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Development of a framework for quality assurance of off-site manufactured building components: A case study of the New Zealand housing sector

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Development of a framework for quality assurance of off-site manufactured building components: A case study of the New Zealand housing sector

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Abstract. A shortage of housing is a prominent issue across the globe. Traditional on-site construction methods seem too inefficient to meet the increasing housing demand. As a solution, many countries, including the United States, Germany, Singapore, Japan, Hong Kong and Australia, have introduced off-site manufacturing methods to increase the housing supply. Different from the traditional way of on-site construction, off-site manufacturing is a technique that involves manufacturing building components in a controlled environment. Despite strong government support and industry attempts to increase off-site manufacturing, the current building consenting and inspection processes in New Zealand have significant quality-related issues. Therefore, this study aimed to identify the gaps in current quality assurance processes used in off-site manufacturing and recommend a framework in order to gain credibility and the acceptance of the construction market. The study collected qualitative data from industry experts (e.g., developers, architects, engineers, project managers, quantity surveyors, head contractors and council officers) who had significant experience in current quality assurance regimes in New Zealand prefabrication construction. The key themes for designing the proposed framework were generated using content analysis of the primary data collected from semi-structured interviews with industry experts. The study has found that standardisation in off-shore products regarding the New Zealand Building Code remains the biggest challenge in the consenting process. Quality assurance and inspection test plans are the developer's responsibility and are typically provided by third-party inspectors. In this post-Covid-19 world-building, consent authorities rely heavily on third-party inspection companies that apply more rigorous auditing. Essentially, the most important parts of quality assurance are to have an experienced team and to adopt a holistic approach by engaging stakeholders early in the design stage. The stakeholders should consider recommendations for mandatory after-service insurance to ensure end-customer interests are protected. The findings of this study can contribute to the early engagement of different stakeholders to ensure overseas manufacturing of building components meets New Zealand quality standards. It is expected that the new quality assurance framework would help to promote off-site manufacturing for the New Zealand housing sector.

1. Introduction

Housing affordability is a long-term problem affecting New Zealanders as the building industry struggles to provide stock [1]. To assist with mitigating the issue, in March 2021, the New Zealand

Government recently announced its Housing Acceleration Fund. According to the factsheet unveiling the fund, New Zealand has some of the fastest-growing house prices in the OECD, with a 266% increase from 1991 to 2019 [2]. The global Covid-19 pandemic has not slowed New Zealand house prices; on the contrary, there was a 23.6% increase in median house prices from March 2020 to March 2021 [3]. The Housing Acceleration Fund and other measures, such as increasing the bright-line test, were introduced to increase supply, improve affordability, and encourage homeownership [2].

However, the fundamental issue is the “demand and supply” balance. PrefabNZ [4] has indicated in its report that Auckland alone would need approximately 400000 new dwellings over the next 20 years; however, due to low productivity, it is estimated there would be a supply shortfall of 90000 units [4]. The Government has promoted an intensive housing model by transforming and upgrading New Zealand’s economic and social growth [5]. The “Kiwibuild” scheme introduced in 2012 aimed to boost homeownership. The target was to build 100000 high-quality, affordable homes nationally over ten years, with 50% in Auckland [6]. With Kiwibuild and a planned additional 9959 public housing units per annum nationwide [2], the labour-intensive traditional construction methodology might not be able to achieve those targets. Several issues would need to be addressed, including a shortage of skilled labour, barriers from regulations such as the Resource Management Act, and local councils’ low infrastructure growth [7]. From our observations in the construction industry, these deterrents increase the degree of difficulty and extend the timeframe for private developers to supply new stock to the market.

The principal construction methodology in the New Zealand market has been on-site building with intensive involvement of skilled labour and engineers [4, 8, 9]. According to a study on the impact of prefabrication in New Zealand construction undertaken by BRANZ [10], prefabrication constituted just 17% of all building work [11]. However, the prefab component has the potential to grow with the implementation of the Government-supported Kiwibuild scheme [12].

Unlike the traditional method of on-site construction, prefabrication means assembling building components in factories and manufacturing sites and transporting either the ‘finished product’ or a ‘semi-finished’ product to a construction site for the final assembly of the building [13]. Among the different construction methods in the industry, prefabrication and off-site construction are gaining momentum worldwide due to them being economical in cost-reducing construction time and being more sustainable for the environment [14]. Prefabrication has become the trending method for new builds in countries such as the US, Germany, Singapore, Japan, Hong Kong, among others. There is a high reliance on imported construction labour, materials and other resources [13, 15]. The New Zealand Government encourages prefabrication technology so as to accelerate supply in the housing market [2]. The crown entity, Kāinga Ora – Homes and Communities, is expanding its use of prefabrication construction by using modular design and innovative materials such as cross-laminated timber [16]. Although the Government promotes prefabricated construction methodology, the industry faces many deterrents that prevent the wider implementation of off-site construction [5]. One of the issues is how QA is conducted in the prefabricated construction sector and prefab manufacturers’ long-term responsibilities [17]; in this study, we explored the quality assurance processes.

The building industry is highly regulated in nations such as Australia, the UK and New Zealand [18]. New Zealand’s Building Act 2004 stipulates that all building work and materials must meet the Building Code and New Zealand Standard [19]. A building consent is required before work starts on-site, and on completion of a building, a Code of Compliance Certificate would be issued as evidence of compliance with the Building Code [19].

This research focused on how the inspection regimes are determined and assessed in the case of prefabricated construction. It has been noted that prefabrication is a construction methodology in which the supply chain is more dynamic and involves international parties and responsibilities that are harder to define [20]. This brings interest in determining what warranties and guarantees the factories/manufacturers provide to the developer or end-user. Is there a standard schedule of warranties and guarantees one must meet under the Building Code? With the absence of a regulatory body and sole dependency on a developer- or factory-appointed third party, how do councils and regulatory bodies ensure the materials they “inspected” are appropriately utilised in the manufacturing process? These questions require further research and exploration.

The current New Zealand consenting and inspection process for prefabrication lacks standardisation and reference to off-shore standards [21]. It was recommended to be included in the existing Building Act [22]. Moreover, studies of off-site practices at an organisational level have not been widely studied [23]. It is essential to review and identify the issues of current quality control processes implemented by the authorities and manufacturers/developers. – furthermore, possible technologies that could be adapted as standard acceptable solutions for the industry need to be identified. This study aimed to examine the obstacles in quality assurance and how a Code of Compliance could be achieved in a prefabrication construction project when components are manufactured overseas. This research would help create an improved quality assurance/quality control (QA/QC) framework for prefabrication construction in New Zealand. The following three objectives were established in order to achieve the overarching research aim.

1. Identify the gaps/issues in current QA/QC methods for off-site manufactured building components
2. Recommend a framework for QA/QC for off-site manufactured building components
3. Recommend measures to extend the QA in warranties/guarantees of modular prefabricated products to the end-user.

Identifying the gap in current consenting processes regarding the QA/QC of prefabricated building products would reduce the risk for the various stakeholders in the New Zealand industry. The significance of recommending a framework for QA/QC is for the prefabrication construction methodology to gain credibility and acceptance within the market. The current New Zealand legal structure deems the liability for the damage caused by multiple parties as joint and several [24]. The New Zealand Government has inherited a burden for leaky buildings with an estimated $47 billion in required remediation work [25]. If QA/QC is not closely monitored, history may repeat itself with prefabrication construction. Knowing the current limitations would allow process improvements and risk reduction. Building defects would be reduced when the correct QA and QC procedures are implemented in the factory [26]. The developer would benefit if a more structured framework of QA/QC was available as an industry-standard to reduce uncertainty and risk. This would also give the end-users of prefabrication builds greater peace of mind.

2. Literature review

Prefabrication construction was categorised into four sets by Shahzad et al. [9]. Componentised prefabs are individual building components such as columns and beams [11]. Extension to a single component within a building panelised prefab is common in New Zealand and includes precast walls, wall frames and floor panels [11]. Modular prefab refers to structural forms or boxes built off-site, such as a bathroom pod; these are three-dimensional and would be assembled by the project’s main body on-site, thus shortening construction time [11]. The most advanced technology prefabricates the complete building with only foundations and service connections constructed on-site. One other method mentioned by Page and Norman [26] is hybrid prefabrication, a combination of traditional construction and assembling a prefabricated portion of the building [11].

Prefabrication construction is a global trend popular in Germany, Singapore, Japan, and a number of other countries and economic entities. There is a high and often unsatisfied demand for construction with a high dependency on imported construction labour, materials and other resources [15]. The current New Zealand construction industry has similar constraints regarding skilled labour shortages and materials. Building off-site is not new to New Zealand–as early as the mid-1800s, settlers brought small pre-built cottages with them. In the 1920s, New Zealand Railways manufactured cottages in Frankton for railway workers. However, the public perceived prefabricated housing to be low budget and of inferior quality [11].

Studies to date have found various benefits associated with adopting prefabrication, such as increased quality and sustainability, reduced overall construction time, lower construction waste disposal costs, and reduced health and safety hazards [4, 5, 11]. A key aspect of construction quality is reducing the number of defects post-construction. The cost of remedies to weaknesses in a construction project could amount to 6% of the total cost (Johnsson-Meiling and Henrik 2009) as cited in Burgess et al. [11]. The factory environment can be more controlled and protect materials from the natural elements [4]. Adapting new technologies and equipment implies reducing labour use and thus lowering human error. However, the required skill level of workers would rise [11]. Construction project time could be reduced by 30-50% in the US and European markets [27] by starting site mobilisation and foundation work while the building was being manufactured. Navaratnam et al. [28] and PrefabNZ [4] found when 80% of the build occurs in a factory, a time saving of 60% could result. This could lead to a reduction in the total project costs. A PrefabNZ [4] case study showed a 15% reduction in build cost compared to traditional construction. In contrast, the Prefab Roadmap 2013-2018 [29] indicated the high start-up cost to be a barrier to adoption. For New Zealand, initial start-up costs, of either traditional or prefab, do not seem to be a major factor in determining whether a project is built or not.

2.1. The critical issues in QA and QC in prefabricated construction

The benefits of off-site construction have been widely studied for projects [30, 31, 32, 33] or the entire industry [23]. In contrast, off-site operation at an individual, the organisational level has not been investigated in detail [23]. The process of selecting materials used to manufacture a prefabricated product is complex, and there can be uncertainty about supplier reliability [34]. Among many challenges pointed out in the Prefab Roadmap 2013-2018 [29] was a lack of technical product guidance and the absence of a QA system. Quality issues may arise where standards in the country of production do not meet the New Zealand Standard and Building Code of Compliance [15, 21, 35]. There remains a lack of QA systems and guidance from BCA or the Government, a situation that requires improvement [22]. The study by Xu et al. [15] presented a disturbing picture of prefabricated manufacturers tending not to assume long-term responsibilities. This mentality could cause QA issues. The same study also mentioned that the production supply chain of off-shore prefabrication is so inconsistent that inadequate quality monitoring could be a concern [20]. Though factory certification could reduce such risks, it would be challenging to guarantee production standards in different manufacturing plants [22]. New Zealand does not currently have a factory accreditation scheme.

2.2. QA in the consenting process for prefabrication in New Zealand

QA in Auckland's current prefabrication consenting process has been found to lack standardisation [26]. This was also found by Chang-Richards et al. [22], as off-site construction is not included in current building standards or the Building Act. Under the Building Code, the supplier or manufacturer has three pathways to demonstrate compliance: Acceptable Solution, Alternative Solution and Verification Method [36]. Furthermore, under the current New Zealand Product Assurance Framework, five options exist to demonstrate compliance [36].

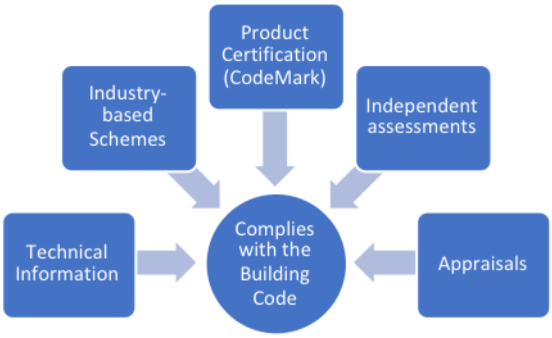

Figure 1. New Zealand product assurance options [36]

In the Manufactured Modular Component Guidance (MMCG) of Auckland Council [19], a Product Technical Statement (PTS) is required to demonstrate compliance with the New Zealand Building Code. The product assurance methodologies are technical information (Mill certificate), independent assessments (SGS certificate/SAI Global Certificate) and appraisals (Knauf test report - BRANZ Appraisal) [19]. The industry-based scheme does not appear to be employed for prefabricated building components.

Chang-Richards et al. [22] investigated QA practices in Australia, the United Kingdom, Singapore, China, Sweden and Switzerland. A manufacturer's most common QA method was self-certification [22]. Although this promotes the growth of prefabrication, it is essential to have balanced risk allocation across the supply chain [21, 22, 35]. Research from Chang-Richards et al. [22] showed three common forms of QA practice:

1. Factory certification: The evaluation of the manufacturing facility against a set of quality management standards. A certificate of compliance is awarded if all criteria are met
2. Third-party certification: Product/process standards are assessed by an independent party that carries out the auditing and issuing of certifications
3. Product identification and traceability: Product identification includes code numbers, label names, and other forms that allow items with similar features to be differentiated from others and product origins traced.

Table 1. Comparison of QA practice [22]

Country	Factory certification	Third-party certification	Product identification and traceability	Education and training
Canada	✓	✓	✓	Not described
Japan	✓	✓	✓	✓
Singapore	✓	✓	Not described	Not described
UK	✓	✓	✓	Not described
New Zealand	×	✓	×	×

Beginning in the 1960s, Japan was an early adopter of prefabrication, developing a QA system where the manufacturer provides a "Home Guarantee System" and an "After Sales and Maintenance Services System" to ensure quality for the purchaser [22]. Japan's Housing Defect Warranty Fulfilment Act and Housing Quality Assurance Promotion Act ensure proper insurances are in place and buildings are adequately rated for structural and fire safety. This could increase security for stakeholders, e.g., banks and insurance companies [22].

Singapore has a two-tiered approval system. The factory must be approved by the Government's Building Innovation Panel (BIP), which considers the code of practice, track record material specifications and quality/test reports of the products [38]. The BIP Application Checklist criteria are similar to Auckland Council's adopted building consent application [19]. Even after BIP acceptance, a supplier/manufacturer must be accredited under the country's Manufacturer Accreditation Scheme run by industry associations. New Zealand does not have a manufacturer accreditation scheme though such a system could promote self-regulation within the industry [22]. A similar process has been adopted in the UK, where the independent British Board of Agreement (BBA) certifies products or systems and conducts QA audits of manufacturers. Its industry-led Build Offsite Property Assurance Scheme (BOPAS) provides assessment accreditation and a register of projects built. The New Zealand Government has issued a discussion document regarding the Building Amendment Bill. This document introduces a Modular Component Manufacturer (MCM) Certification Scheme and Product Certification Scheme to control risk and encourage new technology in the building industry [39]. This is an encouraging step.

Traditionally in New Zealand, 12 inspections are required to obtain a Certificate of Compliance (CCC) for a new residential structure [4]. This is unsuitable when a building is being built whole or in part in a factory environment [4]. The traceability of crucial materials and products is a key QA factor for demonstrating compliance (BCA) [12].

An electronic traceability system and third-party verification digital platform have been recommended to increase the transparency of prefabricated product and material lifecycles in New Zealand [22]. One technology that could be considered is advanced computer-based QA to provide off-site inspections and help monitor progress [40, 41].

Introducing electronic verification on products during manufacturing would ensure quality and enable self-certification during production, resulting in fewer building inspections [4] and a potential increase in productivity [1]. New Zealand's building consent and CCC processes must move towards QA software to enable remote site inspections and tracking [39]. This would be useful where strict Covid-19 restrictions prevent inspectors from travelling to off-shore factories.

3. Research methodology

Identifying issues in current QA processes and the recommendation of a framework for QC both suited the phenomenography method where a collective group experience could be considered to find an alternative way of experience [42]. A qualitative research methodology is often adopted when wanting to solve a poorly understood problem [43]. Furthermore, due to the constraints of the availability of the current number of physical causes in the New Zealand market, qualitative inquiry can help detect people's underlying perspectives, experiences and ideas [44] so as to define prefab consent and manufacture QA issues. Therefore, a qualitative approach was adopted for the research methodology of this study.

The study's participants (P_1 to P_5) comprised industry experts or parties who had experienced the current QA regime in New Zealand for prefabrication construction. Table 2, Participant Profile, disclosed the role and experience of the property industry experts. The participants had significant expertise in the property and building sectors. It should be noted that having five years of construction experience as a developer, P_4 was managing two large modular projects in New Zealand (each with approximately 200 units) and had international construction experience.

Table 2. Participants' profile.

	Position	Location	Type of development projects involved in	Typical size of development projects involved in	Construction industry experience
P_1	Project Manager	NZ and off-shore	Apartments and hotels (high-rise)	180-200 units	30 years

P_2	Consent Approval Officer	NZ and off-shore	Residential and commercial (high-rise)	Varies	35 years
P_3	Contractor	NZ and off-shore	Hotel (high-rise)	180 units	25 years
P_4	Developer	NZ and off-shore	Apartments and hotel (high-rise)	180-200 units	5 years
P_5	Shareholder of prefab manufacturer and developer	NZ	Residential	25 Terrance houses	23 years

The transcripts of the interviews were analysed using content analysis. The first step required categorising the transcript content by assigning codes to relevant keywords, phrases, patterns, actions, and concepts relative to the research questions [45]. As per the step-by-step content analysis process illustrated by Merriam and Tisdell [45], the categories were named and sorted after the codes were identified to determine the themes to the research question. The codes were created inductively during the research process, and the coding system adapted to the progression of the meaning units [46]. The researchers also captured any keywords with similar underlying meanings. The key themes were identified through the analysis of the interview transcripts. They established relationships to the research question raised in the introduction section of this article in order to achieve the research objectives.

4. Findings

The research objectives and key findings of this research are summarised in Table 3.

Table 3. Summary of key findings in relation to research questions and objectives.

Research objective	Key findings
To identify the gaps/issues in current QA or QC methods of off-site manufactured building components.	• In this post-Covid-19 world, the BCA has relied heavily on internationally reputable third-party QA companies. This started with forming a QA Plan Inspection Test Plan (ITP) and a more robust auditing system. PTS was mentioned as one of the developers' tools to demonstrate product traceability. Innovative technology had not yet been fully explored, but images and videos were used for inspection and auditing during manufacturing. It was found that BCA had requested prototypes and samples of materials from every participant interviewed. • Inspection regimes were provided by developers who usually outsourced this to internationally reputable and independent third-party QA inspectors to form the ITP for BCA to assess. The Auckland Council discussed and agreed with the ITP with the manufacturer and third-party QA inspectors. Examples of such third-party inspection firms mentioned were SGS and Bureau Veritas. P_1 , P_3 and P_4 also mentioned utilising consultants with international offices at the location of manufacture. • P_5, being previously involved in the business of an NZ local modular manufacturer, mentioned the inspection regime was a collaboration with BCA to determine the inspection and or auditing system of the project. • Manufactured Modular Component Guidance was used to standardise the process. However, there were no standardised platforms in off-shore product referencing. • PTS was the biggest challenge in the prefab modular construction experience.

	• A good design was vital to the success of prefabrication; however, a lack of international product referencing from design consultants may have been the fundamental issue.
To recommend a framework for QA or QC for off-site manufactured building components.	• Early stakeholder involvement was implemented. Auckland Council manufacturer design consultant off-shore engineering firms, third-party QA inspector's contractor via ECI and hotel operator (end-consumer) were engaged at the early design stage. The experience of the selected design consultant team and the manufacturer was vital in implementing a modular project. • Further education and training were required for design consultants to understand BIM implementation and international product referencing.
To recommend measures that would extend the QA in warranties/guarantees of modular prefabricated products to end-user.	• NZ legislation such as the Building Act, Fair Trading Act and Consumer Guarantees Act safeguarded the warranties and guarantees. The warranties and guarantees responsibility fell on the main contractor based in New Zealand and needed to comply with the Building Act. It was found that the developers had voluntarily bought building warranty insurance such as the NZ Certified Builder 10-year residential guarantee (Halo) and Stamford insurance for the commercial project.

5. Discussion

5.1. The gaps in current QA or QC methods of off-site manufactured building components

5.1.1. Lack of standardisation. The building consent process in the MMCG [19], as demonstrated in Figure 1 of this article, is consistent with the applicants' points of view (P_1 P_3, P_4 and P_5) and validated by P_2. Although this may improve what was found by Page and Norman [26], four of the five participants expressed that there is still a lack of standardisation in the overseas product, as noted by Masood et al. [21]. Furthermore, the participants found the biggest challenge was to reference overseas products to New Zealand standards.

Although overseas certification and standards were mentioned in some material, there was a lack of formal referencing in all the international standards. As noted in Chang-Richards et al. [22], a recommended electronic platform for product traceability and international referencing remains a gap in the current compliance system. As P_2 expressed, although BCA would encourage the Alternative Solution pathway for compliance under the Building Act, the lack of analysis between overseas and New Zealand standards would incur cost and time upfront, which is not attractive to developers. The high initial cost has been established as a barrier to prefabrication [4].

5.1.2. Inspection regime issues. As specified in the MMCG, the developer must provide both the QA plan and the ITP when applying for modular building consent for projects in Auckland [19]; the findings from the interviews were consistent with this. ITP forms part of the QA system for building consent applications [19] and requires the developer to propose the inspection regime for materials and procedures in the PTS. Appendix 7 of the MMCG contains examples of the ITP. Third-party inspection requires third-party consultants, an engineer (Producer Statement 4), a council inspector, a Producer Statement 3 New Zealand representative, a New Zealand Electrical Certificate and acoustic consultants. Producer Statements (PS) are required under the New Zealand Building Act 1991 [47] supplied by the expert who designs or conducts the work to declare that it will be (or has been) carried out to approved technical specifications [47]. The PS requirements are challenging for the developer under current Covid-19 restrictions as specialists registered as PS authors cannot travel to off-shore factories.

As P_2 indicated, BCA would require sign-off from an independent third party with appropriate qualifications and experience when installing a New Zealand system. This poses an obstacle as there is no clear definition of what is acceptable to Auckland Council (BCA) or the appropriate experience and qualifications required. In the example of an ITP in the MMCG, only New Zealand certification is accepted for specific trades like plumbing and electrical [19]; this is the reason P_4 reduced their prefabrication to “frame-only” while all internal fit-out was to be done in a New Zealand prefab factory by P_3. As for the modular production of the framing, P_4, procured a qualified engineering consultant with global exposure and offices in both the factory location and New Zealand to provide the required PS.

5.1.3. Poor design coordination. It was found that a good design was essential, and P_2 identified a current gap in the use of BIM coordination in design phases, similar to Sooriyamudalige et al. [1]. All five participants reported early involvement with stakeholders, including the design team, BCA, the manufacturer contractor, and a hotel operator in their ongoing projects. However, design coordination remains one of the most significant issues in terms of QA [1]. This phenomenon can be linked to what P_2 said*: “sometimes, the reputable manufacturer with decades of modular manufacturing experience may have a better system than New Zealand’s”*. However, the lack of understanding of overseas design and product referencing would create a fundamental issue in design quality. Given the limited technical knowledge of design consultants [4], Chang-Richards et al. [22] recommended education and training in the prefab manufacturing compliance process. This would require more industry and government support.

5.2. A framework for QA and QC of off-site manufactured building components

5.2.1. Holistic approach. The importance of integrated design and stakeholder communication in the early stage of the design phase has been discussed by several researchers, such as Li et al. [48], Finnie et al. [49] and Masood et al. [21]. Traditionally in New Zealand, the BCA and contractor would only understand the scope of work after a detailed design has been created [49]. Design coordination is one of the significant contributors to QA and successful prefabrication [1]. As a contractor/subcontractor, P_3 was engaged at the design development stage; this engagement of ECI enhances buildability and minimises design risks [49]. QA plans would be strengthened, and any uncertainty about technical issues and design risks would be reduced if BCA design consultants, the manufacturer and third-party inspectors collaborated from the start of the project [15]. Early engagement of the BCA could allow the developer and design team to understand the expectations of building consent documentation, thus enabling the design team to provide the appropriate PTS paperwork and discuss the ITP with the third-party inspector or off-shore engineers. The participants agreed and implemented a holistic approach with early engagement of stakeholders to guarantee that end-product quality was approved from many perspectives. These results are similar to those reported by Li et al. [20], Finnie et al. [49], and Masood et al. [21]. Further promotion of this approach is recommended.

Figure 2. A holistic approach to the early engagement of stakeholders

5.2.2. Third-party QA entities. Independent third-party QA inspectors' role is more vital than ever under Covid-19 travel limitations. It was found that BCA is restrained by regulations restriction from providing a formal panel of QA entities. The participants reported that only a few international QA companies had experience with New Zealand's BCA and prefab industry. Furthermore, the details around qualifying a third-party QA inspector are vague in the MMCG, which states that acceptance would be based on appropriate experience or qualifications. The researcher thinks more guidance should be given regarding the specific experiences and qualifications acceptable to the BCA.

5.2.3. Innovative technologies. Contrary to Sooriyamudalige et al. [1], two participants did not believe innovative technologies such as production surveillance or 3-D monitoring would increase QA. However, two other participants felt that introducing innovative technology would increase the effectiveness of QA primarily when in-factory inspection from BCA could not be conducted. This response was similar to that in PrefabNZ [4] and Sooriyamudalige et al. [1]. The lack of knowledge about available technologies may be contributing to this split in participant responses. Further studies could explore this when the industry is better educated about QA-related technologies.

5.2.4. Manufacturer accreditation. Manufacturer experience and reliability were essential decision-making factors and a recurring theme in this study. This aligns with Pan et al. [23], which found limited manufacturers' studies at an individual and organisational level. One reason developers P_4 and P_5 changed manufacturer after their projects began was that the manufacturer's vision might have been short-sighted [15], or manufacturers were experiencing difficulties at an organisational level. P_4 changed from a Chinese manufacturer to factories in Poland (hotel project) and Vietnam (apartment project).

Nevertheless, P_5 had a similar experience even though the factories were in New Zealand. P_5 went through three prefab factories to find a suitable manufacturer to complete their project but finished it with a traditional build. This was due to the experience and reliability of the factories rather than their technical capabilities. This experience is consistent with Masood et al. [21]. New Zealand modular manufacturers have relatively short two- to three-year lifespans and low survival rates. This is an obstacle to implementing prefabs in New Zealand [21], as developers may lose faith when trying to find a reliable prefab manufacturer that could finish their project.

Uniquely the hotel project's interiors were finished in a New Zealand prefab facility. This approach may be adopted to overcome PTS complications in ITP and difficulties with PS provision during the pandemic. This takes us back to when P_2 said New Zealand developers attempted to re-invent overseas modular manufacturing methods to meet local requirements. If altering reputable overseas manufacturers' production systems could introduce unintentional risks, why not use established procedures to certify the New Zealand Building Code?

Factory certification is one of the most common practices in the study of Chang-Richards et al. [22]. Although the Government's discussion paper for implementing the MCM scheme is in progress, New Zealand does not have a factory certification scheme for off-shore manufacturers.

For an overseas manufacturer to become a PS author, BCA would test their manufacturing capability as a contractor (PS3) [47]. At the same time, products or systems (PTS) would be certified by third-party entities or gap analysis. The consent and CCC process could become more efficient. Although self-certification has been widely applied in other countries, we still need to balance risk [21, 22, 34]. Independent third-party auditing should be used with MCM certification to increase overseas manufacturer reliability and decrease the time for compliance [22].

5.3. Measures to extend QA in warranties/guarantees of modular prefabricated products

5.3.1. Warranties and guarantees. As stated by P_2, warranties and guarantees are safeguarded by the Building Act 2004 Fair Trading Act 1986 and Consumer Guarantee Act 1993. Responses from P_1, P_3 and P_4 indicated that warranty and guarantee responsibilities are identified in the contract conditions in NZS3910:2013 [50]. However, P_3 was still unsure who would provide the warranty and guarantee for off-shore modular frames but suspected it would be the main contractor.

Within NZS3910:2013, there are specific clauses – G11.5 Warranties G11.6 Guarantees and a form of warranty in Schedule 13, which lists the particular warranties provided [50]. The main contractor would be responsible for providing the warranty and guarantee when they enter the contract unless specified otherwise in particular conditions. This might become a deterrent for main contractors locally to undertake a project with modular prefabrication unless ECI has been engaged at the early stage of design [49] so they could understand the risks involved. Another approach could be to nominate the modular manufacturer as a "nominated subcontractor" under clause 4.2 of NZS3910:2013, thus indemnifying the contractor from liability [50]. This would mean the risk of all work related to modular units would be borne by the principal [50]. This also comes back to the reliability and mentality of the manufacturer and supply chain [15] and the off-shore manufacturer not having a New Zealand arm. If the overseas manufacturer ceased operation or did not provide a warranty, the developer, end consumers and especially the BCA would be at risk. It is often the "last man standing" in the chain of responsibility.

5.3.2. Insurance. Insurances were mentioned and utilised by the developers interviewed in the study. By purchasing building warranty insurance such as that from Stamford Insurance or New Zealand organisations such as the Master Builder or Certified Builder's Hola, both P_4 and P_5 protected the interests of their companies and the end-user. Chang-Richards et al. [22] found in countries like Japan and UK, the insurance company partnered with government authorities to oversee the compliance process, thus increasing confidence for developers and end-users to embrace prefabrication construction. As discussed, insurance reduces the risk to BCA as the last remaining entity responsible for warranty and guarantee. To protect the interests of all stakeholders, it would be good practice for all prefab construction projects to procure a mandatory 10-year building warranty insurance policy.

6. Conclusions and further research

From the literature reviewed, there is evidence that prefabrication construction could be one of the solutions to easing the current housing crisis in New Zealand. Adopting new technical knowledge and training are required across the industry. Enhancing the QA framework of prefabrication construction in New Zealand could be done by taking a holistic approach and engaging different stakeholders from the start of the project. The council contractor, manufacturer consultants, developers and even sales professionals should all be engaged early to ensure an acceptable level of quality of the end product. This study also found that off-shore product referencing remains the most significant obstacle due to its complexity. However, implementing the MCM scheme could simplify the building consent process. Although the participants supported utilising innovative technologies such as 3D scanning/surveillance monitoring, a third-party inspector was the preferred method of monitoring for quality. Furthermore, third-party inspection has become more critical post-Covid-19 as it has replaced the BCA entirely. However, there is a lack of clarification on qualifying a third-party inspector in the MMCG.

Due to research limitations in scope and duration, the sample size may not represent the entire experience of the prefabrication industry in New Zealand. Therefore, it is difficult to recommend a complete framework that could be validated. However, the following recommendations could be considered when undertaking further research into the QA process and the implementation of off-shore modular prefabrication.

1. The BCA should establish a standardised gap analysis for products referencing overseas materials. This could be an online platform with ease of access like that suggested in Chang-Richards et al. [22].
2. The construction industry should continue to encourage a holistic design approach and early engagement of stakeholders and continuously engage a team with experience in prefabricated construction.
3. The MCM scheme should be extended to overseas manufacturers in order to streamline the building consent process, minimise unintentional risks and increase manufacturer reliability. A rigorous auditing system should be in place to renew factory certification.
4. Due to limited knowledge and skill in the prefabrication industry in New Zealand, Government authorities and industry associations should promote further training and education to design consultants, contractors, developers and funders such as banks.
5. MBIE should adopt the prototype model of QA and compliance established by Chang-Richards et al. [22].

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