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Prioritising quality: Literature review of common residential housing defects

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Abstract

The aim of this project is to determine the barriers to achieving quality housing in New Zealand. 369 sources of literature were identified through keyword searching of databases and hand searching of relevant New Zealand industry websites. Final data presentation is based on inductive thematic analysis, resulting in four themes describing 159 relevant sources:

- Housing quality issues – categorised in the report by Building Code clause.
- Life cycle quality issues – documenting barriers to quality within each stage of a building's life.
- Quality perception, satisfaction and end use – describing issues reported in relation to the consumer or end user.
- Improving the building process – grouping together different types of quality-raising measures.

The sources provide useful data on a wide range of complex multidimensional issues and relevant remedial measures. These can be used to inform further research aiming to raise residential building quality in New Zealand. Overall, it was found that quality issues are generally not the result of inadequate Building Code clauses or developed best practices. Rather, they are determined by the ability and willingness of industry professionals to communicate, achieve requirements and manage errors. It was also found that defects and rework are widely deemed as unavoidable, and the achievement of quality is greatly affected by subjective factors. This and the extremely varied nature of construction projects has provoked many sources to suggest the need for continuous evaluation and development rather than one-off solutions. This needs to take place within project teams, companies and the industry as a whole.

Keywords

Housing quality issues, life cycle design, performance, defects, Building Code, NZBC, building construction process

Contents

Executive summary

The aim of this project is to identify the barriers to achieving the consistent construction of quality housing in New Zealand.

This has been done by reviewing and summarising the existing literature relating to building quality and defects. This report presents the findings of that review. It also provides important insight into the barriers preventing quality construction in New Zealand housing projects.

The research has identified the key building defects and quality issues discussed within existing literature. It identifies the level of concern regarding each issue or combination of issues.

The review was conducted using a thematic analysis, with four themes:

- Housing quality issues – categorised in the report by Building Code clause.
- Life cycle quality issues – documenting barriers to quality within each stage of a building's life
- Quality perception, satisfaction and end use – describing issues reported in relation to the consumer or end user.
- Improving the building process – grouping together different types of quality-raising measures.

The key findings are that the most important quality issues in New Zealand homes are generally not the result of inadequate Building Code clauses or accepted best practices. Rather, they are caused by the ability and willingness (or otherwise) of industry professionals to communicate, achieve those requirements and follow best practice. It is also caused by inability to manage errors well to provide effective remediation.

It was found that defects and rework are widely deemed as unavoidable. This and the varied nature of New Zealand residential construction projects means many sources in the literature have suggested there is a need for continuous evaluation and development to ensure high-quality builds. This needs to take place within project teams, companies and the industry as a whole.

Measures to raise quality need to focus on the reduction and better management of common issues. These measures need to include improved methods for detecting, recording, communicating and managing errors to allow quality issues to be resolved more efficiently. It is also important to use these processes to provide useful data for learning and for informing continuous improvement strategies.

The definition of quality was found to be a subjective issue when it comes to achieving consumer satisfaction. This means that developing consumer-focused criteria will be required if the industry wishes to work towards achieving not only compliance but also meeting the quality expectations of their clients.

Finally, the report includes a discussion of what the literature has to say about improving the building process, grouping together different types of quality improvement measures. The sources identified provide useful data on a wide range of issues and relevant remedial measures that can be used to inform further research aiming to raise residential building quality in New Zealand.

Definitions

'Quality' has a wide range of definitions, varying amongst different consumers and authors. For the purpose of this report, the following definitions and terms will be used to discuss quality and barriers to quality.

The definition of quality from BRANZ Study Report SR380 (Page & Gordon, 2017, p. 1) will be used as a basis for searching and evaluating the relevance of potential sources of information.

In general, quality in buildings may include:

- compliance with building regulations and standards
- suitability for its intended use
- sustainability in construction and use
- adaptability
- being aesthetically pleasing
- avoiding defined defects in performance, durability, functionality and safety.

A range of different terms, such as 'defects', are used within literature to refer to shortfalls in quality. The following terms were found to be the most significant keywords used within the literature and will be referenced within this report.

'Rework' is defined as the "unnecessary effort of redoing a process or activity that is incorrectly implemented the first time" (Love & Edwards, 2004b, p. 207). It is referred to commonly within studies discussing errors and defects that are discovered and remedied during the construction phase of building projects.

A 'handover defect' or 'snag' refers to a defect that is absorbed during the construction phase and found at the completion of the project when the building is ready for occupation (Sommerville & McCosh, 2006). The terms 'handover defect' and 'post-handover defect' are most commonly used by Spanish authors to describe defects found at or shortly after project completion. 'Snags' and the process of 'snagging' are common terms in the UK.

Outside of these sources, the term 'defect' is most commonly used, including within the New Zealand Building Act 2004, to describe any shortfall in quality after the construction phase has ended.

Within the literature, 'latent defects' typically refer to defects that become apparent during the occupancy phase of a buildings life, affecting the building in the long term.

1. Introduction

This literature review has analysed New Zealand literature on common quality issues in newly constructed houses, and also draws on international literature where relevant. This work has been undertaken to support our research programme Eliminating Quality Issues. It is part of a stream focusing on understanding priority areas for attention in terms of quality issues in New Zealand housing.

The analysis has been structured around the following approach:

- What does the literature say about quality issues in relation to the New Zealand Building Code?
- What does the literature say about quality issues in relation to house life cycles?
- What does the literature say about quality issues in relation to user perceptions and experiences of those people living in their new homes?

In each area of enquiry, New Zealand literature has been examined, analysed and prioritised. This analysis has then been contextualised in a review of the international literature.

This research utilised database and hand searching of sources relevant to defects and achieving quality in residential buildings to inform the improvement of new housing in New Zealand. Keywords were identified and tested to develop a comprehensive search strategy to identify relevant literature to answer questions surrounding the types and extents of quality issues evident within New Zealand and relevant international contexts. Data selection and coding was based on inductive thematic analysis to best represent apparent trends within the literature and present a coherent narrative of the information identified.

2. Findings

A range of sources in the literature discuss shortfalls in specific aspects of housing performance that have the potential to result in houses with low-quality or potentially unsafe living conditions.

Overall, it was found that defects and rework are generally not the result of inadequate Building Code clauses or developed best practices. Rather, they are determined by the ability and willingness of industry professionals to communicate, achieve requirements and manage errors. The definition of quality was found to be a subjective issue when it comes to achieving consumer satisfaction. This would require the development of consumer-focused criteria if the industry wishes to work towards achieving not only compliance but also the quality expectations of their clients. Most importantly, defects and errors are reported as an unavoidable part of the building process. Therefore, measures to raise quality focus on the reduction and better management of common issues through improved methods for detecting, recording, communicating and managing errors. This would allow them to be resolved more efficiently and provide useful data for learning and informing continuous improvement strategies.

2.1 Conclusions

Analysis of Building Code quality issues

Defects in performance are not commonly reported in the literature as being the result of inadequate regulation or lack of developed standards. Rather, these relate to the ability of designers, builders and occupants to achieve requirements and follow best practice. Each clause of the Building Code is extensive and comprehensive of building performance requirements. However, much of the literature focuses on addressing only a few sources of discomfort for occupants, such as mould, acoustics and temperature. There is some additional attention towards health and safety hazards, energy efficiency and structural and material durability.

It is unclear whether further aspects are not quality concerns or have not been identified by researchers in the literature reviewed. These include lighting, air quality, provision of amenities, consideration of people with disabilities and many other factors relating to the fitness for purpose of homes.

Life cycle quality issues

Issues of rework and defects are prevalent through all project stages. They affect the cost and quality of a building throughout its life. Rework and defects are almost always attributed to a process or activity that is incorrectly implemented or insufficiently considered. Unavoidable human error, made worse by poor management and communication, is commonly blamed for the high instances of rework.

Defects that remain after handover, however, are more often reported as the fault of poor error detection and inspection processes. Transference of information is widely discussed across the literature. The conclusion is that accurate and timely communication between project participants across all project stages to manage problems that arise and ensure errors do not impair the final building is crucial. Designers, according to the literature, must translate project needs into solutions. Contractor need to detect and communicate defects and errors so they can be managed and reworked as efficiently as possible. Homeowners or their employed inspectors must recognise and communicate any still-remaining defects missed by building professionals and compliance inspections.

Users' quality perceptions

Quality perception has been found to be complex. It is affected by a wide range of factors and varies from person to person. What one person perceives as a quality issue may not be perceived by another in the same way.

Achieving consumer satisfaction relies on the wants and priorities of the consumer. Much like any transaction, consumer satisfaction is related to more than the physical product. It also encompasses good customer service. Good communication ensuring a cordial relationship that enables needs to be met and changes to be managed satisfactorily is important to consumers. Similarly, effective communication involves more than the designer and builder. Dissatisfaction and latent defects can be caused by consumers who are inexperienced or uninformed of how to best involve themselves in the design, building and operation of their new homes.

3. Housing quality issues in relation to the New Zealand Building Code

The New Zealand Building Code is designed to ensure that "buildings are safe, healthy and durable for everyone who may use them" (MBIE, n.d.a). The New Zealand and international literature has been reviewed and analysed in relation to the Building Code in order to assess how well buildings are performing and the common quality issues.

The approach has been to analyse the literature in relation to the Building Code on a clause-by-clause basis as follows:

- Clause B *Stability* – this includes structural issues.
- Clause C *Protection from fire.*
- Clause D *Access*.
- Clause E *Moisture*.
- Clause F *Safety of users*.
- Clause G *Services and facilities*.
- Clause H *Energy efficiency*.

In each case, the most common and therefore most important quality issues have been discussed first.

The literature review finds evidence of problems in the quality of housing and living standards achieved despite the Building Code regulations.

Overall findings are that performance defects identified have been found that impact on the health, safety and comfort of occupants. These relate to defects in terms of:

- internal moisture and mould
- structural deficiency
- unwanted noise
- material degradation
- thermal comfort
- energy efficiency
- weathertightness.

3.1 Clause B *Stability*

This clause requires "buildings, building elements and sitework to withstand the combination of loads and physical conditions they are likely to experience during construction, alteration and throughout their lives … [and] ensures that a building throughout its life will continue to satisfy the performance of the Building Code" (MBIE, n.d.b). The clause is split into two parts:

- B1 *Structure* – buildings must be able to withstand wind, earthquake, live and dead loads (people and building contents).
- B2 *Durability* – aims to ensure the functionality of materials for specified minimum periods.

Information on structural defects within New Zealand was only identified within post-earthquake building analysis, quantifying damage caused by extreme events. Sources discuss damage from the 2009 Fiordland earthquake (Beattie, 2009) and the series of Canterbury earthquakes in 2010 and 2011 (Beattie, Shelton & Thomas, 2015; MacRae, 2012), investigating the performance of different building types and materials. Analysis of housing stock after the Canterbury earthquakes found that, overall, newer houses performed better. Adjustments to building requirements, such as plasterboard linings and screw fix ties for brick veneer cladding, were found to be beneficial improvements for seismic performance (Beattie et al., 2015).

Rather than performance, as analysed in New Zealand, a study in California provides investigation into the quality of seismic design and construction (Schierle, 1996). The study investigated levels of compliance with seismic safety features in light timber-framed buildings, collecting data through mail surveys to architects and engineers in combination with site surveys of buildings under construction. The study revealed that 40% of surveyed units had more than one-third of seismic safety items either missing or flawed. Analysis found it “alarming that the key items to resist wind and seismic loads are among those most frequently missing or flawed” (Schierle, 1996, p. 90).

Further information on structural issues was identified within an article produced by Spanish researchers. They examined judicial files to create data on reported anomalies and defects within the foundations and structures of residential buildings after building completion (Carretero-Ayuso, Moreno-Cansado & Cuerda-Correa, 2016). Damages caused by infiltrating humidity, fissures in walls, partitions and/or floorings and cracks account for 80.20% of the defects, with 66.63% of defects affecting the foundations (Carretero-Ayuso et al., 2016). A similar study in the UK, examining structural defects with the aim of determining their causes, surveyed residential masonry properties in the East Midlands region (Page & Murray, 1996). It was found in this study that 83.1% of defects could have been avoided by designers, builders and owners. This provided “clear evidence that many structural defects are still occurring because of ignorance, negligence and false economy and, in the case of contractors, faulty workmanship resulting from cost-cutting” (Page & Murray, 1996, p. 38).

Six sources provide information about stability-related issues, discussing the durability and premature failure of materials and building components (Brown, 1990; Gajjar, Kashiwagi, Sullivan & Kashiwagi, 2013; Jordan, Kimble & Sharer, 2015; Marston & Jones, 2007; McNeil, Li, Cox-Smith & Marston, 2016; Sharara, Jordan & Kimble, 2010; Trebilco, 1992). US studies discuss the common material and installation defects encountered when assessing roofs for storm damage (Sharara et al., 2010) as well as how different contractors and seasons of installation affect the long-term quality of sprayed polyurethane foam roofs (Gajjar et al., 2013). Additionally, in the US, a study describes the various causes of ceiling failures. There is a focus on residential gypsum board and plaster systems and the wide range of defects and failures that have occurred in the authors’ experiences as forensic engineers (Jordan et al., 2015). Issues relating to durability include “long-term wear and tear (sometimes referred to as ‘fatigue action’ and ‘embrittlement’) of drywall attachment resulting from cyclical dimensional changes within wood framing combined with aging materials” (Jordan et al., 2015, p. 888). These articles, however, have been written with a focus on understanding and identifying different types of failure rather than to determine or prevent any reoccurring issues.

Two surveys conducted in New Zealand identify the common problems found with metal and plastic within the building industry (Brown, 1990; Trebilco, 1992). However, since those surveys are over two decades old, it is unclear whether similar problems are still an issue. A more recent BRANZ report investigates the weathering of polymeric materials within the New Zealand environment. It states that premature failure of these materials is a “major concern” in the construction industry (Marston & Jones, 2007, p. ii). The experimental study confirmed the issue of New Zealand climatic effects on polyolefin materials with rapid surface and mechanical degradation resulting almost entirely from UV radiation. The study concludes that the durability of the non-UV stabilised, clear, polyolefin materials tested is “clearly insufficient to give them any significant service life in the NZ environment … [and that it is] highly unlikely that clear polyolefin materials will meet the Building Code B2 Clause 2.3.1(c) requirement of five years durable life when exposed outside in NZ” (Marston & Jones, 2007, p. 59). Polyolefin materials containing pigments and/or UV stabilisers are expected to have a longer lifetime in the New Zealand environment. There are recommendations for materials to be “carefully formulated, in close consultation with the material and additives manufacturers … [as well as] systematically examined, under representative conditions, to ensure acceptable performance prior to sale” (Marston & Jones, 2007, p. 59).

3.2 Clause C *Protection from fire*

This clause relates to “protecting people in and around buildings, limiting fire spread and helping firefighting and rescue” (MBIE, n.d.c). Aspects of this clause provide guidance on the prevention of fire occurring and spreading, movement to a place of safety, access and safety for firefighting operations and the structural stability of building elements during a fire. No literature was identified in the search relating to this clause. This provides no insight into any potential issues with the design, construction or regulations surrounding fire safety in residential builds within New Zealand or internationally.

3.3 Clause D *Access*

This clause aims to “safeguard people from injury during movement into, within and out of buildings … [and] ensure that people with disabilities are able to carry out normal activities and functions within buildings” (MBIE, n.d.d). When searching with the keywords chosen relating to defects and quality, only one article was identified in relation to this clause, discussing stairway falls (Cohen, LaRue & Cohen, 2009). Nothing was found in the literature examining quality issues or defects relating mechanical access installations or to accessibility for people with disabilities. Stairway falls in the US have been examined retrospectively over a 15-year period to provide an overview of the causes of their related injuries. The analysis found dimensional variation followed by non-compliance with design rules for the sizes of risers and treads to be the most significant factors in stairway injuries, which are regulated and prescribed by clause D1 *Access routes*. The effects of the user, which cannot be regulated, are also discussed. Age, gender, footwear, the carrying of items, handrail use and drug and alcohol use affect the occurrence of a fall (Cohen et al., 2009).

3.4 Clause E *Moisture*

Provisions in this clause are intended to “ensure conditions for healthy, safe and durable buildings … [by protecting] people and other property from the adverse effects of surface water, from penetration by water, and the accumulation of moisture from both the outside and inside. Adverse effects, for example, include undue dampness, damage or degradation to building elements, condensation, or fungal growth” (MBIE, n.d.e). While the effects of surface water have not been found, internal moisture problems are commonly examined, with 10 sources discussing inadequate moisture removal and nine additional sources discussing the issue of weathertightness. The common impacts of the moisture-related defects discussed within the literature include the growth of mould, which is also related to indoor temperatures, and the deterioration of building materials.

A European study outlines health risks associated with excess moisture in the residential environment, testing over 270 flats and finding the presence of 82 species of mould (Piontek, Luszczynska & Lechów, 2016). Tests demonstrated the frequent occurrence of *Aspergillus versicolor* mould in building partitions, a species that risks the synthesis of toxic and carcinogenic sterigmatocystin, which is reported to be dangerous for animals and humans. Causes of mould growth within the literature are most commonly attributed to improper ventilation of homes, describing performance issues in terms of three major factors – inadequate provision, incorrect operation and poor installation.

The trend of increasing airtightness in New Zealand homes aims to improve thermal efficiency. However, it increases the risk of inadequate ventilation provision and the accumulation of internal moisture in new homes (McNeil, Plagmann, McDowall & Bassett, 2015). For successful passive ventilation, the design provision of natural and mechanical ventilation must be able achieve the necessary rate of ventilation. This then must be operated at the correct times, meaning 'educating occupants on how to 'drive' their passive designed house is also critical' (Su, 2002; 2006, p. 389). Natural ventilation, as prescribed in the Building Code, relies on the provision of openable windows within the design (McNeil, Plagmann & Bassett, 2014). The operation of these windows, however, may be undesirable to occupants due to security problems and bad weather, causing occupant misuse and inadequate ventilation to be achieved in practice (McNeil et al., 2014). The misuse of mechanical ventilation by occupants has also been reported as an issue in the UK. High noise emission levels has meant these systems are also undesirable for use by occupants when needed (Harvie-Clark & Siddall, 2014).

A study of multi-family dwellings in the US found mechanical ventilation systems to be performing well below design intent (Prezant & Hartman, 2006). In the homes tested, fan efficiency and flow were found to be below the prescribed design, with evidence of crushed ducts, clamping problems and leakage impacting system performance due to poor installation. A UK article describes similar issues surrounding the gap between the design and as-built performance of domestic ventilation systems due to errors of design, installation and commissioning (Gilbert, 2014). The influence of these factors was inferred by BSRIA studies to mean a large number of newly installed systems do not comply with British building regulations. Further problems with the continued performance of mechanical ventilation systems are also discussed, with a lack of dedicated schemes for maintenance and inspection to prevent the cause of latent defects.

The problem of toxic mould is also described as the result of weathertightness issues. Lawsuits associated with this issue are reported as an increasing problem in the US. This has led to the industry "reevaluating the design, supervision, and work associated with projects in an effort to reduce the possibility of water intrusion and toxic mold growth" (Carson, 2003, p. 171). 2007 research from the University of Florida emphasises this issue further in the US. It reports that 69% of all construction defect claims relate to moisture penetration through the building envelope – 53% of all claims were the result of poor workmanship, supervision and inspection during construction (Grosskopf & Lucas, 2008).

Despite continued concern about weathertightness in New Zealand dwellings (Murphy, 2011), few sources were identified addressing the issue of weathertightness-related defects in New Zealand. Study reports from BRANZ investigate the weathertightness of flashings (Bassett & Overton, 2015a, 2015c), weather grooves (Bassett & Overton, 2015b) and brick veneer walls installed with urea formaldehyde foam insulation (UFFI) (Bassett et al., 2010). The only major problem was found to be caused by water bridging within UFFI walls. Similar controlled studies in the US investigate the weathertightness of window to wall interfaces. The aim is to verify and improve installation detailing practice and standards to improve industry practice (Lacasse et al., 2010; Mathis & Johnson, 2007).

Finally, condensation problems are also discussed as a moisture-related issue, attributing to accelerated material degradation and decreased thermal performance. A BRANZ report on subfloor moisture investigates the effects of moisture condensing on metallic construction elements and thermal insulation, finding a lack of ventilation of subfloors to be an issue (McNeil et al., 2016). This is, however, reported to be adequately provisioned for within Acceptable Solutions to the Building Code, meaning it should not be an issue unless a building does not comply with the current Code. Another article investigating the 3D visualisation of thermal resistance discusses the problem of condensation caused by areas of low thermal resistance in the building envelope (Ham & Golparvar-fard, 2014). The technique developed allows for interactive 3D environments to be created, visualising surface temperature data and thermal resistance defects. This "enables practitioners to better understand the as-is building conditions" to diagnose where potential condensation problems and material degradation may be present (Ham & Golparvar-fard, 2014, p. 1).

3.5 Clause F *Safety of users*

This clause "safeguards people from injury or illness" (MBIE, n.d.f). Parts of the clause regulate hazardous building materials, substances and processes, safety from falling, construction and demolition hazards, visibility in escape routes, warning systems, signs and access to residential pools. While not relating specifically to any clause F criteria, four articles were identified that discuss housing quality and its impact on occupants' health and safety. These describe rating systems that evaluate housing beyond the pass/fail factors regulated in the Building Code to improve living conditions and reduce home injuries. An article from the UK describes the development of the Housing Health and Safety Rating System (HHSRS) through literature review and matching of housing condition data and health outcome data (Ormandy, 2010). The HHSRS shifts the focus to the potential threat to health and safety from any defects and deficiencies, allowing housing inspections to identify potential hazards to occupants' health so positive interventions can be made. Dwellings with poor health and safety are estimated in the UK to cost the healthcare service £600 million per year. There are additional costs that are difficult to estimate, such as "time away from employment, state benefits, and diminished quality of life", showing health and safety to be a significant issue (Ormandy, 2010, p. 65).

Similar work has been done in New Zealand through the development of the Healthy Housing Index (HHI). This looks to provide data to inform the improvement of occupant health, the reduction of home injuries and an increase in energy efficiency (Gillespie-Bennett, Keall, Howden-Chapman & Baker, 2013; Keall, Baker, Howden-Chapman, Cunningham & Cunningham, 2007; Keall, Baker, Howden-Chapman, Cunningham & Ormandy, 2010). These are all features outlined in the definition of housing quality. Future application of the HHI aims to quantify health and safety issues present in New Zealand homes. This is to provide policy agencies and local authorities "robust data" on the quality of housing stock and the impact of policies and compliance tools (Keall et al., 2010, p. 766).

3.6 Clause G *Services and facilities*

This clause provides guidance for personal hygiene, laundering, food preparation and prevention of contamination, ventilation, the interior environment, airborne and impact sound, natural and artificial light, electricity, piped services, gas as an energy source, water supplies, foul water, industrial liquid waste and solid waste. The clause is designed to safeguard "[w]ellbeing and physical independence [which] are influenced by factors such as indoor climate, space, protection from noise, light, connection to the outdoors, and access" (MBIE, n.d.g). The only issues found in the literature associated with aspects of this clause relate to acoustics and noise transmission in building elements between occupancies or common spaces in household units. Acoustical comfort is reported internationally as "one of the most important factors of a healthy living environment" with the potential for greater issues as "acoustical defects often become subject of argumentation" (Vargová & Pavčeková, 2013, p. 281).

Excluding the problem with excessive noise from ventilation systems (Harvie-Clark & Siddall, 2014), the remaining four articles identified that discuss acoustics describe unwanted noise transfer, which is regulated by the Building Code. The problem of inadequate sound insulation is most commonly discussed in the UK. Two articles describe the impact of building regulation standards relating to noise transmission through the building envelope and between attached dwellings (Dunbavin, 2012; Hepworth, 2007). A UK study in 1992–1994 investigated noise complaints due to a lack of sound insulation between dwellings, finding the majority of complaints to be due to non-compliance with sound insulation standards (Grimwood, 1997). A 2012 UK article describes a significant increase in compliance since the 2003 introduction of mandatory pre-completion testing and the later developed alternative compliance route, achieved by following verified robust details. The analysis suggests that the house building industry is now able to achieve "very close to full compliance" with sound insulation requirements (Dunbavin, 2012).

A European article further discusses the problem of inter-tenancy noise transfer (Vargová & Pavčeková, 2013). It investigates beyond compliance with regulation requirements of sound insulation, by suggesting a greater number of variables that affect levels of unwanted noise. Factors reported as creating significant acoustic variation include consideration of apartment layout, cultural standards and interests of occupants, floor coverings and background noise levels onsite. A UK article reinforces the need to consider variation within each unique site. It suggests the requirement of "a detailed noise survey to be carried out to quantify the existing noise environment" to enable designers to better provide "noise attenuation measures for the building envelope" and manage the risk of unacceptable noise levels within new buildings (Hepworth, 2007).

3.7 Clause H *Energy efficiency*

Sustainability issues, such as energy efficiency, are an important aspect of building quality and are somewhat regulated by clause H of the Building Code. This clause requires "an adequate degree of energy efficiency to modify temperature, humidity, ventilation, the provision of hot water and artificial lighting" (MBIE, n.d.h). Building energy codes in the US reportedly reduce building energy use by 30% or more compared to buildings designed without energy efficiency in mind (Vine, Williams &

Price, 2016). This research demonstrates the importance of addressing sustainability concerns as they create great benefits to occupants, such as money savings and improving the levels of comfort (Vine et al., 2016).

Three articles were identified discussing the issue of energy efficiency compliance, examining levels of compliance with energy codes in the US and UK. Pan and Garmston (2012) investigated 404 new build houses in the UK. They found two-thirds of the buildings to be non-compliant with the energy clause in UK building regulations, meaning they do not meet minimum performance requirements. US studies also found a high number of compliance violations, both in documentation and on site. Common issues related to discrepancies between plan-specified, calculation-specified and actual-built elements (Vine, 1996). Common issues identified include problems with insulation, in the building envelope and around water heater tanks and ducts, as well as errors and inappropriate reporting relating to glazing area and type, thermal mass credits and HVAC system ratings. The key reason for non-compliance is reported as the attitude towards the importance of energy efficiency within the industry (Vine, 1996). This is claimed to be due to the perception of low concern, especially when compared to other codes affecting health and safety. There is also a lack of enforcement or likelihood of being held accountable for violations (Vine et al., 2016).

Reduced energy efficiency, in terms of maintaining comfortable temperatures within a dwelling, has been discussed by a further 13 sources, which evaluate the thermal performance of building envelopes. New Zealand sources report a trend of increasing airtightness in new dwellings (McNeil et al., 2015). However, an article surveying Irish homes indicates there is a “misconception that newer buildings are more airtight than older buildings” (Sinnott & Dyer, 2011, p. 376). Testing evidenced a lack of airtightness, reducing the thermal performance of dwellings, resulting from poor workmanship and construction detailing. Common problems resulting in high air leakage rates involved internal service ducts, draught stripping and leakage paths between window frames and external walls. The article aims to “provoke policy makers to enhance the control requirements of on-site workmanship, and designers to be vigilant about the effect particular details can have on airtightness” (Sinnott & Dyer, 2011).

The remaining 12 documents centred on thermal performance and look at insulation and the effectiveness of thermal resistance through the building envelope (Allen & Allen, 1983; Cox-Smith, 2009, 2010; Cox-Smith, Hearfield, Jones & Marston, 2010; Fox, Coley, Goodhew & De Wilde, 2014; Fox, Goodhew & De Wilde, 2016; Ham & Golparvar-fard, 2014; Korniyenko, 2015; McNeil et al., 2016; Seeber, 1984; Sinnott & Dyer, 2011; Taylor, Counsell & Gill, 2013). Reports from BRANZ investigate the installed performance of insulation in a range of contexts. These include the effect of different installation methods of ceiling insulation (Cox-Smith, 2009), the effect of moisture on subfloor insulation (McNeil et al., 2016) and the performance of UFFI (Cox-Smith et al., 2010). Reports conclude that careful attention to detail during installation of ceiling insulation and UFFI within wall cavities is necessary to ensure the required thermal resistance is achieved (Cox-Smith, 2009; Cox-Smith et al., 2010). McNeil et al. (2016) conclude that moisture is a minimal issue with regards to subfloor insulation performance. Additional sources investigate thermography techniques for testing the thermal performance and energy efficiency of the building envelope. However, these studies are not aimed at testing and improving the performance of new builds but rather at detecting latent defects and informing retrofits (Allen & Allen, 1983; Cox-Smith, 2010; Fox et al., 2014; Fox et al., 2016; Ham & Golparvar-fard, 2014; Korniyenko, 2015; Seeber, 1984; Taylor et al., 2013).

4. Life cycle quality issues

Another group of sources look to identify and address problems within different stages over the life of a building. These stages include design and documentation, construction, handover and occupancy, with sources looking at when defects are caused or, alternatively, when defects are found. A variety of methods are used to discuss these problems including surveys of occupants or building professionals, large-scale or small-scale building inspections, analysis of data from various databases and literature review. Rework, enabling defects detected by design professionals to be remedied before project handover, is the most commonly discussed issue during the design and construction stages, affecting project budget, schedule and scope. After this, shortfalls in quality become an issue for the occupant over the life of the building, affecting consumer satisfaction, life cycle costs and creating unexpected latent issues.

4.1 Design and documentation

Design errors as a result of ignorance, lapses of attention and omissions are a common issue. These are reportedly made worse by organisational practices and time and cost constraints placed on design tasks (Love, Lopez, Goh & Tam, 2011). Most errors are found by contractors, subcontractors and manufacturers during the construction phase, leading to rework, and do not result in issues within the final building. However, those that remain undetected may have serious ramifications that in extreme cases have led to injury or death (Love, Lopez et al., 2011). The majority of sources examine projects during or shortly after their completion, documenting minor design errors that occur and their effect on project budget, quality and schedule. Additionally, the long-term impact of design for maintenance is discussed in terms of ease and cost of maintenance over a building's life.

The idea of design error-induced rework is a frequently mentioned issue in studies investigating the time and cost over-runs of projects. This occurs due to errors and omissions in project drawings that are not detected until the construction phase commences (Love, Mandal, Smith & Heng, 2000). A study by BRANZ investigated documentation problems, looking specifically at the quality of drawings provided for consent for new housing (Page, 2016). The drawings were evaluated for readability and completeness, with an overall finding of a high percentage of inadequate or incomplete drawings. Similar problems are reported in Australia and the US, finding incomplete drawings and specifications as major factors affecting rework and the productivity of construction projects (Halvorson, 1990; Hughes & Thorpe, 2014).

International sources also identify contract documentation as an issue in the initial stages of a project, resulting in problems and rework during the construction phase. Canadian, American and Australian contractual agreements have been examined and evaluated with the ultimate goal of waste reduction and sustainable construction through the minimisation of rework (Mendis & Hewage, 2012; Mendis, Hewage & Wrzesniewski, 2013; Mendis, Hewage & Wrzesniewski, 2015). Problems identified through a multinational study include general errors, deficiencies and ambiguity, with an additional major focus on exculpatory clauses that unfairly transfer risk and create rework (Mendis et al., 2013).

The construction industry forms a “complex communication environment”, relying on effective transference of information between different project participants through different project stages (Harstad, Lædre, Svalestuen & Skhmot, 2015, p. 391). Sources identified find communication as a common issue between the design and construction phases of the project, with problems arising through a lack of required information, poor intelligibility of information and changes in information. One source investigated the benefits of tablets to improve communication on site. It argues that, during construction, up-to-date information must be readily available for construction personnel “at the point where they are and at the time when they need it”, to prevent rework and time wasted due to lacking or incorrect information (Harstad et al., 2015, p. 392). The BRANZ New House Construction Quality Survey 2014 quantifies the impact of this problem in New Zealand, finding many instances of missing or incorrectly followed plans and details on building sites (Page, 2015). Inspectors from the survey commented that expensive on-off builds were generally of better quality. This was assumed to be from more experienced builders, better supervision, more detailed drawings and the availability of the designer to clarify details for the builders as required.

The long-term impact of design errors, through the consideration of maintenance during the design phase, is also discussed within the literature, impacting lifetime maintenance costs and influencing the frequency of unplanned maintenance. A design quality and building life cycle cost database was created using Canadian buildings. This demonstrated that the better the design quality, the lower the building’s annual equivalent maintenance and rehabilitation costs for the first 20 years of service life (Newton, 2004). In addition, a literature review study of the relationship between design and maintenance establishes the requirement of post-occupational surveys, maintenance and user feedback. This is to ensure more effective design and the reduction of unplanned maintenance throughout a building’s life (Chohan, Ani, Memon, Ishak & Zubair, 2010).

A US survey of designers and facility managers further describes this issue, comparing the perspectives and knowledge of maintenance issues between the two professional groups (Sohi, 2015). The top issues identified within the study include a lack of awareness about maintainability in the construction industry. Deferred maintenance was often found to be caused by lack of a maintenance schedule, which should be supplied by architects at handover, as well as insufficient funds allocated to perform maintenance. The research advocates for the involvement of facility managers during the design phase to allow for better design and provision for the management of maintenance issues throughout the building’s service life.

4.2 Construction

During the construction phase, the most common issue identified within the literature is rework involving defects that are identified and remedied before handover to the client. These defects do not affect the performance or quality outcome of a building. However, rework is reported to have a significant impact on cost and schedule over-runs, which can result in reductions in project scope or quality (Love, Edwards, Irani & Walker, 2009). The majority of studies attempt to quantify these negative impacts, in terms of project budget or schedule performance, as well as determine their underlying causes to inform rework reduction strategies. As previously discussed, rework is often reported as the result of design errors, picked up and remedied within the construction phase. It is also commonly reported as the result of poor workmanship and on-site management.

The role of human error in the cause of rework in construction is complex, with a wide array of factors contributing to its occurrence. This complexity is due to “the interdependency of work arrangements, dynamic social interactions between project participants, and the socio-economic and political structure” that exists within each unique project (Love & Edwards, 2004b, p. 225). Omissions errors, defined as “failures to follow due procedure when undertaking a task”, are reported in an Australian study, involving interviews with construction industry personnel, as the single most common form of human error (Love, Edwards, Irani & Walker, 2009, p. 425). Excessive workloads, schedule pressure and an overall competitive environment were found to be major factors resulting in the neglect of procedural tasks. A lack of consequence and learning from failure caused the continuation of the problem (Love, Edwards, Irani & Walker, 2009).

Research involving the observational study of housing construction sites in the UK stresses the effect of managerial influence on human error. This is especially related to the idea of communication and the importance of developing management systems to address the reduction of defects (Atkinson, 2002). Further research into human error describes poor workmanship, including the concept of value degradation through sub-optimal execution of tasks (Patton, 2013), missing or flawed items in seismic construction elements (Schierle, 1996) and lack of quality control resulting in poor airtightness (Sinnott & Dyer, 2011) or water penetration (Grosskopf & Lucas, 2008).

Non-compliance is another issue occurring during the construction phase, usually picked up through inspection and again resulting in rework. An assessment of construction defects in Spain found issues of non-compliance to be the result of poor workmanship (Forcada, Macarulla, Gangolells & Casals, 2014). Similar research in the UK agrees with this finding. It also attributes compliance failures to a lack of skills and knowledge on the part of operatives in relation to required standards (Bousmaha, Walliman & Ogden, 2006). A survey of construction inspectors in the US found training and management direction as consistently high-ranking factors influencing quality and conformance. Electricians were reported as the top ranking trade for conformance to code requirements (Kirsh, 1995).

A report on issues of compliance in Auckland emphasises this issue. It reports an average 23% failure rate of inspections between 2013 and 2015 over all inspection types, with an average 48% failure rate for final inspections over the same period (Taylor, 2016). A BRANZ study of residential construction projects found an average of 2.2 compliance defects per house. Some houses had four or more compliance defects even after Code Compliance Certificates were issued (Page, 2015). A survey of problems builders face in producing good work was also reported, finding a lack of buildable details and a lack of appropriate skills to be the top issues.

4.3 Handover

Handover defects, or snags, are those quality issues that are not remedied during the construction phase. They therefore remain in the finished building to be detected by homeowners upon occupation of the building (Sommerville & McCosh, 2006). Sources reporting on this type of defect investigate the prevalence of any trends, causes and origins and ways to manage the snagging process through the classification and reporting of defects.

Assessment of post-handover defects in Spain found a common trend of defects resulting from bad workmanship resulting in minor defects in installation, appearance and finishing tasks. More significant design defects were addressed and absorbed during the construction phase (Forcada, Macarulla, Gangolells et al., 2013; Forcada, Macarulla & Love, 2013). A greater range of investigations were found relating to snagging in the UK, describing homeowners' greatest concern to be of functional quality, which relates to aesthetics and use (Craig, 2007). Additional research focused more on trends within the number of defects found in new homes rather than the nature (Sommerville & Craig, 2007; Sommerville & McCosh, 2006). Australian research suggests an increasing trend in the number of defects found in new homes, as well as in the number of consumers requesting inspections by industry professionals before handover is complete. This is despite regulations in place aimed at reducing these defects (Georgiou, 2010).

Research into snagging trends within New Zealand was conducted through surveys and interviews with homeowners and house developers. The 10 most common defects at handover are uneven painted surfaces, nail pops, poor finishes, poor flooring, poorly fixed door and window handles, poorly installed kitchen units, building cracks, poorly fixed toilet/WC, locks and poor concreting (Rotimi, 2013). The top causes of these were attributed to poor workmanship, resulting from a lack of skills, poor building materials, particularly imported materials, and design errors. BRANZ studies on quality of new home construction and satisfaction of new homeowners utilise surveys of new homeowners and builders and independent inspections of construction projects at various stages of completion (Page, 2015). Final inspections found 27% of homes with no compliance defects at completion and only 8% of homes with no quality defects at final completion. This showed a similar trend as the UK towards concerns with functional quality. Due to the instances of defects found after first occupancy, the BRANZ 2015 New House Owners' Satisfaction Survey found 84% of new homeowners had to call back their builders after handover (Curtis, 2016a).

Sources in the UK and New Zealand investigate the need to manage the snagging or defect reporting process to improve the quality of new homes through improved recording and communication of defects. The process is investigated during construction, with the aim of reducing the number of defects still present at handover (Sommerville, Craig & Ambler, 2005; Sommerville, Craig & Bowden, 2004). It is also investigated after completion, to improve defect detection and rectification after handover has taken place (Rotimi, Tookey & Rotimi, 2015a).

UK sources discuss a need for improved snagging processes, describing the "highly fragmented" construction industry and the collected data that "varies widely between the construction organisations" (Sommerville et al., 2004, p. 257). Further problems arise through the ineffective storage and communication of snagging information. This is described as a "meticulous task" requiring a "great deal of patience unless there are processes in place" (Sommerville et al., 2005, p. 1). It is therefore argued that "enhancing the flow of defect information between the different members of the project team makes it easier for the defects controller to monitor, assess and process defect data … [requiring the industry to] adopt a more standardised approach to the collection of defects data" (Sommerville et al., 2005, p. 1). This is in order to support site workers and contractors in the defect eradication process.

Research in New Zealand claims that "the need for defect reporting is becoming increasingly difficult to ignore at handover of new residential buildings … [suggesting] sufficient evidence to suggest that the numbers of defects in new residential buildings are significant and demand attention" (Rotimi et al., 2015a, pp. 39–40). There is evidence that a significantly higher number of defects can be detected by professional building inspectors. However, the study found the use of independent inspectors to be low for new homes when compared to existing buildings, with homeowners relying on their own visual inspection. The study argues that “a firm process for defect identification and rectification” would give consumers confidence in the quality of the final product (Rotimi et al., 2015a, p. 40). It would do this by better regulating aesthetic defects not picked up during building compliance inspections. It is also concluded that opportunities exist for post-handover defect reporting to facilitate performance measurement for future quality improvement industry wide.

4.4 Occupancy

Compared to the previous life stages, there is less literature regarding the instances, causes and prevention of latent defects that arise during occupancy. Articles discuss the difficulty in detecting these latent defects due to limitations of building inspection post construction unless defects are serious enough for complaints to the authorities (Chong & Low, 2005, 2006). A lack of detection creates a gap between perceived construction quality at the time of completion and the defects experienced by occupants later in the building’s life (Chong & Low, 2005). This reportedly results in project participants being unaware of the impact of their decisions, practices and procedures. This means mistakes cannot be identified or learned from until a failure occurs (Chong & Low, 2006; Love, Lopez & Edwards, 2013).

A study of residential buildings in Singapore compares the instances of defects during construction with defects found 2–6 years after completion (Chong & Low, 2005). This demonstrated a significant number of defects found during occupancy that were not evident during construction. The most important design-related causes of latent defects found were due to insufficient consideration of weather impact, occupant impact and loads and moisture from wet areas. More serious latent failures have also been examined retrospectively through the investigation of case studies such as Hotel New World (1986), Sampoong Department Store (1995), Versailles Wedding Hall (2001), Charles de Gaulle International Airport (2009) and other major building and infrastructure projects (Love et al., 2013). Lessons drawn from these failures shed light on the causes of defects that prevail after completion. The conclusion is that many errors could have been prevented by design checks and reviews as well as the implementation of appropriate project management practices (Love et al., 2013).

Aside from weathertightness concerns (Murphy, 2011), minimal research has been conducted in New Zealand into latent building defects. House condition surveys by BRANZ provide data on common types of problems experienced and the overall condition of New Zealand’s housing stock (Buckett, Marston, Saville-Smith, Jowett & Jones, 2011; Clark, Jones & Page, 2005; Clark, Page, Bennett & Bishop, 2000). They also identify shortfalls and priorities in maintenance and repair (Page & Curtis, 2013). In addition to these large-scale studies, smaller investigations have looked at mould problems within Auckland housing (Su, 2002) and surveys of homeowner perceptions of general condition, dampness and mould (Statistics New Zealand, 2013, 2015). They have also looked at pilot studies in the development of a Healthy Housing Index (Keall et al., 2007).

Only one source identified in New Zealand attempts to investigate the prevention of latent defects, providing insight into the perceptions of designing for durability within industry practice (Clark & Bennett, 2001). The greatest barriers to design for durability and sufficiently meeting clause B2 of the Building Code are identified to be a lack of reliable information and a lack of appreciation of its importance. There are additional concerns from building officials around correctly assessing the requirements set out in the Building Code.

5. Quality perception, satisfaction and end use

A range of articles look at the occupants as a focus rather than the physical buildings. They discuss quality perceptions and tolerances for functional and aesthetics aspects, consumer satisfaction with the building process and end result, and the effects building occupation has on performance of a building and presence of defects. The involvement of consumers in the design and construction stages has also been investigated in terms of the effect it has on project performance and the satisfaction consumers experience at completion. Factors outside the physical end project are also discussed with respect to their influence on perceived quality. This includes client relationships with contractors, previous building experience and expectations and tolerances relating to imperfections or defects. Occupants are also investigated with respect to their effect on the cause of defects through unexpected or incorrect use of buildings or their services and levels of maintenance.

5.1 Consumer satisfaction

Consumer satisfaction depends on subjective, perceived quality, relying on personal judgement rather than measurement (Auchterlounie, 2009; Eley, 2004). Statistics New Zealand (2013) has attempted to collect data on perceived housing quality, using heating, size, dampness, general condition, pests, cost and accessibility, measuring quality through a limited number of factors. In other sources, a wider range of quantitative and qualitative dimensions are used and proposed to measure housing quality, including economic, political, ecological, architectural, technical and qualitative (Lawrence, 1995). There is continuous change in perception and little agreement in definitions of failure causing further variation (Porteous, 1985). Due to this wide range of quality measures, conformance to identified consumer requirements is argued to be necessary as the “cornerstone of any quality scheme” (Auchterlounie, 2009, p. 241).

Homeowners often do not have the expertise of building professionals when assessing housing. Therefore, they are likely to give more weight to the “softer issues of quality”, such as aesthetic aspects. They assume technical compliance as a ‘given’ due to the regulations and standards in place (Craig, Sommerville & Auchterlounie, 2010, p. 1200). Discussion of these soft issues or human factors include terms such as ‘perception’, ‘attitude’, ‘satisfaction’, ‘judgement’, ‘experience’ and ‘expectation’. Therefore, because “most humans are different it is quite possible for each of these factors to be seen differently by each person” (Auchterlounie, 2009, p. 244). This UK survey demonstrated that consumers and professionals in the construction industry are working towards different quality criteria. Yet, despite these differences, quality standards in the UK are reportedly set by the builder, giving the new home buyer no control over the quality of the finished product (Sommerville & Craig, 2006). This lack of consideration for consumers results in low satisfaction with new houses and constant calls for quality improvement within the industry (Auchterlounie, 2009). The development of consistent quality criteria by house builders is suggested as a way to “significantly improve the current consumer satisfaction ratings and frequency of defects reported in new houses” (Auchterlounie, 2009, p. 250). This set of criteria, based on what consumers want, alongside a robust management strategy is aimed to ensure tradespeople and consumers have consistent criteria to work towards and judge upon. This is rather than making “subjective assessments on non-existent criteria” (Auchterlounie, 2009, p. 250).

Consumer perception of quality also extends to physical tolerances of construction finishes, where inconsistency and misalignment can become a significant aesthetic issue (Forsythe, 2006). Through conversion of consumer perception into quantifiable physical tolerances, this study aims to provide a more balanced approach to the establishment and assessment of quality criteria that takes consumer expectations as well as technical standards into account. The Ministry of Business, Innovation and Employment attempts to achieve such definable tolerances through their *Guide to tolerances, materials and workmanship in new residential construction* (MBIE, 2015). The guide sets assessable criteria for acceptable aesthetic deviations and defines what is and is not acceptable, allowing for agreement in quality criteria between the house builder and the homeowner.

“Overall satisfaction is the customer’s overall satisfaction or dissatisfaction with the organisation based on all encounters and experiences with that particular organisation” (Kärnä, Juha-Matti & Veli-Matti, 2009, p. 113). Therefore, in addition to the finished product, consumer experience and service has been discussed in relation to satisfaction (Auchterlounie, 2009; Curtis, 2016a; Rotimi, Tookey & Rotimi, 2015b). Levels of satisfaction with this experience have been found to be affected by the contractor’s ability to cooperate through communication and the management of changes. Consumers require “open cooperation, flexibility, and more transparent operations from the contractors” (Kärnä et al., 2009, p. 123). Additionally, surveys and interviews with new house owners and house building developers in New Zealand have also reported that “home owners are satisfied when their needs and expectations are met on the backdrop of quality service before and after occupation” (Rotimi et al., 2015b, p. 290). The results of the study found that New Zealand homeowners “generally have cordial relationships with their developers, and are satisfied with the levels of service they provide”. However, it is concluded that “the result does not reduce the need for house developers to give greater consideration to the needs and expectations of home owners” (Rotimi et al., 2015b, p. 289).

Experience prior to the building project is also reported as a factor in determining consumer satisfaction. The BRANZ 2015 New House Owners’ Satisfaction Survey reported a significant difference in how clients rate their builders based on whether or not they had built previously. This demonstrated that clients with previous building experience had higher levels of satisfaction overall (Curtis, 2016a). Focus groups with New Zealand new-build housing clients outlined many issues with client satisfaction with the design, despite varying levels of involvement in the design process. Many problems also resulted from clients’ lack of inexperience with the house building process. In an attempt to bridge the knowledge gap, a BRANZ study report aims to help educate new-build clients to have a more satisfactory building experience. It also offers suggestions for improvements in the way builders deal with their clients in future (Curtis, 2016b, p. 31).

5.2 Consumer-caused rework and defects

The level and time of involvement of consumers within a project has also been found to impact the amount of changes required throughout a project, causing rework. Rework is reported to be caused by a number of interconnected factors. However, studies have found client-initiated changes to be a major determinant (Hwang, Zhao & Goh, 2014; Li & Love, 1998; Love & Edwards, 2004a, 2004b; Love, Edwards, Smith &

Walker, 2009). Because design is an iterative process and clients cannot always be explicit about their requirements from the project outset, design changes are inevitable (Love & Edwards, 2004b). The level of rework resulting from these changes is reportedly affected by management practices. This requires a focus on change mitigation and effective scoping strategies to minimise the risk of cost and schedule over-runs (Love & Edwards, 2004b). A study of client-related rework in Singapore reported that the client contributed most to rework. Client replacement of materials was found to be the most common change. The change of scope or plans by the client had the biggest impact on client-related rework in terms of cost, schedule and quality performance (Hwang et al., 2014). Additionally, rework can result from a client's inability to visualise and gain a realistic appreciation for the end product, especially from 2D drawings during the design development process. This results in clients introducing last-minute changes (Li & Love, 1998).

Occupant actions and knowledge also have an impact on long-term quality issues, with inadequate maintenance and incorrect operation reported as the cause of some latent defects and performance issues. A study of New Zealand housing stock found a large amount of outstanding maintenance requirements in New Zealand homes. This caused occupants "health and safety implications as well as diminishing the investment value of their house" (Page et al., 2013, p. 2). Barriers to sufficient maintenance were identified in terms of affordability. However, outstanding maintenance was still an issue for high-income households. This demonstrated a believed lack of knowledge on the part of homeowners on how to assess the condition of their homes or other spending priorities taking precedence (Page et al., 2013). Research of residential properties in the UK revealed 83.1% of latent structural defects found were avoidable, confirming the importance of implementing a programme of preventive maintenance (Page & Murray, 1996). Ineffective operation of natural and mechanical ventilation systems is a well reported factor in moisture and mould problems in homes, resulting in latent performance issues (Harvie-Clark & Siddall, 2014; McNeil et al., 2014; Su, 2006).

6. Improving the building process

While errors and defects are widely deemed as unavoidable, many techniques and technologies have been developed and investigated to reduce errors, improve defect detection and increase project performance. This includes methods of design and construction, technology and processes for detecting defects and checking compliance, project management techniques and regulatory processes. Contemporary design and construction methods, such as prefabrication and building information modelling (BIM), are investigated as a way to improve quality in new builds and better control project budget and schedule. The idea of quality management and the adoption of lean principles are also discussed as a way to improve project performance through reducing human error, rework and defects. Improved methods to detect defects and check compliance are also discussed in the literature, as well as the standardisation and reporting of defects for the implementation of industry benchmarking. The regulatory process is also reviewed by a number of sources with the aim of better compliance and improved quality in new buildings.

6.1 Skills and practices

Research suggests a skills shortage in New Zealand within the construction industry. Key shortfalls discussed include the ability to read plans, the ability to understand and implement manufacturer correspondence, poor work supervision and the ability to use set out equipment (Hogarth & Kestle, 2014). Findings suggest the importance of carpentry apprenticeships in the long-term solution to the skills shortage, concluding the financial risk to be outweighed by the value gained by employers and the wider industry. Similar US research outlining a skilled labour shortage concludes the key to raising the quality of conformance in the construction industry is education and training in the workforce at a national scale. This needs to be paired with effective supervision (Dubey-Villinger & Dubey, 2003). In addition, the benefits of collaboration and the sharing of skills and experience through supply and subcontractor networks is described. Research findings suggest the benefits of key supplier and contractor involvement. This is to identify problems and defects earlier, when they are easier to correct, as well as propose best-practice solutions and help to avoid problem reoccurrence in the future (Kalu, 2003; Taggart, Koskela & Rooke, 2014).

The need to keep track of industry performance is also discussed, through the establishment of performance metrics and benchmarking to allow for continuous evaluation and improvement within construction companies and industry wide. Benchmarking is discussed as a step towards remediating rework in construction projects and as a means of acquiring knowledge of the magnitude and causes of rework. It also allows preventive activities to be designed and a continuous improvement strategy to be implemented (Love, Smith & Li, 1999). Studies aiming to quantify the effects of rework in construction have been found to have a large variance. Due to the specific nature or small sample sizes, costs reported are not deemed representative or usable for benchmark metrics (Love & Smith, 2003). Therefore, a number of sources investigate the development of industry-wide key performance indicators and metrics programmes to overcome this lack of data. They discuss the need for comparative and standardised benchmarks to allow for continued industry improvement (Ling & Peh, 2005; Love & Smith, 2003; Love et al., 1999; Nasir et al., 2012). One source discusses metric collection specifically for housing quality (Menicou, Vassiliou, Charalambides & Christou, 2012).

Further sources describe the need for evaluative learning tools and strategies for continuous process improvement, based on company or industry-wide metrics. The aim is to improve management strategies and develop a positive error-management culture (Love et al., 2016; Titov, Nikulchev & Bubnov, 2015; Zhang, Haas, Goodrum, Caldas & Granger, 2011). Specific methods for the improvement of quality management within construction are most commonly investigated in relation to lean principles and lean construction methods. Lean construction methods aim to create “sustainable development, continuous improvement, waste elimination, a stronger user focus, increased value for money along with high quality management of projects and supply chains, and improved communications” (Ogunbiyi, Adebayo & Goulding, 2014, p. 88).

A survey of UK-based construction professionals looked at the implementation of lean principles such as just-in-time, visualisation tool, value analysis, daily huddle meetings and value stream mapping. These created improvements with respect to corporate image, process flow and productivity, environmental quality and compliance with consumers’ expectations (Ogunbiyi et al., 2014). Interventions implemented in small UK design and build construction projects demonstrated the benefits of promoting lean thinking tools and process improvement in creating time and cost savings (Emmitt, Pasquire & Mertia, 2012). Similar research in Australia utilised lean thinking to implement a defect incident record process into construction sites, finding benefits in reducing rework costs and eliminating defects (Perera, Davis & Marosszeky, 2011). Additional research looks at supplier quality surveillance, suggesting improvement in the inspection process to ensure acceptable condition of components before installation to provide expected client value (Da Alves, Walsh, Neuman, Needy & Almaian, 2013).

6.2 New technology and processes

Errors on construction sites have been deemed unavoidable, relying on robust inspection processes to detect and communicate errors early and effectively to reduce rework costs and improve quality (Boukamp, 2006). Thirteen sources describe the development of new and improved inspection methods. These utilise technology to improve the efficiency, accuracy or capability of inspections, allowing for defects to be found more easily or recorded in a more reliable manner. These describe:

- the application of thermography to inspect defects in the building envelope (Allen & Allen, 1983; Cox-Smith, 2010; Fox et al., 2014; Fox et al., 2016; Ham & Golparvar-fard, 2014; Korniyenko, 2015; Seeber, 1984; Taylor et al., 2013)
- the development of semi-automated defect detection or expert systems to identify design errors and check compliance through the analysis of drawings (Heikkila & Blewett, 1992; Li, Cao & Lu, 2004)
- CAD-aided robotic on-site defect recording (Paterson, Dowling & Chamberlain, 1997)
- the use of indicator materials with marks that change with environmental exposure (Marston, 2007).

Additionally, the need for industry-wide standardisation in the defect recording processes is outlined. The varied professionals involved on a construction site are found to be producing information incompatible with each other or the next stage in the building process (Sommerville et al., 2004). A New Zealand source calls for adoption of defect reporting as industry best practice and employment of independent inspectors by new homeowners to improve the detection process at handover (Rotimi et al., 2015a).

The investigation of the benefits of building information modelling (BIM) is another common theme among sources aiming to reduce defects or improve building quality. BIM looks to address a wide range of issues including:

- planning and communication (Chelson, 2010; Fan, Skibniewski & Hung, 2014; Rwamamara, Norberg, Olofsson & Lagerqvist, 2010; Sheppard, 2004)
- conflicts, clashes and constructability (Chelson, 2010; Rwamamara et al., 2010; Sheppard, 2004; Valdes, Gentry, Eastman & Forrest, 2016)
- defect data collection (Park, Lee, Kwon & Wang, 2013)
- change management (Fan et al., 2014; Francom & El Asmar, 2015).

Love, Edwards and Han (2011) report a widely advocated reduction of design and construction errors through BIM implementation. However, it is argued the adoption of BIM can only be effective if implemented correctly and utilised as an enabler for error containment and reduction strategies (Love, Edwards & Han, 2011; Love, Edwards, Han & Goh, 2011). The wider adoption of BIM within New Zealand construction projects has been investigated. However, this is only with respect to large-scale public sector construction projects, looking at the government as a client (Cunningham, 2015), as well as in general, with respect to promoting innovation within the New Zealand construction industry (McMeel & Sweet, 2016).

Further sources promote 3D computer-aided design (CAD) in general for its improved ability to:

- communicate design ideas to clients, reducing client-initiated changes (Li & Love, 1998)
- communicate engineering information, with the aid of 3D printing (Dadi, Taylor, Goodrum & Maloney, 2014a; Dadi, Taylor, Goodrum & Maloney, 2014b)
- facilitate piping assembly and inspection with the aid of augmented reality (AR) (Hou, Wang & Truijens, 2015; Moon, Kwon, Bock & Ko, 2015).

Prefabrication, standardisation and automation are also suggested as new technologies and strategies to improve the construction process. A study of robotic systems for on-site construction works found reduction in time, cost and rework and an increase in quality compared to manual labour (Kumar, Balasubramanian & Raj, 2016). More commonly, sources discuss prefabrication or off-site construction techniques as an alternative to traditional construction. They argue benefits such as reduction in construction time, cost and defects (Murray, Fernando & Aouad, 2003) and improved quality (Simion-Melinte, 2013).

The implications of various types of prefabrication have been investigated in the New Zealand context, providing information at project and industry scale. Commercial, housing, apartment, educational and community buildings in Auckland were studied. An average of 34% reduction in time and 19% reduction in cost through the use of prefabrication systems compared to traditional building systems was reported (Shahzad, Mbachu & Domingo, 2015). Further research by BRANZ concludes that the prefabrication of buildings and building elements in New Zealand provides greater security and potential for further improvement in economic outcomes. It also provides greater opportunity for enhanced environmental sustainability than traditional construction (Burgess, Buckett & Page, 2013). Studies into opportunities and impacts of advanced residential construction techniques within the New Zealand construction industry discuss off-site construction as a promising solution to addressing industry criticisms of productivity, quality and value for money (Buckett, 2013, 2014). The current and potential uptake of standardisation and prefabrication and the obstacles faced by the industry in wider adoption of these methods have also been analysed. This sets out a strategy for "boosting uptake" of standardisation and prefabrication in New Zealand (Page & Norman, 2014, p. 32).

6.3 Regulation and certification

Various certification processes have been implemented or suggested as ways to improve quality and provide quality assurance to the consumer. In New Zealand, the Licensed Building Practitioner (LBP) Scheme was implemented to restrict aspects of the design and construction of residential buildings. This was to address deficiencies in the industry resulting in inadequate contract documentation, trade skills and supervision on site, as well as a lack of cooperation and sharing of responsibility on site (Murphy, 2014). However, there "remain concerns … [that the new legislation] does not address all of the issues necessary to achieve the desired result of greater accountability for LBPs and, as a result, better quality building outcomes for all New Zealanders" (Murphy, 2014, p. 300).

A study compared defects in houses constructed by registered builders with houses built by unregistered owner builders in Australia. It found no significant difference in the type or number of defects between the two groups. It concluded with the suggestion that registered builders in Victoria are "providing little added value" (Georgiou, Love & Smith, 1999, p. 167). A more recent study in Victoria compared the number of defects in houses built under the House Contracts Guarantee Act (1987) with those built by registered builders under the Domestic Building Contracts Tribunal Act (1995). It found an increase in the number of defects per house under the new Act rather than the decrease desired through the implementation of the new legislation. It concluded that "government legislation alone does not influence and improve the quality of house construction" (Georgiou, 2010, p. 380).

Rather than compulsory legislation, further studies discuss voluntary quality certification under the ISO 9000 series. In Australia, the certification is only required for those organisations wishing to do business with government agencies and major private companies (Love & Li, 2000). The purpose of the certification is to facilitate continuous improvement within an organisation and provide the consumer with quality assurance (Love & Li, 2000). There are major barriers to using the ISO 9000 series effectively by implementing a sustainable continuous improvement strategy. These are reported to be the large amount of paperwork required as well as organisations opting to "go through the motions" to achieve marketing benefits (Love & Li, 2000). Similar pressure to become ISO compliant in the UK is reported for organisations with consumers in the public sector. The presumption is that ISO 9000 implementation will successfully address quality issues (Sommerville et al., 2005). Despite concerns of ISO 9000 ineffectiveness in the UK, a survey of Australian organisations reported 72.4% of respondents found the benefits of ISO 9000 and similar quality systems outweigh their disadvantages. Benefits include reduction in defects, rework and repair and an improvement in operational efficiency, risk management and documentation (Karim, Marosszeky & Kumaraswamy, 2005).

6.4 Conclusion

Many innovative new processes, technologies and techniques have been proposed by researchers in a range of New Zealand and international contexts, addressing a wide range of identified issues within the building process. However, due to the extremely varied nature of construction projects, no one solution fits all. Results of studies provide mixed views on the effectiveness of each measure from different projects and participants. For this reason, sources often suggest the need for continuous evaluation and development within companies and the industry as a whole. This would utilise new technologies and ideas as tools to inform and carry out this process improvement rather than expecting them to be effective one-off solutions in isolation.

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Appendix A: Methodology

Initial scoping searches were done in a range of databases using the search terms 'building' or 'construction' or 'hous*' and 'defect' or 'quality', taken from the initial literature review proposal. These sought to determine the extent to which defects are a cause for concern in achieving quality residential buildings. The databases Proquest and Scopus were selected, producing the most relevant search results, and used to identify, test and refine the search terms.

Search terms

Terminology is essential in searching for and understanding the literature. The key terms that describe building quality are outlined and defined to illustrate the range and variation evident. Using these terms, found within initial review of the literature, the development of a keyword search strategy and data screening criteria are described.

The results of this search are presented in four themes, apparent through data coding and inductive thematic analysis. These themes cover specific housing quality issues categorised by Building Code clause, life cycle quality issues throughout the project stages, consumer quality perception, satisfaction and end use and methods for improving the building process.

From initial scoping searches, the term 'defect', in combination with either 'building' or 'construction', was found to produce the most effective results. It was found that the term 'quality' produced a very wide range of results, often irrelevant to the identified definition of quality above. Within the relevant results found by searching 'quality', the phrase 'quality control' was frequently found, leading to the use of this phrase instead to better refine search results. The term 'hous*' also produced a large number of results irrelevant to the construction, performance and defined 'quality' of residential buildings. Many results related to the housing of people with specific health conditions, low-income housing in developing countries and the housing of animals or mechanical equipment. The terms 'building' and 'construction' were found to produce a much higher proportion of relevant results and were therefore used instead of 'hous*'.

Further search terms, such as 'snagging', 'handover defect*', 'latent defect*', 'quality defect*' and 'rework', were then identified from common words and phrases within the initial relevant literature and tested for effectiveness. Additionally, synonyms to the word 'defect' were tested, such as 'issue', 'fault', 'imperfection, 'deficiency' and 'negligen*'. However searches using these terms were found to be less effective, with relevant results often referencing the word 'defect'. The keyword 'compliance' was also tested, derived from the quality definition above, resulting in effective searches using both 'compliance' and 'non-compliance'.

Search terms used

'building' or 'construction' AND 'defect*' or 'snagging' or 'latent defect*' or 'quality control' or 'compliance' or 'non-compliance' or 'quality defect*' or 'handover defect*' or 'rework'

Search terms that were tested but not successful

'building' or 'construction' or 'hous*' AND 'quality' or 'amenity defect' or 'issue' or 'fault' or 'imperfection' or 'deficiency' or 'negligen*'

Searches undertaken

Searches were conducted in December 2016, with results limited to the period between and including January 1980 and November 2016. The databases Proquest and Scopus were searched for dissertations and theses, conference papers and proceedings, articles from scholarly journals and books. Grey literature from relevant New Zealand institutional websites was also searched for. Literature was sourced from BRANZ, Statistics New Zealand, Ministry of Business, Innovation and Employment (MBIE), Building a Better New Zealand and New Zealand Construction Industry Council (NZCIC).

Document screening and inclusion criteria

Initial screening of search results was done by title, excluding results not relevant to the built environment. Further screening was done by abstract. This excluded results deemed not to fit within the overall theme of defects or quality and/or relating specifically to countries deemed to be irrelevant to the New Zealand context, non-residential and/or high-rise construction and historic buildings. 369 sources were deemed relevant after this screening and were downloaded into EndNote. This data comprised of 369 documents, including 295 identified through keyword database searching and 74 through hand searching of relevant New Zealand institutional websites.

Further screening was then done again by abstract. This was to remove any results that did not correspond with the definition of quality for this investigation and were deemed not to be applicable to informing new, low to medium-density housing projects within New Zealand. 159 sources were found to be relevant to the aims of this project, through illustrating the range and extent of issues affecting the quality of housing as well as measures to improve these issues. These sources were therefore reviewed further and included within the results section of this report.

Data analysis

The final data, found to meet the screening criteria, was coded into themes that became apparent through review of the abstracts of the relevant literature. Thematic analysis was conducted using an inductive approach, guided by Braun and Clarke's six-phase approach (Braun & Clarke, 2012). This process included:

- familiarisation with the data
- generation of initial codes
- searching for themes
- reviewing potential themes
- defining and naming themes
- producing the report.

Emerging codes were discussed and reviewed amongst the researchers, resulting in an agreement of four main themes that best represented the data within the relevant literature. These themes include sources that discuss specific defects or aspects of building performance that have been coded and discussed under relevant Building Code clauses. Another theme uses the life cycle of a building project to organise sources that investigate when quality issues are caused and found. The third theme focuses on the building user, incorporating the sources coded to concepts such as consumer satisfaction, quality perceptions and client-caused issues. Finally, measures to raise quality found within the literature are outlined by grouping the sources that look to improve the building process.