estimate may likely result in a slashed claimed amount by the employer using a valid payment schedule.

The Construction Contracts Act (CCA) 2002 aims to promote cashflow in the construction industry and could mitigate the security of payment issues faced by subcontractor. The Act provides a party to a construction contract with the ability to issue payment claims and, where not responded to fully or on time, could give the claimant legislative backing to elevate the amount claimed to a debt that is due and owing (Bates and Wray, 2011). The Act provides the context of operation for adjudications pursuant to this Act. It is possible for a party to a construction contract to refer a matter to adjudication under the Act. This is a fast-track dispute resolution mechanism that potentially places a duly appointed adjudicator under an obligation to make a determination within 35 working days of the adjudication claim being served by the claimant (Bates and Wray, 2011).

Though standard terms of contracts and the CCA 2002 provides avenues for subcontractors to speedily seek judicial enforcement for payment of their claims, only a fraction of the claims and associated costs get awarded for payment. For instance, Bates and Wray (2011) observe that, in practice, judicial awards in favour of the plaintiff are around two-thirds of actual costs incurred. That means a third of the costs will remain unrecoverable. Added to this inherent risk is the fact that the

Act gives the payer the right to respond with a payment schedule that schedules zero payment, so long as a valid payment schedule is served on the payee within the specified period. It is then up to the payee to seek appropriate payment through adjudication, arbitration or litigation. The question remains, how many subcontractors are willing to take their employers to adjudication, arbitration or the courts? The current climate in the construction industry is one where relationship matters. It indicates that a subcontractor that makes a case with an employer might be blacklisted from invitations to tender for future jobs. So when faced with the choice to achieve two-third payment of what is owed through courts or tribunal and risking future income stream in the process, most subcontractors would prefer to suffer all manner of payment-related unfairness in the hands of the employer in order to preserve existing harmonious relationships and pipeline for future job orders. This scenario nurtures and propagates myriads of security of payment problems that subcontractors face. With subcontractors being responsible for 80-90% of the construction industry workload (Mbachu, 2012), security of payment issues they face have a cascading effect on the rest of the construction industry, including poor quality of work and productivity.

Many researchers have looked into security of payment issues between the clients and the main contractors (Hughes, Hillebrandt, & Murdoch, 2000; Steelman, 2013). However there is limited research on how to minimise the issues faced by the subcontractors. There is therefore the need to investigate subcontractors' security of payment issues and how to mitigate them.

Research aim and objectives

This study aims to provide answers to the following research questions.

1. What factors undermine subcontractors' security of payment in the New Zealand Construction industry?
2. What measures could be put in place to mitigate the security of payment issues faced by subcontractors?

Scope and limitation

Analysis was limited to security of payment issues faced by domestic subcontractors in the New Zealand construction industry. Feedback was received from registered members of the following professional and trade organisations: New Zealand Institute of Quantity Surveyors (NZIQS) for quantity surveyors, Specialist Trade Contractors Federation of New Zealand (STCFNZ) for subcontractors, Registered Master Builders Federation (RMBF) for main contractors, and the New Zealand Institute of Building (NZIOB) for building professionals.

RESEARCH METHOD

Descriptive survey method was adopted in the study because feedback from surveys constituted the empirical data for analysis (Cooper and Schindler, 2006). Two stages of data gathering were involved. In the qualitative data gathering phase, pilot interviews were held with eight interviewees, comprising two interviewees from each grouping of quantity surveyors, contractors, subcontractors, and building professionals. Constructs generated at the pilot interviews were used to design the questionnaires for the quantitative data gathering phase. The questionnaires were first pre-tested for clarity and relevance so as to enhance response rate. The amended questionnaires were hosted online. Owing to privacy reasons, it was not possible to obtain the membership directories of the trade and professional organisations delineated for the study. Requests to participate were circulated to the members of each organisation through their secretariats. The request letter provided links to the questionnaire online.

Method of data analysis

Content analysis was used to analyse the qualitative data, the objective being to establish the frequency of mention of the key constructs to use in the questionnaire design (Cooper & Schindler, 2006). For the quantitative data, descriptive statistics was used to establish the average ratings of the groups. To compare two groups' sets of ranks of some identified variables such as the relative levels of significance of the key problems underlying subcontractor security of payment, the Spearman's rank-order correlation test was chosen as the most appropriate statistical analytic (Mbachu, 2012).

The Spearman's rank-order correlation coefficient measures the level of association (i.e. agreement or disagreement) between ranks of variables in two ordered series as shown in Equation 1 (Siegel and Castellan, 1988).

$$r_s = correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 (y-\bar{y})^2}} \quad (1)$$

Where

- r_s is the Spearman's rank-order correlation coefficient
- *x* and *y* are the ranks assigned to variables in a given set from the analysed ratings of two groups of respondents;
- $\dot{x}$ and $\bar{y}$ are sample means or the average for sets of ranks (i.e. arrays X and Y) for respondent groups X and Y, respectively.

To test the significance of the computed value of Spearman's rank-order correlation coefficient, r_s (i.e. to ascertain whether any observed level of agreement or disagreement is significant or by chance variation), it is compared to the critical values ($rs_{critical}$) evaluated from statistical tables. Depending on the number, *n*, of the variables, Siegel and Castellan (1988) advise that agreement exists between any two arrays of ranked-ordered series if the observed r_s is greater than or equal to the $rs_{critical}$ at alpha level of 5% for which significance tests are usually carried out; otherwise, disagreement exists.

RESULTS AND DISCUSSIONS

Survey responses

A total of 68 survey responses were received as at the cut-off date, out of which only 59 were found usable. The excluded 9 responses were from respondents whose inputs did not meet the quality criteria set for the research such as respondents with less than 3 years of construction industry work experience. Unfortunately it was not possible to calculate the response rates for the various sampling frames. This was because invitations to participate in the surveys were dispatched through the secretariats of the trade and professional organisations. Membership directories were not disclosed due to privacy reasons.

Analysed proportions of the respondents' primary roles in the construction industry are shown in Figure 1. The figure showed that majority (i.e. 31%) were main contractors. The survey responses might therefore be biased towards main contractors' views.

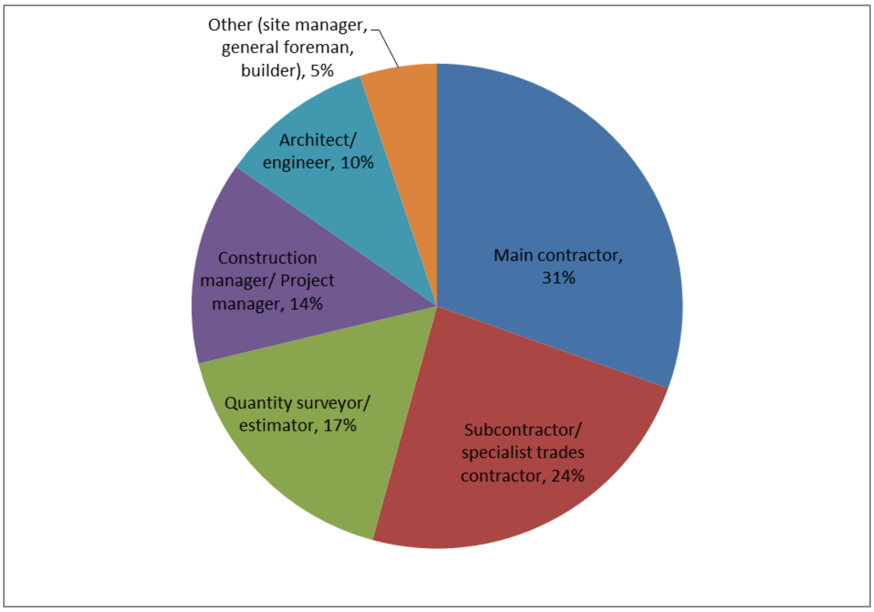

Figure 1: Respondents' primary roles in the construction industry

Other demographic profiles showed that majority (95%) had over 15 years of industry experience, and 85% were directors or senior managers in their respective organisations. Feedback received was therefore from influential and experienced respondents who were quite knowledgeable in the subject matter and whose opinions counted. This adds to the quality of the feedback and the conclusions drawn from the study. However, the small number of responses (i.e. 59) and the inability to determine the response rates of the various groupings mean that the findings cannot be generalised beyond the dataset for the research. Nonetheless, the findings offer starting point for further debate and research on the topic.

Security of payment issues faced by subcontractors

The first objective of the study was to explore the key factors that undermine subcontractors' security of payment in the New Zealand Construction Industry. Some factors were identified during the pilot interviews. At the questionnaire survey stage, respondents rated the relative levels of risk of the factors. Table 1 presents results of the analysis.

Table 2: Factors undermining subcontractors' security of payment

	Factors undermining subcontractors' security of payment	*Mean rating score	Source
1	Main contractor "going bust".	4.8	External (business climate)
2	Poor record keeping, lack of supporting evidence, and omission or poor valuation during claim preparations.	4.5	Subcontractor
3	Retentions not released by due date or not released at all.	4.4	Main contractor

4	Late payment of certified amount.	4.2	Main contractor
5	Dispute over items or quantity of work in the subcontractor's progress or final payment claim.	4.0	Main contractor
6	Dispute over price rates of items in the progress or final payment claims.	4.0	Main contractor
7	Counter-claim, especially for defective work.	3.8	Main contractor
8	Disputed quality of work claimed.	3.7	Main contractor
9	Time and costs spent in resolving disputes, including lost productivity.	3.3	Main contractor
10	Lack of clearly defined practical completion times for subcontract works.	3.3	Main contractor
11	Main contractor's use of subcontract retentions as working capital.	3.2	Main contractor
12	Late payment or underpayment by client to the main contractor's claims.	3.1	Client
13	Lack of clearly defined scope of subcontract work at the onset	3.1	Main contractor
14	Subcontractor undertaking variation orders without prior agreement on implied extra costs and extension of time.	2.8	Main contractor
15	Subcontractor subletting subcontract work without prior consent of the main contractor.	2.8	Subcontractor
16	Poor variation claim management, especially not claiming variations as they occur, only to submit large claim on a retrospective basis	2.7	Subcontractor
17	Subcontractor involving in verbal contract without written agreement on key contract terms and conditions.	2.7	Subcontractor
18	Client or agent giving extra work or variation orders to subcontractor without the main contractor being notified.	2.4	Client

**Mean rating: < 1.80 = "Not at all risky"; 1.80 -2.59 = "Of little risk"; 2.60 - 3.39 = "Moderately risky"; 3.40 - 4.19 = "Risky"; > 4.19 = "Very risky"*

Table 1 shows that of the 18 factors identified at the pilot interview stage, 17 were rated "moderately risky" to "very risky" at the questionnaire survey stage. Analysis of sources of the risk factors showed that main contractors were responsible for the majority (i.e. 61%) of the risks. Subcontractors themselves were responsible for 22% of the security of payment issues they faced, with clients and events in the external business landscape accounting for 11% and 6%, respectively. Main contractor 'going bust' was perceived to be the most risky factor. This result is not surprising, as the incident that heightened attention to the subcontractors' security of payment issues was main-contractor driven, notably the collapse of Mainzeal – one of the leading contracting firms in New Zealand – in February 2013. The incidence resulted in subcontractors losing over $18 million in retention money, not putting into account lost payments from work-in-progress (Quinn, 2014). The losses were largely due to retention money not regarded as part of debt security under the New Zealand Securities Act 1978.

It was surprising to note that subcontractors themselves were responsible for the second most risky set of factors, namely issues relating to poor record keeping, lack of claim supporting evidence, and omission or poor valuation during claim preparations. This finding is in agreement with Collerton's (2014) observation that a frequent problem of subcontractors was not invoicing the main contractor on time or doing so without the necessary supporting documentations. This might be because subcontractors are usually too busy trying to keep up with the required progress of work and do not have quality time for equally important contract administrative issues.

Additional security of payment risk factors
In the open-ended questionnaire, respondents were requested to suggest other subcontractor's security of payment risk factors that were not included in the list identified during the pilot interviews. Content analysis of the respondent's feedback provided 9 recurrent issues that were additional to the earlier identified risk factors:

1) Nature of the relationship between the main contractor and the subcontractor;
2) Terms and conditions of the subcontract and how the associated risks drew upon the head contract, e.g. final release of subcontract retentions tied to end of head contract defects liability period.
3) Global financial crisis (GFC)/ recession – scarcity of jobs in a depressed economy cause some companies to submit zero-profit tenders to just win a project in the hope of attaining breakeven on variations.
4) Devalued, late or non-payment from previous projects effecting cashflow on current projects;
5) Verbal contracts with no clearly defined contract provisions and scope of work, making it difficult to make a case for variation claim;
6) Subcontractor's lack of quality assurance plan and poor health & safety records cause a lot of rework and corrective measures which get charged back on claimed amount via back charges;
7) Insufficient details in variation claims, making it easy for main contractor to dispute a lot of claims.
8) Accepting too many jobs at once which consequently overstretch capacity and resources resulting in delay or complete non-performance.
9) Subcontractor' lack of knowledge of the terms and conditions of contract, especially in relation to issues such as timing of notices and dispute resolution requirements and procedures.
10) Back charges, e.g. for liquidated damages for late completion.

Measures for mitigating subcontractors' security of payment risks

The second objective of the study was to explore measures for mitigating security of payment issues faced by subcontractors. Some mitigating measures were identified during the pilot interviews. At the questionnaire survey stage, respondents rated relative levels of effectiveness of the identified measures. Out of 12 measures identified in the pilot interviews, only 9 were found effective. The mean ratings analysed from the responses provided a basis for rank-ordering the measures, with 1 being the most effective. Table 2 presents the 9 effective mitigation measures and their rankings analysed from all respondents' responses. Rankings analysed from separate responses of subcontractors and main contractors were also presented; these were used in a correlation test to examine whether or not some agreement existed between both groupings.

Table 2: Mitigation measures for subcontractors' security of payment issues

	Mitigation measures for subcontractors' security of payment issues	*Ranking		
		All respondents	'Subbies'	Main contractors
1	Having partnering agreement between all parties at the start of the project with focus on win-win outcomes for all. All parties to aim at transparent and trustworthy relationship for mutual benefits.	1	1	1

2	Adopt fortnightly payments rather than current monthly intervals which means 2 months of zero cash inflow; alternatively split subcontract into weekly milestones with payment made on completion of each milestone.	2	2	3
3	Hold retentions in a trust account with arrangement in place for releasing the retention in case the main contractor goes bust.	3	5	8
4	Revise the Payment Schedule section 21(3) of the CCA 2002, to prohibit self-serving basis for calculating scheduled amount and withholding or refusing payment.	4	6	4
5	Subcontractor to offer discount for prompt payment of subcontract progress or final claim to main contractor or building owner; discount to be equal to bank charges for project finance overdraft or loan.	5	7	2
6	Main contractors to issue Payment Bond in favour of subcontractors, guaranteeing that the main contractors will meet their payment obligations in the subcontract as and when due, including subcontract retention money and works-in-progress.	6	8	9
7	Provide subcontract performance bond in lieu of retentions.	7	9	5
8	Upfront payment for materials: Materials to be insured in both parties' names with a copy of the insurance policy, detailed list of materials & photos to be provided to the main contractor & a site visit by a QS to inspect quality of materials.	8	3	6
9	Provide start-up or mobilisation deposit payment to subcontractors to get the work started.	9	4	7

*[*Ranking: 1 = most preferred]*

Correlation test and significance:

Spearman's Rank Correlation Coefficient (rs) (see Eq.1):	0.38
$rs_{critical}$ from stat tables (for n =9, 1-tailed test, 0.05 alpha):	0.12

Result: $rs < rs_{critical}$, implying no significant correlation exists, or no agreement in ranking between subcontractors' and main contractors' sets of ranks for the mitigation measures.

Table 2 shows that the most effective measure for mitigating the security of payment issues faced by subcontractors in New Zealand is by having partnering agreement between all parties at the start of the project with a focus on win-win outcomes for all. The partnering agreement should be drafted to promote transparency, trustworthiness and mutually beneficial relationship amongst all stakeholders. This finding is in agreement with the New Zealand Construction Industry Council's (NZCIC, 2004) position that partnering approaches should be encouraged in the industry as best practice approach; this involves all stakeholders "working together to improve design, reduce accidents and costly future maintenance activities" (p.5).

It is interesting to note that subcontractors and main contractors also prioritised this measure as being the most effective above all other measures. Perhaps, this result was driven by the unique nature of the New Zealand construction industry, where relationship, reputation and trust are key values that can make or mar a stakeholder's current and future prospects in the industry. Given the small size of

the industry, these values enables a business to build long-term relationships with key partners as well as help to resolve many contractual and legal issues amicably without the need for confrontations and litigations.

The second most effective mitigation measure calls for adoption of payment periods that are fortnightly rather than monthly. The alternative measure is to breakdown subcontract work into weekly milestones with payments made for duly completed milestones. The top priority accorded to this measure could be because the two month period it takes for receiving payment from the commencement of the contract period exerts too much pressure on the working capital and cash flow positions of both the main contractors and the subcontractors.

It is surprising to note that the two suggested solutions making rounds in the industry for enhancing subcontractors' security of payment positions were not accorded top priority by any of the survey groupings. These relate to holding retentions in a trust account and the provision of subcontract performance bond in lieu of retentions. This result lend credence to Quinn's (2014) concerns that "while, in principle, retention funds should not be used as working capital by main contractors (thus exposing them in the case of failure, as in the case of Mainzeal), an immediate move to either compulsory bonding or trust accounts for retentions will potentially have a crippling impact on the construction sector's capacity and capability" (p.1). Quinn's (2014) reason was that only few companies within the entire supply chain (including subcontractors and sub subcontractors) would have sufficient capital to operate at their current levels without retentions contributing to their working capital/ cash flow. Furthermore, there are issues with keeping retentions in trust accounts. These include increased construction costs due to cost of administering the trust accounts and the cost of capital. Reflecting the views of the Registered Master Builders' Federation, Quinn (2014) concluded that a move to compulsory bonding or trust accounts for retention may result in unintended consequences whereby "the cost of the cure may be worse than the problem, and the unknown impact on the structure of our companies could be devastating" (p.1).

Provision of subcontract performance bond in lieu of retentions has its own downsides. Russell (2014) notes that surety bond companies calculate bond premium to be paid by an applicant based on type and amount of bond and applicant's risk profile. Subcontractors will likely be perceived as high risk applicants, for the same reason that they find it difficult to obtain bank loan for project finance (Terry, 2014), or obtain such loans at very high interest rates (Mbachu, 2012). Russell puts the range for surety bond premium as 1-15% of the bond amount. Subcontractors will likely be required to pay premiums at the high end of the range, say, 15%. Terry (2014) further observes that few banks that do lend to construction subcontractors will only provide financing to companies that have sizable assets, solid collateral, and a long track record of profitable operations - criteria which most subcontractors will struggle to meet. It is therefore a matter of debate whether or not the high bond premium is a better economic choice for the subcontractor compared to shouldering the main contractor's risk of payment default in the retentions approach.

It should be noted that subcontractors themselves do employ other sub-subcontractors to work for them. This means that any drastic action taken to do away with retention will also affect the subcontractors as much as it will affect the main contractors.

Consensus of opinions between main- and sub-contractors on the ranking of measures for mitigating subcontractors' security of payment risks

Using Spearman's rank correlation test, it was tested whether significant differences existed between the subcontractors' and main contractors' sets of ranks for the identified mitigating measures. The aim was to examine whether consensus of opinions existed between both groupings on the issues. The test results in Table 2 shows significant disparity between the two sets of ranks. This indicated that both groups saw things differently, regarding the priority ranking of the identified mitigation measures.

However, both groups prioritised the first two mitigation measures as being the most effective solutions. These relate to having partnering agreement between all parties at the start of the project with focus on win-win outcomes for all, and adopting fortnightly payments rather than current monthly intervals. Other respondents in the survey such as quantity surveyors and building professionals also rated these two solutions as the most effective. The consensus therefore strongly suggests that the two solutions would receive industry-wide support.

Additional security of payment risk mitigation measures suggested by respondents
Survey respondents were asked to identify further solutions that were not included in rated list. Content analysis of the respondent's feedback provided the following additional solutions:

1) Education and training of subcontractors on the basics of contract administration and specific conditions of contract, especially as it relates to timing of notices, record keeping, valid claims and supporting documentations. Subcontractors need to know their obligations within the contracts and also be aware of, and proactively take measures to guard against, issues that will impact significantly on their security of payment. (Suggested or alluded to by 41% of respondents)
2) Introducing project alliancing, currently used in infrastructure development, and adopting its policies in all construction contracts. (Suggested or alluded to by 37% of respondents).
3) Use of works package form of management contracting procurement system, whereby the main contractor as the appointed management organisation provides the service of managing for a fee, all the works contractors/ subcontractors to deliver the project, but each of them enters into a direct contract with the owner rather than with the main contractor. Payment is made directly to subcontractors by the owner or agent. (Suggested or alluded to by 34% of respondents).
4) Putting more emphasis on simply getting subcontractors to comply with the typical contract requirements for completeness, timing and detail first before adding more tasks to their contracts. (Suggested or alluded to by 27% of respondents).
5) Having in place appropriate contract works insurance which may cover both parties and projects in the event of non-payment or if a company goes into receivership. (Suggested or alluded to by 19% of respondents).

CONCLUSIONS AND RECOMMENDATIONS

This study aimed to investigate factors that undermine subcontractors' security of payment in the New Zealand Construction industry. Investigations also focused on the measures that could be put in place to mitigate the security of payment issues. Results showed that factors that were perceived by the survey participants as being 'very risky' comprised 1) main contractor "going bust"; 2) poor record keeping, lack of supporting evidence, and omission or poor valuation during claim preparations; 3) retentions not released by due date or not released at all; and 4) late payment of certified amount.

Measured perceived by the respondents as being the most effective in addressing the issues included 1) having partnering agreement between all parties at the start of the project with focus on win-win outcomes for all, with all parties aiming at transparent and trustworthy relationship for mutual benefits; 2) adopting fortnightly payment periods rather than the current monthly interval, which in effect extends to 2 months of zero cash inflow; and 3) review of the Section 21(3) of the CCA 2002 (Payment Schedule), to prohibit self-serving basis for calculating scheduled amount and withholding or refusing payment.

Surprisingly, holding retentions in trust account and performance bonds were not rated as top priority measures for addressing the security of payment problems. These were perceived to be dogged by issues such as potential for constricting cash flow for the entire supply chain. The most recurring additional measures freely supplied by the respondents included education and training of

subcontractors on the basics of contract administration and specific conditions of contract, especially as it relates to timing of notices, record keeping, valid claims and supporting documentations.

Overall, collaborative working arrangement such as partnering is recommended as the most appropriate and fundamental solution that could help to resolve wider issues. This approach also resonates well with the key values of trust, relationship and reputation which define the way business is conducted in the New Zealand construction industry.

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SURFACE COEFFICIENTS FOR GLAZING SYSTEMS IN CONSTRUCTION

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ABSTRACT

The sustainability of building systems and products in New Zealand is affected by their thermal performance. This is influenced by the way that we choose to measure thermal performance of building systems and products, and particularly glazing systems which typically have lower thermal performance than opaque materials. In turn, the thermal performance of glazing systems is significantly affected by the design values used for their surface coefficients. Three different sets of surface coefficients for glazing systems have been used historically in New Zealand. There has not been any robust guidance on which coefficients should be used to represent design values for the thermal performance of glazing systems. The work reported here recommends the choice of European surface coefficients for measuring the thermal resistance of glazing systems, on the basis of these being a better match to the conditions experienced in New Zealand. This allows comparison between glazing systems to be undertaken with the same reference, and eliminates confusion in the industry over the choice of coefficients.

KEYWORDS: Sustainability, Glazing; surface coefficients; thermal performance; R-value.

INTRODUCTION

The sustainability of any building product or system is affected by the thermal properties of that product (Burgess, 2014). This is particularly the case when products are required to provide thermal insulation as part of their design specification. The degree to which glazing products provide thermal insulation to buildings has frequently been a disputed area, since there are different approaches internationally to the calculation of this thermal performance, or R-value of glazing products, measured in terms of m^2K/W (ISO10077-2:2012). Commonly the reciprocal of the R-value, the thermal transmission – or U value (in W/ m^2K) is used for glazing, however since the U value drops with better insulation performance, it is somewhat counter-intuitive, so this paper will talk only in terms of R-value.

Background

The total R-value of a glazing system is the sum of the thermal resistance of the glazing materials, coatings and inter-pane spaces, plus the effective thermal resistance of the thin layer of still air that 'sticks' to the inside and outside surfaces of any glazing sheets (EN673:2011). The insulating effects of the layers of air are referred to as surface coefficients, and add to the R-value of the material. In reality, the total thermal resistance of a glazing element or system is constantly changing as the thickness and properties of the air film changes in response to the environment (NZS4243:2007). The surface coefficients are merely an arbitrary set of pre-defined values, which allow a single static number to represent a dynamic R-value, and are chosen as appropriate for the situation. They are different on the outside face of the glazing and on the inside face, given the different environments that the glazing is subject to (Burgess, 2014).

For a typical wall insulation product used in New Zealand (e.g. with a total insulation material R-value of 1.8 m^2K/W), (NZS4214:2006) the surface coefficients (0.12) are already incorporated, and may be 7% of the material R-value. However, for IGUs (e.g. with a total R-value of 0.26 m^2K/W) (NZS 4218:2004) the surface coefficients (0.13) can be 50% of the insulation value, and for single glazing with a total R-value of 0.15 m^2K/W) the surface coefficients (0.13) can be 95% of the R-value. Table 1 displays the three sets of surface coefficients used for the U/R-value of glazing

systems[1] in New Zealand in terms of resistance, and then (in brackets) in terms of transmission. Note that glazing that is currently imported into New Zealand uses either European (ISO10077-1:2006) or ASHRAE/NFRC values (Kohler, 2012).

Surface Coefficients			
Method	**Outdoor coefficient**	**Indoor coefficient**	**Total coefficient (m^2K/W)**
NZS 4214, NZS 4243	0.03 m^2K/W (h_o = 33W/m^2K)	0.09 m^2K/W (h_i = 11 W/m^2K)	0.12
ASHRAE/NFRC (USA)	0.038 m^2K/W (h_o = 26 W/m^2K)	0.12 m^2K/W (h_i = 8.3 W/m^2K)	0.16
EN 673 (Europe)	0.04 m^2K/W (h_o = 25W/m^2K)	0.13 m^2K/W (h_i = 7.7 W/m^2K)	0.17

Table 1: Surface coefficients[2].

HOW ARE SURFACE COEFFICIENTS USED?

Glazing was introduced into the housing insulation standard (NZS 4218:2004 Energy Efficiency – Small Building Envelope) in 2004. At this time the ASHRAE/NFRC values used in North America for surface coefficients (Kohler, 2012) were adopted, to match the choice made in Australia. This conflicted with the surface coefficients used for opaque insulation materials in the New Zealand market and in the New Zealand building standards, such as those used in (NZS4243:2007), and (NZS4214:2006). The coefficients used for glazing in the North America and Europe have also changed over the years, although they currently align with each other quite well, (0.16 versus 0.17 m^2K/W), as shown in Table 1.

Using different surface coefficients means that the resulting R-values for the declared thermal resistance of the centre of glass of an identical single glazing system may be over 40% different. When the R-value of the frame is incorporated with the R-value of the glazing to calculate a total product R-value (R_{window}) the effect of using different surface coefficients for the glazing is reduced, but with highly conductive window frame materials (such as non-thermally broken aluminium) they can still have a noticeable effect.

Industry has often used surface coefficients from North America or Europe since the software modelling programs, and glazing products have originated in these locations. While it is possible to convert from one set of surface coefficients to another, and to use a variety of surface coefficients in the various R-value modelling programs, this process is not always straightforward, and needs to be clearly stated when any claims are being made. This has meant that since the introduction of glazing-

[1] Where the U value is the reciprocal of the R-value. Note however that both IP and SI units are in use for R and U values.

[2] The situation is complicated when low emissivity surfaces are present on the outer face of a glazing layer, which alters the coefficients for these surfaces. For example $h_i = 3.6 + 4.1\ \varepsilon_i /0.837$ under European conditions, where ε_i is the emissivity of the indoor surface. When $\varepsilon_i = 0.84$ (normal glass) then h_i = 7.7 W/m^2K, contributing an R-value of 0.13. However when $\varepsilon_i = 0.3$ (a specific Low –E glass) then h_i = 5.1 W/m^2K, contributing an R-value of 0.20 for the centre of glass.

specific European and the North American surface coefficients, the coefficients from (NZS4214:2006) have not been used for glazing.

A version of the Window Efficiency Rating Scheme (WERS[3]) used in Australia was launched in New Zealand in 2000, and used a complex process to rate window products. However, WERS was oblivious to the choice of surface coefficients since it used hourly calculations including wind speed and solar radiation to calculate R-values on an hourly basis. The second generation window energy efficiency rating system (WEERS) being adopted in New Zealand, does need surface coefficients, since it uses these to define the R-value of glazing products and their star ratings, so it has become important to confirm which should be used.

IMPLICATIONS FOR NEW ZEALAND

Of the three sets of values available (Table 1), the values in Table 2 (being the European values) were chosen by the WEERS technical committee (Burgess, 2014) as suitable for use in New Zealand, for a number of reasons.

Firstly it was judged that the climatic and internal conditions (wind, temperature range, internal space heating practices) on which the European coefficients pertaining to R-values were based, were a closer match than the climatic conditions upon which the ASHRAE/NFRC conditions were based. Further, the North American ASHRAE/NFRC surface coefficients (as implemented in the Window 5/6/7[4] software) were designed to provide accurate numbers for glazing that was 600 mm in height, while the European (EN12898:2001) coefficients[5] were designed for windows up to 1.23 x 1.48 m in size. While the size recommendations from North America and Europe are not directly comparable (glazing size versus window size), the average size of a New Zealand window has been found in the WEERS development work to be 1430 mm wide by 1410 mm high[6].

The European method is also favoured since a method for adjusting the R-value for the impact of a low emissivity surface facing the inside of a building is available in a nationally published standard in Europe (EN12898:2001) whereas the US ASHRAE/NFRC method for determining emissivity (NFRC300-2001) has not been adopted as a national standard.

It can be seen from Table 1 that the European values (EN410:2011) are close to the ASHRAE/NFRC values used in North America, so the choice between these two sets of coefficients is not highly significant for many insulating glazing systems, except as noted previously for single glazing systems, which are still used in some glazing installations in New Zealand.

It should be noted that Section 9.1 of EN 673 requires that U values be expressed in W/m².K, rounded to one decimal figure for glazing systems. The implication for R-values for glazing purposes is that these should be rounded to two decimal figures, and the use of more than two decimal places does not provide any further information.

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[3] WERS is a method for rating the thermal performance of domestic window systems in Australia, which has been superseded in New Zealand by WEERS – to be launched in 2014.
[4] This is a reference to the Window 5, Window 6 and Window 7 versions of the thermal modelling software developed by LBNL in California, widely used internationally for modelling the thermal performance of window systems.
[5] Annex F of ISO 10077-1:2006 makes reference to the window size which is used in the standard
[6] Unpublished commercial in confidence work by BRANZ for WANZ.

While the above discussion is a justification for recommendation of the use of European surface coefficients for glazing purposes in New Zealand, it has little scientific robustness, but it does explain the differences in approach.

NZC Surface Coefficients			
Name	**Outdoor coefficient**	**Indoor coefficient**	**Total surface coefficient**
U value coefficients for use with NZC (NZ Conditions)	0.04 m²K/W (h_o = 25 W/m²K)	0.13 m²K/W (h_i = 7.7 W/m²K)	0.17 (m²K/W) (h = 5.88 W/m²K)
		(Varies with ε_i)	

Table 2: The values used for the calculation of the R-value of windows and doors subject to horizontal heat flow, as presented in ISO EN 10077-1:2006 (using the values for determining the U value of the centre of glass contained in section 7 of EN 673:2011) and in Table B1 of ISO EN 10077-2:2012.

It is expected that as WEERS gains traction in the New Zealand market, and as the WEERS window star rating (Burgess, 2014) becomes eligible for endorsement with the ENERGY STAR® rating label later in 2014, that the calculation of surface coefficients, and the justification of the choice will become more important.

CONCLUSION

This work has argued that:

- The European set of surface coefficients (shown in Table 2) should be used for calculating the thermal resistance of glazing systems in the New Zealand environment.
- R values used for glazing purposes in buildings in New Zealand should be rounded to two decimal figures.

This will assist in producing uniformity in the approach used to calculating and reporting the thermal performance of glass and glazing systems for building purposes in New Zealand, and provide a useful reference for engineers and specifiers.

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INTEGRATING CROSS-LAMINATED TIMBER PANELS TO CONSTRUCT BUILDINGS TO TWENTY LEVELS

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ABSTRACT

This research involves a new structural system based on CLT (cross-laminated timber) panels to provide taller and more useful timber high-rise buildings. Because Pinus Radiata is a suitable timber for the manufacture of CLT panels, the system has the potential to add value to planted NZ forests and to earn overseas currency. Timber elements are proposed for a central core, columns and floor beams. The point of difference compared to CLT high-rise buildings to date is the central core which is comprised of integrated CLT panels. The central core runs the full height of the building and is effectively a very large vertical cantilever with a rectangular hollow section. The integrated panel core is the main element for resisting lateral forces and produces taller building with more open floor areas. Various aspects of the system are discussed in the paper. An analysis of the structure is reported and the paper concludes that the proposed system with CLT elements is suitable for buildings to at least twenty levels.

KEYWORDS: Multi-storey, cross-laminated timber, integrated elements

INTRODUCTION

There is a worldwide interest in timber multi-storey buildings due to the environmental advantages of timber construction when compared to buildings in concrete and steel (Waugh et al 2009). Cross-laminated Timber, or CLT, was developed in the early 1990's and glues and clamps timber planks in alternate layers to form large panels. The cross-laminating ensures reliable strength and stability. CLT construction has been used successfully for the nine storey Murray Grove Stadthaus building in London and the ten storey Forte building in Melbourne (Waugh et al, 2009). This paper proposes a new type of structural system that utilises CLT for buildings to twenty levels... The three main aspects of the structural system that makes it different to the current method of CLT construction are:

1. Integrating CLT panels to form elements that are much larger, and hence stiffer and stronger, than an individual panel
2. Ensuring the vertical CLT panels are placed end on end so gravity loads are only transferred parallel to grain
3. The loads between the CLT panels are transferred in direct bearing and do not rely on steel fixings like nails, screws or bolts.

The proposed structural system relies on a central core of integrated CLT panels to support the horizontal loads on the building as shown in Figure 1. The central core is made up of large cross-laminated timber panels, many at full size, 16m long * 3m wide that are integrated together to form a vertical cantilever with a rectangular hollow cross-section. This very large structural element extends the full height of the building. Hoop beams, made of glulam or LVL, are placed around the core at each floor level. The hoop beams are screwed to the core panels and thereby ensure the panels' alignments are maintained. The columns and beams are either LVL or glulam. The resulting floor plan is similar to a typical reinforced concrete commercial building and has considerably more open spaces than are possible with existing CLT multi-level construction which relies on multiple shear walls. The interior of the central core is suitable for service rooms and the vertical circulation of people and services. The proposed timber floor system, which is described later in the paper, was developed at the University of Auckland and achieves acoustic insulation, suitable physical performance and is relatively economic. (Chapman et al, 2009).

To explain the system a prototype building that is proposed and analysed. The wind loads that are applied to the prototype building for the structural analysis are from Eurocode 1, part 4 (BS EN 1991-1-4:2005). The prototype building is considered to be located in a typical large UK city because CLT construction is popular in the UK. The KLH UK website presents 16no. education and 8no. civic & public buildings that have been completed by KLH in the UK using CLT as the main structural material. The analysis does not include earthquake loading but funding is currently being sort for testing a scale model of an integrated panel core on a shaking table to evaluate the efficiency of the system in seismic events. The paper discusses how the effective core section reduces when tension stresses occurs and the factor of safety of the core under these conditions. Attaching the core to the foundations is explained. The paper does not consider the building system for supporting earthquake loadings, but the core to foundation connections has the advantage of allowing controlled core rocking in an E event. As shown in figures 2, 5 & 6, the joints between the CLT panels of the central core only transfer compression and shear and are simpler, more economical, and less likely to have internal slip than joints with steel fixings. Arranging the CLT panels as a core and the associated panel jointing are new departures for CLT construction and no literature exists on the topic.

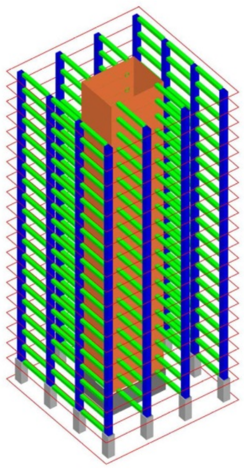

Figure 1: *Isometric of proposed timber structural system for twenty storey building with a rectangular core of integrated CLT panels, glulam columns and floor beams*

Figure 2*: Existing commercial building in downtown Auckland with a floor plan 30m by 30m*

PROTOTYPE BUILDING

A prototype building, similar to that shown in Figure 2 is used to explain the integrated CLT panel core system. It is a typical commercial building that is square in plan with 30m sides. The proposed arrangement of the core, columns and floor beams is shown in Figure 3. The vertical distance between adjacent floors is taken to be 4.0m, and the overall building height is around 80m.

Integrated Panel Core (IPC)

The integrated panel core, or IPC, of the prototype building has a square section with outer dimensions of 10.8m x 10.8m. It is made up of sixty-three CLT panels that are 16m long and fourteen that are 8m long. The width and thickness of the core panels measure 3m and 320 mm, respectively. Close fitting CLT panels are suited for the central core because they will remain dimensionally stable. Previous

investigations found that the most efficient core shape is circular and can potentially support buildings to thirty storeys for a similar volume of timber per square metre of floor area (chapman, 3013). However, a rectangular shaped core is architecturally more useful.

The integrated panel core is a vertical cantilever with a rectangular hollow section and supports the lateral loads on the building. Stability for the walls of the integrated panel core is provided by the floors, ring beams, and the internal CLT walls of the core. As shown in Figure 14, the internal walls of the core define the lift wells and the stairwell. They are not primary structural elements, and are made of screw fixed CLT panels.

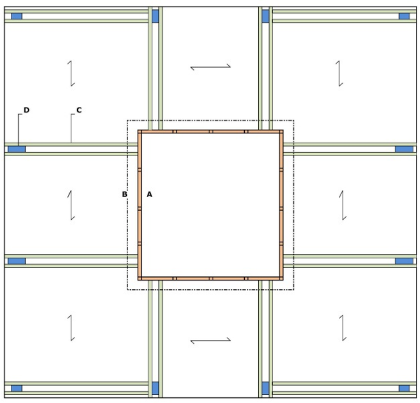

Figure 3: *Plan of structure, A – IPC (integrated panel core), B -'hoop' beam at each floor level, C – engineered timber floor beam, D – engineered timber column, arrows indicate floor joist span*

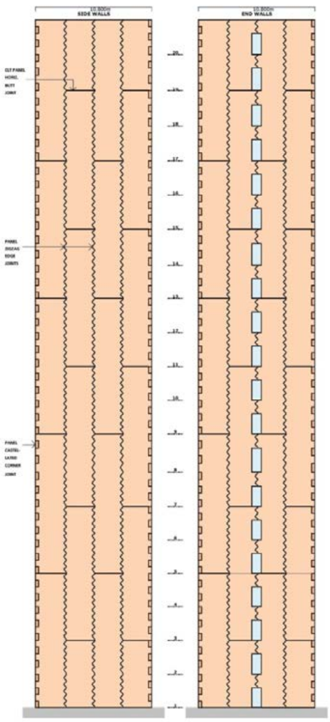

Figure 4: *Twenty level Integrated Panel Core - Side and End Elevations*

Cross laminated panels

The proposed panel core is 280 mm thick with a total of seven laminates that are each 40mm thick. There are four laminates in the vertical or longitudinal direction and three in the horizontal or transverse direction. More laminates could if additional strength or stiffness were needed.

Joints between CLT panels of the integrated core

To ensure that the panels of the central core act in unity as one structural element, shear forces need to be transferred between the vertical joints of adjacent panels. The solution is for the sides of the CLT

panels to be shaped to form 'keys' which mesh with the 'keys' of the adjacent panels. As shown in figures 4 & 8, the corner keys are castellated and the keys between panels in the same vertical plane are zigzag. The next stage of this research is to build and to test these joints. To aid construction and to ensure minimal joint slip, the zigzag joints have an approximately 15mm gap between them which is filled with a high strength but low shrinkage grout, such as Sika Grout 215. Also, the castellated joints have 10mm thick gaps top and bottom which require filling with a drypack grout like Sika Grout 212. Sika Grouts 212 & 215 are described as having the following characteristics (nzl.sika.com, 2014) - positive shrinkage compensation high early age strength development, high final strengths, excellent substrate adhesion, adjustable consistency and high flow characteristics.

For the zigzag jointing, ply shuttering which remains permanent, is placed both sides of the joints to contain the grout when it is pumped into the 15mm approx. wide cavities. The grout is required to only support compression for which the Sika Grout is suitable. It does not need to be an adhesive. Sika grout has proven to have very low viscosity and is used for pumping into rock anchor sleeves. The practicality of pumping this grout for the zigzag joints will be a part of the next phase of this research.

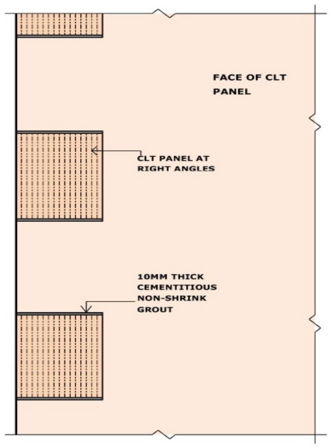

Figure 5: *Elevation of castellated joints at the corners of the central core (the notches' depth is the same as the panel thickness)*

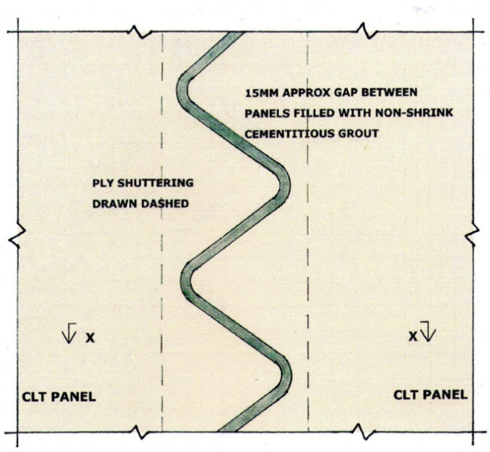

Figure 6: *Elevation of zigzag joint for external walls of the central core*

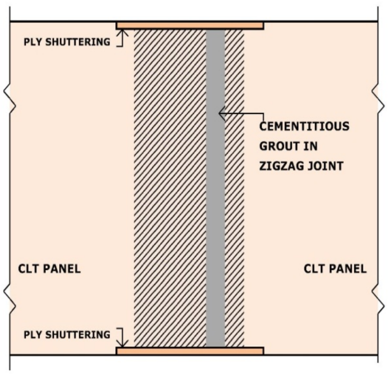

***Figure** 7: Section (X-X) of zigzag joint for external walls of the central core*

Integrated panel core base attachments

The foundation system for the prototype building is designed so that in earthquake events the integrated panel core can ‘rock’ and will return to its original location. When the integrated panel core rocks, vertical hold-down bars between the core and the foundations yield and absorb earthquake energy which reduces damaging stress levels in the structure. These rocking systems are currently being studied in depth (Ma, 2010).

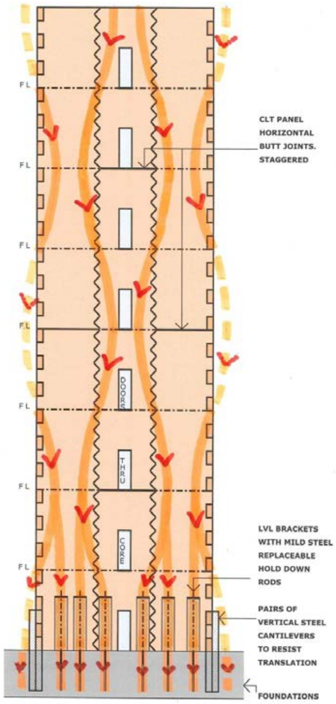

Figure 8: *Elevation of IPC showing how tension flows around end joints of CLT panels. The dashed lines indicate tension transferred through the panels at right angles.*

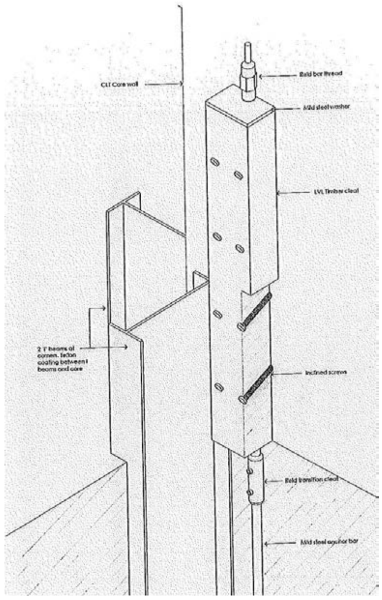

Figure 9: *Part isometric of IPC foundation connections showing pairs of steel members at corners to prevent IPC translation, and one of the vertical hold-down bars. (Sketch is diagrammatic)*

Initially, the tension in the integrated panel core is transferred by inclined screws to vertical LVL brackets as shown in figures 8 & 9. The force in the LVL bracket is transferred to the foundations by a vertical steel bar that is located in a hole through the middle of the bracket. The steel rod has a large steel washer and a nut at the top, and at the bottom it is screwed into a coupling nut that is also attached to a foundation anchor rod. Each vertical hold down bar will have a dedicated ‘fuse’ region so extension and energy absorption can be controlled. The fuses yield before the other structural elements reach their ultimate limit states. As the fuses yield they absorb seismic energy and after the seismic event any fuses that are damaged can be unscrewed and replaced. The vertical steel bars and associated coupling nuts of the Reids Construction Systems would be suitable for the hold-down arrangement (www.reids.co.nz, 2014).

As shown in figures 8 & 9, pairs of vertical steel cantilevers at each corner of the integrated panel core resist horizontal translation of the core but will allow vertical movement and thus not impede rocking. Where adjacent to the CLT panels, the vertical steel cantilevers may benefit from a coating of PTFE, like Teflon, to assist the rocking by reducing friction.

COLUMNS & BEAMS

The columns are pairs of 1.8m deep * 240mm wide glulam elements connected together along one side resulting in a column section of 1.8m * 480mm. The horizontal butt joints of the glulam elements are staggered within each column pair and this ensures that any tension stresses that occur can be transferred to the foundations.
Timber can support considerably more load that is parallel to the grain compared to load that is perpendicular to the grain. The value in characteristic stress parallel to grain is 24Mpa whereas the characteristic compression stress perpendicular to the grain is only 2.7MPa (www.klhuk.com, 2014). For the integrated panel core and columns of the prototype building, gravity loads are transferred only parallel to the grain and not perpendicular to the grain as happens with the 'stacked' construction of present CLT buildings. This means the CLT panels for the prototype building in this paper can support 600% more axial compression.
The floor beams are effectively pairs of 800mm deep * 360mm wide glulam or LVL members. The inner ends of the beams are pinned to the integrated panel core but the outer beam ends are fixed to the CLT columns. This fixity produces frame action when there is bending in the integrated panel core and reduces horizontal drift, and stresses in the core. At the core, the floor beams' have a loose notch as shown in figure 10 that allows rotation between the beams and the core panels. This allowance for rotation will reduce floor damage when the central core 'rocks' in severe seismic events. The hoop beams are screwed to the floor beams, flooring and central core.

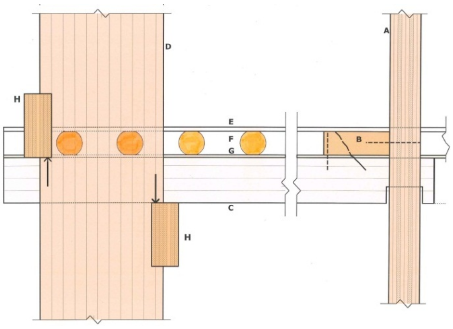

Figure 10: *Floor Beam Elevation, A – IPC (integrated panel core), B - 'hoop' beam (Screw fixings to IPC and floor beams are indicated), C – engineered timber floor beam (loose notch indicated at IPC to allow rotation), D – engineered timber column, E – flooring, F – floor joists, G – ceiling, H – corbels to transmit beam moments to the column.*

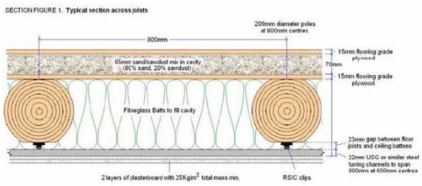

Figure 11: *Transverse section through the proposed floor construction*

The timber floor as shown in figure 11 was developed at the University of Auckland. One of the advantages of the floor not having a concrete topping is that it is more flexible and less likely to be damaged when the core 'rocks' in a seismic event. To minimise costs, the joists are timber poles with the top and bottom of each pole shaved to ensure consistent depth. The flooring is a sandwich of an

upper plywood layer, a filling of sand (80%) & sawdust (20%), and a lower plywood layer. The plywood layers are held apart by 70mm deep timber battens at 400mm centres. The floor joist cavity is filled with sound absorbing blanket. A 24mm thick plasterboard ceiling is attached to the joists using spring clips. The floor is suitable for strength, floor vibration and acoustic performance according to relevant New Zealand building codes (Chapman et al, 2009).

Hoop beams

The hoop beams are shown in figure 3 as engineered timber and as being placed around the core at each floor level in the plane of the floor joists. The beams are held together by steel rods that are placed in ducts within the beams as shown in figure 14. The hoop beams have multiple functions including:

- Holding the core panels together and maintaining them in alignment with each other
- Transferring horizontal forces into the central core from both the floor beams and the flooring
- Reducing the intensity of horizontal bearing pressures on the outer core panels when lateral loads are being transferred into the core from the floor planes

ARCHITECTURE

This research investigates the use of CLT panels, for the main structural elements for buildings to around twenty levels. To date the tallest CLT building, the Forte building in Melbourne, has ten storeys. Currently, CLT construction is stacked wall, floor and roof panels as shown in figure 12. For each level, single storey wall panels are placed. These are overlain by the floor or roof panels. The panels are considered to perform their function individually and not integrated with a neighbouring panel to form a combined unit. This research proposes to overcome the limitations of the 'stacked' approach by integrating CLT panels to form a rectangular hollow core that is much larger, and hence stiffer and stronger, than the individual panels. Because the horizontal loads and a large proportion of the gravity loads are supported by the integrated panel core, the floor areas around the IPC are free of shear walls and have open floor spaces that are similar to a typical modern reinforced concrete commercial building. The core would contain lifts, stairs, service areas etc. An internal arrangement of the core is shown in figure 14.

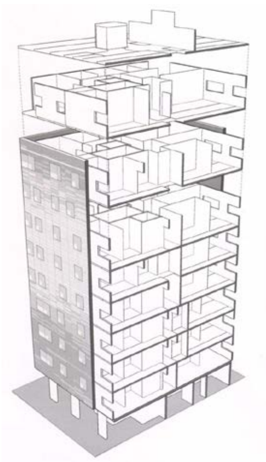

Figure 12: *Isometric of Stadthaus Building. London, showing the closely spaced internal CLT walls*

Reinforced concrete bottom storey

At the ground floor, people movements through the core to access lifts will be extensive and 1.2m wide openings, as used above ground floor, are not likely to be sufficient. To accommodate wider openings in the core at ground level, the ground floor structure should be reinforced concrete. Another advantage of reinforced concrete construction for the ground floor is that the floor to floor measurement can be increased above 4.0m giving a more spacious feel. Also, reinforced concrete for the ground level makes the building less susceptible to large impacts at street level.

Fire

For fire protection, it is most likely that the twenty level building would be sprinklered. Possible types of protection for the timber structural elements include sacrificial wood layers, plasterboard linings, and clear intumescent paint. The charring rate for CLT panels is 0.67mm/minute for the top layers and 0.76mm/minute for the other layers (www.klhuk.com, 2014). At this rate, loss of wood is 40mm/ hour, which is the thickness of the panel laminates. Thus, adding an extra 40mm thick outer laminate layer will give an hour of fire protection. Plasterboard systems can be used for fire ratings up to 3 hours and intumescent coatings have fire ratings up to 90 minutes (www.gib.co.nz, 2014). The Architect, to achieve desired surface finishes as economically as possible, will likely combine all of the above three options in various ways.

STRUCTURAL ANALYSIS

Eurocode 1 is used for determining the loads on the prototype building. The floors' dead and live loads are taken as 3.3kN/m^2 and 3.0kN/m^2 respectively. The wind forces, W, on the building are based on a fundamental value of basic wind speed of 23m/s and a site altitude of 100m which is suitable for most large UK cities. The physical properties of the CLT panels were taken from the KLH UK Engineering Brochure (www.klhuk.com, 2014). An elastic analysis using Multiframe 4D from Bentley Systems indicates that the main structural members and associated jointing have reasonable factors of safety (www.bentley.com, 2014). Also, the analysis shows that suitable inter-storey deflections are achieved during major wind events.

Integrated panel core section for 1.35G+1.5Q+0.9W load case

There are only compressive stresses in the core for the 1.35G+1.5Q+0.9W load case. Tension stresses do not occur. Thus, all the vertical laminates of the section are acting and supporting the compression...

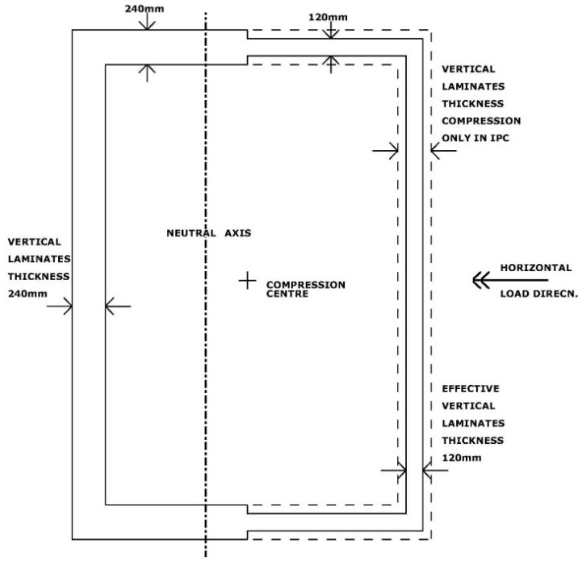

Figure 13: *Effective IPC section when tension stresses occur*

Integrated panel core section for 1.35G+1.5W load case

For the 1.35G+1.5W load case tension stresses up to 6.6 mPa occur in the windward side of the core. The value of the maximum compressive stress in the lee side of the core is higher at 15.6 mPa. Tension cannot be transferred through the horizontal or end butt joints of the CLT panels. As shown in figure 4, the end butt joints of the CLT panels are staggered which results in half the section being available when the resultant stresses are tensile. Thus, when the vertical stress in the integrated panel core is tensile, 50% of the vertical laminates of the core section are available.
A slightly conservative approach to the structural analysis when tensile stresses occur in the integrated panel core is to assume that for the lee half of the core the resultant stresses are compressive and all the vertical laminates are acting; and for the windward half of the core the resultant stresses are tensile and half the vertical laminates are available. This is shown in figure 13. Where the resultant stresses are tension, the available thickness of vertical laminates for structural analysis is effectively reduced from 240mm to 120mm.

Critical member actions in Integrated Panel Core, Columns & Beams

Table 1 presents:

- Critical member actions for the combined load cases from Eurocode 1
- Maximum allowable member actions based on a strength reduction factor, ϕ of 0.85
- Factors of Safety.

The Factors of Safety in the table are calculated using the formula $1/((M^*/\phi Mn) + (Nc^*/\phi Nnc))$. The factor of safety of the central integrated panel core is around 1.27. For the values in table 1, the building forces are increased by around 35% and the nominal member strengths are reduced by 15%. The core factor of safety when the unfactored loads and the nominal member strengths are used is considerably higher at around 2.0. A building taller than twenty levels is possible if the integrated panel core is made with larger plan dimensions. Also, the core could be made stiffer and stronger if additional vertical laminates are included in the CLT panels.

Table1: Material properties, reliable strengths, & actions

	CLT Core	Columns	Beams
Critical load case	1.35G+1.5W	1.35G+1.5Q+0.9W	1.35G+1.5Q+0.9W
E (MPa)	12,000	12,000	12,000
BM Stress, $f_{m,k}$ (MPa)	23.0	23.0	23.0
Max BM, M* (kN.m)	176,364	425	432
BM Strength, ϕMn (kN.m)	410,061	5067	751
C Stress, $f_{c,0,k}$ (MPa)	24.0	24.0	24.0
Max C, N_c* (kN)	36,546	10345	1396
C Strength, ϕN_{nc} (kN)	103,012	17626	5875
Factor of Safety	1.27	1.49	1.22

Building drift

The elastic analysis indicates that the top of the building moves 105mm horizontally under the serviceability limit state wind forces, or 0.0013 times the roof level height of 80m. The maximum inter-storey sway is 7.6mm, which is 0.19% of the inter-storey height. This inter-storey drift is just under the suggested maximum allowable value of 0.2% in AS/NZS1170:2002. There may be some additional inter-storey sway due to joint slippage that has not been accounted for in the elastic analysis. However, the timber member joints are all in direct compression and are considerably stiffer and less likely to slip compared to joints that rely on multiple screw or nail fixings. A factor which reduces inter-storey drift is the damping effects of the internal walls within the central core as shown in figure 14. It is intended to test for these secondary effects in the next phase of this research.

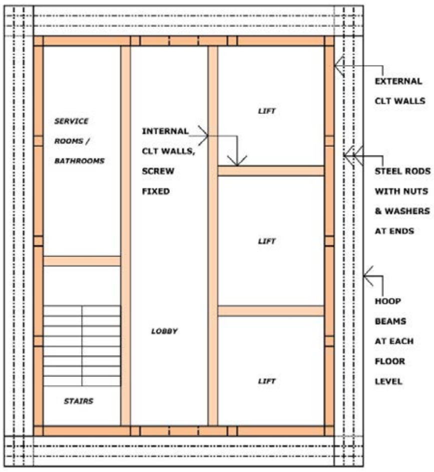

Figure 14: *Plan of architectural functions of the integrated panel core. Timber hoop beams are shown including the internal steel rods.*

CONCLUSIONS

A worldwide interest in timber multi-storey buildings is expected due to the environmental advantages of timber construction when compared to buildings in concrete and steel. The paper proposes a new

type of structural system that utilises CLT for buildings to twenty levels. There are three main aspects of the structural system that makes it different to the current method of CLT construction. The first is the integrating of CLT panels to make a strong and stiff central core for resisting the lateral building loads. The second is to ensure that the vertical structural elements are placed end on end so gravity loads are only transferred parallel to grain; and thirdly that the vertical edges of the CLT panels are shaped so they transfer both shear and compression into the adjacent panels by direct butting action. These joints do not rely on steel fixings like nails, screws or bolts. Hoop beams are placed around the central core at each floor level that hold the CLT panels in position and assist in transferring horizontal building loads into the core. The other major structural elements, the columns and floor beams, are made of glulam or LVL. The floor construction is comprised of timber elements with sand ballast to assist acoustic insulation. The floor plan with a central rectangular core and columns at the perimeter is similar to a typical reinforced concrete commercial building. This arrangement has considerably more open spaces than existing CLT multi-level buildings which rely on closely spaced shear walls. Typically, for the core and columns the stresses are compressive. For a major wind event in a typical large UK city, tension stresses up to 6mPa occur in the integrated panel core and these stresses can be supported and safely transferred into the foundations. The next three phases of this research will be testing the zigzag and castellated jointing, a finite element analysis of the core, and earthquake shake table testing. The foundation system for the prototype building is designed so that in earthquake events the integrated panel core can ‘rock’ and will return to its original location. When the integrated panel core rocks, replaceable vertical hold-down bars between the IPC and the foundations yield and absorb earthquake energy which reduces damaging stress levels in the structure. The bottom storey should be reinforced concrete to assist large flows of people to the lift core, allow a larger ceiling height, and to resist any large impacts at ground level. An elastic analysis indicates that the main structural members and associated jointing have reasonable factors of safety for a major wind event in a major UK city. Also, the analysis shows that suitable inter-storey deflections are achieved. For more building strength and stiffness, the core could be made with larger plan dimensions or more layers of vertical laminates could be included in the CLT panels.The paper concludes that cores of integrated CLT panels will overcome many of the limitations of the current form of CLT construction and are suitable for supporting buildings to at least twenty levels.

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IMPACTS OF AN INNOVATIVE RESIDENTIAL CONSTRUCTION METHOD ON INTERNAL CONDITIONS

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ABSTRACT

New Zealand houses are known for producing sub-optimal internal thermal conditions and unacceptably high internal relative humidities. These contribute to poor levels of health, mould and can coincide with the decay of structural timber frames. A proposed solution is to provide an alternative structure utilising plywood instead of building paper, a wrap on the internal face of the timber frame and an additional air gap serving as an internal service cavity, followed by the internal lining. The internal wrap is designed perform as a vapour check to prevent moisture vapour diffusion from inside into the frame and to permit moisture diffusion from outside through the structure to the internal environment. Two full scale houses had temperatures, dew points and humidity levels monitored in passive, unoccupied conditions over a full season. The test case house for the research incorporated the innovative construction solution. The second, control house was of identical design and location, using standard construction practice. The houses were situated to prevent shading each other, but in close enough proximity to be on identical sites. Results indicated that the calculated internal moisture content profile appeared to be unrelated to the external moisture content as expected in unoccupied conditions. Instead it followed the profile of the changing internal temperature. Whilst the innovative construction appeared to prevent moisture diffusion into the structure in winter and permit it inside in summer this resulted in a generally higher internal relative humidity than the control house.

KEYWORDS:

Housing; internal moisture; innovative construction.

INTRODUCTION

Mackintosh (2001) summarises New Zealand's climate as:

> "Warm subtropical in the far north to cool temperate climates in the far south, with severe alpine conditions in the mountainous areas. Mean annual temperatures range from 10°C in the south to 16°C in the north of New Zealand. Most of New Zealand would have at least 2000 sunshine hours annually"

This data does not describe harsh external conditions but instances where combinations of low temperatures and high moisture levels lead to poor internal environments are documented widely by a number of authors (Howden Chapman et al 2005, NZBCSD 2008, de Groot 2009, Howden Chapman et al 2011)

The World Health Organisation (2009) links poor internal conditions to a range of health problems that are also reported in New Zealand research. In response to the concerns there has been research on solutions that tackle the problems directly or indirectly through improving the sustainability of homes (Howden Chapman et al, 2007), (Easton & Saville Smith 2010), (Callau 2010), (Burgess et al 2010). This work has tended to focus on the thermal solutions and energy consumption aspects. Su (2006, 2013) researched the prevention of winter mould growth in occupied New Zealand houses employing primarily passive and active ventilation and thermal insulation prevention measures. Comparing the static and dynamic simulation methods de Groot (2009) expanded the research to explore in detail the

impacts of moisture transfer through the envelope. He simulated alternative retrofit solutions over a three year period in Auckland, demonstrating that a traditional vapour barrier was effective in preventing interstitial condensation occurring to levels that might encourage mould growth. He cautioned that the increase of thermal insulation without the consideration of interstitial moisture might move the visible mould problem to an invisible one. Leardini & van Raamsdonk (2010) also extend the concerns beyond occupant health to include structural degradation. They outline concerns that increasing levels of thermal insulation increases chances of interstitial condensation. The traditional vapour barrier treatment risks trapping moisture vapour driven from outside rather than inside, into the structure. They propose that a solution is to provide a vapour check that prevents vapour transfer from inside to the wall structure but also permits this externally driven vapour to pass through the structure to the inside. This vapour check provides all the benefits of an airtight barrier, prevents the possibility of interstitial condensation but exacerbates the challenge of increased internal moisture levels and its associated risks. De Groot and Leardini (2012) identified a lack of information on the success of retrofit solutions and the general need to improve understanding of the impacts of combining insulation airtightness and humidity control. This paper outlines the early findings of a research project that moves research from desktop simulation to exploring the impact of a construction employing such a vapour check on a real house.

METHODOLOGY

The fundamental aim of this project is to allow comparison testing of individual or combinations of building materials and techniques that have the potential for improving the building performance of this standard New Zealand house type.

Control House

The houses are single storied with three bedrooms and two bathrooms and are constructed as part of the Unitec carpentry programmes. The houses are completed by students to be relocated, and they are undecorated and without floor coverings or wall finishes. Electrical and plumbing fittings are installed but not connected. Table 1 summarises the materials used in the construction of these houses and identifies the elemental R values in m^2K/W. Overhangs on the north side of the house provide complete shading from direct solar gain through glazing during the hottest periods of the summer months. A standard floor plan is given in Figure 4. These houses are similar in design and construction to thousands of houses found in suburban areas and provide an ideal basis for examining the potential for improvements to a common housing type.

Test House

The modification made to the test house was to replace the building paper with 7 mm thick Ecoply Barrier treated to H3.2 CCA (Copper Chrome Arsenate) in accordance with AS/NZ 1604.3 (SANZ 2012a) to meet AS/NZS 2269.0 (SANZ 2012b). Vertical sheet joints were sealed with flashing tape. This feature was felt to have significant potential as an alternative that provided the functions of bracing and rigid air barrier in a single element. On the internal surfaces of external walls and ceilings the INTELLO vapour check was placed. A 45mmm cavity batten was then added before fixing of the plasterboard.

Diffusion Flow	Moisture Flow Rate in g/m^3 per week	
	Winter	Summer
Direction of Diffusion Flow	Out towards the air barrier	Inwards towards the air barrier
INTELLO	7	560

Table 1. Moisture Flow Rate Performance of the INTELLO membrane.
(Moll & van Raamsdonk 2009)

Element	Common to Control House and Test House			
Construction	Timber Frame on pile foundation			
Sub-Floor	150x25 radiata pine boards with 20mm gap			
Floor	Particle board, foil insulation draped 100mm between joists (R= 1.3)			
Ceiling	R3.6 polyester ceiling batts (R= 2.9),10mm plasterboard			
Glazing	R m^2K/W	SHGC	Shading Coefficcient	Visible transmittance
	0.34	0.74	0.86	80%
	Control House		**Test House**	
Roof	Trussroof (radiata pine treated) Coloursteel roofing on building paper (stapled)		Trussroof (radiata pine treated) Coloursteel roofing on building paper (stapled) INTELLO wrap on bottom chord of trusses.	
Walls	cedar weatherboard cladding, natural finish		cedar weatherboard cladding, natural finish	
	20mm cavity battens		20mm cavity battens	
	Building wrap (stapled)		7 mm Eco ply	
	90x45 radiata pine framing		90x45 radiata pine framing	
	R2.6 polyester batts (R = 1.9 m^2K/W)		R2.6 polyester batts (R = 1.9 m^2K/W)	
			INTELLO Vapour check	
			45mmx45 battens	
	10mm plasterboard		10mm plasterboard	

Table 2. Construction details for the Control and Test Houses

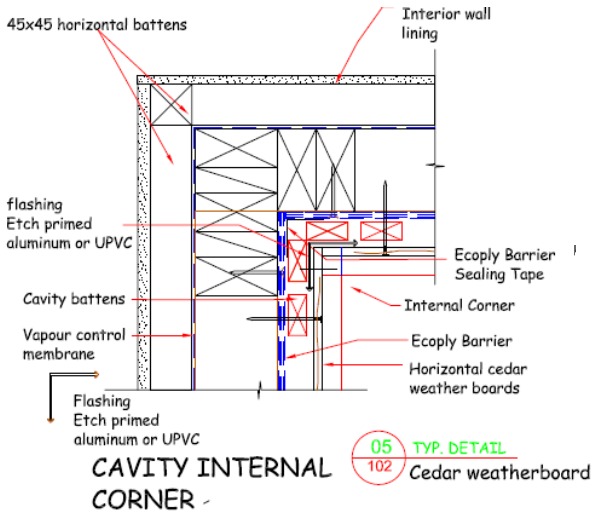

Figure 1. Construction Detail Though an Internal Corner of the Test House

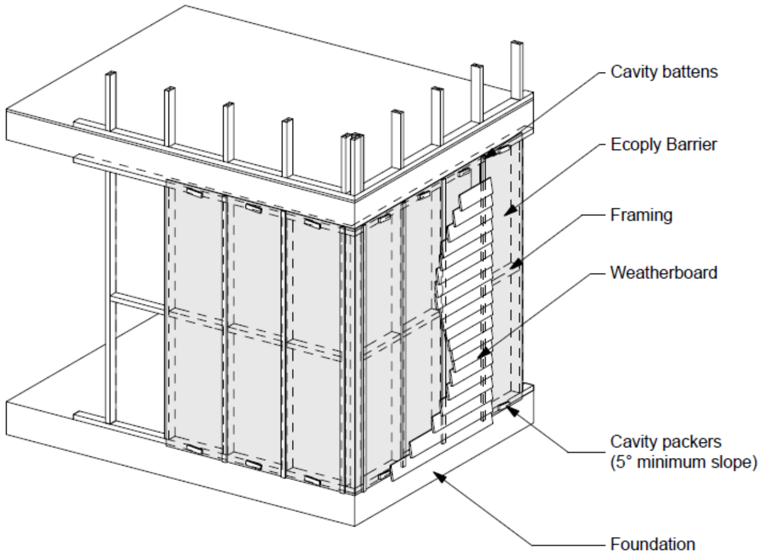

Figure 2. Construction details of the Plywood Rigid Air barrier in the Test House. (Carter Holt Harvey 2014)

Site

The site is on the Unitec Institute of Technology campus in Mt Albert Auckland. The site is relatively exposed with an open grassed area to the northwest. Surrounding buildings are reasonably distant to the south, north and east. Behind the houses to the southeast is a hilly incline and the student building yard. The houses are located with identical orientations but separated to avoid mutual shading. They are monitored in a passive, unoccupied condition.

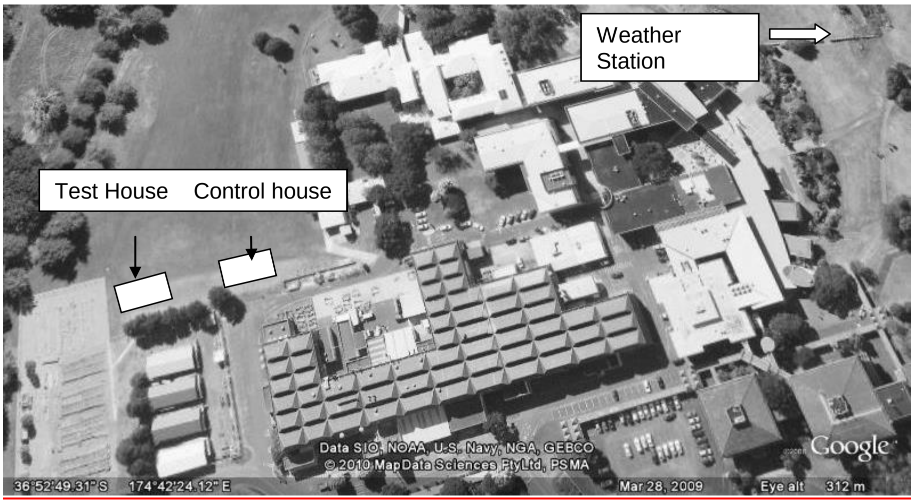

Figure 3. House and Weather station location details

Monitoring process

Temperature sensors have been set up to sample the internal air temperature at hourly intervals. Sensors used are Lascar EL-USB-2 Humidity & Temperature USB data loggers. These measure and store relative humidity, dew point and temperature readings over 0%RH to 100%RH and -35°C to +80°C measurement ranges. Sensors were located identically in the two houses to align with practice outlined by Barley et al (2005) at a height of 1500m above ground level suspended from the ceiling by builders twine. Sensor layout is given in Figure 4. In order to check the appropriate test location for the sensor, a second sensor was located at the edge of the room to check initial operation and determine the degree of variability experienced across each space. It was found that the average variation between measurements from the centre of the room and from the edge of the room vary by an average of 0.2°C over the 168 hourly measurements, with the maximum variation less than 0.5°C. This is well within the accuracy stated for the sensors, and indicates that a single measurement in the chosen position is representative of the overall room conditions.

Dew point measurement has been used as this single figure provides an indicator of absolute moisture content. Localised weather data is measured at a weather station indicated in Figure 3

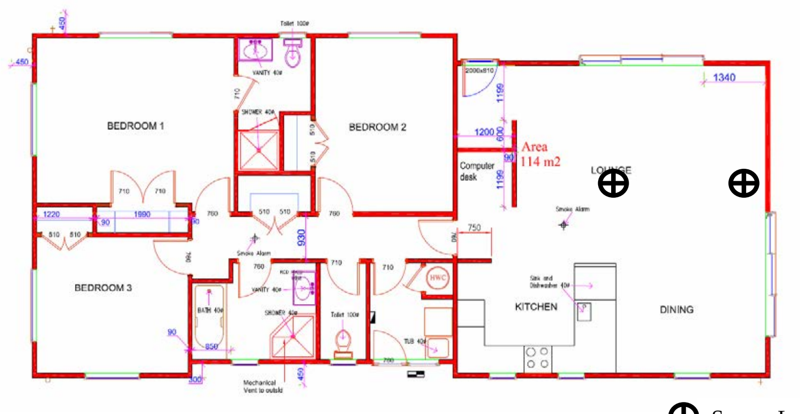

Figure 4. House plan with Sensor Locations

⊕ Sensor Locations

Air Tightness

Both houses were tested for air tightness using the standard blower door test following European standard EN 13829:2000. Openings associated with extract ventilation and unconnected waste pipes were sealed for testing

Room Being Analysed

The room chosen for analysis in this paper was the Lounge Kitchen Dining Room. This is the largest space in the house and is has external walls on the South, East and North Face with glazing in each with a window to wall ratio of 29%. Its inclusion of the kitchen also examines a space where occupancy may generate significant additional internal moisture.

Room	Floor Area	Wall area	Window Area m^2 and Orientation			
	m^2	m^2	South	East	North	West
Lounge Kitchen Dining room	44.6	36.5	2.8	5.4	7.0	0

Table 3. Details of Room being Analysed.

RESULTS

Seasonal Data

The averages of Dry Bulb (DB) Relative Humidity (RH) and Dew Point (DP) measured at hourly intervals for the winter and summer seasons are summarised in the table below for each building. The

summer season is defined as December 1 – February 28. The winter season is defined and June 1-August 31.

	Control			Test			Difference (Test – Control)		
	DB ^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C
Average	25.2	51	14.3	24.6	59	15.9	-0.6	7.3	1.6
Maximum	35.5	69	22.3	34.0	69	23.5	-1.5	0.0	1.2
Minimum	15.0	37	5.8	15.5	46	8.6	0.5	8.5	2.8
Range	20.5	32	16.5	18.5	24	14.9	-2.0	-8.5	-1.6

Table 4. Summary of Summer Season Data

	Control			Test			Difference (Test – Control)		
	DB ^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C
Average	16.3	61	8.6	16.2	63	9.0	-0.1	1.9	0.4
Maximum	28.5	73	16.7	28.5	74	17.5	0.0	1.5	0.8
Minimum	7.0	43	0.0	7.0	47	1.4	0.0	4.0	1.4
Range	21.5	30	16.7	21.5	28	16.1	0.0	-2.5	-0.6

Table 5. Summary of Winter Season Data

The tables indicate that in the unoccupied condition, the Test House construction appeared to have only a very small effect on the average internal conditions over either season. Over the summer the average RH for the Control was 51% and 59% for the Test House with extremes of 37% and 69%. Over the winter period the average RH for the Control was 61% the Test House higher at 63% with extremes ranging between 43% and 74 %. The internal vapour check therefore maintained slightly higher internal RH readings and internal dewpoints over each season. This supports the intended performance of the vapour check, by preventing moisture being absorbed into the structure of the envelope and could explain this elevation. The property of the vapour check, that permits vapour to pass through from outside to inside, could also explain the higher internal dewpoints especially in the summer when external dewpoints tended to be higher than internal measures.

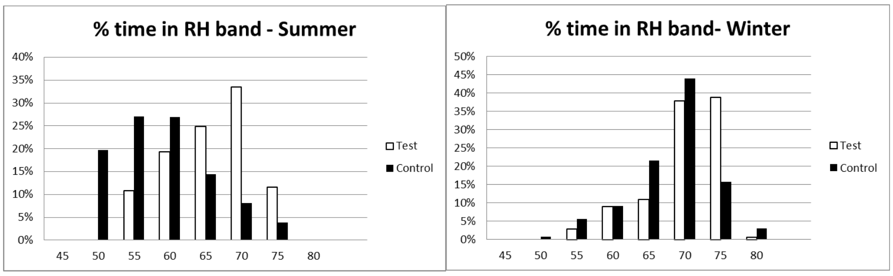

Figure 5. Percentage of Time Spent in Relative Humidity Bands

Research summarised by WHO (2009) indicates that mould formation is dependent upon combinations of dry bulb, RH, time of wetness, surface material, ventilation rate and initial spore concentrations. This prevents the recommendation of a single threshold level but cites work suggesting that surfaces can be kept free of fungal growth “if surfaces are kept below 75% within a temperature range of 5– 40 °C” (WHO 2009, pp38).The graphs above confirm that the test house has smoothed the range of measures by reducing the range of RH’s experienced and increased the instance of higher RH. This is more pronounced in the summer than the winter. However the instances of RH readings above 75% in winter have increased to nearly 40% in the Test House from 18% in the Control House.

Detailed Results of Selected days

The detailed results of a few days in each season are shown in figures 6 and 7. They have been chosen to illustrate the strong influence of solar gain on internal conditions. This indicates that the internal dry bulb temperatures follow the cyclical pattern of the external solar gain. The period of the cycle appears identical but with a lag of between four and six hours. The internal dewpoint also follows with the same period but with slightly reduced amplitudes. There is a very weak connection if any, with the dewpoint of the external air. As there were no occupant generated sources of internal moisture the changing dew points over a daily cycle could be resulting from residual construction moisture. As the temperature rises, moisture still present in the construction evaporates into the air. As it cools it is re-absorbed into the structure. Whilst the test house vapour check is designed to reduce this, the floors of both houses are exposed particle board. The test house is one year newer than the control house which might account for the higher starting values.

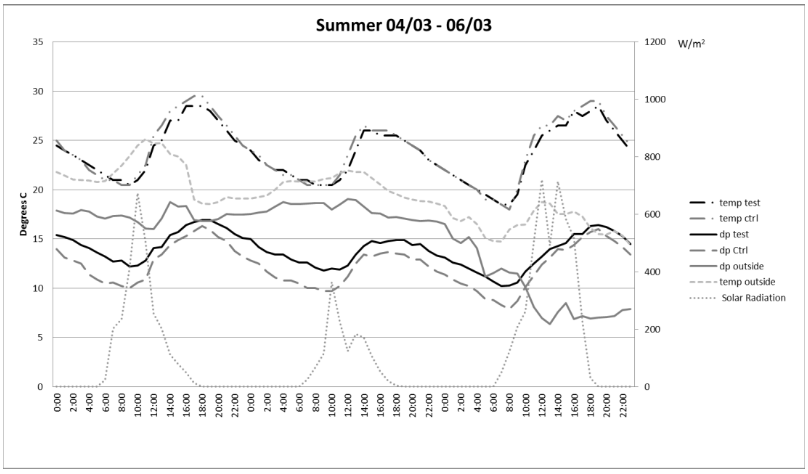

Figure 6. Temperatures and Dew Point comparisons for Houses with External Summer Conditions

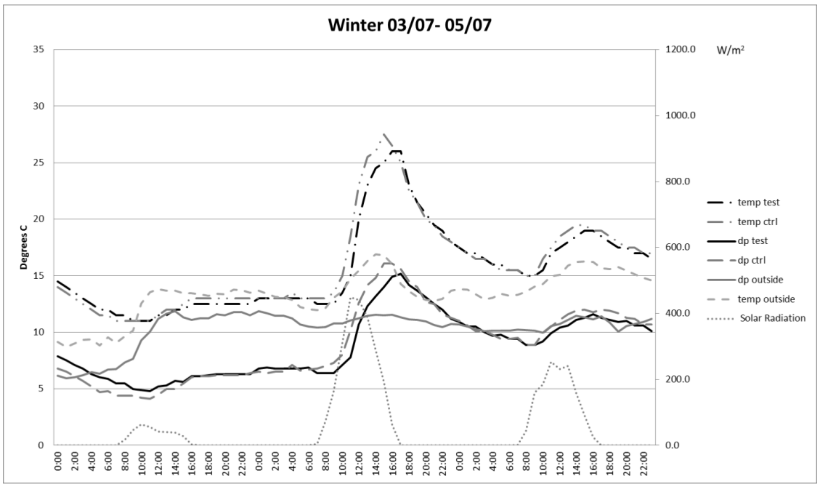

Figure 7. Temperatures and Dew Point comparisons for Houses with External Winter Conditions

The daily cyclical evaporation and re-absorption explanation is supported by comparison of daily results over a whole season. The difference between daily maxima and minima of dewpoints ranges between 6.8^{0}C in the summer and 8.4^{0}C in the winter. Comparison of Dew points in Tables 4 and 5 indicate that the average dewpoint has reduced over the seasons from by 5.7^{0}C for the Control House and by 6.9^{0}C for the Test House. The apparent disconnection with external dewpoints shown in figures 6 and 7 supports an explanation that some long term drying is taking place.

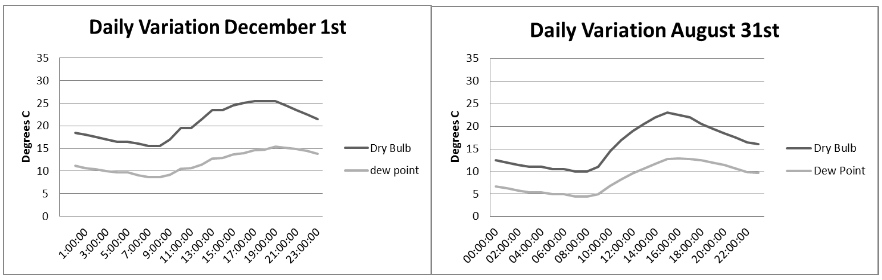

Figure 8. Sample Daily Variations of Dew Points in Both Seasons

Using a Psychrometric chart Moisture Contents in kg of moisture per kg of dry air can be read for given dew points. Using the mean density of the air for the day and the volume of the space, the actual volume of moisture being evaporated and re-absorbed on a daily cycle can be estimated as 0.5 litres. TenWolde & Pilon (2007) suggest that a family of four would produce up to 15 litres per day.

		Summer Dec 1st		
	Dry Bulb ^{0}C	Dew Point ^{0}C	density kg/m^3	Moisture Content kg/kg (Dry Air)
Max	25.5	15.4	1.163	0.0109
Min	15.5	8.6	1.211	0.0069
Difference		6.8		0.004
Mean density kg/m^3			1.187	
Space volume m3		108.54		
Space mass kg		128.809		
Moisture mass kg		0.52		
Moisture volume l		0.52		

Table 6. Data for Estimation of the Moisture Volume Being Evaporated and Re-absorbed

Airtightness

	Control house ac/h	Test house ac/h
Depressurisation	6.58	1.92
Pressurisation	6.93	2.10
Average	6.75	2.01

Table 1. Results of airtightness testing

The figures above represent the air changes per hour of the whole house volume under the standard test conditions of 50Pa +ve and 50 Pa –ve. It indicates that the Test House has an air leakage rate of less than a third of the Control House. The Control House sits just outside the Airtight classification for New Zealand houses which peaks at an airtightness of 5 ac/h. (Stocklein & Bassett 1999) The test house is comfortably in the Airtight classification but is still well above the requirements of the Passive House Institute (2012) of 0.6 ac/h.

CONCLUSION

The internal spatial data supports the expected performance of the vapour check. In winter, higher internal dew points and RH measurements in the Test House compared to the Control House suggest that internal vapour is not being permitted to enter the structure. The risk of interstitial condensation should be reduced. In summer, higher internal dew points and RH measurements suggest that vapour is being allowed to pass through the structure to the inside. This prevents the moisture getting trapped, creating the potential to cause interstitial condensation when the climate permits. This differentiates the performance of the vapour check from a conventional vapour barrier which would trap the moisture within the timber structure.

Minimal differences between the average dry bulb temperatures over both seasons in the control and test buildings suggest that the airtightness properties are having a small effect on unoccupied thermal conditions. This is not what was expected especially during the winter season where it was thought that increased infiltration in the Control House would lower temperatures noticeably. Figure 7 shows that on cloudy winter days the difference between internal and external temperatures was minimal so differences between Control and Test Houses could also be very small. However on sunny winter days, internal temperatures rose nearly ten degrees higher than outside. The Test House was actually slightly cooler than the Control House. This suggests that the heat losses due to infiltration through the closed structure in an unoccupied condition might be much smaller than anticipated or are not being prevented by increased airtightness of the envelope.

Both houses spend significant amounts of time close to conditions that might support mould growth in their unoccupied state. One explanation is that this moisture comes from the construction drying out. The tendency of the vapour check to produce slightly higher internal dew points and RH's emphasises the need to combine this type of structure with minimal ventilation rates to ensure the moisture is ventilated to outside. The combination of the increased time spent in this band, with the recognition that surface RH's may well be higher and that occupant behaviour may exacerbate conditions further underlines the importance of ventilating moisture sources to outside.

Work is underway with the detailed monitoring of temperature and humidity in each layer of the wall construction of each building. This will enable tracking in detail of the passage of vapour through the envelope and the identification of interstitial condensation risk and help confirm the performance of the internal vapour check by keeping moisture out of the structure. Further work will include monitoring conditions under active heating and cooling.

ACKNOWLEDGEMENTS

This research has been carried out with the support of Thomas Raamsdonk of ProClima and the Unitec Internal Research Fund.

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PAVLOVA PARADISE AND THE CURSE OF THE SIDE YARD

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ABSTRACT

One definition of madness is to do the same thing over and over again, and expect a different outcome. New Zealand has a housing problem and this will not change if the same housing model is constructed time after time. To build better, therefore, we need to think different, and we need to build different.

The New Zealand housing model is that of a suburban ideal, developed in the last century and heavily related to the use of the automobile. Oil has a limited future, and our suburbs cannot keep expanding forever. District Plan standards that dictate the size and shape of individual sections and the houses we build upon them are outdated and need to be changed to reflect our changing needs and wants. To build a better New Zealand, we need to change our District Plans.

This paper explores the possibilities of density within the New Zealand suburban housing model, using an example of successful housing development that has created desirable homes at densities higher than those in our recent history. It examines issues of mandatory side yards, front yards and other setbacks, to ascertain how our cities can avoid aesthetic blandness and spatial wastage by challenging some of the basic premises that our "pavlova paradise" has been created on. A project known as The Waterfront in Seatoun, Wellington, is used as an example how an alternative vision for New Zealand can be encapsulated within New Zealand planning law.

KEYWORDS:

Courtyard housing; side yards; Seatoun.

INTRODUCTION

Having been founded on a premise of plenty of land for everyone to have their own house, a doctrine that has sufficed for much of the last 150 years, New Zealand is now in the unenviable position of being the one of the worst (developed) countries in the world in terms of housing affordability. In particular, the city of Auckland is leading the way. New Zealand's one-time much vaunted standard of a quarter-acre section of land on which to build, led to New Zealand being described as *The Quarter-Acre Pavlova-Paradise* (Mitchell, 1972). The title of that book, written and depicting a time in the 1960s, is anachronistic and increasingly inaccurate. The quarter-acre (1012m^2) of land is long gone as the standard unit of property size, with typical suburban residential subdivisions now providing properties more in the region of about a twelth or tenth of an acre (350-400m^2).

While one outcome of the property 'crunch' is to build increasingly smaller apartments in low-quality inner-city developments, as noted by Marriage in 2003 and 2010, enabling what can be described as a rush to the bottom (of the market), another recent outcome is a push towards building smaller houses and siting them on wheels - the recent phenomenon of "tiny houses" (Mueller and Smith, 2013). These answers to the property crisis are, while acceptable as temporary stop-gap measures to enable some sense of home ownership, not a sustainable long-term proposal. Subdivisions continue to be planned in a style and manner suited primarily only to a (minimum) two-car family, with mandatory off-street parking, endless arrays of cul-de-sacs, and in many cases, developer-mandated covenants requiring a minimum house build size. Meanwhile, market forces ensure that in order to ensure adequate returns on property developments in the suburbs, the opposing influence to shrinking section sizes has been the continued growth of house sizes:

> "Average house size has grown steadily over the last 40 years… In the same time, average section size has dramatically shrunk. As a proportion of land use, the typical 1970s single storey 120m2 house on a 1012m2 section (11.85% site coverage), has evolved into a house around 210m2 on a 450m2 site, (46% site coverage)." (Marriage, 2010).

Various economic and demographic factors have been mooted for this growth in house sizes, but a prime factor is the price and scarcity of available land. District Plans, mandated under the 1991 Resource Management Act, have not kept up with this movement in property trends, and still stipulate a maximum proportion of site coverage on residential sections. Typically, this is in the region of 35-45% site coverage (refer table 1), meaning that a typical 350-400m^2 section would only permit a site coverage in the region of 140-180m^2 house coverage on the ground floor, therefore driving larger houses to be double-storied.

The District Plans in force around New Zealand enforce standards around presentation and orientation on the section, through a combination of yard limitations (side yards, front yards) and daylight access planes. This emphasis on the egalitarian nature of the site endeavours to ensure that every plot of land will be able to be provided with clear, unimpeded access to the sun for a certain range of the day, and incidentally also enforcing the notion of large rear yards as the place for the notional 2.4 children to play. Unfortunately it does little to ensure quality of space or sunlight to the house itself, as it is generally not prescriptive in orientation of living spaces towards sunshine.

Table 1. Area, Site Coverage and Yard requirements for 5 Councils
(sources: relevant District Plans). Auckland Council's draft Unitary Plan has not, at time of writing, confirmed figures.

	Auckland Council	**Wellington City Council**	**Christchurch City Council**	**Napier City Council**	**Hastings District Council**
Minimum Site Area (m^2)	Not stated in new draft Unitary Plan	Not stated	Living 1 =450 Living 2 = 330 Living 3 = 300		
Maximum Site Coverage (%)	Approx 30%	35% (outer) 50% (inner)	40% (Living 2)	50%	35%
Density allowed	Not stated (varies by suburb)	Max two household units per site	1 unit per 330m^2 of site	1 unit per 350m^2 of site	1 unit per 1000m^2 of site
Minimum Front Yard (m)	Not stated (varies by suburb)	3 (outer) 1 (inner)	4.5	3	5
Minimum Side Yard (m)	Not stated	None / 1	1.8	1	1
Sunlight access plane	Not stated	45º		45º	
Height at Boundary (m)	Not stated	2.5	2.3	3	2.75
Height overall (m)	Not stated	8		10	8

The New Zealand housing situation is, however, continuously changing, even if the District Plans are (generally) not. Less people are getting married, more people are living alone, and thus the need for a large amount of grassy lawn for children to play on, is arguably far less. While the argument in terms of enforcing set front yard distances ensures opportunity for vegetation and presentation to the street frontage, and the rear yard, as a resulting device, permits outdoor play area away from the dangers of

the street, the side yard has no set purpose except as a means to enable some amount of light into the rooms of the house. Other rational arguments for a side yard include the need for fire brigade access or to wheel a lawnmower from the rear yard to the front yard etc: these arguments are out-dated.

With a typical 4-sided house plan, one side will inevitably suffer from facing south, and therefore be extremely limited in providing adequate lighting levels within. Coupled with this is the corollary that opening your boundary to the neighbour also opens your property to your neighbours views, noise, and potentially unsavoury habits. With 1m minimum side yards, a typical house will lose over $25m^2$ of space from the site for relatively little gain, and in districts where 3m side yards are enforced, a figure of $75m^2$ wasted space is calculable. In an economy bound by financial restrictions on housing, this wasted land is a drain on resources. The question needs to be asked - is there a better way?

THE BETTER WAY: COURTYARD HOUSING

The suburban regions have been subject to an informal policy of infill and gradual densification over the last two decades, with many of the older, larger, quarter acre sites now subdivided into two or even three suburban sites. This has achieved a welcome increase in density, although recent discussions over the Auckland Unitary Plan have made it clear that there is strong opposition in some suburbs to further intensification. Each separate infill action only marginally increases density, but due to the requirements for mandatory side yards and setbacks, property divided this way is an increasingly inefficient uses of resources.

The densification achieved thus far, therefore, does not go nearly far enough. While there is certainly an argument for considerable amounts of apartment building in the inner city, there needs to be an option for a new suburban model. The Anglo-American concept of suburbia as a building surrounded by a doughnut of space is inefficient, especially through the mandated provision of side and front yards as noted above. The alternative argument for a housing model, more successfully utilized by some other cultures, is for courtyard housing, with shared boundary walls and no front or side yards, and yet still achieving excellent sunshine and daylight into the building volume.

A courtyard house will typically be able to achieve a similar amount of residential accommodation onto a smaller site, by means of deleting the encumbrance of side and front yards, and instead building right up to the boundary. In many cultures, the walls thus created are shared between properties (the "party wall"), although the alternative is to have two skins of wall separated by a small movement gap. Advantages of a shared/party wall are plainly evident: this wall does not need to be weatherproofed or maintained externally as it has no external exposure. A party wall does have to comply with New Zealand Building Code regulations regarding Section C: Fire and so it is required to be fire rated and therefore not have any openings. Due to the likely use of fire-resistant and often high-mass materials, a (possibly unintended) consequence of this is that the wall will be acoustically more resistant, and visually impregnable, thus ensuring greater levels of privacy, as well as offering greater use of the site.

SEATOUN COURTYARD HOUSING

An exemplary example of courtyard housing, successfully employed in Seatoun in Wellington, shows how densification of housing can be achieved with positive outcomes. Developer Globe Holdings / Seaside Haven employed Studio Pacific Architecture to master plan and then design housing for the former Fort Dorsett in Seatoun. While much of the perimeter of the site was divided into single sections, each angled to gain spectacular sea views, the hinterland (lot 38) of the flat site was going to be more sheltered, albeit without the same view opportunities. Studio Pacific designed the central core area of the site as a checkerboard grid of 13 houses with courtyards, carefully designed to allow two storey volumes to reach up towards better long-distance views, but thoughtfully interlocked to avoid overlooking and shadowing. Each of the houses within lot 38 therefore share both side walls and rear

walls, while their front walls abut the lane. There are thus no front yards, no side yards, and instead of rear yards there are courtyards to both front and rear. Furthermore, there are no marked footpaths or raised kerbs within the shared space private lane.

> "Clustered together at the centre of the Seatoun waterfront development, these interlocking Courtyard Houses challenge the suburban archetype of detached houses on discrete sections, offering instead a new way of thinking about contemporary suburban life. Because of their siting, the traditional approach to suburban development that places each house at the centre of its section would have produced unusable shady strips of yard at the side of each house and left the section exposed to the buffeting coastal winds. Instead, living and bedroom spaces are shifted to the edges of the section, maximising the use of this space and creating a central sun-filled, sheltered courtyard with which the rooms of the house directly engage." (Studio Pacific).

Winner of an NZIA Local Award for Housing in 2006, the development was not without some considerable controversy at the planning stages. As the plan for this housing was so different from the District Plan, considerable time was spent on a Notified Resource Consent application, which was fiercely opposed by some local residents at the time. Concerns listed by submitters included the use of Rights of Way "not used in a manner consistent with Seatoun character", an expressed preference for "normal footpath kerb and channel", concerns that the housing form would "exacerbate wind issues because of continuous mass", and fears that the housing would be "generally inferior". Amongst these fears was that the raising of density ratios and loss of side yards would be lowering housing standards and creating a "slum" in the area (Davis, n-d).

> "Submitter concern: there is an impression that multi-unit housing is in some way low cost, low quality, and generally inferior. Some submitters made comparisons with terraced housing in Britain and there is a consequent concern that such housing would reduce the value of the submitters' properties in Seatoun." (Davis, n-d).

Instead, the complete opposite has happened. Thanks to high design standards implemented by the architects and the developer, the Courtyard houses are hugely successful and highly sought after, as they bring relative affordability (relative only in terms of the extremely inflated prices of the sea-view houses surrounding the site), security, a strong sense of community, and excellent environmental standards. Building volumes have been designed to have flexible boundaries with partially enclosed 'patio' spaces incorporated, to allow outdoor living in winter or inclement weather conditions. Sunshine into the courtyards has been modelled and carefully planned out, and so cannot be built out, while wind conditions on the site, extremely high nearby, are far more amenable to the courtyard dwellers. Sea views are still available from upstairs rooms, despite the enclosed nature of the site. Privacy and noise transmission is far better than 'normal'.

Table 2. Area, Site Coverage and Yards within Seatoun Courtyard Housing
(source: Studio Pacific Architecture).

	16m deep house	**20m deep house**	**Lot 38 (overall site for 13 Courtyard Houses)**
Site Area (m^2)	208	260	6x16m sites = 1248 7x20m sites = 1820 Total = 3068
Ground floor (m^2)	119	124	1582
Upper floor (m^2)	-	60	420
Ratio footprint/site	57%	47%	51.5%
Usable total Courtyard / patio space (m^2)	89	136	48.5%

Wasted / unused sideyard space (m^2)	0	0	0

The sites, all uniformly 13m wide, vary in length at either 16m or 20m long, putting section sizes at a relatively tiny $208m^2$ or $260m^2$ each (refer to Table 2). There are two courtyards to each house: one to the street-front, often used to park the car, and one at the rear, on which the living rooms open out on. Every house achieves a thoroughly usable outdoor private courtyard space of at least the minimum specified in the Wellington District Plan. The lack of the 1m side yard mandated by the District Plan is rationalised and justified by the architects thus:

> "The requirement for the 1m side yard comes about to enable access from the front of a property to the rear (e.g. to push a lawn mower or wheelbarrow from the 'front' to the 'backyard'). The design of the courtyard house dispenses with the need for this yard, by providing either access directly from the garage to the private courtyard space, or if this is not the case, a cupboard would be built in to the house on the courtyard side. Also, because the 'front yard' is generally hard paved there will generally be no need to push a lawn mower through." (Davis, n-d).

The chief battle to allowing this project was, in fact, the District Plan itself. Considerable expense was incurred by the developer due to the Notified application for Resource Consent. The earlier complaints, by locals scared of "slums", have completely evaporated, and the scheme has become one of the most successful in Wellington history, if measured in terms of happy and satisfied people living in medium density private housing. The following estate agent advertisement is typical of the development:

> "Time To Enjoy The Finer Things - BEO $845,000
> If your busy lifestyle doesn't leave you much time for home maintenance, gardening and renovation – then this Seatoun home is going to appeal. ….Other courtyard homes which have sold in Seatoun's popular Boardwalk Lane precinct have been snapped up with the opportunity to purchase here rare. Don't miss the chance to buy a home that gives you the lifestyle and time to enjoy the finer things." (Leaders, n-d)

A scheme like this therefore appears to have considerable positive aspects to the community. By deleting the side, rear, and front yard requirements, reducing section size and house size, and yet improving environmental considerations such as privacy, security, daylight, wind conditions and acoustics, the developer was able to place more houses on the site than a more 'traditional' 35% site coverage house would have allowed, without loss in quality or amenities.

MULTI-UNIT HOUSING DESIGN

Considerable further work on achieving medium density housing is being undertaken by researchers and students at the School of Architecture in Victoria University, Wellington. Recent research by Master of Building Science graduate Joseph Sturm has investigated whether current Wellington City Council (WCC) changes to the District Plan actually offer demonstrable increases to quality levels within medium density housing projects (Sturm, 2014). Sadly, according to Sturm's research, they do not, with Plan Change 56 largely failing in its intended outcome to raise quality levels. The current Plan Changes being implemented and proposed by WCC do not therefore address the right areas to enable quality increases to take place, and projects such as the Seatoun courtyard housing still remains outside District Plan guidelines, despite the evident success of that project. One obvious next step would be to implement a Plan Change that would enable the creation of quality courtyard housing, using the principles established by Studio Pacific in their design for Seatoun.

Master of Architecture graduates Jared Shepherd and Emily Batchelor also outline the strong interest that the subject raises in the student body (Batchelor, 2014; Shepherd, 2014). Batchelor's thesis

explores the issues relating to inter-locking apartment shapes in both vertical and horizontal layouts, while Shepherd primarily examines the ability of multi-story apartment buildings to create interstitial courtyard spaces in predominantly vertical apartment buildings. Shepherd notes that incorporating these interstitial spaces or voids "highlights the positive role they can play when used correctly, especially when space is scarce. Though the use of voids may seem counterproductive when space is limited and when maximising saleable floor space takes priority, their use can result in a higher quality space proving their success in a design." (Shepherd, 2014, p255).

CONCLUSION

This paper has used one example of successful Courtyard housing in Seatoun, to show that deletion of the restrictive and out-dated suburban concepts contained within standard District Plans, such as mandatory side yards and front yards, can be obtained with no loss of quality or amenity. There is considerable wastage of land for non-productive purposes, which are not achieving quality and therefore not achieving a better New Zealand. One method that could be used is the relaxation of rules regarding the implementation of suburban yards, and the coherent and well-planned design of quality courtyard housing solutions. This paper argues that such a relaxation does not have to be mandatory abolition of side-yard rules, but that a fresh attitude needs to be taken by central and local government, in order to more readily facilitate their use in appropriate residential situations.

ACKNOWLEDGEMENTS

Thanks are given to Michael Davis, Nicolas Barratt-Boyes and Peter Mitchell at Studio Pacific Architecture for their help and assistance in the background information for this paper, and to Emily Batchelor, Jared Shepherd and Joseph Sturm for the research work on housing.

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THE IMPORTANCE OF EDUCATING THE GENERAL POPULATION ON HEALTH RISKS ASSOCIATED WITH VINYL AND LINOLEUM

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ABSTRACT

Recently more information has emerged on possible adverse health effects associated with some building and furnishing materials, with legislative changes towards their reduction or elimination in use initiated in many parts of the world. This paper proposes that such efforts should also include consideration of the level of knowledge in the general population.

In a recent study (Petrović 2014), 182 participants in three samples of the general populations of New Zealand (NZ), the United States of America (US) and the United Kingdom (UK), were asked to rate a number of building and furnishing materials for their perceived impact on human health. The results indicate significant issues with the level of reported knowledge. One of the strongest trends in all samples was the struggle of participants to differentiate between vinyl and linoleum, two similar looking materials but with different chemical compositions and possible impacts on health. These findings are especially disconcerting given that legislation is being enacted to eliminate phthalate plasticizers in Europe and the USA and there is also much discussion over the safety of PVC.

This paper reviews available information on health concerns related to these materials and presents a summary of the survey findings. It proposes that an increase in the level of knowledge of the health risks associated with building and furnishing materials in the general population could make a significant contribution to improvements in indoor air quality.

KEYWORDS:

Building materials and health; vinyl; linoleum; popular perception of materials.

INTRODUCTION

Between 1945 and the early 2000s, the total production of synthetic chemicals has increased more than tenfold (Baker-Laporte 2008: 272), impacting many aspects of human life and the natural environment. Chemicals used in building and furnishing materials are part of this larger problem. Some 15 years ago it was estimated there were more than four million registered man-made chemicals in the world with 60-80,000 in common use, and 1,000 being added every year (Pearson 1998: 61; Saunders 2002: 9; Thompson 2004: 14-5). It is estimated that fewer than 2% of these synthetic chemicals have been tested for their effects on human health and more than 70% have not been tested at all (Snyder in Saunders 2002: 9), and that insufficient information exists for health assessments of 95% of chemicals used in construction products (Pacheco-Torgal, Jalali, and Fucic 2012: xv). However, development of synthetic chemicals is still accelerating, with the suggestion that 'more new materials have been developed in the last 20 years than in the rest of history combined,' with these forming about half of the materials in current use (Schörpfer 2011b: 19; Brownell 2006: 6). There is also a lack of research on the additive and synergistic effects of combinations of chemicals (Armstrong 2007: 61).

Simultaneously, since the 1970s the increasing air-tightness of buildings has led to insufficient air exchange rates, and issues associated with the build-up of indoor toxicants (Clausen et al. 2011: 221; Sundell 2011; Petrović 2014: 46-7). In the early 1980s, this culminated with the recognition of sick

building syndrome (Andersen and Gyntelberg 2011; Rostron 1997). Over the same period it emerged that most people spend between 80-93% of their time indoors (Liu and Little 2012a; Guieysse et al. 2008; Sexton and Dyer 1996; Petrović, 2014: 46). Although building and furnishing materials are not unique in their negative contribution to indoor air quality and health, they are important contributors in this area (Andersen and Gyntelberg 2011; Clausen et al. 2011). While research leading to regulative changes would help solve this problem, there are concerns over a lack of new knowledge (Clausen et al. 2011: 225-226), and regulative changes (Bradman in Curwell and March 2002: ix).

Investigations of ventilation rates since the recognition of sick building syndrome have established a need for their increase (Wargocki et al. 2002). However, the workplace has been the primary focus of developments in ventilation and occupational health (ASHRAE handbook 2009), and more recent studies are indicating indoor air quality in homes is generally poorer than in offices and other public buildings (Nielsen, Larsen and Wolkoff 2013; Wolkoff and Nielsen 2010). The control of conditions in domestic spaces is also harder to achieve (Howden-Chapman and Carroll 2004). On a daily basis homes are where many people not specifically educated in this area make purchasing decisions that could impact on the health of themselves and their families. To evaluate the magnitude and characteristics of this potential impact, an investigation was set up to evaluate the level of knowledge of the general population on the health risks associated with building and furnishing materials (Petrović 2014). This paper presents the results for vinyl and linoleum.

HEALTH EVALUATION OF VINYL AND LINOLEUM

Synthetic chemicals in building materials appear on their own or mixed with other components that could be more natural in origin. This complicates any evaluations of the health impact of such materials, but practically the presence of any harmful chemical could be sufficient to render the whole product a risk. Some chemicals commonly used in vinyl are recognised as presenting health risks and elimination has been initiated. However, there is little discussion of the health issues associated with linoleum. A literature review of architecture related sources indicated these generally struggle with limitations in knowledge about the proven health risks of building and furnishing materials, and this often aligns with a professional responsibility to reflect the current regulations (Petrović 2014: 17-24).

Vinyl

The family of vinyl products has raised concerns over the use of polyvinyl chloride (PVC) as the base material and phthalate plasticisers as additives to it (Petrović 2014: 51-55). World production of polyvinyl chloride (PVC), a significant consumer of phthalates, is around 40 million tons, and forms the second largest plastic by volume after polyethylene (PE) (Akovali 2012). About 70% of PVC consumption worldwide is in the construction industry in applications such as pipes, wiring, cladding, flooring and wallpaper (IHS Chemical 2011; Akovali 2012). Some of these rely on use of plasticised PVC (pPVC in flooring, wiring and wallpaper), while others use unplasticised PVC (uPVC, in pipes and cladding). PVC was first invented in 1872, but its importance was not fully recognised until 1926 (Akovali 2012). In 1933 vinyl flooring was displayed at the Century of Progress Exposition in Chicago, but it did not become commercially available until the end of World War Two.

PVC is produced through polymerisation of vinyl chloride monomer (VCM) (Akovali 2012), and there are serious concerns about the health effect of VCM, which is genotoxic (Kumar et al. 2012), a known human carcinogen, and toxic for immune and cardiovascular systems, liver, and organ development (ATSDR 2013). In addition, the process of manufacturing of PVC, its burning and final decomposition creates dioxins, which are highly toxic and persistent environmental pollutants (Lent, Silas, and Vallette 2009). The Greenpeace group has advocated the complete, global phasing-out of PVC because of its manufacturing by-products and the complex environmental issues which surround its disposal (Akovali 2012). The IHS 2011 review of the world consumption of PVC reports noticeable reductions (IHS Chemical 2011). While they interpreted these as reflecting the 2007/8 recession, some changes were hard to explain in this way. For example, in 2007-9 PVC consumption in the US and Canada declined by 33%, but in 2010 improved only 1%, with another 2.5% expected

in 2011 (IHS Chemical 2011). Unfortunately, globally this makes little change, due to the increased use of PVC in Asian countries, which use 80% of world consumption (IHS Chemical 2011).

However, for indoor air quality the most significant concern for PVC is the use of plasticisers, which generally come in form of phthalates. Phthalates are a group of aromatic chemicals containing a phenyl ring with two attached and extended acetate groups (ASTDR 2013). They are added to polyvinyl chloride (PVC) or other plastics to increase their flexibility and transparency, and are used in proportions as varied as 10-60% of final PVC products (Liu and Little 2012b). Flexible polyvinyl chloride (PVC) accounts for 80-90% of world plasticiser consumption (IHS Chemical 2011). Because they are not part of the chain of polymers that make plastics, they can be slowly released from these products (ASTDR 2013; Liu and Little 2012b). In architecture the main use of plasticisers is for vinyl flooring, while they can be found in a wide variety of everyday products including vinyl upholstery, shower curtains, food containers, cling wraps, toothbrushes, toys, tools, automobile parts, adhesives and sealers (Liu and Little 2012b; ASTDR 2013). They are also used in cosmetics, insecticides, and aspirin (ASTDR 2013). Although in terms of chemistry they form their own subgroup, at a more general level they can be seen as part of the semi-volatile organic compounds (SVOCs) group (Liu and Little 2012b; Xu et al. 2012). In addition to phthalates, other plasticisers currently in use include aliphatics, epoxy, terephthalates, trimellitates, polymerics, and phosphates (IHS Chemical 2013). In recent years the consumption of phthalates has decreased from 88% of all plasticisers in 2005, to 78% in 2012, and is forecast to further decrease to 75.5% by 2018, with China accounting for nearly 38% of world consumption in 2012 (IHS Chemical 2013). Between 2011-2018 world consumption of phthalate plasticisers is forecast to have reduced growth of 2.4%, due to lower-molecular-weight phthalates, such as DEHP, being replaced by nonphthalates (IHS Chemical 2013).

As with other VOCs, the harmfulness of phthalates is acknowledged by different organisations in varied ways. The European Chemicals Agency (ECHA) includes eight phthalates in their list of substances of very high concern (Bis(2-ethylhexyl)phthalate (DEHP) (2008); Dibutyl phthalate (DBP) (2008); Benzyl butyl phthalate (BBP) (2008); Diisobutyl phthalate (DIBP) (2009); Bis(2-methoxyethyl) phthalate (2011); n-pentyl-isopentylphthalate (2012); Diisoentylphthalate (DIPP) (2012); Diethyl phthalate (DPP) (2013); ECHA 2013). The US Agency for Toxic Substances and Disease Registry (ATSDR), however, only lists four (DEHP, Di-n-butyl phthalate, DNOP, and Diethyl phthalate; ATSDR 2013). Generally phthalates are recognised as toxic for reproduction, and since 2008 have been systematically included in the list of substances of very high concern (ECHA 2013).

Historically, different phthalates have been used in different periods. Di(2-ethylhexyl)phthalate (DEHP) is a short chain phthalate frequently found in older PVC products. Before 1999 the European Union regulated against its use in toys, and this was followed by regulations for other products (Holmgren et al. 2012). Since then, longer chain phthalates such as di-iso-nonyl phthalate (DINP) have been used more and there is hope that the 2005 European Union ban of use of all phthalates in toys that can be put in a baby's mouth will have the same positive effect, and that development of non-phthalate plasticizers could follow (Holmgren et al. 2012). Because of this historical background, DEHP is more researched than other phthalates.

There is still limited epidemiological evidence related to phthalates, with classifications of these as being of very high concern mainly based on animal studies. Studies of the health impact of DEHP on rats have established it as an endocrine disruptor with antiandrogenic activity, suppressing testosterone-related processes (Martinez-Arguelles et al. 2012). Once DEHP is absorbed the lining of the gut metabolizes it into mono-2-ethylhexyl phthalate (MEHP), which has antiandrogenic activity ten times greater than DEHP (Martinez-Arguelles et al. 2012). Biomonitoring of concentrations of phthalate metabolites in the general population using blood and urine gave blood results suggesting over 75% of the US population is exposed to phthalates, and as high as 95% for urine (Xu et al. 2012). DEHP and its metabolites have been found in semen, saliva, amniotic fluid, umbilical cord

blood, human milk and baby formula, and currently most humans have estimated exposure levels of 3-30µg/kg/day from various products (Martinez-Arguelles et al. 2012). Animal studies have shown that acute exposure to DEHP in utero disrupts the organogenesis of androgen-dependent tissues by inhibiting testosterone production in a dose-dependent manner (Martinez-Arguelles et al. 2012). Due to this mechanism, DEHP has the potential to influence many other aspects of development, and studies have found that in utero exposure to DEHP induces long-term cardiovascular changes in the male offspring, and affects the behaviour of young adult and elderly male rats (Martinez-Arguelles et al. 2012). When similar animal studies tested the impact of a combination of phthalates (BPA, DEHP, and DBP), they found that the impact increased in subsequent generations, leading to third generation offspring with pubertal abnormalities, and obesity, testis and ovarian disease (Manikkam et al. 2013). This happened to such a degree that the conclusion was that ancestral environmental exposures could be generating trans-generational inheritance of disease, often with adult onset (Manikkam et al. 2013).

Unfortunately, complete epidemiological understanding of the effect of many phthalates on human health is still missing. Thus, recent recommendations to eliminate many phthalates seem encouraging. However, the classification of phthalates by international organisations as substances of very high risk is only part of the process, as it takes much longer for risk to be integrated into regulations. For example, an article from 2009 commented on challenges with integrating such regulative changes into the NZ context (Consumer NZ 2009). Echoing the 2005 European ban of phthalates in children's toys that can be put into a baby's mouth, a similar regulation took effect in the US in 2009, while in NZ at that date phthalates were only regulated in cosmetics (Consumer NZ 2009). The article explained that because different possible sources of phthalates are regulated by different bodies (the Ministry of Consumer Affairs is responsible for toy safety, while food packaging comes under the Food Standards Australia New Zealand, and the New Zealand Food Safety Authority), a series of individual evaluations and decisions must be made before phthalates can be consistently removed from the NZ market (Consumer NZ 2009). Even then, the chances of imported products containing phthalates remain. Nevertheless, with phthalates classified as substances of high concern, some labelling schemes have responded quickly. The Blue Angel label specifies that 'no plasticising substances from the class of phthalates may be used in the manufacture of floor coverings,' and also that floor coverings 'shall not contain more than 0.1% by mass of phthalates as impurities' (Blue Angel 2011).

Evaluation of the release of phthalates from pPVC in interiors established that because of saturation and sorption processes that establish equilibrium over a long period of time, a very small amount of pPVC emits almost as many phthalates as a large area, and that this did not change with increased ventilation rates (Afshari et al. 2004), leading to the conclusion that 'if there is any surface material in an interior that contains plasticisers, it is impossible to avoid the phthalates in indoor air.' Similar difficulties with saturation, sorption and long equilibrium states were observed by others (Xu et al. 2012). Once emitted into the indoor air, phthalates find their way into household dust (Gevao et al. 2012; Bornehag et al. 2005). Studies of dust samples for phthalates have found vinyl flooring should be considered a source of non-dietary exposure to phthalates and that, just as with lead paint dust, children, especially toddlers, are more at risk than adults (Gevao et al. 2012). DEHP was generally the predominant phthalate found in these dust studies (Gevao et al. 2012; Bornehag et al. 2005).

Because epistemological evidence of the impact of phthalates on human health is still limited, it seems reasonable to expect future discoveries in this area. Current studies confirm that during the second half of the 20th century vinyl flooring contained DEHP in combination with other phthalates (Gevao et al. 2012; Bornehag et al. 2005). Therefore, as the second and third generation of offspring from those exposed to such flooring are born, more adverse health effect on humans could be expected. Increases in human obesity and reproductive difficulties are both associated with DEHP.

This illustrates many of the complexities in assessing the health impact of vinyl. In addition, it should be noted that the vinyl and PVC industry have repeatedly rebutted the relevance of such concerns. For example, in 2013, the *Indoor Air* journal published in the same issue two articles which disprove each

other. Carlstedt, Jönsson, and Bornehag (2013) asserted that the use of soft PVC as flooring material may increase the human uptake of phthalates in infants, while Blakey et al. (2013) (all authors are employed in the vinyl industry) have challenged the result based on small number of procedural imperfections. Because any early work is likely to suffer from procedural imperfections, these types of study have been going through the many challenges of developing a new body of knowledge.

Linoleum

Linoleum was invented in 1860 by Frederick Walton, and was the first form of resilient flooring to replace more traditional bare wood or dirt floors (Lent, Silas and Vallette 2009). It is made by mixing oxidized linseed oil with resins from pine trees, wood flour, cork, and limestone fillers, with added pigments, which are then pressed onto a backing to make sheet linoleum (Lent, Silas and Vallette 2009). These are natural and renewable materials (Akovali 2012). This general formula has remained largely unchanged since linoleum was first made (Lent, Silas and Vallette 2009). However, during the 1960s, vinyl flooring rapidly overtook the use of linoleum as the predominant resilient floor covering (Lent, Silas and Vallette 2010). The last US linoleum plant closed in 1975 (Lent, Silas and Vallette 2009: 14) with only three linoleum producers in the world by the mid 1980s (BBC 2014).

More recently, with the recognition of health and environmental concerns associated with vinyl there has been an upsurge of interest in linoleum (Lent, Silas and Vallette 2009). In 2009, Lent, Silas and Vallette conducted a comprehensive review of the available resilient floor coverings for the Healthy Building Network recommending linoleum as either already better than all other alternatives or more able to be improved. Their and similar comparisons show some possible concerns associated with linoleum. Because oxidation of linseed oil is at the core of the process, while the flooring is new, this oxidation can continue, leading to persistent odours (Lent, Silas and Vallette 2009; Wilke, Jann, and Brödner 2008). Recently, the VOC emissions of linseed based paints have also been investigated, showing that a number of aldehydes are produced in the early hours and days post application (Fjällström, Andersson, Nilsson and Andersson 2002). In one State of California study, two linoleum products failed due to the high emissions level of acetaldehyde (Lent, Silas and Vallette 2009). However, this is not an unavoidable problem, but rather indicative of the relative neglect of linoleum production during the second half of the 20th century. Not all samples of linoleum suffer from the same problems and by developing new combinations of linseed and other oils this chemistry can be significantly improved (Fjällström, Andersson, Nilsson and Andersson 2002; Lent, Silas and Vallette 2009). Similarly, farming of flax (linseed) as a crop has been associated with use of environmentally persistent pesticides (such as trifluran) and eutrophication (overloading of waterways by run off nutrients), both avoidable through improvements in farming practices (Lent, Silas and Vallette 2009).

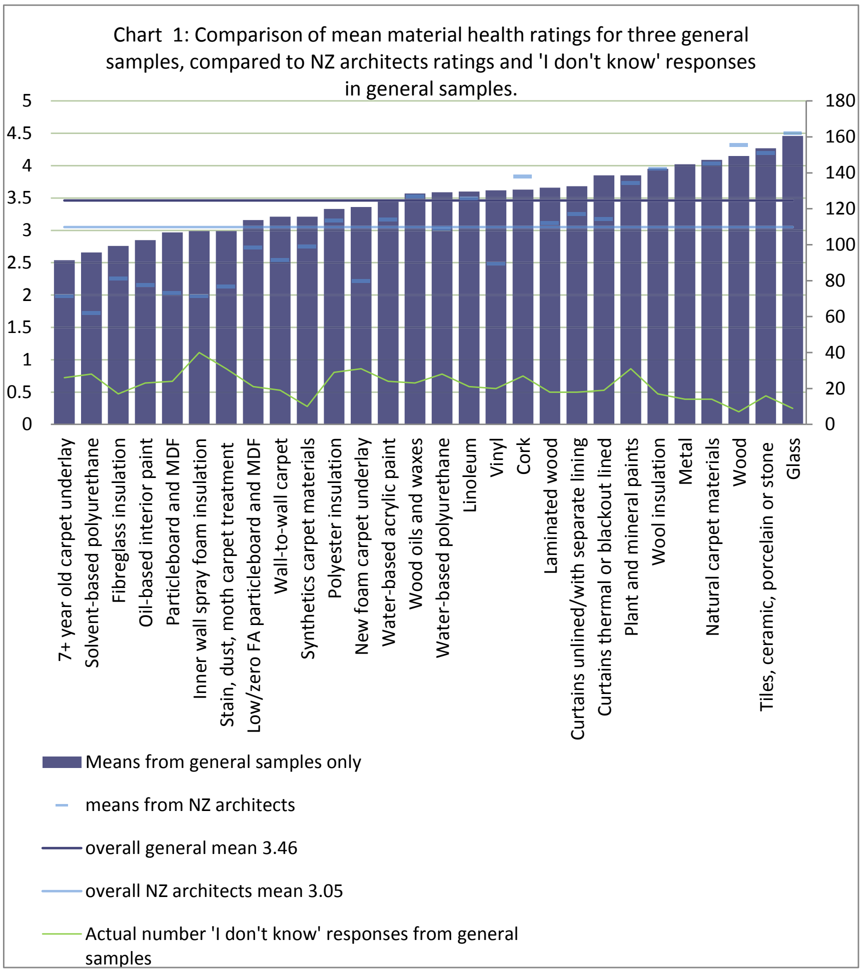
Therefore, it is possible to conclude that linoleum is healthier for the users and better for the environment than vinyl, although it is important to research specific linoleum products, as these vary.

STUDY OF POPULAR PERCEPTON OF BUILDING AND FURNISHING MATERIALS

A recent PhD study (Petrović 2014), surveyed 182 participants from general populations (61 from New Zealand (NZ), 60 from the United States of America (US), and 61 from the United Kingdom (UK)). For comparison, a similar survey was completed by 65 NZ architectural academics and practitioners. Although there were some differences between the administered questionnaires, the shared core was a health rating of 28 building and furnishing materials, including vinyl and linoleum, which revealed some useful patterns. Approval was obtained from the Human Ethics Committee of Victoria University of Wellington for this work.

Participants were asked to provide health ratings of materials on a five point Likert scale: unhealthy 1-2; neutral 3; 4-5 healthy, with an option ‘I don’t know 0.’ Chart 1 shows the means from the three general samples, compared with the overall mean of their ratings for all materials of 3.46. This overall mean indicates materials were generally rated as neutral towards healthy. Of the 28 rated materials, 5 materials had a mean rating over 4 (glass; tiles; wood; natural carpet materials; and metal), 7 materials

had a mean rating under 3 (7+ year old carpet underlay; solvent-based polyurethane; fibreglass; oil-based paint; particleboard and MDF; inner wall spray foam insulation; and stain, dust, moth protection built into carpet), while the remaining 16 materials received means between 3 and 4. Therefore, generally ratings differentiated between more healthy and less healthy materials.



A very similar trend was seen with the ratings from the NZ architects sample (Chart 1). Although their overall mean for all materials was noticeably lower at 3.05, there is a stronger polarisation of ratings, with somewhat higher means for the highly rated materials, and noticeably lower means for the low rated materials. Nevertheless, with exceptions, the extremes of the scales are held by the same materials.

Standard deviations and 'I don't know 0' responses were also considered indicative of the overall patterns in ratings. For all the materials, in the three general samples the average standard deviation was 1.08. Generally, low standard deviations were paired with high ratings of materials; for example glass received the highest overall rating of 4.46 and had the lowest standard deviation of 0.80 and was

followed in both by tiles (mean 4.27, SD=0.90), indicating that for these materials responses were most strongly grouped. As the means dropped, standard deviations increased. At the lower end of the scale, ratings tended to be less grouped and had much higher standard deviations. For example, the highest standard deviation was recorded for fiberglass insulation (mean 2.76, SD 1.26) and 7+ year old carpet underlay (mean 2.54, SD 1.25), which were among the lowest rated materials. This trend was not as strong as for the top of the scale.

When designing the surveys it was anticipated that the general population might not have strong opinions about some building materials. Rather than trying to 'force' them to form opinions, the 'I don't know' choice was provided to measure this tendency. Generally, the highly rated materials received a low level of indecisiveness rating, while all low rated materials received higher indecisiveness rates (Chart 1). This could indicate some participants opting for 'I don't know' instead of providing very low ratings. Additionally, several peaks in 'I don't know' responses for the mid-range rated materials generally indicate which materials are less known. While it seems reasonable participants might select 'I don't know' for less known materials, this seems to have occurred about equally for both unhealthy and healthy materials.

Jointly these features indicate that participants tended to consider materials as neutral or healthy, even for materials which are currently most discussed for their adverse health effects. There was also a clear trend to choose 'I don't know' instead of a low rating. Furthermore, the overall patterns in ratings strongly indicate that the more common materials were better known and more likely to be rated as neutral or healthy. This potentially indicates the conservatism of participants in accepting both healthier alternative materials and changing their views about the suitability of established materials, which have since been recognised as unhealthy. The ratings for vinyl and linoleum clearly show a number of related problems.

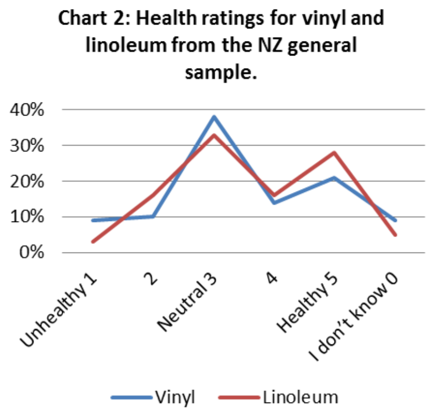
Vinyl and linoleum

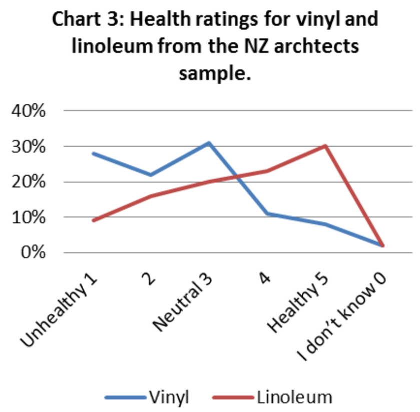
Charts 2-5 give the distribution of ratings per sample for vinyl and linoleum, showing a very similar distribution of ratings for the three general samples. The nominal difference between the means for the two materials in the three general samples is small. Ratings of both vinyl and linoleum exhibited a strong tendency towards bi-polar distribution for all three general samples, indicating a level of confusion regarding the perceived healthiness of these materials (Table 1; Charts 2, 4-5). For the three general samples the mean ratings for vinyl and linoleum were very similar at 3.62 and 3.60 respectively. Both materials received ratings in the full range, and had similar standard deviations of 1.09 and 1.11 respectively. Visually, this similarity is clear in charts 2, 4-5. When this similarity of ratings was explored in terms of statistics, the paired-sample t-test correlation was 0.764, $p=0.000$, significant at $p<0.01$ level (for 150 participants from three general samples who rated both materials), indicating statistically significant similarity in ratings. Nevertheless, when the individual ratings were considered, it was possible to observe that most participants did not rate these two materials the same.

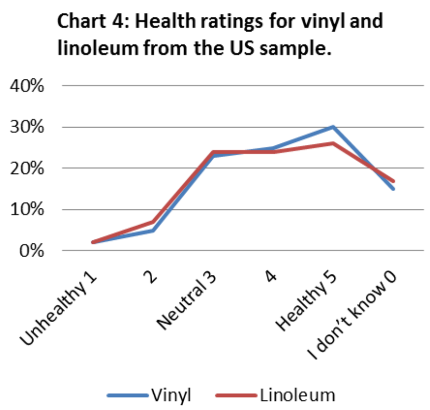
However, the NZ architects ratings for vinyl and linoleum had a different pattern (Chart 3). Their mean rating was 2.48 for vinyl (SD 0.15) and 3.49 for linoleum (SD 1.33), almost a whole point difference in mean. Furthermore, although the NZ architects mean rating of linoleum was comparable with the means of the other samples (greatest difference of 0.3), there were larger differences in the mean rating of vinyl, with the NZ architects almost 1.5 points lower than the highest rating of 3.90 (SD 0.14) from the US sample. This difference was also statistically significant, as confirmed by a one-way between subjects ANOVA test conducted to compare the effect of sample on health rating of vinyl ($F(3,220)=18.15$, $p=0.000$; at the $p<0.01$ level of significance), with the NZ architects rating vinyl lower than the other samples. Although this shows that as a sample the NZ architects generally differentiate between vinyl and linoleum it is important to consider whether these ratings are as low as they should be. Chart 3 shows that even their ratings used the whole range and included healthy ratings, and the mean was not much lower than the neutral of 3.

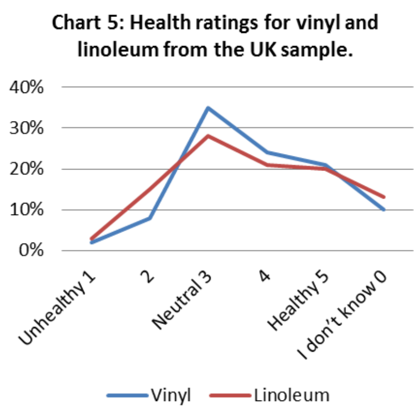
Table 1: Mean, standard deviation and standard error for health ratings of vinyl and linoleum.

	Vinyl				Linoleum			
	N	Mean	Standard Deviation	Standard Error	N	Mean	Standard Deviation	Standard Error
NZ general	58	3.31	1.21	0.17	58	3.52	1.18	0.16
NZ architects	65	2.48	1.23	0.15	64	3.49	1.33	0.17
US	60	3.90	1.03	0.14	58	3.79	1.05	0.15
UK	62	3.65	0.95	0.13	61	3.50	1.09	0.15
Total sample	245	3.29	1.24	0.08	241	3.57	1.18	0.08









The high level of similarity in ratings for vinyl and linoleum in the three general population samples from the three countries implies participants struggled to understand the difference between vinyl and linoleum. Realistically, these materials look very similar once installed, and others have also reported that the two are 'often mixed up' (Engman, Bornehag and Sundell 2007). However, this absence of differentiating patterns, even between samples from different countries (which might have a

colloquial preference for use of one over the other term), is problematic given that vinyl is recognised for its adverse health effects, while linoleum has not raised significant concerns.

CONCLUSION

The example of vinyl and linoleum starts to illustrate the problems associated with the lack of knowledge of the general population over health issues associated with these materials. While there is a reasonable level of scientific acceptance over the risks associated with vinyl and PVC, and some legislative changes have been made, it is currently hard to predict whether such concerns will continue to complete elimination of the products. What is known is that for the well known risks associated with lead and asbestos, regulations aimed at reductions came before regulations aimed at elimination (Petrović 2014). The same examples show that such processes can take a very long time, easily 20-30 years, and unfortunately vinyl and PVC seem to be in relatively early stages of recognition of risks. Adding to this, industry is encouraging and supporting research to challenge any claims that the issues are serious, elongating the process.

Meanwhile, the general population is poorly informed of any such discussions. Survey participants struggled to differentiate between the two materials, and considered both reasonably healthy. Although the NZ architects seemed to differentiate between them, a more dramatic polarisation was expected, based on their anticipated knowledge of the materials. Because these materials are commonly used in architecture and building construction, it is essential for architects and the building industry to take a leadership role in educating the general population of associated health risks.

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ENERGY SYSTEM DESIGN FOR AN AUTONOMOUS SOLAR PV POWERED DWELLING WITH SEASONAL ENERGY STORAGE

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ABSTRACT

New Zealand's temperate climate offers the opportunity to power an energy efficient house throughout the year using only the solar energy available within the immediate vicinity. Insolation can vary by a ratio of more than 3 between seasons, and solar PV capacity factors are typically between 10% and 14%, so to achieve this goal with technical efficiency, i.e., without using a PV array that is over-sized during the summer, both diurnal and seasonal storage must be provided. An affordable autonomous solar powered dwelling project has been initiated to evaluate and demonstrate the near commercial status of suitable technologies. These consist of a combination of battery and hydrogen energy storage to deliver an emerging technology solution for "energy independent" thermally efficient rural dwellings. In this analysis, hydrogen gas is shown to be a viable seasonal energy storage vector. Two scenarios are developed representing the inter-seasonal energy storage requirements in a dwelling powered solely by the sun in southern and northern parts of the country. Technology components and the energy system operation are outlined. Results indicate that energy storage technologies have matured to the point where volume production might achieve a cost effective solution for remote and rural locations. A demonstration project is planned which aims to test the concepts, further develop the expertise to create an energy self-sufficient home at an affordable price within New Zealand, and to attract investment for business innovation and commercialization.

KEYWORDS: Energy; Dwelling; Seasonal; Storage; Hydrogen

INTRODUCTION

This paper assesses the feasibility of an energy self-sufficient home entirely powered from rooftop solar PV, using hydrogen as the main energy storage vector. The hydrogen is produced on-site from PV electricity by water electrolysis. The house would be designed for off-grid remote and rural sites. It could be manufactured off-site and may be relocated during its lifetime, so features that reduce weight and minimise a permanent footprint would be beneficial. The present-day economics of the concept are not quantitatively addressed here. Rather, the energy system is modelled to obtain a preliminary estimate of the PV plant and hydrogen store capacity required to provide seasonal energy storage, in combination with diurnal battery storage for day to day electricity needs.

Low Energy Houses and Inter-Seasonal Storage

Many projects have modelled, analysed and in some cases built low energy use houses incorporating local generation capability. These designs mostly differ from the present study because they rarely attempt to be completely self-sufficient, or autonomous in energy supply. They aim to achieve an annual net zero or neutral energy flow, and are generally termed net zero energy buildings (ZEB). They usually rely on and energy network (ie are grid-connected) to provide supply–demand energy balancing, or energy "storage". This grid service is not free, although at present cheaper and more practical than storing the energy balances on site.

Energy self-sufficient housing studies that include local inter-seasonal secondary energy storage are far fewer, although investigations into inter-seasonal storage in houses have a long history. In 1939 MIT built "Solar House#1" which used seasonal thermal energy storage (STES) for year round heating (Wikipedia, 2014). The design of an energy-autonomous house in Victoria, Australia has been analysed (Fuller, 2011). This study determined that it is technically possible for a very energy efficient house design, but not practical because it would increase the capital cost of a house between 15% and 33%, and there would be insufficient roof area to accommodate the additional solar technologies required. The possibility of seasonal hydrogen energy storage was considered but no attempt was made to specify or size the storage system. Owing to the technology configurations studied, rooftop energy collection systems were oversized for summer and therefore greatly underutilised, which is not desirable in an "energy efficient" house.

Fuller concluded that the alternative option of a low-energy house, which exports electricity produced from renewable sources to the grid offers advantages in comparison to the autonomous version. Electricity storage systems are not necessary and the energy generating systems could be smaller and cheaper because seasonal differences could be balanced out by the grid. Furthermore, any excess energy produced in summer is not wasted but supplied to other grid users. However the house is no longer off-grid, and unfortunately this solution, if replicated across network regions creates an undesirable seasonal demand profile for electricity suppliers to grapple with. In the open electricity market which now largely exists, they would price their electricity sales and purchases accordingly.

The Cost of Energy Balancing

For renewable energy systems, the cost of energy (COE) is a combination of the <u>power</u> conversion capacity costs and the <u>energy</u> storage capacity costs. For regular, short term storage cycles (minutes to hours) the power conversion system is the main contributor to COE. This is because the COE component attributed to storage is recovered over many cycles. The cumulative energy stored over the store design life is high, leading to a low cost per kWh cycled. However, for longer term balancing (days to months of storage) the energy storage capacity requirements overtake the power capacity costs. For inter-seasonal storage, there is only one major cycle per year, so relatively few cycles are accumulated over the store lifetime. Energy storage/kWh capital cost must therefore be inherently low for viable seasonal storage. Our recent studies suggest that as the storage capacity grows, hydrogen offers a competitive opportunity in remote locations.

ELECTRICAL DEMAND

It is assumed that low voltage AC mains distribution is used within the house and that the usual range of energy efficient appliances is deployed, including microwave oven and an efficient (low thermal loss) electric oven. LED lighting is used throughout. As the house is well insulated and sealed, active cooling from a heat pump integrated with an air change unit can provide more effective cooling than passive ventilation. Because of higher summer insolation levels, electricity is readily available for summer cooling by heat pump. The heat pump can boost winter space heating, and also provide back up if there are operational issues with the hydrogen system.

THERMAL DEMAND

Thermal Loads

Hydrogen is produced and stored whenever the PV supply exceeds demand, and is the main fuel used for cooking, water heating and space heating. Standard gas cookers are not as efficient as electric

hobs, but in this case the hydrogen gas ring design is assumed to be partially condensing, does not emit hot CO_2, and is therefore nearly as efficient as a typical electric cooker (~70%).

Hot water is supplied from an instant water heater operating on hydrogen. This is a fully condensing unit and very efficient (>95%) compared with a typical storage hot water cylinder (~80%).

Space heating is also fuelled by hydrogen. Air change heat exchanging is incorporated. A substantial reduction in heating loads relative to the current NZ household average is assumed. Winter space heating represents the main demand for long term energy storage.

Solar Gain and Thermal Mass

The availability of year-round heating capability using stored "renewable" hydrogen fuel along with high thermal insulation levels raises the question of how much thermal storage within the structure is necessary. Low thermal mass allows the temperature of the heated space to be rapidly adjusted (by hydrogen combustion) to match occupant heating preferences, and respond to variable heat losses caused by difficult-to- predict weather conditions. Thermal storage is useful for distributing solar gain over a diurnal timeframe, but it represents a delayed response within the temperature control system. It is not helpful for example in achieving rapid early morning heating, since some fuel is used to heat the thermal mass. This trade-off requires further exploration, but for the current analysis a low level of thermal storage within the building is assumed.

ANNUAL HOUSEHOLD DEMAND

Energy Efficient House Annual Demand

In the proposed energy system, hydrogen gas will supply most of the thermal end use, so the household requirements are split into electrical and thermal.

HEEPS (Isaacs, 2006) reported that annual energy use ranged from an average of 6,900 kWh for the lowest 20% of houses to 14,450 kWh for the highest 20% of houses. Of this consumption, about 6% is used for cooking, 29% water heating, 34% space heating, 8% lighting, 10% refrigeration, and 13% other appliances. Electricity use is about 7,000 kWh, of which only 12% on average is space heating. This electricity use figure gives no clear indication of average heating load because many houses use alternative forms of heating as well as some electricity. Assuming a baseline annual energy use of 10,000 kWh for an all-electric house, we estimate that some 3,500 kWh (35%) is required for space heating, 2,800 kWh (28%) for water heating and 420 kWh (4.2%) for non-electric cooking, leaving 3,280 kWh (33%) annual energy use in electrical appliances.

Based on a very low-loss building envelope, average demand for space heating is assumed to be reduced by 50% to 1700 kWh. Water heating is reduced from 2800 kWh to 2000 kWh through various means including heat recovery, non-electric cooking remains at 420 kWh, and the electricity consumption including summer cooling is reduced from 3,280 kWh to 2,360 kWh through the use of energy efficient lighting and appliances.

New Zealand spans a range of warm (northern) to cool (southern) climatic conditions. Many rural and remote regions are elevated and therefore cooler. In this analysis we consider scenarios for typical warm and cool climatic conditions, "northern/warm", and "southern/cool". Heating and cooling degree day criteria (Degree days, 2014) are used to modify this energy demand profile for the scenarios modelled.

In summary, baseline annual end use energy for the study (after conversion losses) is shown in Table 1.

Table 1: Baseline annual end use energy

Energy Use	Annual kWh	%	Notes
Electricity (average power =384W)	2360	36.5	From PV direct and from battery.
Lights and miscellaneous intermittently used appliances.	2000	31	Combined monthly demand assumed to be relatively constant.
Heat pump – summer cooling	360 nominal	5.5	Proportional to cooling degree days.
Hydrogen (average power = 470W)	4120	63.5	From hydrogen store.
Cooking	420	6.5	Monthly demand assumed constant.
Water heating	2000	31	Monthly demand assumed constant.
Space heating	1700 nominal	26	Proportional to heating degree days.
Total annual energy use (nominal)	6480	100	Depends on climate (degree-days).

MONTHLY DEMAND VARIATIONS

To establish the hydrogen storage capacity required, demand profiles for both hydrogen and electricity are required. All surplus electricity is used to produce hydrogen. The annual PV electricity generation must meet the combined annual electrical and thermal demand including losses, so that at no time of the year is PV production wasted. Obviously, a design factor would be included to account for annual variability in both supply and demand. Hydrogen storage introduces the ability to convert energy either way (electricity to gas via the electrolyser and gas to electricity via a fuel cell). This improves the flexibility and resilience of the energy system.

Fuller developed an energy use profile for his analysis as shown in Fig. 1. Space heating was represented by a variable monthly demand. We adopt a similar approach, and also include a variable cooling demand.

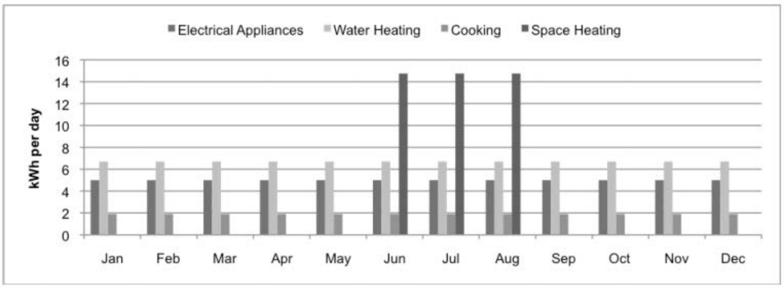

Fig. 1: From Fuller 2011 – synthesised energy efficient home monthly demand pattern.

IRL studies of remote community electricity use at Totara Valley farmhouses and at Te Puia Springs urban houses (IRL, 2003) examined the seasonal electricity load profile for an "averaged" house, using a sample of 8 houses. The Te Puia Springs profile is shown in the "contour" map of Fig. 2. The total annual electricity consumption for this "averaged" house was 9,590 kWh which is within the range observed by Isaccs. "Hot" colours (reds) on the map represent higher levels of electricity use, while "cool" colours (blues) represent lower levels of electricity use. This map illustrates typical seasonal electricity consumption patterns in New Zealand homes – indicating a relatively high demand for heating (and lighting) in the deep winter months (and no summer energy use for cooling). Fig. 3 shows the average and peak electricity consumption for each month. Battery storage is only required to satisfy the hourly fluctuations shown in Fig. 2, while hydrogen storage must address the monthly variations shown In Fig.3.

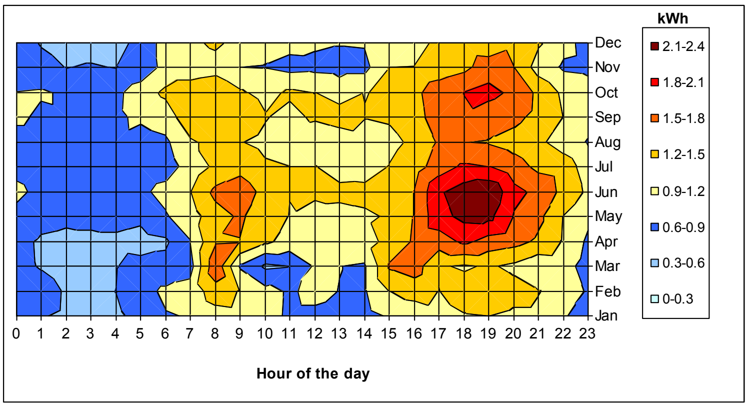

Fig. 2: Contour map of the annual electricity use in the "averaged" Te Puia Springs home (kWh/h).

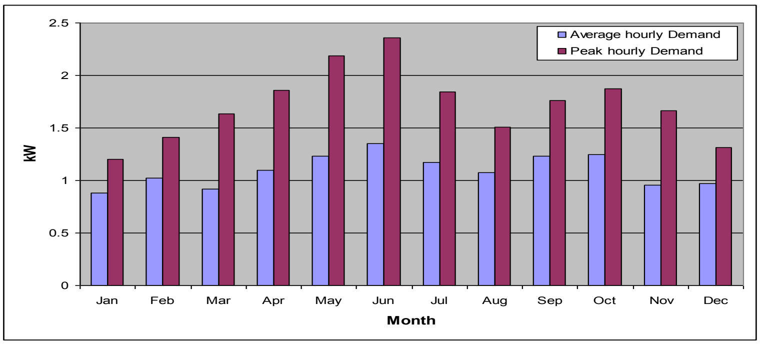

Fig: 3: Data from Fig. 2 presented as average and peak kW for each month.

Heating and Cooling Degree Days

The main variation in thermal energy use is due to seasonal space heating. Fig. 4 (Heerdegen, 1988) shows the typical linear relationship between heating degree days (HDD) and household electricity demand. A thermal loss profile based on heating degree-days is used to adjust the monthly heating needs and therefore the hydrogen fuel requirement for each of the scenario.

We used 16°C as the external temperature below which heating is required. Typically, annual HDDs for a 16°C threshold vary between 600 and 3000 for New Zealand locations (Degree days calculator, 2014).

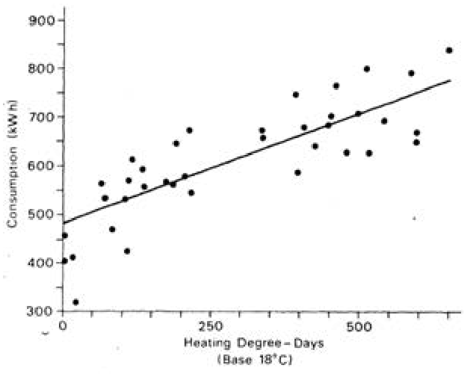

Fig. 4: Average 2 monthly domestic electricity consumption of 10 Palmerston North households against heating degree days during 1980-86.

Cooling degree day (CDD) data is also available and is used to estimate the cooling needs. We have used 22°C as the external temperature

threshold above which cooling is required. Typically, annual CDDs (22^{o}C threshold) vary between 5 and 30 for New Zealand locations (Degree days calculator, 2014), which explains why summer cooling does not represent high component of household energy consumption. The temperature threshold for cooling is chosen to be higher than the temperature threshold for heating. The range between the two bases (in this case 22-16= 8^{o}C) helps to account for the effects of internal and solar heat gain, thermal mass, and a comfort tolerance band. When used for temperature control purposes, degree day data is usually calibrated for actual building performance, which helps to account for effects such building thermal gain and storage. This approach provides only an approximate comparison of the heating and cooling energy requirements for a building of the same performance at different climatic locations.

Energy Consumption Budget

An annual by-month energy budget for the house is estimated from the above data and assumptions. The annual demand is summarised for the northern/warm and southern/cool scenarios under Table 2 in the Inter-Seasonal Analysis and Discussion section.

ANNUAL RENEWABLE ENERGY SUPPLY

Solar energy is the most dispersed (and accessible) renewable resource for New Zealand locations. Solar hot water systems can be used to off-load thermal demand from the electrical supply. However, this is not useful on a seasonal basis since it is at present impractical to store excess summer hot water for use in the winter. Partial supply of hot water from a solar system sized more for summer production may be cost effective in conjunction with hydrogen storage, but this complication is not considered here. The use of hydrogen gas for all solar energy storage reduces the rooftop technology requirements to a PV array only, so water heating by hydrogen fuel only is used in this preliminary evaluation.

ANALYSIS MODEL

Fig. 5 shows the block diagram of the house energy supply system. All energy is supplied from a solar PV system. In the model, the PV supply capacity factor is adjusted to account for the variation between sites, assuming 13% for the northern site. Based on the ration of annual solar insolation at the two sites this sets the southern site PV capacity factor at 11.3%. A monthly insolation profile appropriate for the latitude and panel tilt is applied in each case, and the electricity production profile derived. A fixed average electrical system loss of 20% is assumed for this study. A small battery provides daily support for the electrical loads. All solar PV energy which is surplus to daily requirements is converted and stored as hydrogen fuel. Electrolysis conversion loss is also fixed at 20%. The large hydrogen store provides daily and seasonal storage for the thermal loads, and hydrogen can also be used for regeneration of electricity in a fuel cell during periods of very low solar energy production.

A spreadsheet model was constructed to investigate the inter-seasonal hydrogen storage requirements. Monthly hydrogen demand is calculated, based on the thermal energy required. Electricity regeneration by fuel cell was not considered. Monthly electricity demand is the sum of electricity needed for hydrogen production and the electrical loads. From this the monthly after–losses electricity supply needs are calculated, and summed to get the annual energy supply requirement. This total is distributed across the year, based on the monthly solar insolation for the location. The monthly hydrogen storage energy flows (+ and -) are represented by the difference between available supply and demand. The approximate quantity in the store (kWh) is the difference between the cumulative monthly flows into and out from the store; the maximum difference over the year representing the

required storage capacity. The PV plant peak capacity (kWp) is found from the annual energy supply (at the chosen capacity factor) required to meet the estimated annual demand.

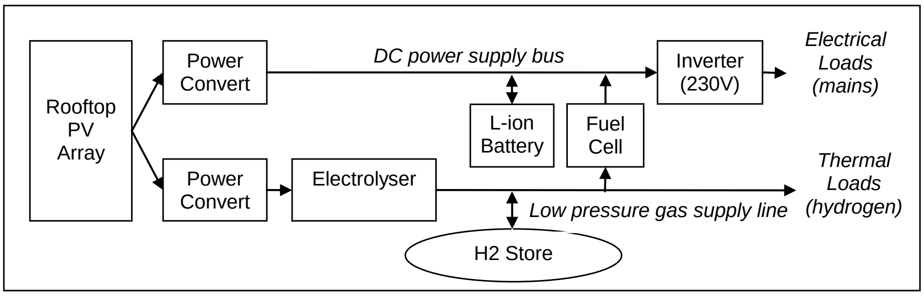

Fig. 5: Block diagram of the autonomous off-grid energy system.

INTER-SEASONAL STORAGE ANALYSIS AND DISCUSSION

Monthly Energy Flows

Table 2 provides a summary of the annual energy budgets for the two scenarios, when degree day adjustments are taken into account (with an arbitrary calibration factor). The annual energy demand for the northern site is 5,875 kWh, compared with 8,859 kWh for the southern site. This difference is primarily due to the higher hydrogen consumption for space heating at the cooler site. The difference between electrical supply and total end use demand represents the hydrogen conversion losses. The cooling demand at the northern site is higher than at the southern site, but for the degree-day parameters chosen, there is only a minor increase in the electricity consumption.

Table 2: Annual demands and storage requirements for the two scenarios

Energy (kWh)	**Northern/Warm Scenario**	**Southern/Cool Scenario**
Ave. solar/day/m^2 at tilt	4.34	3.78
Electrical supply/yr (after losses)	6,832	10,571
Electrical demand/yr	2,048	2,014
Thermal demand (H_2 prodn.)/yr	3,827	6,845
Total end use demand/yr	5,875	8,859
Hydrogen store capacity (HHV)	1,270	1,974

The required PV power capacities are estimated at 7.5 kWp for the northern site (assumed 13% capacity factor, fixed array tilt of 31^o and 20% electrical losses), and 13.3 kWp for the southern site (11.3% capacity factor, fixed array tilt of 40^o and 20% electrical losses). The southern site solar PV installation is considerably larger due to a combination of higher heating load **and** lower insolation. However, it is not too large to fit onto an appropriately designed roof structure. The southern site hydrogen storage requirement is correspondingly also larger, at 1974 kWh. This represents 617 Nm^3 of gas storage, while the northern site requires a volume of 397 Nm^3. Containment of this gas is discussed under the Hydrogen Technologies section.

Figs. 6 and 7 illustrate the main monthly energy flows: solar PV supply (after losses), electrical demand, thermal (gas) demand, and the hydrogen flows through the store to achieve supply-demand energy balancing (positive values represent charging and negative values represent discharging). Inspection shows that for both scenarios the store will be empty at the end of September and full at the end of March. The difference between solar PV energy production and the combined demand is represented by the stored energy flow (plus system losses). Fortunately, in both cases monthly solar

energy production in winter comfortably exceeds the electrical demand, so excess PV capacity or extensive regeneration of electricity is not required.

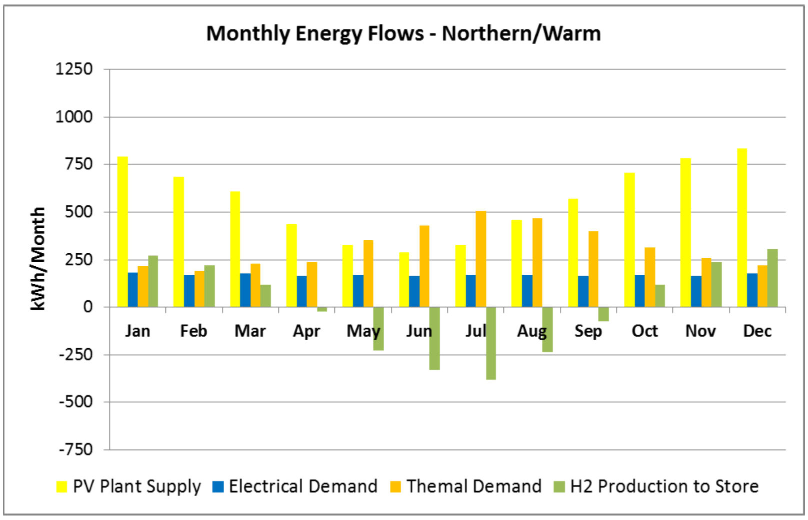

Fig. 6: Energy flows for the northern/warm scenario.

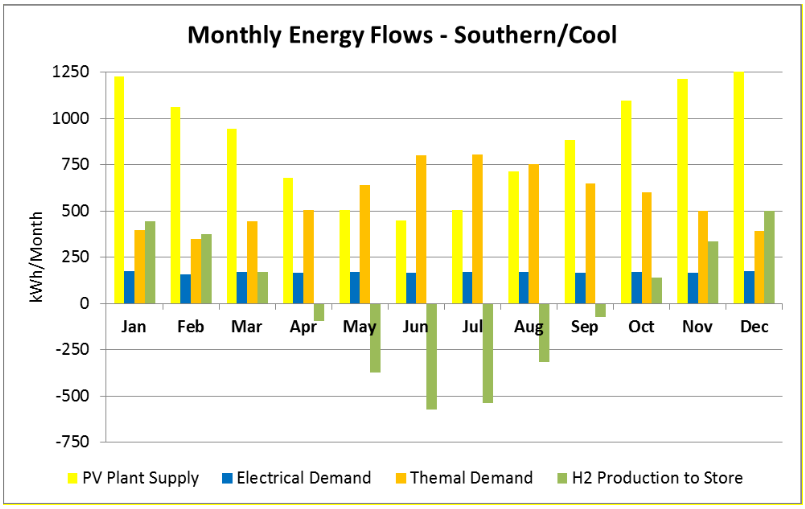

Fig. 7: Energy flows for the southern/cool scenario.

The higher winter heating needs and the lower quality solar resource for the southern/cool scenario combine to increase the size and cost of the installation. For more northern but still cool sites, PV plant size would be moderated because of better insolation levels. Warm northern sites also require less hydrogen energy storage capacity. Because of these trends, energy self-sufficiency using these energy resources appears to be more suitable for warmer climates. This is aided by high coefficient of performance heat pump space cooling coinciding with seasonal insolation levels.

HYDROGEN TECHNOLOGIES

Hydrogen Production and Use

Hydrogen can be produced from potable water with good efficiency (>70%) by modern small-scale electrolysers. This has been practically demonstrated in several projects around the world. On Matiu/Somes Island in Wellington Harbour, a small pilot demonstration system using a New Zealand developed electrolyser has been running for over 18 months at just under 80% voltage efficiency. As a chemical fuel, hydrogen can be stored for long periods of time. When used to produce electricity, hydrogen can fuel an engine genset at 30 to 50% efficiency depending on scale, or a fuel cell with higher efficiency (>60%). However, the round trip efficiency (electrical to electrical) when using hydrogen as an energy store is not high (20 to 50%). A better use for the bulk of the stored hydrogen is to produce thermal energy, where it can be used to replace natural gas, LPG or firewood. In the proposed house all normal cooking, water heating and space heating services are assumed to be provided from hydrogen gas.

The hydrogen appliances are assumed to be available at similar prices to conventional gas appliances, although this is not yet the case. There is no anticipated technical barrier, simply a lack of demand. Some characteristics of hydrogen combustion will need to be addressed. For example the flame is almost invisible, and it has a tendency to produce NOx emissions. However, under the right conditions it burns more cleanly and hotter than other fuels. It emits no CO_2, but slightly more water vapour. Escaped hydrogen gas rises and disperses very rapidly rather than pooling as a hazard at ground level.

Hydrogen Storage

One normal cubic metre of hydrogen gas contains 3.2 kWh of HHV thermal energy. Hydrogen gas is normally stored cryogenically or at pressures up to 700 bar. Our studies show that if ground space is available (the case in many rural and remote regions) then storage at atmospheric pressure has advantages. The storage vessel walls must be flexible so that it can collapse as gas is withdrawn. We have identified a number of membrane materials which are suitable for storing hydrogen at atmospheric pressure, and have tested some for gas diffusion rates. At the low operating pressures, hydrogen diffusion out is low, such that storage for the periods of interest can be considered largely lossless. Air will diffuses in at a lower rate (due to the larger molecules), and this (specifically oxygen) needs to be managed. Techniques are being considered to maintain safe operation.

Fig. 8 shows, for various storage capacities on the horizontal axis, the volume (Volume formula, 2014) of a simple hydrogen storage bag along with the normalised materials cost on the left-vertical axis, and the side length of a square base footprint on the right-vertical axis. It can be noted that the specific area of material reduces as the volume increases, i.e., the bag becomes cheaper per unit volume stored.

An advantage of storing larger volumes at atmospheric pressure becomes obvious. Material stresses are minimal (only sufficient to lift the top layer of the membrane against its weight) irrespective of the size of the bag. Large bags also have lower gas diffusion rates per unit volume. For the two scenarios analysed, the bag footprint varies from 12 m x 12 m to 15 m x 15 m square. This might be thought of as quite a large container, but is not an unusual size for a range of rural and remote infrastructure facilities for water storage, stock food, (eg silage), grain, sludge ponds, biogas collection and the like.

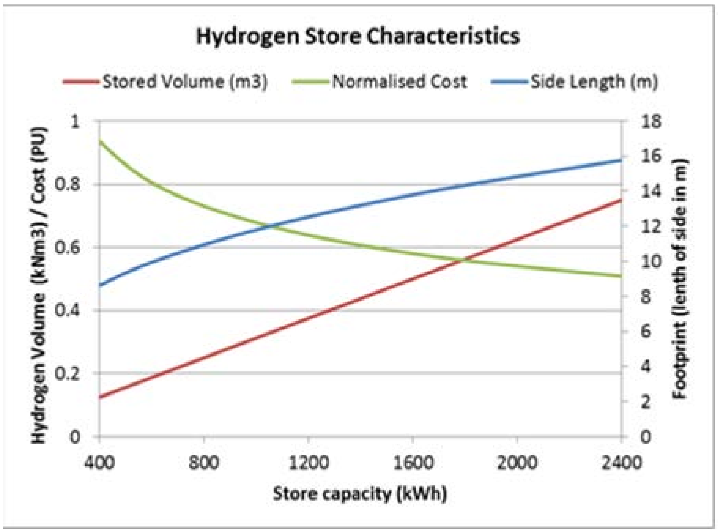

Fig. 8: Containment sizes for storage at atmospheric pressure hydrogen .

Regulations, Codes and Standards

Safety requirements are beyond the scope of this paper. However preliminary assessment suggests that no existing hazardous gas safety requirement presents an insurmountable challenge.

CONCLUSIONS

For off-grid households entirely powered by rooftop solar PV, the need to collect abundant summer energy to satisfy winter heating demand presents a substantial challenge. This preliminary analysis suggests that for rural and remote households and communities, hydrogen stored at atmospheric pressure shows promise as an energy storage medium. Flexible bags have low material costs, and the small number of full range stress-strain cycles imposed makes this a promising option with sufficient durability for inter-seasonal hydrogen gas energy storage.

The storage combination of battery and hydrogen offers very good energy security and resilience for an autonomous energy system, with the ability to regenerate on-site electricity via a fuel cell. Additional sources such as wind, microhydro and even a grid supply can be easily integrated to improve supply reliability and flexibility.

There may be an opportunity to use relatively low thermal mass in these homes to reduce transportation and installation costs and still provide efficient thermal performance.

FURTHER WORK

This is a preliminary study. The analysis took no account of daily solar gain, or how much electricity needs to be regenerated (with additional losses) during poor solar conditions. These factors will have an impact in both summer and winter. Detailed integrated analysis of energy flows and the building design needs should be undertaken using industry-standard analysis tools available for energy systems

and building energy efficiency. Better understanding is required on how to optimise the interaction between electrical demand, battery storage and backup charging from a fuel cell, and on the impact that thermal mass has on use of stored hydrogen fuel. Techno-economic analysis is required to examine the technology costs of inter-seasonal storage.

This analysis has been undertaken as the first stage of a project to experimentally evaluate the performance of the energy system described. It is the intent to build a pilot transportable house to test the concepts discussed in this paper. A site has been selected and planning is underway.

ACKNOWLEDGEMENTS

The hydrogen technology development work was undertaken under Public Good Science Fund (PGSF) research programmes within Industrial Research Limited. The analysis for this paper was carried out within the successor organisation Callaghan Innovation's Research and Technology Services Group.

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SUSTAINABLE BUILDING FEATURES AND FIRE SAFETY

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ABSTRACT

It is often a challenge to design buildings to be more energy efficient and environmentally friendly. The impact of building features that meet this challenge on fire safety can be positive, neutral or negative. A list of common features of such buildings has been developed and their implications for fire safety investigated with the aid of an expert group. The most positive feature is distributed heating and cooling, which unlike central systems does not require the movement of large volumes of air and hence potentially smoke around a building in the event of a fire. Use of natural ventilation, commonly with atria and double skin facades allows for relatively unimpeded smoke transport in the event of a fire. Fire engineering design and fire safety mitigation measures such as natural draught and mechanical extract systems, for atria is well developed and understood. This is not the case for double skin facades. Computational Fluid Dynamics modelling of prototype buildings with a double skin façade has been carried out. Provided the vents to the double skin facade close in a fire, smoke spread via the double skin faced is prevented. The New Zealand Building Code, Framework for Fire Safety Design, C/VM2, and normal good practice, requires a robustness check, that is allowing for failure of one system such as that closing of vents to the inside of the building. In the event of such a failure the Fire Engineering design of a double skin facade, is unlikely to be successful unless a building is sprinklered. Other sustainable building features with less significant effects are also discussed.

KEYWORDS:

Sustainable Buildings, Fire Safety, Fire Engineering, Fire Regulations, Energy Efficiency

INTRODUCTION

There is a growing trend to construct green or sustainable buildings that have benefits environmentally through promoting recycling, energy efficiency and efficient use of resources. (Voss, Musall, 2012) However, a well-designed building must meet other design objectives such as usability, aesthetics, potential for redesign for alternative uses and safety. There are also statutory requirements that must be met. A building that does not meet all the design objectives is unlikely to be truly sustainable as it may quickly become obsolete or unfit for purpose, and substantially altered or demolished and replaced. Fire safety has and will continue to be an objective of building design. Despite advances in fire safety systems the objective of design for fire safety has remained the same for centuries, to reduce ignitions, warn occupants, supress fires and subdividing buildings to prevent rapid spread of fire. These methods can limit the use of recyclable and reusable materials, and restrict the layout of buildings to smaller spaces with implications for daylighting and natural ventilation (Krause, Grosshandler and Gritzo, 2012). This limitation can be extreme, in jurisdictions where highly restrictive, prescriptive fire codes limit design choices. This difficult with regulators is highlighted in a paper by Short, Whittle and Owarish (2006), in which the authors say “that natural ventilation systems are unlikely to proceed due to regulatory risk in the then current, UK 2006, environment”.

As the design of sustainable buildings is a recent and growing trend, research on the complementary topic of fire safety of sustainable building features is somewhat limited to date. In addition to the two papers mentioned above, the US National Association of State Fire Marshalls commissioned a project in this area resulting in a short book (Tidwell and Murphy 2010). The authors have a background in

regulating fire safety and it focuses on potential problems rather than solutions. There are a number of papers about fire safety in houses, but many of the publications are generalised with reference to anecdotes. Several scoping studies have been published, notably Meacham, Poole, Echeverria & Cheng (2012), which includes a comprehensive list of sustainable building features and fire safety implications and qualitative risk analysis, but again focuses more on potential problems than solutions. BRE 2709 (2010), is focused more on the environmental costs of both fire and fire-fighting systems and Robbins (2012), is again a qualitative summary, but is more positive with an emphasis on how sustainability and fire safety concerns could be addressed together. There is also a summary of research need published by a group representing fire research laboratories (Krause, Grosshandler and Gritzo, 2012). These studies highlight a lack of information and a need for more case studies and research. The most detailed research on particular aspects of sustainable buildings has been published by Chow concentrating on atria (Chow & Chow, 2004) and double skin facades (Chow & Hung, 2006, Chow, Hung, Geo, Zou & Dong, 2007). These are both types of systems which allow for passive ventilation and environmental control, but also potentially allow for free passage of smoke between floors in buildings.

This study, by contrast focuses on assessing the sustainable features that predominate in buildings in New Zealand. It uses an expert group of fire engineers to rank common sustainable features in terms of both fire safety and the availability and design knowledge in regard to mitigating fire risks in these features. This list is not therefore exhaustive as is the case with Meacham, Poole, Echeverria & Cheng (2012). The biggest risk identified is double skin facades due to the lack of known mitigation measures. Further analysis of prototype buildings with double skin facades was carried out in the computational fluid dynamics (CFD) model, Fire Dynamics Simulator (FDS), (NIST, 2007).

IDENTIFYING COMMON FEATURES OF SUSTAINABLE BUILDINGS.

Fifty-four commercial NZ green rated buildings were identified as being certified by the New Zealand Green Building Council (NZGBC, 2012), between 2007, the start of the scheme, and May 2012. Information on fifty of these buildings was accessed from a variety of written and online sources to determine the types of sustainable features they utilised. Information on four buildings was not available. The results are shown in table 1 below:

Table 1 : Common Sustainable Features in Commercial Buildings.

Number of Features Used in NZGBC certified Green Buildings		
Building Features	**Total**	**Percentage**
Sustainably Sourced Materials	50	100%
Recyclable Materials	50	100%
Rainwater Harvesting System	50	100%
Lower Energy Mechanical Ventilation System	20	40%
Atrium	19	38%
Double Skin Facade	7	14%
Green Roof	6	12%
Local Power Generation	6	12%
Storage Area for Recyclables	4	8%

These are broad classifications. Lower energy ventilation systems include heating, ventilation and air-conditioning (HVAC) systems with localised heating and localised cooling such as chiller beams, zoned control of heating and cooling, variable air volume and variable air flow systems. Local power generation can be of many types, with the most common being solar panel, and wind turbines.

INITIAL QUALITATIVE ASSESSMENT AND DISCUSSION

Sustainably sourced and recyclable materials may have a positive, neutral or negative impact on fire safety. This impact depends on their susceptibility to ignition and their effect on rates of fire spread, smoke development, toxicity of combustion products and structural performance in fire compared with less sustainable alternatives. Many natural products are organic compounds, and all organic compounds are flammable. Some may require fire retardant treatments which tend to be more toxic after the material is burning, and also in situ. However some natural products perform better in terms of fire safety than alternatives, for example wool and cotton compared with many synthetic fabrics, and heavy timber structures compared with lightweight or unprotected steel structures. A type of material whose first known installation was in 1948 (http://www.eoearth.org/view/article/51cbef047896bb431f69bdc9/) that is nearing commercial application and may be utilised in sustainable buildings is phase change materials (PCMs), (Sharma, Tyagi, Chen & Buddhi, 2007). These materials usually have low melting points and are used to store heat with the latent heat of the phase change from solid to liquid providing higher density energy storage. Although relatively uncommon to date their use may increase, if draw-backs with them are overcome, notably common types of PCMs, paraffin wax, and organic fatty acids are both highly flammable.

Rainwater harvesting requires the storage of water that also has the potential to be used for firefighting. However fire-fighting water must always be available, so some part of the volume of stored water needs to be permanently stored and is not therefore normally available. Water stored on roofs has the same implication in terms of the effect of its mass on the buildings structure as green roofs. Recycled water is precluded from use in fire-fighting as distributing water that may contain microbes and other contaminants in aerosol form may lead to infection of personnel and other contamination.

Techniques to reduce energy consumption of mechanical ventilation systems are generally of benefit to fire safety. These techniques often involve only heating or cooling of areas of the building as needed or distributing heating and cooling to local zones. Both of these techniques result in less air being distributed around a building, as volumes of air flow required for ventilation are much lower than those required for heating and cooling. Any system that distributes air around the building will also distribute smoke from a fire, and even if the system is turned off smoke spread is possible through ducting and fixed vents driven by buoyancy. Localised heating and cooling, with lower air flow volumes therefore results in less potential for smoke spread via the ventilation system. Zoned systems can be designed to have the mutual benefit of reducing energy consumption by only ventilating, cooling and heating areas that are used, but can also be used for zoned smoke control, that helps confine smoke to the immediate area of a fire using airflow and differential pressures. With a system with controllable supply and/or extract air dampers, the fire floor or area can be negatively pressurised by extracting air from that area only and supplying air only to all other areas. This prevents or minimises smoke spread to other areas, giving more time to escape and reducing smoke damage to contents and building materials.

A common cause of extensive damage to property in even a small fire is corrosive acids from products of combustion such as hydrogen cyanide or sulphur compounds dissolving in water, either from sprinkler spray or as a product of combustion. These acids have a particularly severe effect on electronic equipment. Reducing property damage has an obvious benefit for sustainability as smoke damaged property will not need to be cleaned, repaired or discarded and replaced.

Atriums are a vertical space linking floors in a building. They may be enclosed with glazing, or open to some or all floors. An atrium precludes dividing the floors of a building with fire separations, so all atriums permit fire spread between floors. An open atrium permits the ready passage of smoke between floors and may substantially reduce the amount of time occupants have to escape from upper floors without having to escape through smoke, as the rate of smoke entrainment into a fire plume

increases rapidly with height and more so when smoke spills into an atrium from under balconies. A glazed atrium may allow fire to spread between floors if the glazing fails in an uncontrolled fire or due to localised flame impingement on the glazing.

Double skin facades (DSF) are a system of glazing with a large cavity between two sets of glazing, typically with a cavity of between 0.5 and 2.0m wide. These are most often used for natural ventilation with automatically operable louvers or windows on the outer glazing to outside in various arrangements, and operable louvers or windows on the inner glazing to inside. They allow greater control of ingress of noise from outside, and operation of the ventilation in strong winds without compromising the flow of fresh air into the occupied zones. They are similar to atria in that they allow for the passage of smoke when the interior louvers are open, and in the later stages of the fire, the glass may break permitting passage of fire between floors, leading to greater property loss.

Green roofs are essentially gardens on the top of roofs. These add substantially mass to the top of a building as do rainwater or recycled water tanks if located on the roof. The materials used in these may be flammable, and they are likely to prevent the use of the fire-fighting technique of venting fires by removing roof cladding. A less obvious implication is that by adding a long term load to the building, the structural design of the building for fire safety is more onerous. Most building codes throughout the world require the building to be designed for gravity or normal loads with a large margin of safety (an overload), and then assume that as the probability of a fire and an overload at the same time is low. It is therefore reasonable in design to assume a reduced gravity load in conjunction with a fire condition. The reduced load is calculated by removing the factor of safety from the permanent (dead) loads, and using a factor of safety of less than one for the moveable (live) loads. The load from a green roof should be treated as a permanent load, so the reduced gravity load in a building with a green roof will be significantly higher than that for a building without. With such a high reduced gravity load, it is more likely the structural design of the entire building is governed by the fire load condition rather than the normal condition, and to a greater extent, so the provision of a green roof may have a more substantial impact on the structural design of a building due to the fire loading than the normal design would suggest.

Localised power generation is most commonly provided by photovoltaic cells (PV or solar panels) and wind turbines. These have issues in terms of structural load on buildings, and photovoltaic cells can cause access problems for fire-fighters. Unlike a mains electricity supply, or generators which can readily be isolated when a fire service attends a building, localised generation still produces current unless stopped from operating. Wind turbines are designed to depower by "feathering" the blades so the force of wind upon them is minimised, and the blades then allowed to freely rotate. Stopping the operation of PV panels is more complicated as the AC power output from the inverter needs to be shut off near the inverter, and then every individual panel circuit needs to be shut down. Even when the panel circuit is broken the panels will be energised if there is short circuit across them and there is incident light upon them. The panels should be capable of being isolated from the fire service access point to the building, unlike the photovoltaic panel fire on the Target store in Bakersfield California, on April 5, 2009 where the only way to isolate the panels was to open 56 fuses in the combiner box on the roof (http://nfpa.typepad.com/files/target-fire-report-09apr29.pdf).

A storage area for recyclables must be managed well to prevent ignitions and though should be given to fire rating this area. If materials placed there are not controlled, there is some potential for reactive substances to be stored together with potential for ignition and then rapid fire spread through combustible recyclables.

EXPERT RANKING

As there is little experience and literature in regard to the real fire safety hazard of sustainable building features, an expert panel of fire engineers was formed to assess the fire safety hazard, risk and state of the art in potential mitigation measures for sustainable building features. An invitation was distributed

by the Society of Fire Protection Engineers New Zealand Chapter and five fire engineers took part in the panel. This panel were sent questionnaires and then interviewed in person. The purpose of this type of research is not to find average responses but to form a consensus on the issues. A panel of five is sufficient to identify most issues, with increasing the panel size above this of little or no significant benefit (Turner, Lewis, & Nielsen 2006). The panel of experts provided a background to the issues that were faced in their experience and provided opinions or suggestions to eliminate, avoid, and manage risks as follows:-.

1. Identifying features' issues concerning fire safety.
2. Identifying mitigation measures for the fire safety issues identified
3. Rating and ranking the fire risk severity level of the features, taking into account both (1) and (2).

A table of the common features identified in the review of NZGBC buildings was given to the panel to rate and rank fire safety. The fire safety concerns were subdivided into the categories from the requirements of the New Zealand Building Code Clauses C2 – C6, that is:-

C2 Prevention of fire occurring
C3 Fire affecting areas beyond the fire source
C4 Movement to place of safety
C5 Access and safety for firefighting operations
C6 Structural stability (during fire)

The fire engineers were asked to rate and rank the top five features that are considered as a high risk and questions were asked according to their choice. The interviews were analysed using the grounded theory method which includes three stages of analysis:

1. Open coding.

Open coding is a process of constant comparison, memoing, categories, sub-categories, and themes. The transcripts are broken to sentences, categories and paragraphs which then are collected and sorted under different categories. At this stage, all data are initially examined and no extraneous information is removed to allow the analyst to spot patterns. The main categories are identified through their densities of information which are referred to as 'core categories' (Jones & Alony, 2011).

2. Selective coding.

Selective coding is more thorough and produces denser results than open coding although it follows the same process, but the process is more refined. Further, at this stage extraneous information is removed and information that explains the concepts and core categories are kept (Jones & Alony, 2011).

3. Theoretical coding.

Theoretical coding is sorting the categories with reference to the literature. This stage is putting the fractured information back together to allow a coherent flow of concepts and ideas. Then it allows the researcher to compare, contrast, and make connections to the literature regarding the theories and their justifications (Jones & Alony, 2011).

RESULTS

A scoring system was established to determine which feature had the most impact on life safety according to the expert panel with the results for the five worst ranked features in terms of fire safety shown in Table 2. One of the panel declined to rank the features so only four individual results are shown.

The ranking is due to the summation of the individual ranking from each member of the panel. The features that are ranked as 1 are the worst, the number attributed to it was 5, 2 is 4, 3 is 3, 4 is 2, and 5 is 1. This means that if atrium was ranked 1 twice, 2 once then it was calculated as 2X5+1X4=14. The same scoring system was used to find the highest score meaning the worst perceived risk. DSF had

the highest risk score, closely followed by atria and storage areas for recyclables. The panel believed that mitigation measures for atria, and storage of recyclables are well understood and readily implemented. There are potential fire safety issues and with double skin facades that are poorly researched and understood, as are potential mitigation measures, so it was decided to investigate double skin facades further.

Table 2: Questionnaire results.

Individual Ranking	Features				Overall Ranking	Top 5 Features	Score
	Expert 1	Expert 2	Expert 3	Expert 4			
1	Atrium	Atrium	Recyclables Storage	DSF	1	DSF	15
2	DSF	Recyclables Storage	Variable Air Volume	Atrium	2	Atrium	14
3	Recyclable Materials	Recyclable Materials	DSF	DSF	3	Recyclables Storage	13
4	Recyclables Storage	Recyclable Materials	Green Roof	Recyclables Storage	4	Materials	8
5	Variable Air Volume	Variable Air Volume	Rain Water Harvesting	PV Panels	5	VAV	4

The main concern with DSF was smoke and fire spread through the cavity, with the main mitigation measure being closing of the internal vents in the event of fire. If the system does not close due to failure of the alarm signal through to the BMS (Building Management System), failure of the BMS to close the vents, or other failure such as that due to fire damage of the circuits or vents themselves, then smoke spreads to other floors and fire can spread to floors above. It was mentioned by a member of the panel, that with smoke spreading though the DSF it may be harder for the Fire Service to locate the seat of the fire, but another panel member stated “access for fire-fighting is positive” because there will be less smoke spread compared to an atrium.

Most of the panel mentioned that installing smoke extract would eliminate the risk of smoke spreading because the smoke is buoyant and the facade area is small. Hence, smoke extraction is effective and ensuring the cavity closes off in the event of fire would keep the fire and smoke trapped in the area of origin; further, the panel also mentioned that DSF is similar to atrium and it should be dealt with the same way in terms of risk and mitigation measures.

DOUBLE SKIN FACADES

Previous Research

Chow, Hung, Geo, Zou & Dong (2007) carried out full scale fire tests on double skin facades and determined that the width of the cavity is critical, as in narrower cavities the smoke adhered to the inner glass wall. Chow & Hung (2006) concluded that tempered glass would give more protection and a vertical spandrel of 900m m or more extending downwards from the floor would be beneficial. Deng, Hasemi and Yamada (2005) found in a model and CFD study that smoke would not enter a building if a DSF was vented in such a way that the cavity was at a lower pressure than the inside of the building, and so the DSF could be used for smoke control.

Double Skin Façade Fire Performance Simulation

Seven out of the 50 green buildings in the sample contained either or both atria and double skin facade. The floor area and number of levels of these varied significantly, so gave little guidance on the appropriate scale for a prototype building to model in the Fire Dynamics Simulator program FDS (http://www.nist.gov/el/fire_research/fds_smokeview.cfm) . Two sizes of building were modelled,

60m by 60m and 30m by 30m, both with 3 levels. The inter-storey height is 3.0m, with a floor to ceiling height of 2.7m. The DSF connects the 3 floors on one external wall. Buildings with a DSF and atrium were not modelled, as this was outside the scope of this study. The smaller size building was used for most analysis, as the time required to run the simulation was significantly less, and any problems with smoke control will be more severe with a smaller building with less space for smoke to accumulate at the top of the DSF (Figure 1).. The larger building is of such a size that automatic sprinklers would almost certainly be installed, so running scenarios without sprinklers is more realistic in the smaller building. Multiple scenarios were applied to the small model and then the worst and best case scenarios were modelled in the large building to compare the effect of building size.

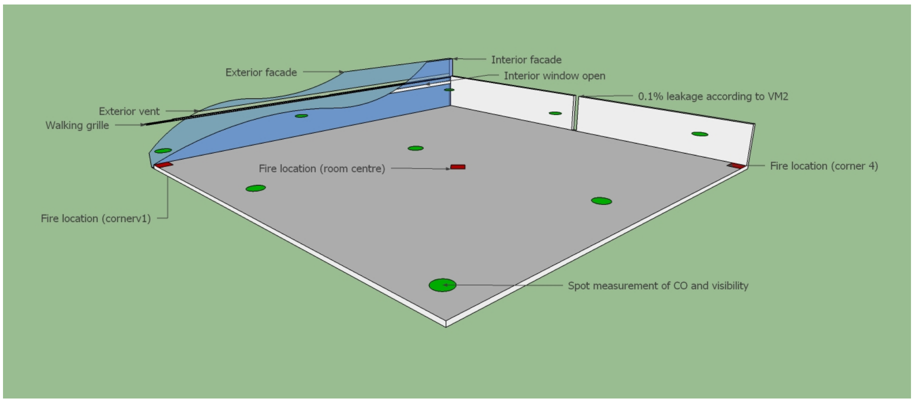

Figure 1. Model layout (one floor only shown)

The mesh size used was 0.5m for all simulations which is suitable for the characteristic diameter of a fire being at least 4 times the cell width (McGratten et al, 2007, p29-30). As DSF have structure to support the facade inside them, and frequently floors with grates for maintenance access and other impediments, the flow of smoke may be impeded. These obstructions are modelled in FDS as 0.5m by 0.5m horizontal barriers to fit the FDS grid every 2.0m along the DSF and offset from floor level to floor level to mimic as best as reasonably possible the hit and miss nature of these obstructions.

Fires were located in the centre of the room, in a corner next to the DSF (corner 1), and in a corner on the opposite side of the building to the DSF (corner 4), as shown in figure 1.

Spot measurements of visibility and carbon monoxide are recorded at 2.0m above each floor level, near the corners, hallway along the sides, and in the centre of the building as shown in figure 1. The CO level is reported as a fractional equivalent dose (FEDCO), which is a cumulative measure with a FED of 1.0, corresponding to incapacitation of 50% of the population.

DSFs of both 0.5m and 1m width were modelled, with 25% openings to the interior, 12.5% and fully closed. The exterior façade could have vertical openings up the building, and a horizontal opening at the top. These openings were set to be closed or open in various combinations. In some simulations the building has sprinklers installed, in which case the fire is assumed to be controlled and stop growing in size when the sprinklers activate. The various combinations of the above modelled in FDS is shown with the results in Table 3. The fire is a fast growth rate fire, defined as a fire with a growth rate proportional to time squared, reaching 1.055 MW in 150s, with combustion parameters as specified in the New Zealand Building Code document, Framework for Fire Safety Design C/VM2 (MBIE 2013) .

Table 3: Scenarios simulated in FDS and small building results.

Scenario	Smoke Detection	Sprinkler	Fire Location(1)	Interior facade open area (%)	Exterior facade open	Top vent open	Cavity width (m)	Level 1 Time to: FED$_{CO}$ ≥0.3	Level 1 Time to: visibility <10m	Level 2 Time to: FED$_{CO}$ ≥0.3	Level 2 Time to: visibility <10m	Level 3 Time to: FED$_{CO}$ ≥0.3	Level 3 Time to: visibility <10m
Base	√	X	C	25	X	X	0.5	≥900	36	≥900	314	≥900	201
1	√	X	1	25	X	X	0.5	50	48	≥900	93	≥900	65
2	√	X	4	25	X	X	0.5	517	30	≥900	320	≥900	166
3	X	√	C	25	X	X	0.5	≥900	149	≥900	469	≥900	356
4	√	X	C	0	X	X	0.5	≥900	35	≥900	≥900	≥900	≥900
5	√	X	C	12.5	X	X	0.5	≥900	33	≥900	397	≥900	284
6	√	X	C	25	√	X	0.5	≥900	34	≥900	436	≥900	291
7	√	X	C	25	X	√	0.5	≥900	33	≥900	324	≥900	869
8	√	X	C	25	X	X	1	≥900	36	≥900	328	≥900	230
9	√	X	C	25	X	√	1	≥900	34	≥900	708	≥900	≥900
10	√	X	C	25(2)	X	√	0.5	≥900	34	≥900	900	≥900	≥900
11	√	X	C	25(2)	X	√	1	≥900	38	≥900	900	≥900	≥900
12	√	X	C	25	√	√	0.5	≥900	34	≥900	410	≥900	≥900
13	X	√	C	25	√	√	0.5	≥900	145	≥900	560	≥900	≥900

1. C for centre, 1 for corner 1 and 4 for corner 4.
2. Openings on ground floor only

The criterion for FEDCO is 0.3 respectively. The visibility criterion is a minimum of 10m visibility at 2.0m above floor level. These are as specified in the New Zealand Building Code document, Framework for Fire Safety Design C/VM2 (MBIE 2013). As is expected in a large space, the temperature rise, away from the fire was small and did not affect tenability.

FDS Results

The results of the scenarios for the small building are shown below in table 4 and the results for the large models are shown in table 5.

The results show that the FEDCO criterion is not reached except when the fire location is at the corner then CO is exceeded at only one point near the fire. However, visibility limits were reached in all scenarios, but differed in terms of the time taken for the visibility to drop below 10m. In scenarios 4, 10 and 11 where the internal vents were closed on the fire floor, no smoke spread to the upper levels. When all exterior vents were open (scenario 12), no smoke spread to the upper levels, despite the interior vents being fully open, so all the smoke generated has spilled to the outside, a result consistent with Deng, Hasemi and Yamada (2005). Doubling the width of the facade, slightly decreased the tenability time in upper floors with the external vents closed (scenario 8 compared with base scenario), however with the top vents open it dramatically reduced the tenability time (7 vs 9), this doesn't seem right – need to check data. Opening the top vents or half closing the interior vents results in a moderate improvement in the tenability time (scenario 5 and 6). Installing sprinklers increased the

tenability time on the top floor from about 200 to 360s, which is about the time that would be required to evacuate the floor.

Table 4: LargeBuilding Results

Scenario	Level 1		Level 2		Level 3	
	Time to FED_{CO} ≥0.3	Time to visibility <10m	Time to FED_{CO} ≥0.3	Time to visibility <10m	Time to FED_{CO} ≥0.3	Time to visibility <10m
1	396	673	≥900	709	≥900	687
11	601	285	≥900	≥900	≥900	≥900

The larger building is fitted with sprinklers, so the best comparison is large building scenario 1 with small building scenario 3. The larger building has about double the tenability time which simply reflects the larger size of the smoke reservoir compared to the smaller building.

The literature review raised the issue of glazing breaking under high temperatures, but temperatures found in the FDS were not high enough for this to occur. However, if a fire is close enough to the glazing for flames to impinge upon it, localised breakage will occur. If the flames then impinge upon the interior glazing on the next level, glazing on the upper level may also break. Counter-intuitively, this may be more likely to occur with a wider cavity where the smoke is more likely to impinge on the internal glazing (Chow et al, 2007).

Chow et al (2006) did not mention any mitigation measures that would reduce the impact of the DSF on the building, except for the use of tempered glazing and using small sheets of glazing to reduce the risk of glass breaking. Closing of the interior vents is an obvious mitigation measure, and one stated by the panel, but this relies on the vent closing system working and the glazing not being damaged by fire. Other options are to pressurise the DSF, but this is impractical, as the vent area is large, or to mechanically extract from the DSF. As this analysis and Deng et al (2005) have shown, with large amounts of external vents, the DSF will be at a lower pressure than the rest of the building and smoke will flow into the DSF and hence to the outside, so the addition of mechanical extract is unlikely to be warranted.

Recommendations for DSF

The simplest way to prevent smoke spread is to prevent smoke getting into the DSF by closing the internal vents. It is prudent to design for the situation where these vents fail to close. It is also prudent to assume that the vents fail to close if the glazing fails due to flame impingement. The simulation results suggest therefore that prudent design will also provide either 1) sufficient external vents, at the top and external side of the DSF so that smoke will travel from the interior of the building and into the DSF and thence to the outside; or 2) sprinklers should be installed throughout the building, and analysis confirm that the tenability time on the upper floors exceeds the time taken to evacuate those respective floors. This type of analysis may not be accepted in jurisdictions were performance based fire safety design is discourage or prohibited.

Although buildings with both atria and DSF have not been modelled, and the behaviour of smoke will be significantly more complex, an appropriate design approach may be to use the DSF for supply air, and extracting smoke from the atrium, which is likely to have a larger smoke reservoir than the DSF.

CONCLUSION

An analysis of common sustainable building features in 50 buildings in New Zealand found that sustainable and recyclable materials and rainwater harvesting were used in all buildings surveyed.

Systems to reduce energy usage by mechanical ventilation systems and atria were found in about two-fifths of those buildings. Distributed power generation, green roofs and dedicated storage areas for recyclables were less common. The fire safety issues from most of these can be readily addressed. Ventilation systems that reduce energy use tend to reduce airflow between spaces in a building and therefore are likely to have positive benefits in terms of reducing flow of smoke. Ventilation systems with a high degree of local control may be interfaced with the fire alarm system and programmed to further reduce smoke spread in the event of fire. Passive ventilation systems may also be designed to be used as smoke control systems.

From these common sustainable features, an expert panel ranked double skin facades (DSF) as the biggest risk in terms of fire, slightly ahead of atria and storage areas for recyclables. As potential mitigation measures for DSF are less well understood these were investigated further using a computational fluid dynamics (CFD) model, Fire Dynamics Simulator (FDS). Several strategies were found to be successful in minimising smoke spread:

- closing the internal vents,
- providing sufficient external vents, that smoke flow is to the outside, and
- installing sprinklers throughout the building.

For a robust design, it is recommended at least two of these three options is utilised along with a performance based design fire safety design to demonstrate their adequacy in each individual building design.

In the future more buildings will be built with sustainable features and some of these features have fire safety issues which need to be addressed. Most fire safety issues are obvious as are methods to mitigate the risk, and some of these features will, or can be used to, improve fire safety

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OVERCOMING THE BARRIERS TO CONSTRUCTION PRODUCTIVITY

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ABSTRACT

To achieve real change in construction productivity will require significant changes in the construction sector. The need for changes is currently being stimulated by the government's need to increase productivity and affordability.

There are a number of barriers to lifting productivity in the New Zealand construction sector spanning from system wide to individual project level. The focus on a 'silver bullet' has produced systemic failure in the past. A new perspective for addressing productivity is needed. The premise of this research was that overall the sector knows the barriers and the solutions to improve productivity. However, no single person has the full perspective; hence an approach that sought to integrate the various perspectives would produce a more robust result than a search for a panacea.

A recent study involving over 150 participants from across the construction sector from design to demolition aimed to find the points in the construction life cycle that can make significant differences to productivity. An integrated series of actions that can potentially achieve those desired changes was devised. Implementation of these actions will have a significant effect to overcome the barriers to construction productivity.

This paper considers the barriers and provides recommendations an integrated course of action.

KEYWORDS:

Construction productivity; life cycle; productivity barriers; systemic approach.

INTRODUCTION

The New Zealand construction sector represents a significant portion of the economy. The sector is the fifth largest employing over 157,000 FTEs, which represents 8% of the employed. A further 42,000 FTEs are employed in construction related services giving the sector 10% of New Zealand's employment. In the past 10 years, the construction sector generated 14% of all new employment. The sector is dominated by small businesses. While generating 4% of national GDP, it accounts for 10% of all businesses (PWC, 2011).

The nature of the building sector is characterised by:

- complexity – many actors with multiple dynamic relationships and different drivers;
- multiple stakeholders trying to account at project, company, local and central government level;
- conflict over desired outcomes, the means to achieve them and power relationships that make change difficult;
- uncertainty about possible effects of action;
- data that is often uncertain or missing;
- political, economic and social constraints;
- numerous possible intervention points; and
- a great resistance to change.

With a focus to improve productivity, the Productivity Partnership defined productivity in terms of (Kane, 2012):

- Inputs and outputs;
- Value;
- Procurement efficiency;
- Increased standardisation;
- Whole of life;
- Skills development; and
- Technology and innovation change.

To achieve change in such a complex sector needed an approach that took account of the nature of the building sector. A systemic approach is just such a method.

METHOD

The overall purpose of the project was to evaluate the life cycle of buildings to determine potential productivity increase leverage points. A full life cycle was chosen because productivity information provided from the post-construction phase was considered valuable for productivity improvements in the construction phase.

The key issues for the project were derived from the Research Action Plan (Building and Construction Productivity Partnership, 2012) and were to:

- understand how interviewees defined productivity;
- understand the key components relevant to productivity of how the New Zealand construction sector interacts through the life cycle of a building;
- understand the key interactions and influences across the industry related to productivity;
- identify the loops that provide feedback to, and critically influence, the construction system; and
- identify the critical intervention points across the life cycle of a building to maximise the productivity gains.

Forty-one key people (with over 600 years of experience between them) from across the sector and the life cycle of a building were interviewed to determine answers to the issues outlined above. The interviews produced 484 factors affecting productivity. These factors were amalgamated together to 123 with 705 links between them. Information on causes of actions, potential intervention points showed where interventions can potentially affect the system under study. The process encompassed all stages of the building life cycle as shown in Figure 1.

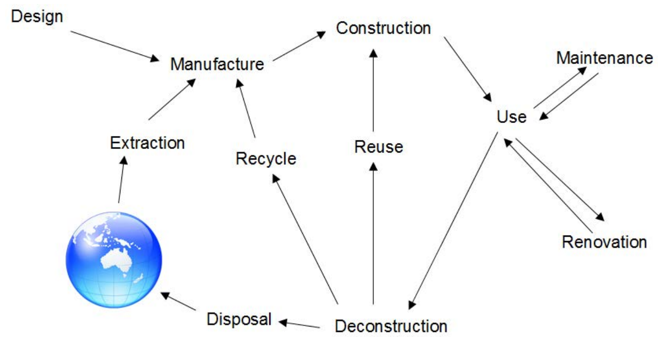

Figure 1: A basic life cycle of a building (Adapted from SETAC, 1991)

A series of workshops in Auckland, Rotorua, Wellington and Christchurch for key stakeholders from across the life cycle interacted and discussed the relationships between the factors and provided amendments to better reflect the actual situations.

Analysis of the number of connections produced a numerical hierarchy for potential nodal points. A second set of workshops considered those nodal points that had the greatest numbers of causes and effects. Participants then identified interventions that would provide the greatest potential leverage for the effort expended. The potential levers were considered in the light of the effectiveness of the operation of a system.

Following the workshops an action plan was produced showing the way forward.

RESULTS

Productivity

Interviewees for the project produced ninety concepts that were divided into four categories as summarised in Table 1.

Table 1: Productivity categories

Category	Concepts
Process	Inputs; outputs; labour; timelines; supply systems; centralisation.
Quality	Training; needs; effectiveness; value; workmanship; materials.
Affordability	Efficiency; income (for the customer and the building team); living well (for the customer and the building team).
Sustainability	Whole of life; lean manufacturing; lean construction; waste minimisation; feedback systems; boom-bust absence.

Past consideration of the four categories as unique entities results in a breakdown in the system. This is a weak productivity model where emphasis on one category results in neglect of the other categories, sometimes with disastrous consequences. The 1990 reforms were focused on the process category and this did have some spin off into the affordability category. However, lack of consideration of the other two categories resulted in low quality, unsustainable buildings (Hunn, Bond and Kernohan, 2002).

For long term productivity improvements, productivity needs to be framed in terms of all the categories in Table 1. For this to happen, productivity increases in processes need to use quality materials and workmanship, in a manner that is affordable for both the client and contactor and sustainable for a nominated time (50 years unless specified). This strong productivity model will produce the best long term results.

Key Barriers

The study produced 10 key barriers to increasing productivity (in alphabetical order):

- *Appropriate building design*. This is design that meets the requirements of the building code (as a minimum) as well as the needs of the owners *and* occupiers throughout the lifetime of a

building. Appropriate design is principally influenced by the customer, the architect and the engineer producing an affordable package in the construction phase. In addition, the design is applicable to the operational phase;

- *Build cost.* The build cost is the item that is most often focused on, but this research has shown it is the result of many contributors. Hence, build cost in itself is not a good discriminator of productivity. For example, a major focus in the 1990s was on build cost reduction, which had many unforeseen flow-on effects including systemic failure (Hunn, Bond and Kernohan, 2002);
- *Customer affordability*. Customer affordability is the ability of the customer to support the cost of the building they own. Customer affordability is influenced by finances, design and regulation. Financial costs can be front-loaded through the use of low maintenance, quality materials and processes. Alternately the costs can be spread through the life cycle of a building by using cheapest, quickest building practices. These practices reduce the upfront cost but increase maintenance and renovation costs. With interest rates at historic lows, the cost of borrowing money is unlikely to become cheaper and hence solutions to customer affordability need to be more creative than lowering interest rates;
- *Design, build and trade skills*. The skills include trades, professions and management. Development of skills takes place at all stages and experience levels of the sector. A major driver for skills acquisition comes from building activity. As activity increases the level of training also increases. As building activity increases so does the level of on-the-job training away from full time tertiary education. Training over the last couple of decades has been compartmentalised – training in particular concepts or skills which do not consider how the broader system operates. This was seen as one of the contributors to the weathertight homes issue (Hunn, Bond and Kernohan, 2002). Continuing professional development is crucial to increasing work standards on building sites. Experienced professionals considered that the current Licensed Building Practitioner scheme set the bar too low and still enabled too many unqualified people to be able to work on building sites;
- *Financial risk*. Every building project has some degree of financial risk, some of which may not be evident at the outset of the project. Financial risk has the greatest influences during the initial land development stage and the building process. External influences can play a significant role in the levels of financial risk. For example, the standard of living, market competition and even the level of imported components can have influences on the financial risk of a project. Macro influences such as the boom-bust cycles produce a greater risk profile to the industry as the strain on companies causes them to default on financial arrangements (Allan et al., 2008) which has been evident in the post-Global Financial Crisis period (e.g. collapses of Brookfield Multiplex (Underhill, 2013) and Mainzeal (Kiernan, 2013));
- *Liability*. This incorporates the client's responsibility, health and safety issues and contractors' responsibility In the building sector the concept of 'joint and several' has diluted the level of individual responsibility on the work site and increased the responsibility of BCAs as they are traditionally the 'last man standing' with the greatest access to finance;
- *Operational adaptability*. This is the capacity to change to meet the changing needs of building occupiers and owners during the use phase of a building life cycle. Adaptability incorporates the influences from the design and construction phase, the financial drivers and obsolescence. Page (2012) calculated that the cost of incorporating adaptability in the design phase that affects lifetime usability for house owners added an extra 0.04% of a typical house-land package at the new build stage. To incorporate these same features at retrofit stage would cost 14 times higher (based on new build costs);
- *Operational efficiency*. Operational efficiency is the effectiveness of the building for productivity in its use phase. It incorporates the costs of running the building, the occupancy levels and the health and efficiency of the occupants;
- *Standardisation*. Standardisation includes both design and work practices. There is a lack of systems thinking by those in the sector in knowing what combinations could be used together. There is no cost incentive to move to standardisation and the size and shape of the industry did not enhance adoption of standardised approaches; and

- *Work planning*. Work planning involves planning the process before it happens and coordinating the various actors involved. Planning is very much a people management activity. It encourages people to work more independently and enables them to become more productive as they are able to work on their own but are aware of what is happening on the site that could affect their work. Good work planning enhances the design, build and client team collaboration and thus the buildability of the building.

Actions

Actions to achieve change can vary greatly from people spontaneously adopting change (e.g. Mediterranean-style housing in the 1990s) to data collection (e.g. build time for housing). In general, those actions that encourage people to want to make a change are more effective than those that are imposed or just provide data.

This research has uncovered a number of actions that can assist in moving the industry to becoming more productive and thus make new buildings more affordable. The top eight for use in an integrated package are considered below.

1. *Literacy and numeracy*. The key to competent practitioners starts with good literacy and numeracy skills. The research also noted that poor literacy and numeracy was not only in reference to the trades' area, but to the professions as well. The building sector tends to attract people who are more visual learners than the more abstract literacy and numeracy learning so the need for methods of developing literacy and numeracy skills through visual learning techniques are needed.
2. *Management Capability*. This builds on business skills and builds to a development pathway – a reinforcing loop that improves the quality of work, career development and informed decision-making. A result of this approach is that more informed decision-making opened the way to improved design, building and trade skills.
3. *Building Activity*. Information about the future work stream is necessary to provide confidence to the sector. While on its own it is not step-changing, in combination with the previous two actions, long term building activity provides useful information for industry people to evaluate career opportunities.
4. *Customer Education*. Education provides a good grounding for the processes at the beginning of the life cycle – customer affordability, build cost, standardisation and appropriate building design. Customers become aware of their responsibilities throughout the life cycle of a building and methods to discharge those responsibilities at the time of purchase. This applies to existing as well as new buildings. Education enables the customer to engage knowledgeably at the design stage when the most crucial decisions are made.
5. *Life Cycle Impacts*. Customers and builders are able to consider the long term environmental, social and economic effects of their actions at the commencement of the life cycle. Life cycle impacts provide a more comprehensive measure of the real costs when comparing indigenous and imported components. Research has shown that the cost of maintenance and operations of a building is 5 – 10 times the design and construction cost (John *et al.*, 2004).
6. *Refurbishment Intervals*. This maintains the quality of the building. Long refurbishment intervals lower the standard of living and thus when it is done, the costs are considerably larger than if performed at suggested intervals.
7. *Alternative Financial Products*. This develops different ways of addressing the affordability issue. To improve affordability a package of sustainable solutions is needed. For example, this could include changing customer expectations from getting the best house in the best street as their first house to adopting a retirement home type model of 'license to occupy'.
8. *Liability*. Increasing liability costs are passed on to the customer and unclear liability costs (e.g. joint and several) are passed on by all who could be implicated. This snowball effect creates increased costs. An increase in individual liability would result in greater workmanship quality which then flows onto lower maintenance and rework.

CONCLUSION

A narrow view of productivity that considers just processes is not helpful to raise productivity significantly. Instead, a view that considers processes that use quality materials to do quality workmanship in a way that is affordable to the industry and the customer and will stand the test of time is advocated to achieve a sustainable increase in productivity.

It is tempting to cherry pick or just ‘do something’ that will make a difference. However, this sort of approach will not achieve the step change that industry and government are looking for. However, by taking a long term view with a set of intervening steps will achieve a better outcome for the customer, the industry and the government.

ACKNOWLEDGEMENTS

This project was funded by BRANZ from the Building Research Levy and Scion from Core Funding. It was commissioned by the Building and Construction Productivity Partnership

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ENHANCEMENT OF PRE-CONSTRUCTION STAGE THROUGH LEAN THINKING AND ITS IMPACT ON ENVIRONMENTAL PERFORMANCE

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ABSTRACT

Construction projects consist of two distinguished phases of work, which are the pre-construction and construction. Pre-construction phase involves processes and decisions made prior to contractor's involvement, with activities such as procurement and design development. The fragmented nature of construction creates inefficient information and knowledge flow at the pre-construction stage that may affect the downstream works. Designs that are produced without contractor's involvement may create waste in terms of designs that do not fit the constructability aspect during construction. Subsequent design changes will have negative consequences on cost, time and quality as well as the environment. Advanced performance improvement efforts such as lean thinking have always emphasised more on enhancing the production aspect of a project instead of pre-construction. Pre-construction inefficiencies have been side-lined due to its less tangible, lower cost and non-material nature of processes. This research aims to enhance the performance of the pre-construction stage through the implementation of lean thinking. A lean based methodology is proposed to identify production inefficiencies at the pre-construction stage that may also have adverse impact on the environment at the construction stage. The outcome of this research will be beneficial to the construction industry as the methodology proposed could be used to improve the production performance of pre-construction processes, consequently reducing the impact on the environment.

KEYWORDS:

Lean thinking; production waste; environmental sustainability; pre-construction; modified lean tools.

INTRODUCTION

Lean thinking

Lean thinking is a management philosophy that originated from the Toyota Production System (TPS). The focus of lean thinking is to deliver value to customers through five principles (Womack & Jones 1996), given as follows:

- to precisely specify value by specific product (value)
- to identify value stream for each product (value stream)
- to make value flow without interruption (flow)
- to let customer pull value from product (pull)
- to pursue perfection (perfection)

Value is one of the important concepts and most commonly used terms in lean thinking. The definition of value is being defined by the customer, consequently unveiling the importance of recognising customers for the product/ services. Activities within a production process should create value that satisfies the relevant customer. Process activities could be categorised into two types, which are Value Added (VA) and Non Value Added (NVA) activities. VA activities are works that convert material and information towards the output required by the customer. On the other hand, NVA activities do not add value to the end product and can further be divided into NVA (necessary) and

NVA (waste) activities. NVA (necessary) are supporting activities such as inspection and maintenance that do not create the product but are necessary to ensure the smooth flow of processes. NVA (waste) are activities that are essential to be identified and eliminated. The seven types of waste commonly found in production are 1) Overproduction; 2) Waiting; 3) Transportation; 4) Over processing; 5) Inventory; 6) Movement; and 7) Defect (Ohno, 1988) with the addition of unutilised resources/ talents by Bodek (2007). Those wastes could be reduced and eliminated through the application of lean thinking by adhering to its principles and with the support of lean tools (Sayer & Williams 2007).

Causes of pre-construction waste

Lean thinking has been applied across different sectors due to its versatility and benefits. In the construction industry, the lean concept has been improved and seamlessly integrated with current construction management practices and termed as lean construction. From the lean stand point, common construction is laden with waste activities (Polat & Ballard 2004). Construction waste occurs throughout the different stages of a project with a considerable amount generated at the pre-construction phase (Osmani et al. 2008; Ebinger et al. 2006). For the purpose of this research, the pre-construction phase is referred to as processes and decisions made prior to construction or the involvement of contractors (Juzefyk 2012). Pre-construction waste could origin from different areas of works such as contractual, design and procurement (Osmani et al. 2008). Tzortzopoulos & Formoso (1999) factored the problems at design stage as poor communication, inadequate documentation, deficient input information, lack of co-ordination between disciplines and unreliable decision making. Besides that, the lack of construction knowledge during the design stage also contributes to waste (Chandrakanthi et al. 2002). Nonetheless, it is challenging to recognise waste at the design stage as the definition of value generation at this stage also depends on the qualification level of the design team besides the common production processes. Skills, expertise, reputation and intellectual property are sources of intangible resources that could not be measured (Ebinger et al. 2006). Therefore, the meaning of waste should be well defined in order to have the most appropriate tools for process improvement. Besides design, conventional procurement system such as Design-Bid-Build (DBB) has also been recognised to cause long duration, minimal opportunity for collaborated problem solving and inability to view design and construction as whole due to its fragmented nature. In general, the complexity of the pre-construction phase that involves different works with different players has direct and indirect influence on waste increment (Keys et al. 2000).

Impacts of pre-construction waste

The impacts of an inefficient pre-construction stage can be simplified and represented in Fig. 1. Pre-construction waste may range from production inefficiencies as well as lack in tacit knowledge and experience. Pre-construction deficiencies may have direct impact that takes place during the stage itself and indirect impact that occurs down the line, especially during the construction phase (Murnane et al. 2006). Direct impact could be associated with delays in time and escalating cost during the current stage while indirect impact may include time delay, cost overrun, undermined quality as well as damage to the environment at the next stage of work. Nonetheless, indirect impact has commonly being overlooked of its existence because it is often viewed as during construction problem and responsibilities are being shifted to other parties such as contractors, sub-contractors and supplies. This perspective of problem recognition overshadows the origins of the problem and the proposed solution may not eliminate the issue after all. As an example, time delay at the pre-construction stage may extend the time contractors could start work and at the same time, client may have spent cost for non-physical development. It is relatively easier to link inefficient pre-construction activities to indirect impact it has on production values (time and cost), as compared to intangible values such as the environment. However, Miller et al. (2009) claimed that the fragmented nature of pre-construction stage hinders contractors' input that impedes innovation, constructability and creates an adversarial condition for environmental sustainability. Researches recognised that elements of cooperation (Seuring and Muller 2008), information sharing (Kainuma and Tawara 2006), timing of participants' involvement, goal alignment (Lapinski et al. 2006) and owner type (Li et al. 2011) are crucial in

achieving environmentally sustainable project outcome. Therefore, a new perspective in viewing the inefficiencies at the pre-construction stage should be instilled in order to reduce and eliminate both the direct and indirect impacts of the works.

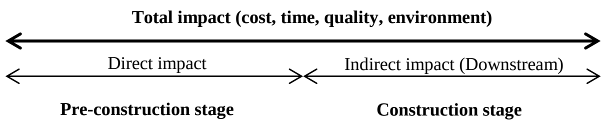

Fig. 1 Impact of pre-construction stage inefficiencies

Proposed pre-construction stage improvement using lean based methodology

Lean thinking has been commonly applied to improve the production processes at the construction stage as compared to the pre-construction stage. The reason may be due to the characteristics of construction that involves a more tangible flow of material, information and bigger budget allocation that disguises the importance of the pre-construction stage in terms of the whole project performance (Austin et al. 1994). Besides lean, other efforts conceived to improve the pre-construction stage involves mostly the improvement of the procurement system through relational contracting that fails to recognise the inefficient processes within the system. A mere change to a more collaborative environment does not recognise the core waste and inhibit the elimination of the root problem. In order to improve the entire aspect of waste at the pre-construction stage, the stage should be viewed as a whole to determine the origins of the inefficiencies. Therefore, it is essential to view the processes through the lean perspective in order to improve its performance using lean philosophy.

This research aims to provide a systematic lean based methodology to improve the pre-construction stage, both in terms of production as well as the environment. The proposed lean methodology will be based on the identification of waste at the pre-construction stage, focusing on the Resource Consent (RC) acquirement process. This exploratory and conceptual paper is part of a long term study that involves the application of lean thinking to improve the production and environmental measures in construction. The proposed step by step lean based approach is conceived to be practical and utilises common construction resources (Gantt chart) with lean tools such as Value Stream Map (VSM) that has been modified to suit the pre-construction stage of work.

THEORETICAL FRAMEWORK

Production vs. Environmental Customer

From a lean perspective, customer definition and determination is crucial when decision is to be made on areas to improve so that the outcome will satisfy customer's needs and value. The common aim of lean is to improve production work processes that involve the three traditional dimensions of cost, time and quality. However, recent concern on the negative impacts of construction on the environment has made the environment an additional measure to the project management triangle. An increasing amount of construction performance measurement and improvement system has included environment as part of a project outcome. The differences between production and environmental aspects from a lean perspective are given in Table 1. Nonetheless, the distinctively different aims of traditional triangle (production) and environmental management system may involve different customers with relatively different set of values and needs. Therefore, a proper balance and mutual benefits of both aspects have to be captured to provide an outcome or value that would be satisfactory to the needs of all customers and stakeholders involved. The environmental aspect should be considered alongside the production processes in order to recognise the impact production may have on the environment.

Table 1 Production vs. environment

		Production	Environment
Lean Core Elements	Customer	Client/ Developer	Community, local authorities
	Value	Min. Cost, Min. time, Max. quality	Min damage to the environment
	Waste	Activities that consume resources but provide no value to the customer. The 8 production waste.	Polluted/ excessive emission (air, water) to the environment.

Lean methodology for improvement measures

The recognition and establishment of lean differences between production and environment (as shown in Table 1) provides a basis for understanding the possible integration between them. The proposed steps to be followed in aim to improve the performance of the pre-construction stage are given in Figure 2. Each step will be discussed and demonstrated in detail using the Resource Consent (RC) approval process. This research will focus on using the lean methodology to understand and recognise current inefficiencies at the pre-construction stage. The discussion on improvement strategies and future map (Step 7-8) is beyond the scope of this paper.

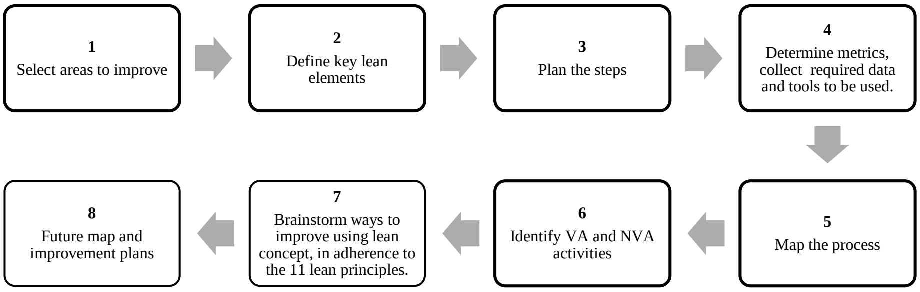

Figure 2 General methodology

1) Select areas to improve

In this paper, the focus of improvement is on the pre-construction stage and the reason to improve this stage has been well discussed in the previous section. The RC approval process is used to demonstrate the application of lean methodology in improving the pre-construction stage due to its relation with both the production and environment. RC has a strong link with the environment as it was established to assist authorities in making sure the activities proposed by the development team does minimal damage to the environment. RC approval process is one of the crucial steps within the pre-construction stage and the complexity of this process is being elevated with the involvement of external parties. Unlike inception or design processes, RC requires the acknowledgement and approval from external stakeholders such as the community and local authorities. The external interferences may cause uncertainties and constraints as well as inspections that may contribute to delays. Hence, this process should be viewed as a production flow in order to identify the root of inefficiencies for improvements to be made through lean thinking (Koskela, 1992).

2) Define key lean elements

After the determination of areas to be improved, the processes are required to be viewed from a lean perspective. Therefore, essential lean elements of the processes need to be ascertained and are shown in Table 2. Client's team may be interested in improving the production rate of this process while the local authorities may have their concern on the environment. Since RC involves different parties, the improvements of this stage of work require mutual understanding and collaborative effort towards

achieving similar aims. In this case, the mutual benefits would be enhancements to the production as well as environmental value.

Table 2 Lean elements for RC process

Process	Output	Customers	Value
RC Acquirement	Approved RC	Client	Fast approval. Minimum cost. Minimum changes.
		Local authorities	Minimum damage to the environment. Minimum rectifications required.

3) Plan the steps

The RC process involves various parties across the pre-construction stage. Therefore, a clear representation of the processes and parties involved should be done at two levels, as follows:

1. High level representation of processes that oversees the entire pre-construction stage. This level highlights the people and timing of involvement besides communication flow across them.
2. Low or detailed level representation of processes that is focused on the RC process.

4) Determine metrics and measurement, data collection and tools to be used

Metrics

In relation to Table 2, metrics could be derived based on the value required by the customers and is shown in Table 3. Even though the interest of client (production) and local authority (environment) are different, some values between them are still similar, resulting in comparable metrics and measurements. Nonetheless, metrics such as prevention measures are unique and valued by the local authorities. Collaboration is also an essential dimension besides the common production values as the fragmentation in construction has proven to cause indirect damage to the environment. Early involvement of contractor enables and eases the use of preventive measures in design and consequently will reduce the negative impact on the environment. Therefore, collaboration is also proposed as an essential element to be measured.

Table 3 Metrics and measurements

Customers	Value	Metrics	Key elements to measure
Client	Fast approval. Minimum cost. Minimum changes.	Time for the process. Changes to original plan. No. of times document returned for changes.	• Time (Concurrent, task duration and start/ stop times). • No. of returns and resubmissions. • Cost for changes to original plan. • Prevention measures applied. • Collaboration (Timing of contractor's involvement)
Local authorities	Minimum damage to the environment. Minimum rectifications. Minimum time.	Time for the process. No. of times application has to be resubmitted. Collaboration Prevention measures applied (Phasing, timing, winter works)	

Data Collection

There are 3 levels of information that can be collected, depending on the level of details required for analysis:

Level 1 - Mapping activities.
Level 2 - Metrics and characteristics of each activity.
Level 3 - Value in activities.

↓ *Harder to collect but enables a more detailed analysis.*

Data can be collected using any method and resources as long as it could provide the input to fulfil the metrics involved for further analysis. Among the easily available resources is construction project's Gantt chart that displays sequence, schedule and dependencies.

Tools

There are varieties of lean and other quality improvement tools that could be used to assist the lean continuous improvement efforts. The selected tools should be capable of representing the processes clearly so that deficient areas could be highlighted, analysed and suggestions for further improvement are appropriate with the identified root problem. In reference to step 3, this research will be represented at higher and lower level of details. At the higher level, modified Gantt chart will be used to represent the processes involving RC at the pre-construction stage. Detailed level RC will be represented using flow chart and subsequently Modified Value Stream Map (MVSM), to represent quantitative and lean details of the processes. In addition to that, other supplementing tool such as the Point system could be used to enrich the usefulness of the model. Brief descriptions of the tools are given as follows:

a) Modified Gantt chart
A modified Gantt chart is used to represent the overall pre-construction stage that involves RC. This tool resembles the common Gantt chart with activities and duration. Additional features included in the modified chart are the representation of parties involved and the link between each activity. The involvement of parties with duration shown could allow the observation for collaboration efforts. The modified Gantt chart could be supplemented with Process-Input-Output table that details each activity. However, the application of Process-Input-Output table is not shown here but could be referred to in Tzortzopoulos and Formoso (1999).

b) Flow chart
Flow chart is drawn at the lower level details to demonstrate activities and its inter-relation to each other in obtaining the RC.

c) Modified Value Stream Map (MVSM)
The MVSM would integrate the environmental matters apart from the production waste that emphasises the view of information flow. Since material flow is not much evident at pre-construction stage as it involves the preparation of information for construction purposes, traditional VSM is modified to suit the current situation. The pre-construction stage, although not having material flow, involves huge information flow that enables better performance during construction. In addition to the common productivity requirement, the addition of environment creates a new dimension to look at, which is collaboration.

d) Point system
Metrics that are not measurable in terms of time or other typical measurements could be represented using a point type indicator as follows:

1 (evident)
0 (non-existence)

The measurement of tacit knowledge and experience applied by engineers in plan and drawings are difficult to be measured in practical, as compared to delay (time), excess budget (cost), and quality (as in specification). Therefore, point system may be used to indicate the subjective nature of measurement, for example environmental efforts applied by designers in the plan. Besides time, point

system could also be used to evaluate and allocate points for activity's value such as -1(waste), 0(NVA) and +1(VA). The accumulated points could paint a large picture of VA and NVA activities within the whole system. However, the nature of those values needs to be defined properly beforehand.

5) Map the process

High level representation of the pre-construction stage is shown in Figure 3 using the Modified Gantt chart. A few obvious deficiencies can immediately be identified from a quick glance through the figure. The observed deficiencies could potentially contribute to both production and environmental waste. In terms of production waste, the sequential nature of processes causes a longer time for project completion. Every milestone across the different activities may have a gate where approval is needed from client or local authority before execution of the next activity. The gate itself could cause delays and consequently escalates the lead time between activities. The figure also relatively portrays a process based on push system whereby work is pushed to the next activity regardless of the availability of the next activity to accept the handed over task. The overloaded activity may cause congestion to the system and causes lengthy waiting period. The portrayal of parties involved within the different activities provides an indication of collaborations that occur within the pre-construction stage. From previous section, collaboration between consultants and contractors has been the key to an environmentally sustainable project. From this figure, it is obvious that contractors are not involved at the early stages of the project, especially environment concerned decision making stages such as design and RC. The timing of contractor's involvement could be seen from timeline y (from preliminary design) and x (from RC). Lack of collaboration between consultant and contractors may pose a high risk to the environment. The unutilised input of contractors coincides with the production waste proposed by Bodek (2007) and consequently enhances the risk of environmental damage.

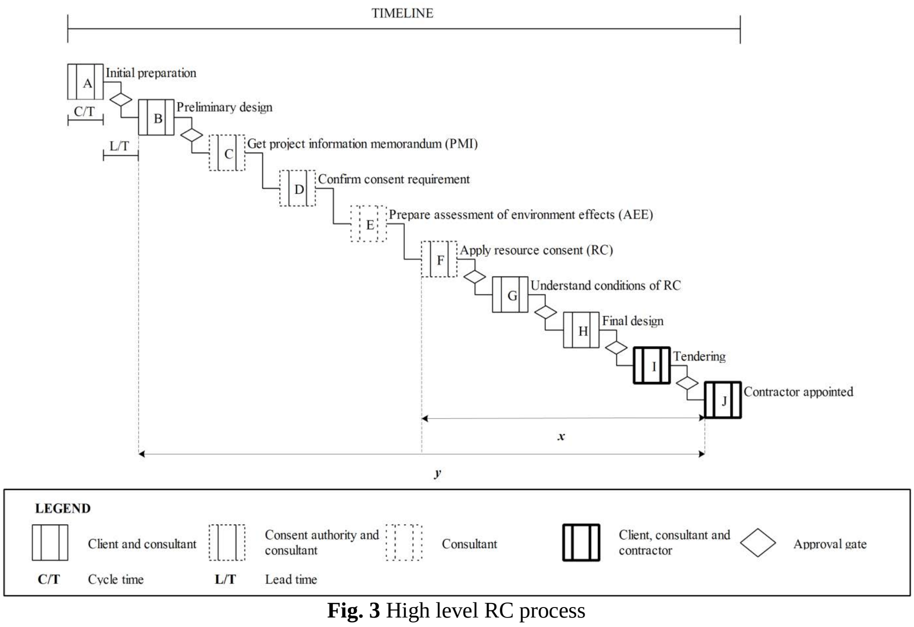

Fig. 3 High level RC process

As the focus of this paper is to improve the RC process within the pre-construction stage, detailed RC flowchart is given in Figure 4. The flow chart is essential to understand the activities involved in the

RC process before current MVSM could be drawn. The Current MVSM will be drawn based on the RC processes for Non-notified cases with no hearings involved.

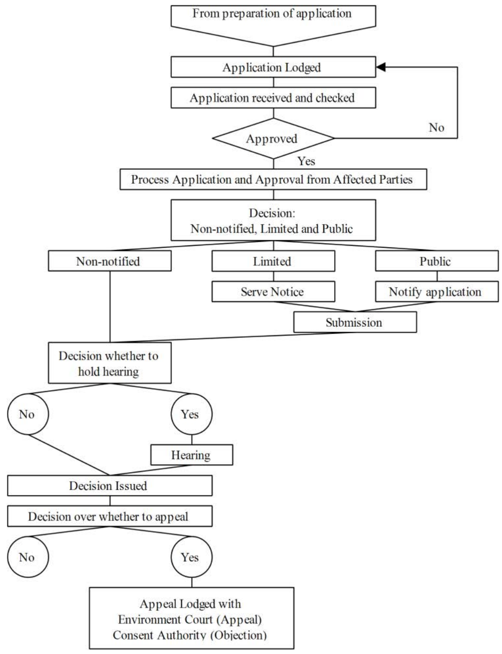

Fig. 4 Detailed RC process flow chart (Adapted from Ministry for the Environment, 2006)

Current MVSM of RC at detailed level is given in Figure 5. The MVSM is slightly different from the common VSM as it maps a transactional process that involves two different customers (client and consent authority) with different aims but requiring the same output, which is the RC acquirement. Therefore, a point of interest should be identified so that the VSM could be modified to suit the requirements of the project. In this case, the metrics that would satisfy both aims were derived and extracted from Table 3. There are some similar (cycle time and lead time) and dissimilar (collaboration, disapproves, returns, prevention measures and cost) measurement aspects across the different processes. Besides that, some aspects could be measured objectively (cycle time, returns and disapprovals) while others (collaboration and prevention measures) are quite abstract and could benefit from the use of the point system. In general, the process involves the flow of RC documents through different parties (consultant-client-consent authority). The flow of processes is based on the push system with lead time in between processes. Since this MVSM does not involve material, the lead time will be associated with queue (Q) of document/ services. From the figure, apparent wastes are observed when RC application is being disapproved or require rework at three different processes. The push based system may also cause queue in between processes that leads to waiting and delays. The delays in processes increase the chances of environmental damage as it creates uncertainty for the proceeding activity of construction, which may have a pre-planned timing of work that considers the environment. A detailed perspective on the possible waste observed within the current MVSM is given in Step 6.

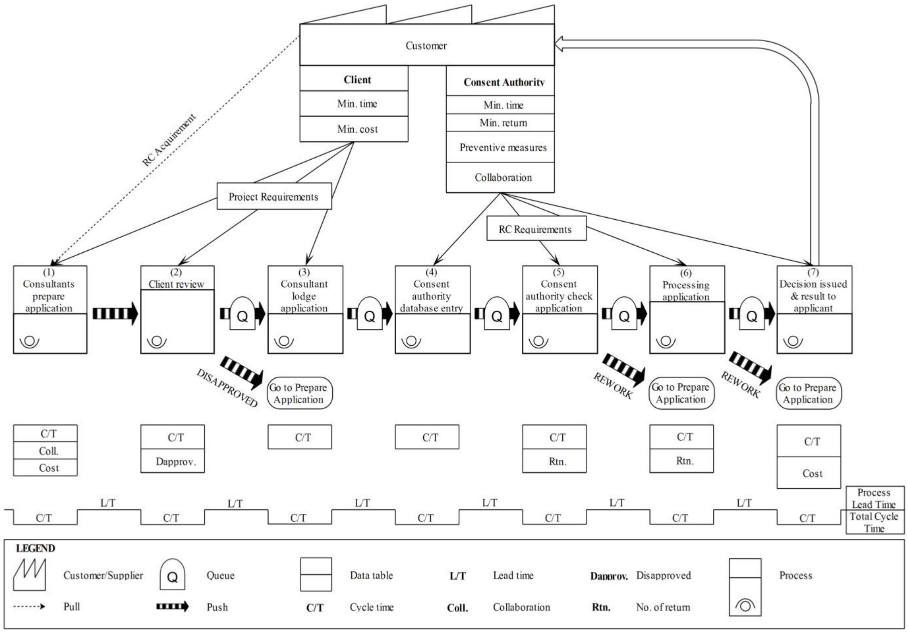

Fig. 5 Current MVSM of RC

6) Identify VA and NVA activities

After mapping, VA and NVA activities could be envisioned for this process of work. The VA processes are commonly the processes given in the process boxes (Box 1-7). However, some of the processes could be integrated such as process 2 and 3. After approval from client's review, the document could be sent off for submission without the need to go through the consultant. Step 4 and 5 can also be done together by the same personnel without going through different personnel and process. In terms of NVA, possible production waste that could be observed within the processes is given in Table 4. . Reasons for the observed waste could be derived based on a lean tool called 5 whys. The 'why' for the waste to occur will be queried for 5 times in order to obtain the root factor. The potential production and environmental impact is also given to highlight the deficiencies it may have on the current and proceeding processes.

Table 4 Waste at pre-construction stage

Production waste	Processes involved	Possible reasons	Production Impact	Environmental impact
Overproduction Push data, unnecessary detail, and redundant work.	1, 3, 4, 5.	Unnecessary extra features in the design. Design produced way before construction. Misinterpretation of requirements. Handover completed works to the next process regardless of availability.	Bottleneck. Improper segregation of work. Cost inefficient. Changes to design. Time delay. Design could be affected and environmental matters will be of least priority.	Changes to design may cause environmental matters to be side-lined. Delay causes uncertainty to environmentally pre-planned scheduled construction works.
Waiting Non-parallel work and information created too early/ unavailable / delay.	2, 3, 4, 5, 6.	Decision making, approval, system downtime, responsive, processing delay.	Time overrun. Affect timing of construction.	Delay could cause changes to the construction start time and will be environmentally negative if it happens during the wet seasons such as monsoon or winter.
Transportation/ Complexity	1, 5, 6.	Excessive changeover of document, designs.	Resubmissions when document not as required.	Constructability issue during construction that may enhance

Multiple sources, incompatible information and communication failure.			Unnecessary delay in time.	environmental risk especially when land has been cleared and exposed.
Over processing Too much iteration, excessive verification, unclear criteria, unnecessary effort and unnecessary changes.	1, 2, 4, 5, 6.	Extra steps. Too much emphasis on the same thing. Redundancy of work (design production, RC requirements).	Unnecessary resource waste. Incompatible approaches that causes glitch.	Incompatible approaches that causes disagreement on the best approach to reduce environmental impact.
Inventory/ Queue Too much WIP, poor management and decision making.	2-3 3-4 4-5 5-6	Excessive output/ work, poor resources management,	Waiting and delay between processes. Huge gap between design and construction that may require design changes during construction.	Design changes especially during construction poses a huge risk to the environment.
Movement Manual interference, lack of direct access, information pushed to wrong person and non-standardised.	4	Finding information, data re-entry.	Delay, overlapping and errors when work is being pushed to the wrong person.	Personnel unfamiliar with the RC process could cause delay (construction time) or fast approval (lenient) that may have impact on the environment.
Defect Inaccurate and insufficient information, ambiguous, low quality and error.	1, 5, 6.	Rework, cost, lawsuit, design and engineering, error, delay.	In constructible design. Design with little concern on the environment.	Design changes during construction. Design with little emphasis on innovation such as prevention measures.
Unutilised talent Knowledge, skills and experiences of people not being used efficiently.	1, 6.	Timing of involvement. Hierarchy and bureaucracy.	Design with no input from construction. Low constructability and environmental prevention measures.	Design with least consideration of construction poses higher risk for environmental damage.

CONCLUSION

Inefficiencies at the pre-construction stage may have negative impacts on the production and environmental aspect of a construction project. Elaborate solutions such as relational procurement could solve problems at the surface but not the deficiencies within processes. The lean methodology proposed in this study is beneficial for construction practitioners to improve the performance of their works at the pre-construction stage, that could enhance their production as well as environmental performance. This methodology allows improvements to be made progressively without the need to revamp the whole system. The recognition of inefficiencies through the proposed methodology prepares a platform for improvements to be conducted through lean thinking. This methodology is flexible, practical and useful for differences processes within the pre-construction stage by defining the goal to achieve. Current lean thinking is commonly applied to improve the construction processes rather than the pre-construction processes due to its non-tangible nature. Since this paper only discussed on lean methodology using modified lean tools to identify waste, subsequent research should be conducted to provide solutions to the identified inefficiencies. Further research should be done to demonstrate this lean methodology using a real case and being validated by the practitioners.

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ISBN: 978-1-927258-42-2

Published: March 2015

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