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Building-quality issues: A literature review

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Preface

This literature review has been carried out as one component of a programme focused on eliminating quality issues in the New Zealand building industry. It answers these questions:

- What previous work has been completed to try and solve common quality issues?
- What are some good examples of successful solutions to common quality issues that we can publicise and learn from?

For this literature review, a building-quality issue results in *a defect created during the construction process*. Wider notions of quality, including considerations of cost, value, location, visual impact, routes/traffic movement, house size, layout, noise/natural light, adaptability, accessibility, sustainability and performance in use are outside the scope of this project.

Building-quality issues are not uncommon in New Zealand or in other jurisdictions, and a range of factors result in defects. The most common causes are poor workmanship, build error, material faults and failures, poor coordination between trades, poor design or procedural errors. These errors occur within the context of a fragmented construction industry, unique production processes, complex products, a dynamic market, a lack of information flow between members of the industry and a lack of product standardisation.

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BRANZ Study Report SR375

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Abstract

This literature review acts as a stocktake on what work has already been undertaken to solve common quality issues in New Zealand and what successful solutions we can learn from. It finds that the solutions have focused around changes in the regulatory environment, the construction workforce, material testing, construction processes, and knowledge and information.

Keywords

Construction quality, eliminating quality issues, solutions, defects

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1.1 New Zealand's approach to solving common building-quality issues

This section considers five components that have impact on building-quality issues in New Zealand: the regulatory environment, workforce, materials, construction processes, and knowledge and information.

The regulatory environment

The leaky homes problem identified in the early 2000s was a catalyst for regulatory change in New Zealand. The Building Act 2004 promotes accountability of all stakeholders and makes building consent authorities responsible for ensuring that building work complies with the Building Code. Critical work is only to be completed by competent practitioners, and builders are incentivised to deliver a building that is free of defects. Changes to this regulatory system were wide ranging, and some further changes are being considered.

The construction workforce

Training for the building and construction industry has undergone significant and disruptive changes since the late 1980s. After the 2011 Canterbury earthquake, the construction industry, the Ministry of Business, Innovation and Employment (MBIE) and the Canterbury Earthquake Recovery Authority (CERA) developed a construction sector workforce plan. However, the demand for building in Auckland, Christchurch and other parts of New Zealand continues to outstrip the supply of appropriately skilled and qualified construction workers.

Material testing

Material testing is well established in New Zealand, with BRANZ conducting independent assessments of building products, materials, systems or methods of design and construction since 1974.

Construction processes

Internationally and in New Zealand, there has been support for improved project management through an approach called lean construction. The approach is described as fostering a more collaborative approach between companies, improving productivity, reducing waste, creating more integrated project teams with better communication, managing project risks and increasing profitability. Lean construction has a dedicated presence in New Zealand through a collaboration between academia and industry. The most common tool used in lean construction is Last Planner, which has been adopted by several of New Zealand's larger construction firms.

Prefabrication has been recognised for reducing defects and improving quality in house construction, possibly due to the longer design process and limited flexibility for changing a design once the construction process has begun. New Zealand has a higher uptake of prefabrication than many other countries, and there is potential to further increase the proportion of prefabricated components and buildings.

Knowledge and information

New Zealand's BIM Acceleration Committee was established in 2014 to coordinate efforts to increase the use of building information modelling (BIM) in New Zealand, and there is a growing uptake in construction projects. BIM has been widely promoted and adopted as a tool for better planning and management and is expected to result in improved performance and quality. It creates a computer model of an asset and enables sharing that information to optimise design, construction and operation of the asset.

The New Zealand Construction Industry Council has published design guidelines since 2003, which have been widely adopted and used. These guidelines address concerns of poor documentation in the building industry and aim to define the responsibilities of parties involved in design and construction.

Benchmarking has been used in New Zealand over the last 7 years for capital projects and infrastructure maintenance by a range of organisations, including leading construction firms, government departments and local authorities. The aim is better and more consistent information on customer satisfaction, conformance with standards and other results so that a firm can improve its effectiveness and product quality.

Investment in research and development is around the same rate as the New Zealand average, although expenditure per investing firm is significantly below the average. A core part of the building research sector in New Zealand is BRANZ, established under the Building Research Levy Act 1969. One of BRANZ's four core research programmes is focused on eliminating quality issues (of which this paper is part).

1.2 Solutions to common building-quality issues

International reforms

The United Kingdom reforms commenced with the Egan Report, issued in 1998. It proposed five key drivers of change: committed leadership, a focus on the customer, integrated processes and teams, a quality-driven agenda and a commitment to people. While there was significant improvement over the following decade, it was not on the scale anticipated by the Egan Report. Areas of improvement were in perceptions of collaboration across the industry and in the success of demonstration projects.

In Australia, the focus in 2008 was on driving innovation and improving productivity in the construction industry. By 2010, an industry innovation council had been established with a mandate to champion and guide the process of industry transformation. The Built Environment Industry Innovation Council issued a recommendations report in 2010 that expressed the need for major construction companies to focus on continual improvement. A final report in 2012 raised concerns with structural issues in the industry that make it difficult to achieve the innovation and productivity envisaged. No further actions appear to have been taken.

In Singapore, the Building and Construction Authority is charged with shaping a safe, high-quality, sustainable and friendly built environment. Multiple initiatives to improve productivity are in place, including productivity targets and monitoring, funding, mandating prefabrication, incentives and education. The result is a year-on-year improvement in productivity and quality. An important component of Singapore's improvement has been the Construction Quality Assessment System (CONQUAS). This enables each building to be allocated a quality score, which is made publicly available.

1.3 Discussion

New Zealand's experience with leaky buildings highlighted the perils of a performance-based regulatory regime when combined with new and unproven techniques. While we have moved on since then, building-quality issues remain. New Zealand is not alone in experiencing these problems, and other jurisdictions have made attempts to improve quality. While reforms have not been as successful as hoped in the United Kingdom and Australia, the Singapore approach has resulted in improvements in productivity and quality year on year. Although the New Zealand Government is unlikely to exert a similar level of control over construction, there is much we can learn from this example, in particular:

- responsibility placed on a government department for setting benchmarks
- funding innovation and education and monitoring results
- the CONQUAS tool, which is used to incentivise getting it right first time through sampling to determine a quality score
- publicly available information to enable clients to explicitly consider the trade-offs between quality and cost.

Building inspections are a cornerstone of the Singapore approach. Normalising post-construction, pre-possession inspections may result in more defects being found and remedied quickly, proactive rectification of defects in advance of an inspection and establishment of a defect database to enable analysis.

Improved construction processes have the potential to improve building quality. These include using Last Planner and other quality assurance mechanisms along with prefabrication of components or buildings. However, major systemic innovation can be difficult, as a range of factors can influence uptake of new processes. This includes the costs, perceived benefits, willingness of clients to invest and ability of firms to implement new ways of working. Designer, construction organisation and client buy-in is critical to innovation in these areas.

While BRANZ provides an independent testing service, there is a lack of certification for products sourced internationally. A more formal regime of material testing may reduce the defects relating to material failure.

2. Introduction

This literature review has been carried out as one component of a programme focused on eliminating quality issues in the New Zealand building industry. It answers these questions:

- What previous work has been completed to try and solve common quality issues?
- What are some good examples of successful solutions to common quality issues that we can publicise and learn from?

Answering these questions will:

- enable better understanding of what previous work has been completed to solve common quality issues
- contribute to understanding how to encourage industry to change practices.

This paper draws on searches of ProQuest, EBSCOHost and Emerald Insight academic databases as well as Google Scholar and Google.

For this literature review, a building-quality issue results in *a defect created during the construction process*. A defect results in "the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time" (Love & Edwards, 2004).

The Ministry of Business, Innovation and Employment (MBIE) explains that a defect includes:

- anything that does not comply with the Building Code
- variations from consented drawings that have not been agreed
- failure to meet the specifications agreed in the contract
- product failure earlier than expected
- failure to achieve acceptable industry levels of quality or performance on items not covered by the first four bullet points (MBIE, 2015).

Wider notions of quality, including considerations of cost, value, location, visual impact, routes/traffic movement, house size, layout, noise/natural light, adaptability, accessibility, sustainability and performance are outside the scope of this project.

2.1 Context

New Zealand surveys have consistently found defects in new houses:

- The *New House Construction Quality Survey 2014* (Page, 2015) found an average of 2.2 compliance defects per house and estimated that, in 8% of houses, the defects were sufficiently numerous to be considered serious.
- The *New House Owners' Satisfaction Survey 2015* (Curtis, 2016) has consistently found a high level of call-backs to fix defects identified at first occupancy.
- *Evaluating defect reporting in new residential buildings in New Zealand* (Rotimi, Tookey & Rotimi, 2015) found that, of the 216 new home owners surveyed, owners had observed an average of 3.5 visible defects per house.

The issue is not restricted to New Zealand. The UK Construction Taskforce (1998) report (commonly known as the Egan Report) cited studies from the United States of America, Scandinavia and the United Kingdom to argue that rework makes up as much as 30% of construction work. Labour is used at less than 60% of its potential efficiency, accidents add 3–6% to project costs and 10% or more materials are wasted. Surveys in the United Kingdom (Craig, 2008) and Australia (Mills, Love & Williams, 2009) identified an average of 53 visible defects per house (UK) and an average cost of 4% in rework (Australia).

2.2 A range of factors – single and interacting – result in defects

Researchers have identified single and interacting factors that result in defects. Single factors represent the direct cause of a defect – for example, poor workmanship. Interacting factors focus on the conditions that allow a defect to occur – for example, where objectives of an organisation focus workers on timeliness over quality. Rotimi (2013) lists the single causes of defects commonly identified in the international literature. The most common causes (in order of frequency) are:

- poor workmanship
- build error (work in wrong location)
- material faults and failures
- poor coordination between trades
- poor design (difficult to build or incomplete)
- procedural errors (construction methods, timing or sequencing).

Analysis of the *New House Construction Quality Survey* (Page, 2015) and an Auckland building inspector's review of issues encountered identify workmanship, build error and poor design as the most common causes of defects in New Zealand. Material faults and failures appear less common in New Zealand than in some other jurisdictions, which may be attributed to the high standard of material assessment in New Zealand.

External and interacting factors can also play a role in causing defects, with various authors identifying the following as root or underlying causes of defects:

- Organisational influence and defective supervision (Aljassmi & Han, 2013).
- Business models, capability, delivery models and industry structure (Wolstenholme, 2009; Rotimi, 2013).
- Environmental factors, such as economic, political and cultural factors (Minato, 2003).
- Organisational factors, such as objectives, goals and allocation of responsibilities (Minato, 2003).
- Client factors, such as their leadership skills or timeframe, budget and scope constraints (Minato, 2003).
- Workplace factors, such as teamwork (Minato, 2003).

Rotimi (2013) identified characteristics of the building industry contributing to building-quality issues in New Zealand as:

- fragmentation of the industry
- uniqueness of each production process
- complexity of the product
- dynamism of the market
- lack of information flow between industry members
- lack of product standardisation.

The construction sector is growing, with 9,500 more businesses in 2012 than in 2002 and 30% more employed workers in the same period. The construction workforce is predominantly male (80%), younger than other high-risk sectors and with a higher proportion of Māori workers than average. A higher proportion of people employed in construction have lower or no qualifications than the New Zealand average (WorkSafe, 2015). A 2013 report estimated the total workforce at around 170,000 people (MBIE, 2013).

The construction sector comprises residential builders (houses and apartments), commercial builders (commercial structures), construction services (the trades, such as electricians, plumbers and concreters) and heavy and civil engineering (such as roads, dams and tunnels). The residential and construction services subsectors are dominated by small businesses, including self-employed contractors (WorkSafe, 2015).

The industry has been subject to significant demand cycles, making investment in firm expansion and the recruitment and retention of skilled staff difficult (WorkSafe, 2015). The consequence of the short-term cycle is that the stakeholders in the industry have a short-term focus. Companies cannot justify investment in training or build a skills pipeline. The industry is encouraged to buy in contractors as needed rather than develop its own capacity (PricewaterhouseCoopers, 2011), and immigration often fills the gaps in the workforce when demand is high (MBIE, 2013). In times of high demand (such as seen in the Canterbury rebuild), project managers may take on significantly more projects concurrently, increasing the risk of errors (MBIE, 2013).

However, the boom-bust cycle is likely to be less pronounced over the next 5 years, as demand for construction in Auckland and Canterbury and on national transport projects is expected to continue (MBIE, BRANZ & Pacifecon, 2016).

The New Zealand construction industry has a culture of working long hours. Workers are more likely to work very long hours than those in other industries and have less employees working flexibly than in other industries. Workers on site were more likely to work very long hours, compared with office-based employees (Morrison & Thurnell, 2012).

Workers in the Australian construction industry were “collectively weary” about the adverse impact on family, mental and physical wellbeing that stems from the confrontational, high-pressure work combined with long working hours (MacKenzie, 2008, as cited in Morrison & Thurnell, 2012). It is likely that, given similarly long working hours, New Zealand construction workers will also experience impacts on their mental and physical wellbeing, leading to errors.

3. What has been done in New Zealand to address building-quality issues?

This review considers five components that impact on building-quality issues: the regulatory environment, the workforce, materials, construction processes, and knowledge and information.

3.1 The regulatory environment

Leaky homes as a catalyst for change

Between the late 1990s and early 2000s, an estimated 42,000 homes vulnerable to damage from leaks were built in New Zealand. Most of the damage from the leaks was done between the 1990s and 2004 (Murphy, 2011). The problem was attributed to the use of new and unreliable designs and materials that were unsuitable for the New Zealand environment (Hunn, Bond & Kernohan, 2002; PricewaterhouseCoopers, 2009). Additional contributing factors included:

- lack of skill among construction workers and supervisors
- poor risk assessment
- consent authority failures
- lack of a systems view when considering building products (Mumford, 2010).

The leaky homes issue was the catalyst for a significant overhaul of the regulatory environment, with the aim of avoiding any such failures in the future.

The Building Act 2004

The Building Act 2004 is legislation to promote accountability of owners, designers, builders, product manufacturers and suppliers, and building consent authorities for ensuring that building work complies with the Building Code. It replaced the Building Act 1991, which consolidated and reformed the law relating to building and to provide for better regulation and control of building.

A system to set standards, provide guidance and monitor compliance

The Building Act 2004 enables government to:

- set expectations for the standards that buildings must meet (the Building Code) – section 400
- provide guidance to all parties involved in building work on how to meet the standards – section 401
- authorise building consent authorities to monitor compliance with the Building Code at the design stage, during the construction process and after completion – section 14F.

The Building Code sets clear expectations of the standards buildings should meet. It covers aspects such as structural stability, fire safety, access, moisture control, durability, services and facilities, and energy efficiency. It states how a building must perform in its intended use rather than how it is designed and constructed (MBIE, 2017).

Critical work only to be completed by competent practitioners

The Licensed Building Practitioners Scheme is intended to ensure that only appropriately skilled practitioners work on or supervise critical parts of the design and building process. This results in a reduced risk of defects through poor workmanship.

Subpart 4 of the Building Act 2004 sets out the requirements for building work. These include that restricted building work is only carried out by licensed building practitioners (LBPs). LBPs are designers, carpenters, bricklayers and blocklayers, roofers, external plasterers, and site and foundations specialists who have been assessed to be competent to carry out work essential to a residential building's structure or weathertightness (MBIE, 2016c).

Restricted building work is building or design work that is critical to the integrity of a building. It ensures the building is structurally sound and weathertight. It includes:

- **the primary structure** (construction or alteration) – all the structural elements of the building that contribute to resisting vertical and horizontal loads
- **external moisture management systems** (construction or alteration) – the building elements and systems that prevent the ingress of external moisture and help control moisture within the building fabric
- **fire safety systems** (design) – the building elements intended to protect people and property from fire (MBIE, 2016e).

The Building Practitioners Board (also enabled through the Building Act 2004) has the power to set the rules for LBPs and receive, investigate and hear complaints about LBPs. This process provides a check that LBPs are delivering work per the standards.

Incentives to deliver a building that is free from defects

Part 4A of the Building Act 2004 sets out the consumer rights and remedies in relation to residential building work. It includes:

- prescribing minimum requirements for residential building contracts over a certain value
- implying warranties into residential building contracts
- providing remedies for breach of the implied warranties
- requiring defective building work under a residential building contract to be remedied if notified within 1 year of completion
- requiring certain information and documentation to be provided on completion of building work under a residential building contract.

By incorporating requirements around warranties and defect remediation, the incentive is for the builder to deliver a building that is free from defects.

3.1.1 Next steps for the regulatory environment

PricewaterhouseCoopers (2009) argues that the incidence of leaky construction had reduced, noting that failure rates since 2006 appeared to be much lower than in previous years. It suggested changes in the regulatory requirements and building practices had addressed the major problems identified in the past and reduced the incidence of weathertightness failures. Regardless, MBIE has several initiatives under way to address problems in the building regulatory system (MBIE, 2016b).

Initiatives that are likely to impact building-quality issues include:

- clearer accountabilities for owners, designers and building consent authorities
- consumer protection and new remedy measures
- implementation of the new risk-based consenting system.

3.2 The construction workforce

Training for the building and construction industry has undergone significant and disruptive changes since the late 1980s. Successive governments have modified the policy settings and structures for industry training, which, at the end of the 1990s, was facing market failure, with acute skills shortages nationwide.

In 1999, Modern Apprenticeships were created to encourage young people into training, although by 2010, the Ministry of Education argued that industry training was delivering a poor return on investment. Changes introduced in 2010 included performance-based funding and minimum achievement requirements. The latest reforms were passed in 2014, which included changes to focus industry training organisations on setting skill standards and arranging training (Piercy & Cochrane, 2015).

After the 2011 Canterbury earthquake, the construction industry, MBIE and the Canterbury Earthquake Recovery Authority (CERA) developed a construction sector workforce plan. This plan addressed issues such as skills shortages, cost escalation, quality problems and challenges in maintaining a skilled workforce (Construction Sector Leaders Group, 2013). In March 2013, the Apprentice Re-Boot initiative was launched to increase the number of apprentices in training. This is expected to increase the number of apprentices in the trades area by 8,000 (MBIE, 2013). Budget 2011 included a $42 million package for trades training in the Canterbury region (Chang-Richards, Seville, Wilkinson & Brunsdon, 2012) to support expanded trades training at institutions across the country. This represented a significant increase in funding for priority trades (for example, carpentry, painting, bricklaying and blocklaying, plumbing) (MBIE, 2013).

The Building and Construction Industry Training Organisation (BCITO) is responsible for developing and implementing industry qualifications for the building and construction sector. It is the largest provider of construction trade apprenticeships in New Zealand. While apprenticeships place trainees on site with supervision provided by experienced tradespeople (BCITO, 2016), some academic institutions, such as Unitec offer entry-level qualifications where trainees work in on-campus workshops (Unitec Institute of Technology, 2016). The BCITO also offers qualifications for supervisors and managers who want to upskill or have their experience recognised (BCITO, 2016).

A media release from the BCITO in December 2016 indicated that, while it is growing, the construction industry has insufficient numbers of skilled people to successfully respond to building consent figures. This same release argued that, as most apprenticeships are with firms who traditionally have apprentices, training programmes need to better recognise the business needs of those who have not previously taken on apprentices (BCITO, 2016).

Along with the shortage of people available to carry out construction, councils report a shortage of building inspection staff (Cairns, 2015; Scoop, 2015, 2016). This shortage is expected to continue due to the increasing demand for construction.

3.3 Material testing

Since 1974, BRANZ has conducted independent assessments of building products, materials, systems or methods of design and construction. This provides owners and clients with confidence that the product has been subject to in-depth and rigorous examination. BRANZ provides this service within New Zealand and in other countries, including Australia (BRANZ, 2016).

3.4 Construction processes

Lean construction and the Last Planner system

Both in New Zealand and internationally, there has been support for improved project management through an approach called lean construction. The approach is described as fostering a more collaborative approach between companies, improving productivity, reducing waste, creating more integrated project teams with better communication, managing project risks and increasing profitability. Lean construction is reported as achieving significant benefits in the United Kingdom, Singapore, Brazil, Chile, the Netherlands, South Africa, Turkey, the United States of America and many other countries (Ogunbiyi, Oladapo & Goulding, 2014). However, some research has shown that lean implementation systems may not be implemented effectively. A study of Australian construction firms showed the implementation of the lean construction approach was hindered by several misconceptions about the concept. Misconceptions included issues of how much process standardisation was required, whether the agenda for change needs to be set centrally or at the local level and what sort of overall company strategic direction is required for successful implementation (Cheswith, 2015).

Lean construction has a dedicated presence in New Zealand through the Lean Construction Institute of New Zealand, a collaboration between industry and academia. A study on the use of lean construction in New Zealand identified that the Last Planner system is the vehicle used most commonly to implement lean construction. Other lean construction ideas such as continuous improvement, supply chain management and waste minimisation and JIT (a lean tool) have also been implemented, albeit to a lesser extent (Sadler, 2011).

Since 2009, Last Planner has been adopted by several of New Zealand's larger construction firms (Constructing Excellence New Zealand, 2016a). The Last Planner system is intended to promote communication at the worksite, allowing people to deal with problems as they emerge. A 2013 report on Last Planner (Mossman, 2013) drew on other research that showed a range of impacts from the Last Planner system, including:

- greater safety – lower accident frequency and severity
- improved predictability of projects
- more proactive project management
- reduced waiting times during projects
- effective work relationships.

Last Planner is intended to decentralise decision making by giving authority to people on the worksite to make decisions about project delivery. Mossman describes it as involving 5+1 conversations:

1. Agreeing on the sequence of production activities. This collaborative programming is expected to engage all parties, including specialist contractors, so they sign up to the plan and schedule.
2. Make ready: preparing for tasks in the upcoming period so they can be carried out.
3. Making a collaborative agreement on the tasks to be carried out in the next day or week.
4. Collaborative production monitoring to keep tasks on track.
5. Ongoing measurement, learning and continuous improvement. At regular meetings, participants report on the percentage of promises completed, a measure of delivery in accordance with the current schedule for a given period.

The +1 conversation is a First Run Study, which could occur at any time during the project. First Run Studies focus on selected processes to improve them. They are based on the plan-do-check-act cycle. All last planners take part in a regular production evaluation and planning meeting, usually on a weekly basis (Mossman, 2013).

Prefabrication

Prefabrication has been recognised for reducing defects and improving quality in house construction (Blismas & Wakefield, 2009; Burgess, Buckett & Page, 2013; Johnsson & Meiling, 2009; Nadim & Goulding, 2011; Prefab NZ, 2014). A study by KPMG found that off-site manufacturing improves building quality and may reduce the life cycle costs of a building (KPMG UK, 2016). A report from McGraw-Hill Construction noted that most respondents to a US survey of construction firms, architects and others believed that prefabrication improves building quality. In part, this is because factory conditions allow for greater quality control than is achievable on a building site. It was also noted that building work done in a factory is not subject to the elements in the same way as on-site construction (McGraw-Hill Construction, 2011).

Off-site manufacturing includes a longer design process and limited flexibility for changing a design once the construction process has begun (Blismas & Wakefield, 2009). This is likely to reduce the errors relating to poor design or design changes throughout the construction process.

New Zealand has a higher uptake of prefabrication than other countries, with an estimated 32% uptake. For comparison, Australia (3%), the United Kingdom (4%) and Spain (5%) have very low uptake. Alternatively, panellised housing is the norm in Sweden, with 90% uptake (Prefab NZ, 2015). In New Zealand in 2011 and 2012, prefabricated panels and roof trusses were the most common elements of prefabrication in use (Burgess et al., 2013).

3.5 Knowledge and information

Building information modelling (BIM)

Building information modelling (BIM) has been widely promoted and adopted as a tool for better planning and management, expected to result in improved performance and quality (Poirier, Staub-French & Forgues, 2015). The Australian Built Environment Industry Innovation Council recommended industry-wide use of building information modelling (Built Environment Industry Innovation Council, 2010), and in some countries, BIM processes have been mandated (MBIE, 2016d).

Building information modelling creates a computer model of an asset and enables sharing that information to optimise the design, construction and operation of that asset (MBIE, 2016a). Researchers are positive about the ability of BIM to improve quality in construction due to the potential to improve planning (Jrade & Lessard, 2015). In the *New Zealand BIM Handbook* (MBIE, 2016d), the identified benefits of using BIM include:

- better planning of site activities and optimisation of the construction sequence
- quicker and more accurate set-out
- more prefabrication off site as building elements can be modelled, documented and manufactured with greater precision.

These all contribute to fewer errors in the construction process.

There is limited information available on the effectiveness of BIM or consistent definitions of the concept (Barlish & Sullivan, 2012). One example of relevant research is provided by a case study of a relatively small construction firm in Canada. It concluded that the software helped the company control costs but did not affect the numbers of change orders or the level of rework required (Poirier et al., 2015). A significant demonstration project in the United Kingdom (new build, £96 million) was brought in on time and on budget with zero defects. This result was “greatly aided by the use of BIM” (Constructing Excellence in the Built Environment, 2010).

The BIM Acceleration Committee was established in 2014 to coordinate efforts to increase the use of BIM in New Zealand. It is sponsored by the Productivity Partnership and BRANZ. A National Standards Technical Committee is overseeing the development of standards for building and location data to ensure compatibility between systems and data (MBIE, 2016a).

A baseline study of the use of BIM in New Zealand identifies a growing uptake of the use of BIM in construction projects. In 2016, there were increases in the use of BIM in each of the preplanning, design and construct phases of projects. Further measurement of BIM uptake is planned in 2017 and 2018 (EBOSS, 2015).

Design documentation guidelines

The New Zealand Construction Industry Council publishes design guidelines focusing on defining the responsibilities of parties involved in design and construction on a phase-by-phase basis (MBIE, 2016d). In 2003, the New Zealand Construction Industry Council developed guidelines (based on wide industry consultation and international experience) to address concerns of poor documentation in the building industry in New Zealand. These guidelines have been widely adopted and used, with the latest update completed in 2016. The intention is to undertake a structured process of review every 3–5 years, taking into account developments in the industry such as BIM, environmentally sustainable design and health and safety in design (New Zealand Construction Industry Council, 2016).

Benchmarking

Better and more consistent information on customer satisfaction, conformance with standards and other results is seen as critical to improving firms’ effectiveness and product quality (Department for Communities and Local Government, 2007). Leonard (2010) argues that companies should benchmark their performance against other construction firms and against firms outside the construction industry. Wider benchmarking is seen as essential for introducing new management tools and techniques and promoting quality, safety and sustainability. The Australian Built Environment Industry Innovation Council also recommended the use of performance metrics (Built Environment Industry Innovation Council, 2010). The Egan Report calls for measurable improvement targets that are agreed with clients, allow for comparison across the industry and are shared with customers.

Benchmarking has been used in New Zealand over the last 7 years for capital projects and infrastructure maintenance by a range of organisations, including leading construction firms, government departments and local authorities (Constructing Excellence New Zealand, 2016b).

Research

Investment in research and development in the construction industry is around the same rate as the New Zealand average, although expenditure per investing firm is significantly below the average (MBIE, 2013). Section 8(1) of the Building Research Levy Act 1969 enables BRANZ to collect levies from builders "for the purposes of promoting and conducting research and other scientific work in connection with the building construction industry". As well as conducting research in house, BRANZ partners with other organisations to develop solutions to industry issues. In 2016/17, one of BRANZ' four core research programmes is focused on eliminating quality issues (of which this paper is part).

4. What solutions to common building-quality issues can we learn from?

United Kingdom

In 1997, the Deputy Prime Minister set up a Construction Task Force to advise on opportunities to improve efficiency and quality in the delivery of construction in the United Kingdom (UK Construction Taskforce, 1998). The result was a wide-ranging report (commonly known as the Egan Report after the Chair, Sir John Egan) that had influence on the direction of construction in the United Kingdom into the 2010s (Cabinet Office, 2016).

The Egan Report proposed five key drivers of change:

1. Committed leadership.
2. A focus on the customer.
3. Integrated processes and teams.
4. A quality-driven agenda.
5. A commitment to people.

It also proposed targets for improvement, including annual cuts of 10% in construction cost and time and annual cuts of 20% in construction defects. To achieve the targets and fulfil its potential, the report recommended radical changes to processes and a change in culture and structure of the industry. Standardisation was also recommended. It also called for large firms to take leadership on the recommendations and for a fund for demonstration projects (UK Construction Taskforce, 1998).

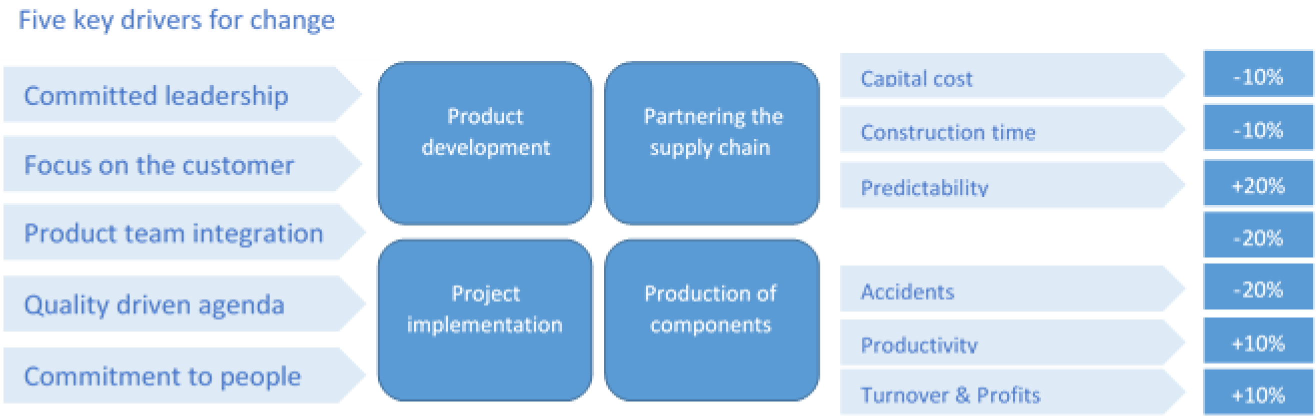

Figure 1. Egan Report summary.

Source: Adapted from Wolstenholme (2009).

An earlier report on the United Kingdom construction industry had promoted the idea of partnerships between clients and contractors, with ongoing relationships to promote better-quality results (Latham, 1994). The Egan Report built on this with a call for long-term relationships or alliances throughout the supply chain. The report argued that construction teams should stay together for learning and greater efficiency over time and that suppliers should form long-term alliances, relying less on contracts (UK Construction Taskforce, 1998).

Four years later, the Strategic Forum for Construction, also chaired by Sir John Egan, strengthened the call for strategic partnerships. Doing so would reduce costs and improve outcomes for all parties in the supply chain, up to and including clients (Strategic Forum for Construction, 2002).

While there was significant improvement over the following decade, it was not on the scale anticipated by the Taskforce. Reasons for the lack of progress included the following:

- **Business models**: It was the larger firms with repeat business and ongoing client relationships that best implemented changes.
- **Capability**: There was a lack of industry leaders, difficulty in recruiting young workers (new talent) because they do not see construction as a career path, a lack of industry accreditation and a lack of career paths.
- **Delivery model**: Only 50% of projects come in on budget, prime contractors tend to pass risk down the supply chain, public sector procurement departments fail to take operating costs into account, clients do not define what provides the greatest value to them and contractors are appointed separately and do not create an integrated design.
- **Industry structure**: This is fragmented and dominated by small and medium enterprises, there is no single voice for the industry and there are too many industry bodies (Wolstenholme, 2009).

Areas of improvement were in perceptions of collaboration across the industry and in the success of demonstration projects. A programme of demonstration projects was implemented, and 10 years after the report, this was continuing at around 100 projects a year. Based on the key performance indicators suggested in the Egan Report, these demonstration projects consistently outperformed the rest of the industry (Wolstenholme, 2009). However, they have not resulted in significant changes throughout the industry. An analysis of demonstration projects after 10 years of operation found that individuals in the demonstration projects have built knowledge and can use this knowledge in other projects. However, the form of reporting used for demonstration projects does not enable knowledge transfer (Smyth, 2009).

Also in response to the report, industry groups were formed. The United Kingdom was the first to form Constructing Excellence, a platform for industry improvement through collaborative working. Other groups in the United Kingdom include:

- The Housing Forum – a membership network of organisations and businesses who collaborate to develop and improve the nation's housing stock
- Movement for Innovation, which aims to lead radical improvement in construction in value for money, profitability, reliability and respect for people, through demonstration and dissemination of best practice and innovation.

A Constructing Excellence consultancy is based in New Zealand.

Finally, the UK Government's *Government Construction Strategy: 2016–20* (Cabinet Office, 2016) describes how it plans to become a better client of construction, thus improving productivity. Core areas for improvement include understanding building information modelling and other construction technologies, undertaking construction cost benchmarking and publishing a government construction pipeline. The aim is that the construction industry has sufficient information to effectively respond to government's construction needs.

Australia

In 2008, the Built Environment Industry Innovation Council was established to advise the Australian Government on how to drive innovation and improve productivity in the Australian construction industry (Built Environment Industry Innovation Council, 2010). High hopes were held for the group, with the responsible Minister expecting the Council to address challenges like 'climate change, sustainability and industry competitiveness' (Ministry for Innovation, Industry, Science and Research, 2008).

By 2010, the Australian Government had established eight industry innovation councils, each with a mandate to champion and guide the process of industry transformation. The Chair of each of these councils collaborated in development of a set of outcomes for the councils, underpinned by strategic roadmaps for the Built Environment, Future Manufacturing, Information Technology, Space and Textile, Clothing and Footwear Industry Innovation Councils. The Built Environment roadmap set out desired outcomes to be achieved by 2014, pathways to achieving the outcomes and eight milestones for 2010. It had a strong focus on developing and promoting building information modelling to improve practices and processes (Department of Innovation, Industry, Science and Research, 2010).

The Built Environment Industry Innovation Council issued a recommendations report (Built Environment Industry Innovation Council, 2010) that expressed the need for major construction companies to focus on continual improvement. It identified better-practice improvements as:

- working in collaborative teams
- using new tools and technologies
- using procurement practices that require integrated working and supply chains
- focusing on value rather than the lowest price
- paying on time
- training staff
- maintaining high safety standards
- delivering projects on time.

The four recommendations relating to better practice were:

- consider the establishment of an organisation like the United Kingdom's Constructing Excellence
- encourage industry-wide use of building information modelling and support pilot projects that demonstrate the benefits of applying new technology
- establish common performance metrics for the industry
- develop a national industry education and training action plan.

A final report from the Built Environment Industry Innovation Council in 2012 raised concerns with structural issues in the industry, including its fragmented nature, resistance to change and crisis in the materials sector. Training and skills development was identified as critical for the future of the industry (Built Environment Industry Innovation Council, 2012).

Despite the calls for continued government focus on innovation in the construction industry and a reduction in construction industry productivity in Australia (Loosemore & Richard, 2015), there appears to be no ongoing government-led reform.

Singapore

In Singapore, the lead government agency for construction is the Building and Construction Authority. This agency is charged with shaping a safe, high-quality, sustainable and friendly built environment (Building and Construction Authority, 2016). Its 2015/16 Annual Report highlighted year-on-year improvements in productivity and a need to do better. It stated "the more productive we are, the better our architects, contractors, technicians and construction workers can put effort and produce results instead of generating work which then has to be reworked …" (Building and Construction Authority, 2016, p. 32).

Initiatives to improve productivity include:

- setting productivity targets and measuring results across a range of variables
- government funding of S$450 million for a Construction Productivity and Capability Fund
- development of a Productivity Gateway Framework to help raise construction productivity of public sector projects – key considerations were the adoption of transformative technologies and design for manufacturing and assembly (DfMA) and collaboration and integration through virtual design and construction (VDC)
- mandating DfMA technologies such as prefabricated prefinished volumetric construction and prefabricated bathroom units as a condition for government land sales
- setting buildable design (B-Score) and constructability scores (C-Score) for all building projects
- incentivising private residential construction by allowing bonus gross floor areas for balconies if productivity prerequisites were met
- more timely construction market information
- opening a construction productivity gallery dedicated to educating the industry on productivity (Building and Construction Authority, 2016).

An important component of Singapore's improvement in productivity and quality has been the Construction Quality Assessment System (CONQUAS). This system allows for each building to be designated with a quality score of between 0 and 100%. The scores are publicly available through the Building and Construction Authority website, along with the main contractor's name (Building and Construction Authority, 2017). As scores are assessed during construction, the incentive on contractors is to get it right first time, avoiding any defects and rework. Analysis of house prices has shown that, the higher the CONQUAS score, the higher the sale price, and this result persists in subsequent house sales (Ooi, Le & Lee, 2014).

5. Discussion

International experience

New Zealand's experience with leaky buildings highlighted the perils of a performance-based regulatory regime when combined with new and unproven materials and techniques. Building-quality issues continue in the industry today. These issues can be attributed to a range of causes, including poor workmanship, build error and poor coordination between trades. At a higher level, the fragmentation of the industry, uniqueness of each production process, complexity of the product and dynamism of the market make it difficult to avoid building-quality issues.

New Zealand is not alone in experiencing these problems, and other jurisdictions have made various attempts to improve quality. One of the most comprehensive calls for reform was based in the United Kingdom and has driven change in the industry for 15 years. However, limited success has been achieved due to:

- smaller firms being unable or unwilling to make changes
- capability that reflects a perception of the industry as being an undesirable career pathway
- a delivery model that encourages competition rather than cooperation
- a fragmented industry structure.

The Australian challenge for a more innovative construction industry over the last decade appears to have been mired in similar issues. These are all problems that New Zealand faces.

In contrast, the Singaporean experience has resulted in improvements in productivity and quality year on year. The comprehensive approach includes targets, measurement, funding, education, incentivisation and inspection, underpinned by publicly available information. The result is higher-quality buildings that consider user-friendly design and sustainability.

While the New Zealand Government is unlikely to exert a similar level of control, there is much we can learn from this example, in particular:

- a government department has responsibility for setting benchmarks, funding innovation and education, and monitoring results
- the CONQUAS tool uses sampling to determine a quality score for each building, considering structural defects (covered in New Zealand by building consent authorities) and visible defects (the responsibility of the client to identify and negotiate repair in New Zealand)
- the method used to implement the CONQUAS tool incentivises builders to get it right first time rather than rely on going back to repair defects
- publicly available information identifies construction companies with a track record of delivering higher-quality buildings, enabling clients to explicitly consider the trade-offs between quality and cost.

Building inspections

The New Zealand regulatory system aims to ensure critical work is carried out by competent people and that incentives are in place for builders to get it 'right first time'. However, there are not enough trained people, including building inspectors, to respond to the demand for construction. The risk is that higher numbers of defects are being created that are missed by building inspectors. The inexperience of clients may also mean delayed identification of visual defects or unrealistic expectations for builders. A concentrated effort is required to forecast the demand for construction workers and building inspectors and to respond with appropriate training so that future shortages are avoided. There may also be merit in considering whether visual defects should form a part of the building consent process or, as Rotimi (2013) suggests, whether to normalise independent building inspections when buildings are completed. More accessible information for inexperienced clients may also support a reduction in defects that are left unaddressed.

Learning from defects is commonly advocated as a way to reduce recurring defects in the new-build housing sector (Hopkin, Lu, Rogers & Sexton, 2016), and building contractors consider defect data an untapped source of improvement (Lundkvist, Meiling & Sandberg, 2014). However, research has found a lack of comprehensive defect feedback systems that are used proactively (Hopkin et al., 2016; Lundkvist et al., 2014).

Craig (2008) notes there are two opportunities to inspect new builds for defects: during construction and after completion. Rotimi et al. (2015) report on a survey of new homeowners in New Zealand and their experience of defects after completion. Their survey found that, when a building inspector was engaged, on average, more defects were found. However, relatively few homeowners engage a professional building inspector after completion of a build, possibly due to a sense of costs avoided. Note that building inspection is common practice in the purchase of an existing home.

Implications of this study are that normalising the use of independent building inspectors when purchasing a newly built house may result in:

- a greater number of defects found – and rectified – before possession is taken of the house
- tradespeople pre-empting the inspection with their own assessment and proactively rectifying defects
- establishment of a defect database providing a benchmark for future performance and opportunities for more thorough analysis of where defects occur.

A further recommendation of Rotimi (2013) was that financial institutions should only release funds on provision of an independent building inspection report.

Construction processes

Improved construction processes using tools such as Last Planner and quality assurance mechanisms may improve building quality. Building information modelling may also reduce the amount of rework due to requirements being fixed at an earlier stage. These tools require commitment from the industry, and we note the high number of small to medium-sized firms involved in the industry. Many of these firms will need to be convinced of the benefits of adoption of new ways of working and support to do so.

Similarly, prefabrication is one area that has potential to grow. However, while it is relatively easy to implement small changes, systemic innovation on a large scale (such as dramatically increasing the amount of prefabrication) often fails (Lindgren & Emmitt, 2017). For this approach to be successful, designers and clients need to be convinced of the benefits.

Analysis of systemic innovation in Sweden, using a longitudinal study of a multi-storey timber house system, found that the main factors that influence systemic innovation (as it related to multi-level timber housing) are:

- recognition and tradition, where the innovation is seen to be an improvement on an existing system
- external drivers, such as sustainability or cost considerations
- complexity in managing the system and clients, where simplicity is desirable
- financial aspects, such as setting competitive prices
- the level of definition of the system.

The uptake of off-site production by the construction industry has been low in the European Union and elsewhere. Reasons given for the low uptake have generally focused on the difficulty in ascertaining benefits and a negative image of prefabrication, including poor quality, poor aesthetics, lower choice and previous failures. A 2008 study across the construction industry in four European countries found five main patterns of interrelated concerns, which were the:

- process – legislation, construction processes, information and production
- product – cost, quality, design and sustainability
- technology – product technology, information technology and process technology
- people – skills and culture
- market – willingness to invest (Nadim & Goulding, 2011).

Addressing these concerns is key to enabling more extensive prefabrication in the European market. Finally, care should be taken to ensure that quality improvements are achieved. A study in Sweden of two construction firms used quality audits at different stages of the building process to estimate the level of defects in on-site and off-site construction. Most defects were small, resulting from human error and requiring minor adjustments for correction. The study concluded that the overall level of defects in on-site and off-site construction projects was the same (Johnsson & Meiling, 2009). A further study quoted in Burgess et al. (2013) noted off-site construction reduces the skill level needed on site but that this may result in a higher risk of defects for on-site processes.

Materials

While BRANZ provides an independent testing service, Rotimi (2013) notes a lack of certification for products sourced internationally. Concern was raised that no products were banned, including those with asbestos. Similarly in Australia, concern has been raised that inferior, untested products are being used in construction due to their cheaper price (Built Environment Industry Innovation Council, 2012). A more formal regime of material testing, especially on imported products, may reduce the number of defects related to material failure.

6. Conclusion

This work will inform work going forward in the eliminating quality issues research programme at BRANZ. It complements other work currently under way and upcoming projects within the programme, providing an overview of the existing knowledge base in the area.

References

Aljassmi, H. & Han, S. (2013). Analysis of causes of construction defects using fault trees and risk importance measures. *Journal of Construction Engineering and Management, 139*(7), 870–880.

Barlish, K. & Sullivan, K. (2012). How to measure the benefits of BIM – a case study approach. *Automation in Construction, 24*, 149–159.

BCITO. (2016). *Construction training requires greater industry alignment*. Retrieved 16 January 2017 from http://bcito.org.nz/news-and-publications/news/construction-training-requires-greater-industry-alignment/

Blismas, N. & Wakefield, R. (2009). Drivers, constraints and the future of offsite manufacture in Australia. *Construction Innovation, 9*(1), 72–83.

BRANZ. (2016). *Appraisals*. Retrieved 16 January 2017 from http://www.branz.co.nz/aboutappraisals

Building and Construction Authority. (2016). *Changing the way we build: Building and Construction Authority annual report 2015/16*. Singapore: Author.

Building and Construction Authority. (2017). *Construction Quality Assessment System CONQUAS*. Retrieved 7 January 2017 from https://www.bca.gov.sg/Professionals/IQUAS/conquas_abt.html

Built Environment Industry Innovation Council. (2010). *Recommendations report*. Canberra, Australia: Commonwealth of Australia.

Built Environment Industry Innovation Council. (2012). *Final report to the government*. Canberra, Australia: Commonwealth of Australia. Retrieved from https://timhortonblog.files.wordpress.com/2013/01/beiicfinalreporttogovernment2012.pdf

Burgess, J., Buckett, N & Page, I. (2013). *Prefabrication impacts in the New Zealand construction industry*. Study Report SR279. Judgeford, New Zealand: BRANZ Ltd.

Cabinet Office. (2016). *Government construction strategy: 2016–20*. London, UK: Author.

Cairns, L. (2015, 20 March). Consents delayed by inspection failures. *The Press*, p. A4.

Chang-Richards, A., Seville, E., Wilkinson, S. & Brunsdon, D. (2012). *The Canterbury earthquake: Challenges and opportunities for construction organisations* (5). Auckland, New Zealand: Resilient Organisations.

Cheswith, B. (2015). *Misconceptions of lean: Why implementation fails.* Paper presented at the 23rd Annual Conference of the International Group for Lean Construction, Perth, Western Australia.

Constructing Excellence in the Built Environment. (2010). *Wellcome Trust Sanger Institute demonstration project*. London, UK: Author.

Constructing Excellence New Zealand. (2016a). *Last planner*. Retrieved 18 January 2017 from http://www.constructing.co.nz/Service/Constructing-Excellence/Last-Planner

Constructing Excellence New Zealand. (2016b). *Performance measurement & benchmarking*. Retrieved 18 January 2017 from http://www.constructing.co.nz/Services/Constructing-Excellence/Benchmarking

Construction Sector Leaders Group. (2013). *Construction sector workforce plan for greater Christchurch*. Retrieved 17 January 2017 from http://www.constructionstrategygroup.org.nz/downloads/Construction_Sector_Plan_-_FINAL.pdf

Craig, N. (2008). *The prevailing trend of defects and snagging in new homes in the UK* (PhD, Glasgow Caledonia University, Glasgow).

Curtis, M. (2016). *New home owners' satisfaction survey 2015.* Study Report SR348. Judgeford, New Zealand: BRANZ Ltd.

Department for Communities and Local Government. (2007). *The Calcutt review of housebuilding delivery*. London, UK: Author.

Department of Innovation, Industry, Science and Research. (2010). *Industry innovation councils update: Towards innovative Australia*. Canberra, Australia: Commonwealth of Australia.

EBOSS. (2015). *BIM in NZ: An industry-wide view 2015*. Retrieved 16 January 2017 from https://www.eboss.co.nz/bim-in-nz-an-industry-wide-view

Hopkin, T., Lu, S-L., Rogers, P. & Sexton, M. (2016). Detecting defects in the UK new-build housing sector: A learning perspective. *Construction Management and Economics, 34*(1), 35–45.

Hunn, D. Bond, I & Kernohan, D. (2002). *Report of the overview group of weathertightness of buildings*. Wellington, New Zealand: Building Industry Authority.

Johnsson, H. & Meiling, J. H. (2009). Defects in offsite construction: Timber module prefabrication. *Construction Management and Economics, 27*(7), 667–681. doi:10.1080/01446190903002797

Jrade, A. & Lessard, J. (2015). An integrated BIM system to track the time and cost of construction projects: A case study. *Journal of Construction Engineering* (579486).

KPMG UK. (2016). *Smart construction: How offsite manufacturing can transform our industry*. London, UK: KPMG LLP.

Latham, M. (1994). *Constructing the team*. London, UK: HMSO.

Leonard, D. (2010). Quality management practices in the US homebuilding industry. *The TQM Journal, 22*(1), 101–110. doi:10.1108/17542731011009658

Lindgren, J. & Emmitt, S. (2017). Diffusion of a systemic innovation. *Construction Innovation, 17*(1), 25–44.

Loosemore, M. & Richard, J. (2015). Valuing innovation in construction and infrastructure. *Engineering, Construction and Architectural Management, 22*(1), 38–53.

Love, P. E. D. & Edwards, D. J. (2004). Forensic project management: The underlying causes of rework in construction projects. *Civil Engineering and Environmental Systems, 21*(3), 207–228.

Lundkvist, R., Meiling, J. & Sandberg, M. (2014). A proactive plan-do-check-act approach to defect management based on a Swedish construction project. *Construction Management and Economics, 32*(11), 1051–1065. doi:10.1080/01446193.2014.966733

MBIE. (2013). *Construction*. Wellington, New Zealand: Author. Retrieved from http://www.mbie.govt.nz/info-services/business/business-growth-agenda/sectors-reports-series/pdf-image-library/construction-report/construction-report.pdf

MBIE. (2015). *Guide to tolerances, materials and workmanship in new residential construction 2015*. Wellington: MBIE.

MBIE. (2016a). *Building information modelling (BIM) in New Zealand*. Retrieved 16 January 2017 from www.building.govt.nz/projects-and-consents/planning-a-successful-build/scope-and-design/bim-in-nz

MBIE. (2016b). *Legislative and other reviews*. Retrieved 16 January 2017 from http://www.mbie.govt.nz/info-services/building-construction/legislative-other-reviews/

MBIE. (2016c). *Licensed building practitioners*. Retrieved 12 January 2017 from www.lbp.govt.nz/lbp

MBIE. (2016d). *New Zealand BIM handbook: A guide to enabling BIM on building projects*. Wellington, New Zealand: Author.

MBIE. (2016e). *Restricted building work*. Retrieved 12 January 2017 from www.lbp.govt.nz/lbp/im-an-lbp/restricted-building-work-rbw

MBIE. (2017). *How the Building Code works*. Retrieved 11 January 2017 from https://www.building.govt.nz/building-code-compliance/how-the-building-code-works/

MBIE, BRANZ & Pacifecon. (2016). *National construction pipeline report 2016*. Wellington, New Zealand: MBIE.

McGraw-Hill Construction. (2011). *Prefabrication and modularization: Increasing productivity in the construction industry*. New York, NY: Dodge Data and Analytics.

Mills, A., Love, P. & Williams, P. (2009). Defect costs in residential construction. *Journal of Construction Engineering and Management, 135*(1), 12–16.

Minato, T. (2003). Representing causal mechanism of defective designs: A systems approach considering human errors. *Construction Management and Economics, 21*(3), 297–305.

Ministry for Innovation, Industry, Science and Research. (2008). Built environment innovation leaders announced [Press release]. Retrieved from http://archive.industry.gov.au/ministerarchive2011/carr/MediaReleases/Pages/BUILTENVIRONMENTINNOVATIONLEADERSANNOUNCED.html

Morrison, E. & Thurnell, D. (2012). *Working hours in a large New Zealand construction company.* Paper presented at the 28th Annual Association of Researchers in Construction Management Conference, Edinburgh, UK.

Mossman, A. (2013). *Last Planner: 5+1 crucial & collaborative conversations for predictable design & construction delivery*. Retrieved from https://dl.dropboxusercontent.com/u/3369275/Mossman-Last-Planner.pdf

Mumford, P. (2010). *Enhancing performance-based regulation: Lessons from New Zealand's building control system* (PhD, Victoria University of Wellington, Wellington, New Zealand).

Murphy, C. (2011). Building control changes: The on-going battle against leaky building. *Architectural Science Review, 54*(2), 157–163.

Nadim, W. & Goulding, J. (2011). Offsite production: A model for building down barriers. *Engineering, Construction and Architectural Management, 18*(1), 82–101.

New Zealand Construction Industry Council. (2016). *Design guidelines*. Retrieved from http://nzcic.co.nz/resources/guidelines/

Ogunbiyi, O., Oladapo, A. & Goulding, J. (2014). An empirical study of the impact of lean construction techniques on sustainable construction in the UK. *Construction Innovation, 14*(1), 88–107.

Ooi, J. T. L., Le, T. T. T. & Lee, N-J. (2014). The impact of construction quality on house prices. *Journal of Housing Economics, 26*, 126–138. doi:10.1016/j.jhe.2014.10.001

Page, I. (2015). *New house construction quality survey 2014.* Study Report SR335. Judgeford, New Zealand: BRANZ Ltd.

Piercy, G. & Cochrane, B. (2015). The skills productivity disconnect: Aotearoa New Zealand industry training policy post 2008 election. *New Zealand Journal of Employment Relations, 40*(3), 53–69.

Poirier, E., Staub-French, S. & Forgues, D. (2015). Assessing the performance of the building information modelling (BIM) implementation process within a small specialty contracting enterprise. *Canadian Journal of Civil Engineering, 42*, 766–778.

Prefab NZ. (2014). *Value case for prefab: How offsite construction can deliver better cost-effective housing to more New Zealanders*. Wellington, New Zealand: Author.

Prefab NZ. (2015). *Levers for prefab: How offsite construction can deliver better cost-effective housing to more New Zealanders*. Wellington, New Zealand: Author.

PricewaterhouseCoopers. (2009). *Weathertightness: Estimating the cost*. Wellington, New Zealand: Author.

PricewaterhouseCoopers. (2011). *Valuing the role of construction in the New Zealand economy: A report to the Construction Strategy Group*. Wellington, New Zealand: Author.

Rotimi, F. (2013). *An evaluative framework for defects in new residential buildings: The New Zealand case* (PhD, Auckland University of Technology, Auckland, New Zealand).

Rotimi, F., Tookey, J. & Rotimi, J. (2015). Evaluating defect reporting in new residential buildings in New Zealand. *Buildings, 2015*(5), 39–55.

Sadler, L. (2011). *The adaptation and implementation of lean production in the New Zealand construction industry* (Bachelor of Construction, UNITEC Institute of Technology).

Scoop. (2015). *Extra building inspection shift created to clear backlog*. Retrieved from http://www.scoop.co.nz

Scoop. (2016). *Moving to meet demand for building inspections*. Retrieved from http://www.scoop.co.nz

Smyth, H. (2009). Construction industry performance improvement programme: The UK case of demonstration projects in the ‘continuous improvement’ programme. *Construction Management and Economics, 28*, 255–270.

Strategic Forum for Construction. (2002). *Accelerating change*. London, UK: Department of Trade and Industry.

UK Construction Taskforce. (1998). *Rethinking construction*. London, UK: UK Government.

Unitec Institute of Technology. (2016). *Building and carpentry*. Retrieved 20 January 2017 from http://www.unitec.ac.nz/career-and-study-options/building-and-carpentry

Wolstenholme, A. (2009). *Never waste a good crisis: A review of progress since rethinking construction and thoughts for our future*. London, UK: Constructing Excellence.

WorkSafe. (2015). *Construction in New Zealand*. Wellington, New Zealand: Author. Retrieved from http://www.worksafe.govt.nz/worksafe/research/health-and-safety-data/pdf-and-documents-library/construction-sector-by-numbers.pdf

Appendix A: Building regulation changes in New Zealand

Significant changes have been made to the way building regulation is specified and carried out in New Zealand over the last 25 years. Table 1 provides a timeline of the most recent and significant changes.

Table 1. Timeline of regulation changes in New Zealand 1991–2012.

Year	Action	Comment
1991	Building Act 1991 enacted performance-based regulation of building work and a new national Building Code	Expectation of greater innovation, including more research and development
1990s–2000s	Weathertightness issue emerges	Evidence of systemic failures in the building industry
2002	Review of the regulatory regime for the building and construction sector	
2004	Building Act 2004 enacted stricter controls on practitioners, consent authorities and products	Sector becomes highly risk averse
2007	Licensed Building Practitioners Scheme came into force	Greater assurance for clients that building practitioners had the necessary skills
2009	Building and Construction Sector Productivity Taskforce established	New focus on productivity in the industry
2009/10	Review of Building Act 2004	Found the system was working but not creating the right incentives to improve productivity and is costlier than necessary
2012	Restricted building work regime came into force	Restricted building work only completed by competent practitioners

Source: Adapted from MBIE (2013).