MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Te Kāwanatanga o Aotearoa
New Zealand Government

Building and Construction Sector Trends

ANNUAL REPORT 2022

MINISTRY OF BUSINESS,
INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Ministry of Business, Innovation and Employment (MBIE)
Hīkina Whakatutuki – Lifting to make successful

MBIE develops and delivers policy, services, advice and regulation to support economic growth and the prosperity and wellbeing of New Zealanders.

MORE INFORMATION

Information, examples and answers to your questions about the topics covered here can be found on our website: **www.mbie.govt.nz** or by calling us free on: **0800 20 90 20.**

DISCLAIMER

This document is a guide only. It should not be used as a substitute for legislation or legal advice. The Ministry of Business, Innovation and Employment is not responsible for the results of any actions taken on the basis of information in this document, or for any errors or omissions.

ONLINE: ISSN 2744-6743

OCTOBER 2022

The contributors to the report in alphabetical order are: Dr Alice Cleland, Dr Iman Khajehzadeh, Simon Leong, Satnam Singh, and Dr Eric Wu.

Please cite this report as: MBIE (2022). *Building and construction sector trends annual report* 2022. Wellington: MBIE.

Contents

List of Figures

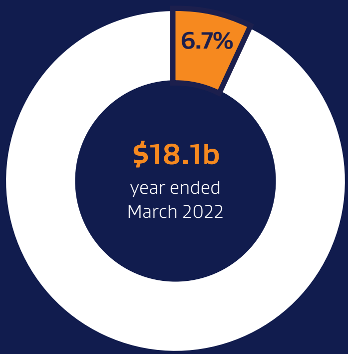
List of Tables

Executive summary

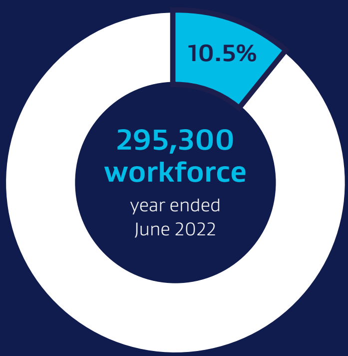
The purpose of this report is to provide an overview of the key trends in the building and construction sector, and covers the period from July 2021 to June 2022.* The key trends are outlined below.

THE BUILDING AND CONSTRUCTION SECTOR IS A MAJOR CONTRIBUTOR TO NEW ZEALAND'S ECONOMY:

Real GDP



Employment



Businesses

ACTIVITY ACROSS THE SECTOR REMAINED STRONG DESPITE THE ONGOING CHALLENGES BROUGHT BY THE COVID-19 PANDEMIC:

Building consent numbers reached record-level highs.

The workforce pipeline continued to grow.

However, the sector continued to be impacted by supply chain disruptions and rising construction costs. Additionally, the complexity of global supply chain issues means that the full impacts may still be felt for some time to come.

THE BUILDING LANDSCAPE IS ALSO CHANGING WITH THE INTRODUCTION OF INNOVATIVE BUILDING DESIGNS, TECHNOLOGIES AND MATERIALS:

Climate change is one of the key drivers shaping new building trends.

Digitalisation and decarbonisation are two key concepts behind new and emerging trends, which will enable the sector to be more environmentally friendly, less labour intensive, safer for workers, more cost efficient and resilient.

The circular economy concept is also being introduced in the new generation of construction materials that are being developed.

*Depending on the availability of the data, there may be some variability in the reporting period.

1. Introduction

The building and construction sector is a significant contributor to New Zealand's economy. It contributed 6.7 per cent of real Gross Domestic Product (GDP) for the year ended March 2022 [1]; and was the third largest employer, employing 295,300 people in the year ended June 2022 [2]. Strong demand for residential housing in the last 12 months saw 50,736 new homes consented in the year ended June 2022 [3].

1.1. Background

The purpose of this report is to meet the requirements of section 169 of the Building Act 2004, which states that the "*Chief executive must monitor current and emerging trends in building design, etc., and must report annually to Minister*" [4]. The reporting period covered is from July 2021 to June 2022.

The aim of the report is to provide an overview, rather than an exhaustive compilation, of the key trends in the building and construction sector. Desktop research and analysis was undertaken between May and July 2022, with the relevant content sourced from available data and information sources. Where annual comparisons are provided, the reporting month may vary depending on the availability of the data. This report does not provide policy advice, solutions, or recommendations.

1.2. Report structure

The report is organised into the following sections:

- **Section 2** – the context within which the sector operated in the past year
- **Section 3** – key New Zealand trends in building and construction data
- **Section 4** – emerging global trends in building design, materials and technology
- **Section 5** – conclusion.

2. The wider context

This section outlines the wider environmental context within which the building and construction sector operated in the past year. These are briefly discussed below.

2.1. COVID-19 pandemic

Over the past year, the building and construction continued to be impacted by the COVID-19 pandemic. Throughout 2021, there were periods when construction activity slowed due to social distancing restrictions and health and safety protocols. For example, during Alert Level 4, businesses had to close except for necessities and lifeline utilities [5]. During Alert Level 3, businesses could operate but inter-regional travel was restricted and people were asked to stay local. People were also asked to keep a metre distance from others in controlled environments like workplaces.

The impact of the pandemic was most noticeable for Auckland and Northland, where there were periods of heightened restrictions compared with the rest of the country. This created difficulties for the distribution of building and construction goods as the majority of domestically-manufactured building products were made in Auckland [6]. This was reflected in the media, which stated that "*Auckland warehouses stored almost all New Zealand's construction supplies*" [7]. In addition, some Auckland-based construction and design companies (and consequently their workers) were involved in projects that were located outside Auckland boundaries. To address this, the Ministry of Business Innovation and Employment (MBIE) established the Business Travel Register in August 2021, to facilitate travel and enable the flow of goods between Auckland and the rest of the country [8].

Research commissioned by MBIE in 2021 found that the rising costs of construction, widespread supply chain issues, difficulty in finding suitable staff, and project management difficulties and delays were challenges the sector faced as a result of the COVID-19 pandemic [9].

For the migrant workforce, there was a staged re-opening of New Zealand's borders to skilled workers, temporary visa holders, and class exemptions for critical workers [10, 11]. The re-opening of New Zealand borders will allow more construction workers to enter the country, although there is also a potential risk of workers leaving the sector. A total of 1,920 migrants from construction-related occupations arrived in the year ended June 2022 [12].

2.2. Global supply chain disruption and inflation

The COVID-19 pandemic, and the resulting restrictions on business operations and international movement, had a significant impact on global supply chains, which have been slow to recover, and exposed the vulnerabilities of freight networks [13, 14].

The building and construction sector felt the effects of these supply chain impacts acutely, particularly against the backdrop of increasing demand for construction across New Zealand. As restrictions eased and projects resumed at pace and scale, suppliers struggled to meet the demands of the sector [15]. This resulted in shortages in some materials, such as structural steel, timber, and plasterboard. Coupled with rising freight costs, these have impacted the affordability of importing products into the market [16].

These supply chain disruptions and the challenges in meeting market demand have contributed to high inflation around the globe. As at June 2022, the annual inflation in New Zealand was at its highest rate in more than 30 years [17]. This has had a significant impact on the construction of new dwellings, where costs have increased by an annual rate of 18 per cent [17].

Therefore, although the sector is showing signs of recovery from the immediate impacts of the COVID-19 pandemic, the complexity of global supply chain issues means that the full impacts may still be felt for some time to come.

2.3. Emissions Reduction Plan

In May 2022, the Government released its first Emissions Reduction Plan, which sets the direction for meeting New Zealand's carbon emission reduction targets. The Plan contains actions and accountabilities across every sector of the New Zealand economy, including building and construction [18].

The plan sets out five key focus areas for the building and construction sector [18, 19]:

- Reducing the whole-of-life embodied carbon of buildings
- Accelerating the shift to low carbon buildings
- Improving the energy efficiency of buildings
- Shifting energy use away from fossil fuels
- Establishing the foundations for further emissions reduction in the future.

Work is underway to progress regulatory changes that will help to meet these objectives and to work alongside the industry as it transforms the way it operates. Part of this work will include the development of data and reporting tools to monitor progress towards the objectives of the Emissions Reduction Plan [19]. As these are developed, they are likely to be included in future editions of this report.

3. Key New Zealand statistics and trends

The building and construction sector played an important role in New Zealand's economy in the past year. An overview of the key trends in the following are outlined in this section: economic performance; the workforce; locality; and imported building and construction products. An outline of the key statistics is provided in Appendix A.

3.1. Economic performance

The construction sector is a major contributor to New Zealand's economy. It is New Zealand's fifth largest industry, produces 6.7 per cent of real GDP, comprises approximately 70,600 businesses nationwide, and directly employs almost 300,000 people (around 10.5 per cent of the total workforce) [20].

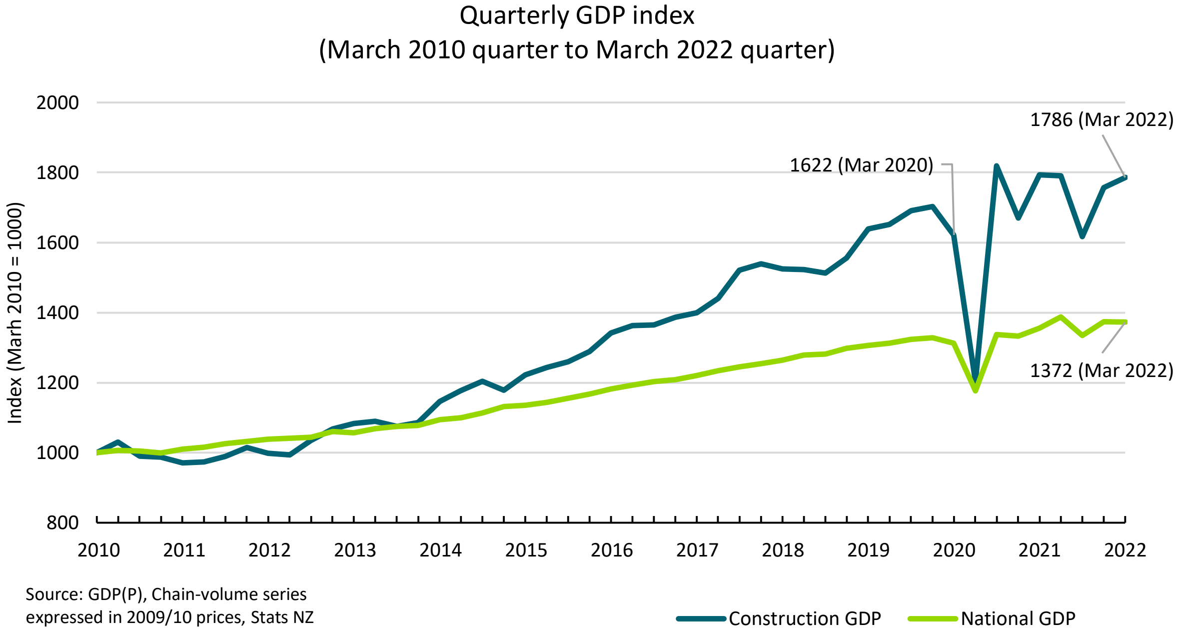
3.1.1. Gross Domestic Product (GDP)

In the year ended March 2022, the sector's contribution to GDP rose 7.1 per cent, driven by construction services and residential building construction [1]. The rise in construction mirrored investment in fixed assets, with growth in residential buildings (up 7 per cent) and non-residential buildings (up 4 per cent) for the year ended March 2022 (refer to Figure 1).

Between the year ended March 2018 and March 2022, the sector grew 15.3 per cent and was ranked 5th in its contribution to GDP growth. It contributed around 46.7 per cent of New Zealand's 2022 Gross Fixed Capital Formation (GFCF), which is a measure of the economy's investment in capital assets.

The sector has also indirectly contributed to GDP by supporting a wide range of industries in the New Zealand economy. For example, in the year ended March 2020, it bought $1,767 million worth of products from wood product manufacturing, and $2,584 million of fabricated metal product manufacturing. This accounted for 45.6 per cent of wood product manufacturing, and 45 per cent of fabricated metal product manufacturing.

Figure 1



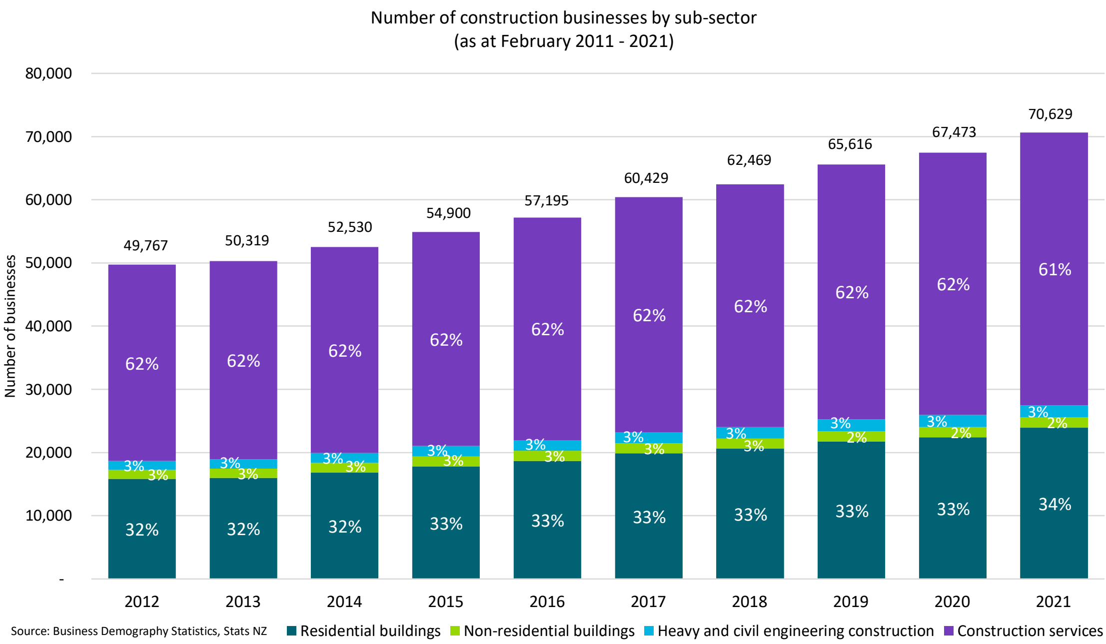
The sector also played an important role in New Zealand's regional economies and saw strong growth in these areas. In the year ended March 2020 (the latest data available), the sector's contribution towards Otago and West Coast's regional GDP was 9 per cent and 8.4 per cent, respectively (refer to Figure 2). Canterbury and Marlborough were the only two regions where the sector's share of the regional GDP decreased between the year ended March 2019 and March 2020.

Figure 2

3.1.2. Business demographics

Since 2012, there was an increase of 41.9 per cent in the number of construction businesses. As of February 2021, 70,629 businesses were registered as operating in the construction industry, comprising 12.6 per cent of all businesses in New Zealand [21]. These included residential and non-residential building construction (36.2 per cent), heavy and civil engineering construction (2.7 per cent), and construction services (61.1 per cent) (refer to Figure 3).

Figure 3



Most construction businesses (97.9 per cent) were small businesses with fewer than 20 employees. Of these, 65 per cent were sole operators with no employees [21]. Medium-size businesses (i.e., those employing between 20 and 49 employees) made up 1.6 per cent of the total number of businesses, while large businesses (employing 50 or more people) accounted for just 0.5 per cent of the total.

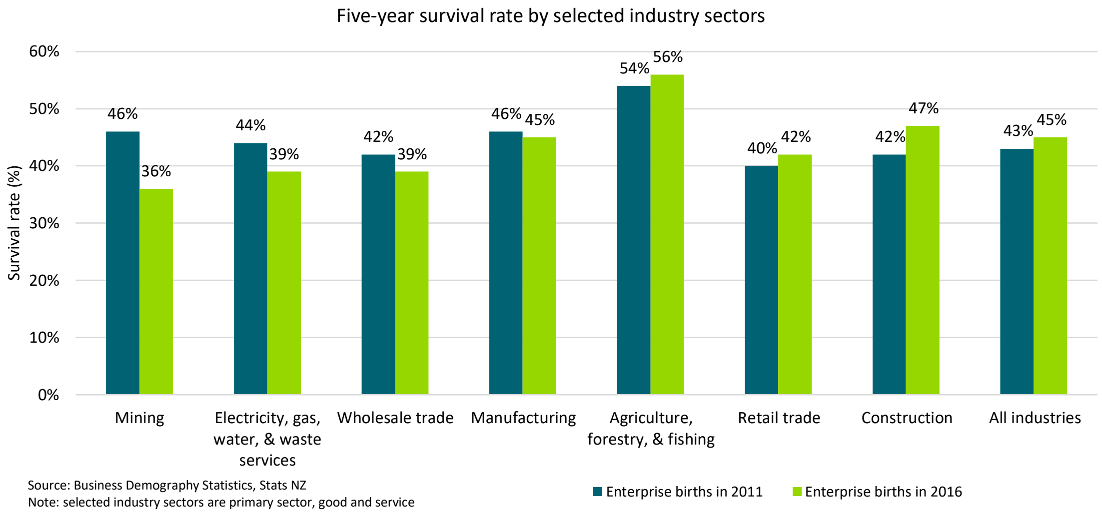
In 2021, the majority of construction businesses (75.9 per cent) generated a turnover of less than $500,000, while 2.9 per cent generated $5 million or more in turnover.

3.1.3. Business survival[1]

For the year ended May 2022, 220 companies registered as construction businesses were liquidated, accounting for 19 per cent of all insolvent liquidations. That was lower than the 221 and 236 companies liquidated in 2021 and 2020, respectively (during the same 12 month period) [22].

In terms of the five-year survival rate, construction businesses that were established in 2016 had a better survival rate than the average rate for all industries (47 per cent survived compared with 45 per cent across all industries) (refer to Figure 4). Moreover, those that were established in 2016 were five per cent more likely to survive than those established in 2011 [21].

Figure 4

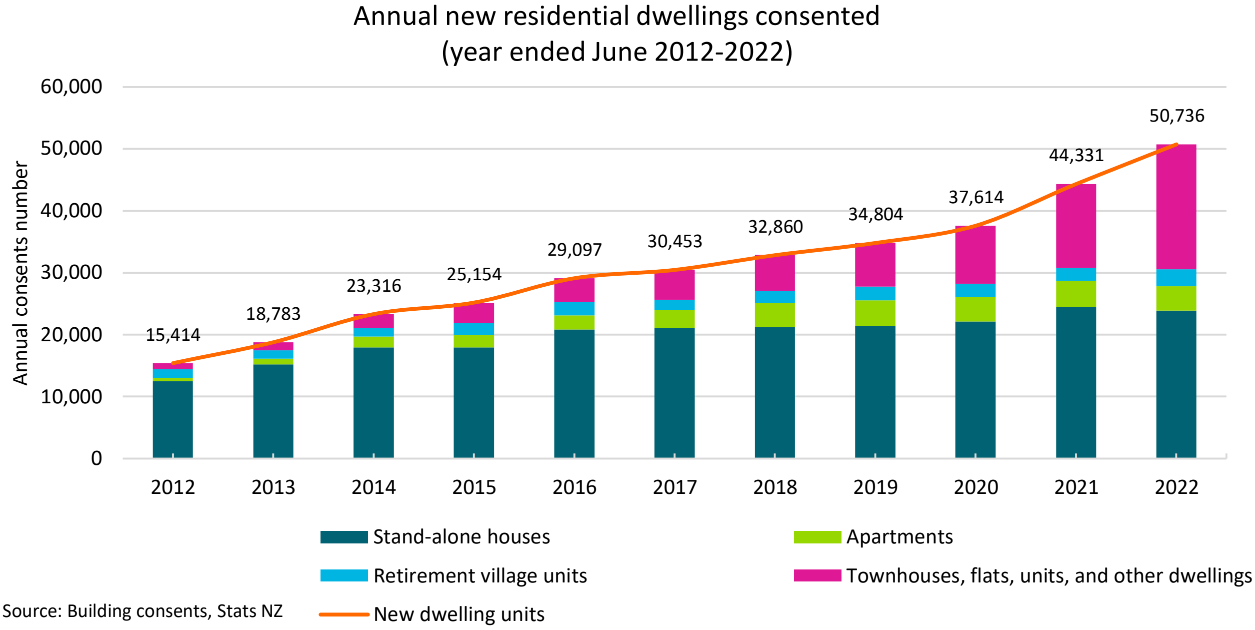


3.1.4. Building consents, typologies, and completion

There were 50,736 new homes consented in the year ended June 2022, up 14.4 per cent from the year ended June 2021 (and slightly below the record of 51,015 homes consented in the year ended May 2022). The increase in consents was largely driven by the growth in the number of consents for multi-unit homes (refer to Figure 5). There were 26,823 multi-unit homes consented in the year ended June 2022, up 35.5 per cent compared with the year ended June 2021 [23].

[1] The liquidation data is sourced from the NZ Companies Office. Industry information is supplied on a voluntary basis by companies and is based on the Business Industry Classification (BIC) Code.

Figure 5

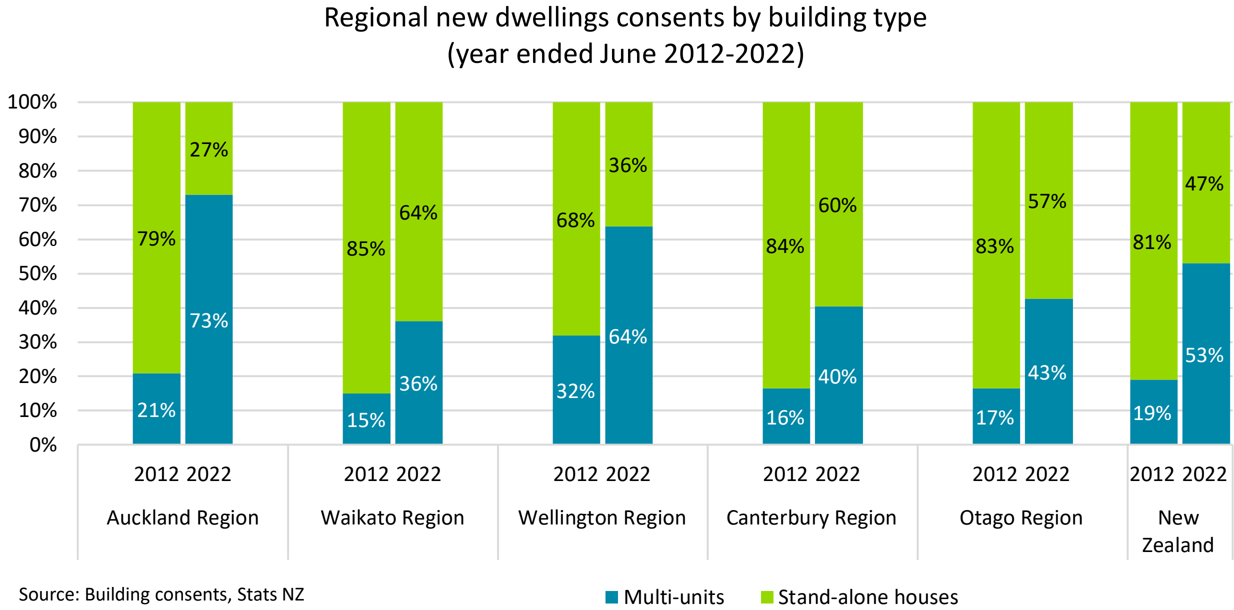


Source: Building consents, Stats NZ

The number of building consents for multi-unit homes has increased significantly in the past decade. Nationally, the share of stand-alone houses decreased from 81 per cent to 47 per cent of dwellings consented between the year ended June 2012 to June 2022, while the proportion of multi-units increased from 19 per cent to 53 per cent (refer to Figure 5).

At the regional level, Auckland and Wellington saw the most notable changes in building typology (refer to Figure 6). For example, the proportion of multi-unit dwellings increased to 73 per cent in Auckland and 64 per cent in Wellington in the year ended June 2022, making up the majority of dwelling types consented in those regions.

Figure 6



Source: Building consents, Stats NZ

The change in building typologies is reflected in the trends in the average size of new dwellings consented. Between the year ended June 2012 and 2022, the average size of stand-alone houses decreased by seventeen square metres to 195 square meters, while new apartment units increased from 105 square metres to 109 square metres. However, in the past five years, the average size of all new dwellings consented decreased from 172 square metres to 150 square metres.

Stats NZ estimated that almost 35,000 homes received a Code Compliance Certificate (CCC) in the year to March 2022 [24]. This figure was consistent with the number of new residential electricity connections for the same time period at 33,800 new connections [25]. However, the pace of completion has slowed in the last few quarters. The rolling average of the median completion time (from the issuance of the building consent to the CCC) was 406 days in the year ended March 2022. This was 19 days longer than the 387 days in the year ended March 2020.

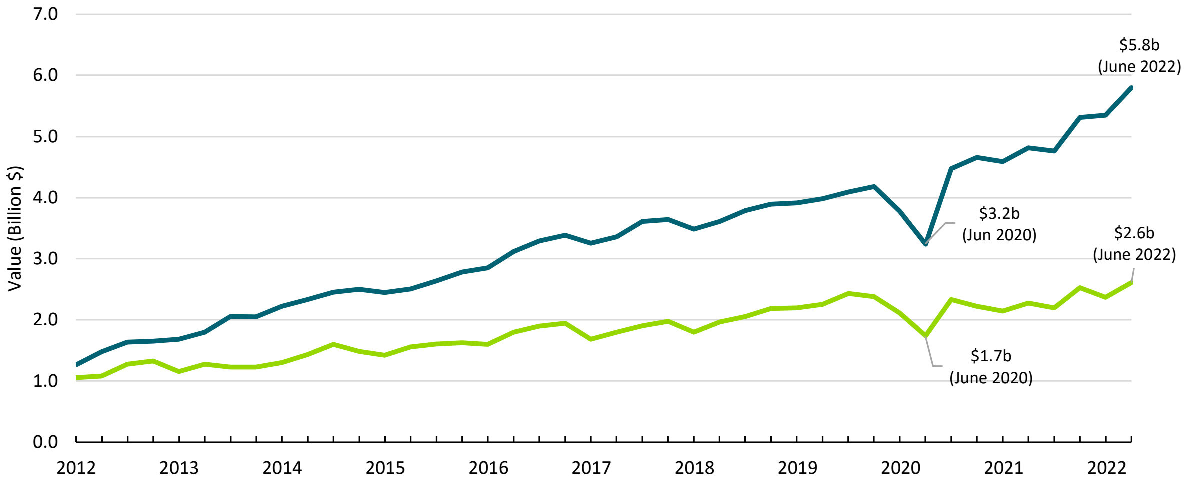
3.1.5. Building value[2]

The total construction activity for the year ended June 2022 was valued at $31 billion, and rose 12.4 per cent compared with 2021. For the June 2022 quarter, total building value was $8.4 billion, up 18.7 per cent from the June 2021 quarter (refer to Figure 7).

The value of non-residential building activity in the year ended June 2022 was 8.1 per cent higher than in the year ended June 2021 [26]. This could be a reflection of the 11 per cent increase in non-residential building costs over the same period [27].

Figure 7

Quarterly value of residential and non-residential building work put in place
(March 2012 quarter to June 2022 quarter)



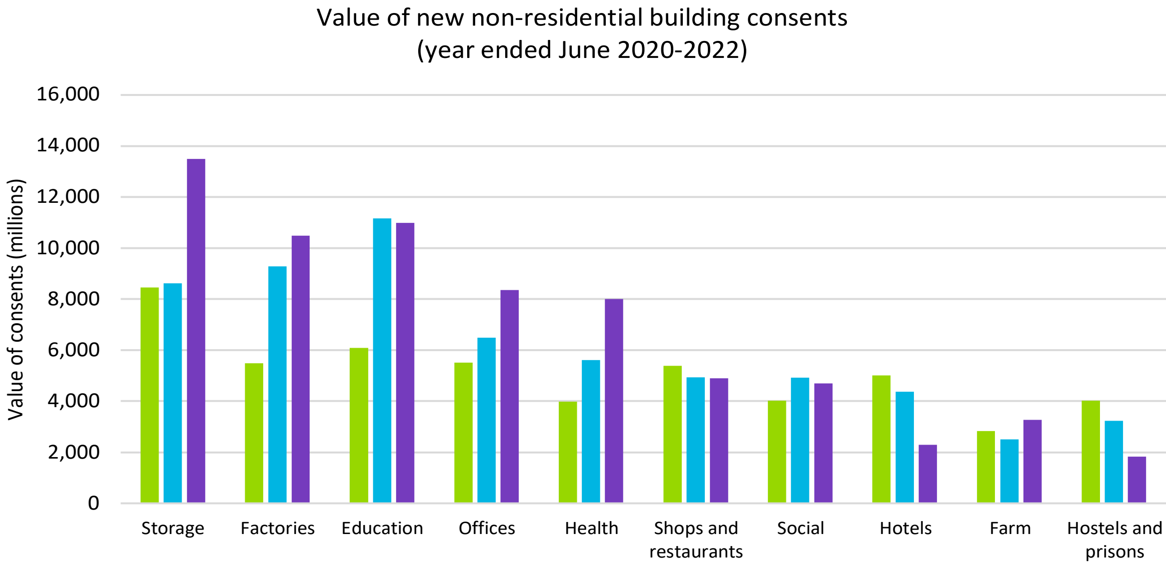
Source: Building Activity Survey, Stats NZ

Residential buildings — Non-residential buildings

There was strong growth in the value of consents for industrial, healthcare, and education buildings (refer to Figure 8). The infrastructure sector (which includes construction of roads, water networks, hospitals, schools and defence facilities) is an important part of the construction sector. Te Waihanga (the New Zealand Infrastructure Commission), reported that the value of infrastructure projects in the National Infrastructure Pipeline increased from $69.2 billion to $72.6 billion in June 2022, a five per cent increase from the March 2022 quarter [28].

2 The value of building work put in place includes both building work done and cost increases.

Figure 8

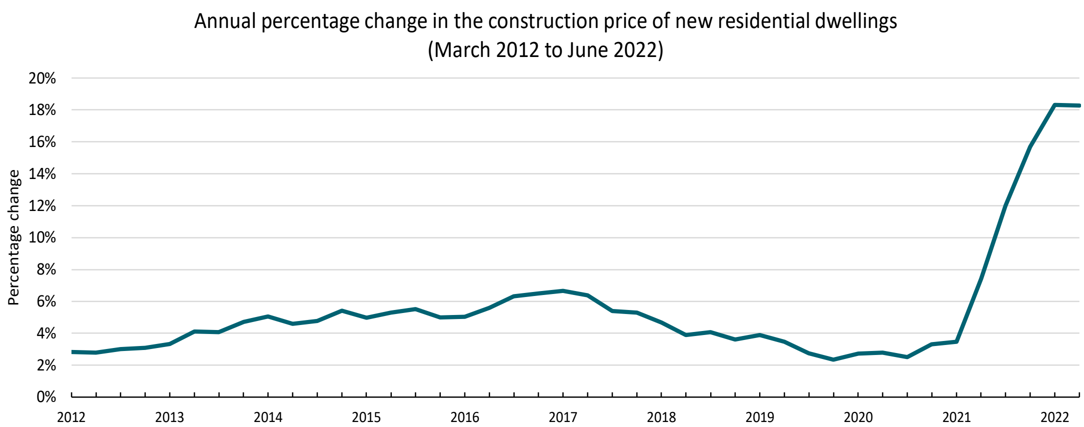


Source: Building consents, Stats NZ

3.1.6. Building costs

The cost of building a new house increased by 18.3 per cent in the year to June 2022, and was a major driver of the annual Consumer Price Index (CPI) increase (refer to Figure 9) [29].

Figure 9

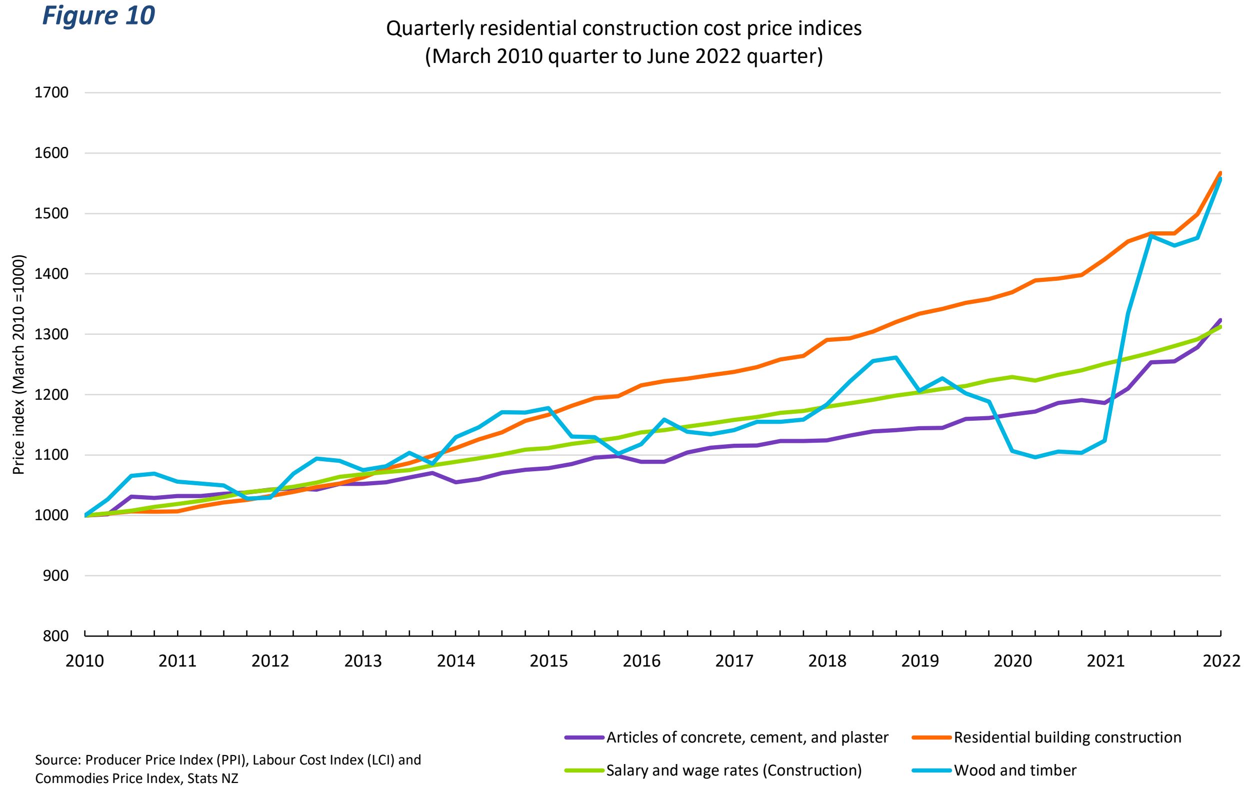


Source: Consumers Price Index, Stats NZ

Residential building costs rose 16 per cent (as measured in the output Producers Price Index (PPI)), while non-residential building costs rose 11 per cent since the June 2021 quarter. The increase in construction costs is partly due to increases in the cost of construction materials and labour (refer to Figure 10) [30, 31]. Specifically, wood and timber increased by 17.1 per cent, concrete by 6 per cent, and labour by 4.2 per cent. The increased cost of shipping materials is also likely to be a contributory factor [32].

The Labour Cost Index for construction industry wage and salary workers increased by 4.2 per cent for the year ended June 2022 (compared with 3.4 per cent growth for all industries). The average hourly rate for construction industry workers was $33.99 in the June 2022 quarter, which was an increase of $1.90 from the hourly rate of $32.09 in the June 2021 quarter.

Figure 10

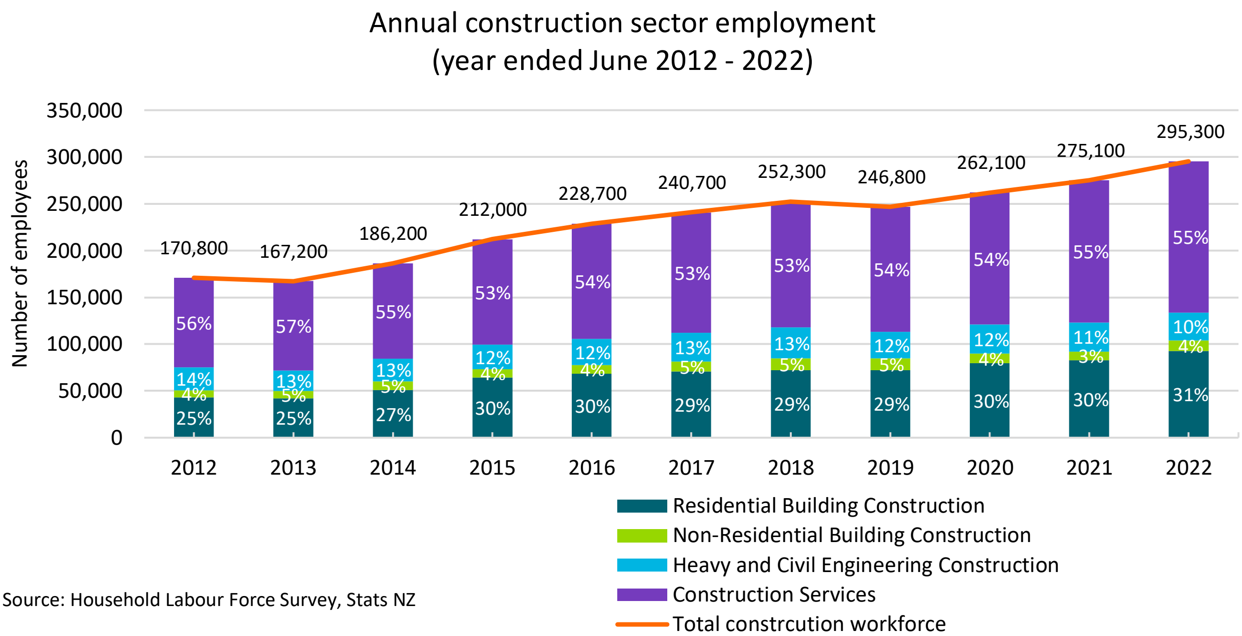


Source: Producer Price Index (PPI), Labour Cost Index (LCI) and Commodies Price Index, Stats NZ

3.2. Construction workforce

The construction industry is the third largest employing industry in New Zealand with 295,300 employees (around 10.5 per cent of all workers) for the year ended June 2022. In the past decade, employment in the building and construction sector was characterised by solid growth (refer to Figure 11). This reflects strong building activity and employment gains in the sector. The majority of construction workers were employed in construction services (54 per cent), such as plumbing, electrical and carpentry services.

Figure 11



Source: Household Labour Force Survey, Stats NZ

3.2.1. Construction workforce demographics

A snapshot of the key demographic characteristics of the construction workforce for the year ended March 2022 is provided in Figure 12.

The sector is characterised as having a higher share of males and certificate-qualified workers than most other industries. Male representation was particularly high in building structure services (92.6 per cent) and building completion services (92 per cent).

Most workers (90 per cent) were employed full-time, compared with 80 per cent across all industries. The workforce was also relatively young: 42 per cent were aged 15 to 34 years, compared with 36 per cent across all industries. It was also the industry with the largest number of workers aged 15 to 24 years, employing 44,500 (or 15 per cent of all construction workers) in the year ended March 2022. The median age of workers was 38 years, which was slightly below the median age of 40 years recorded across all industries.

Forty-two per cent of the construction workforce had completed a post-school certificate, which was above the 27 per cent for all industries. Just 14 per cent had attained a Bachelor degree or higher, compared with 34 per cent for all industries.

Figure 12 . Key demographic characteristics of the construction workforce

Source: Household Labour Force Survey, Stats NZ

For the year ended March 2022, construction trades workers accounted for 32.4 per cent of the total construction workforce. Of those, the most common occupations were: electricians (20 per cent); bricklayers, carpenters and joiners (16.7 per cent); and plumbers (15.7 per cent).

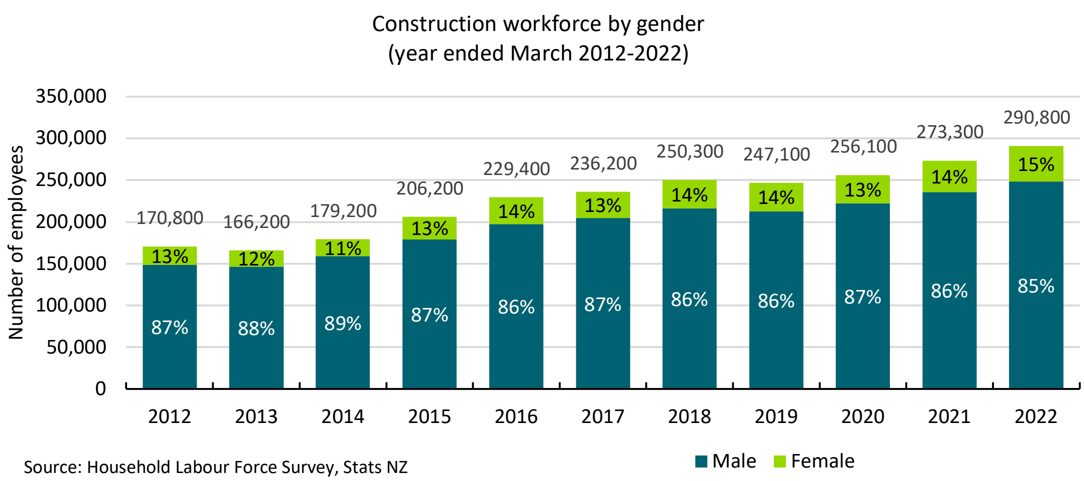
The average weekly ordinary time earnings for full-time workers in construction was $1,330 in the March 2022 quarter, which was lower than the average of $1,376 for all industries for the same time period.

3.2.2. Trends in demographic characteristics

Gender

Although there are fewer female workers in construction than in other sectors, the number of female workers in the sector has been increasing steadily. Between 2012 and 2022, the number of female workers increased by 93.7 per cent, equating to 20,500 workers (refer to Figure 13). This was comparatively higher than the 66.9 per cent growth in the number of male workers during the same time period.

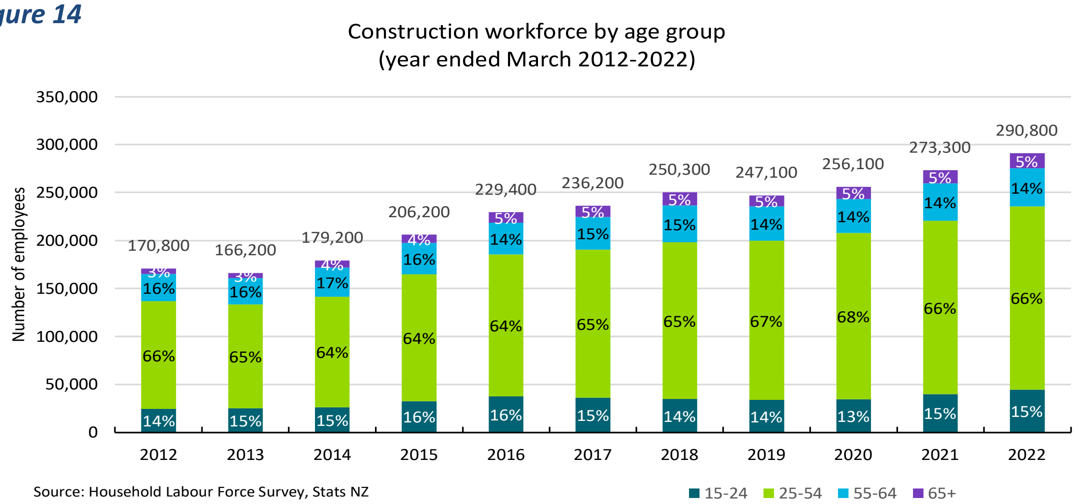
Figure 13



Age

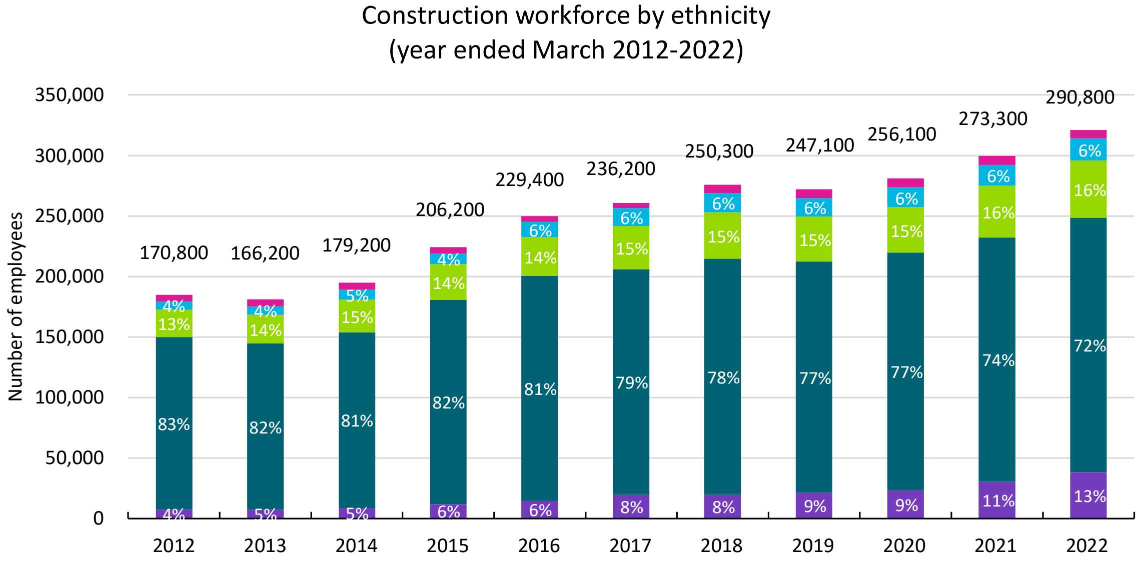
The number of workers of retirement age (65 + years) grew from 6,000 (3.5 per cent) in 2012 to 15,500 (5.3 per cent) in 2022 (refer to Figure 14). The number of workers aged 15 to 24 years increased significantly from 24,500 to 44,500 between the year ended in March 2012 and March 2022.

Figure 14



Ethnicity
The sector is also becoming more ethnically diverse. In the past decade, the proportion of workers from ethnic backgrounds has increased (refer to Figure 15). Noticeable trends include the proportion of workers of Asian ethnicity increasing from 4 per cent in 2012 to 13 per cent in 2022. The proportion of Pacific peoples also increased from 4 per cent in 2012 to 6 per cent in 2022.

Figure 15



Note: MELAA refers to the Middle Eastern/Latin American /African ethnic groups
Source: Household Labour Force Survey, Stats NZ

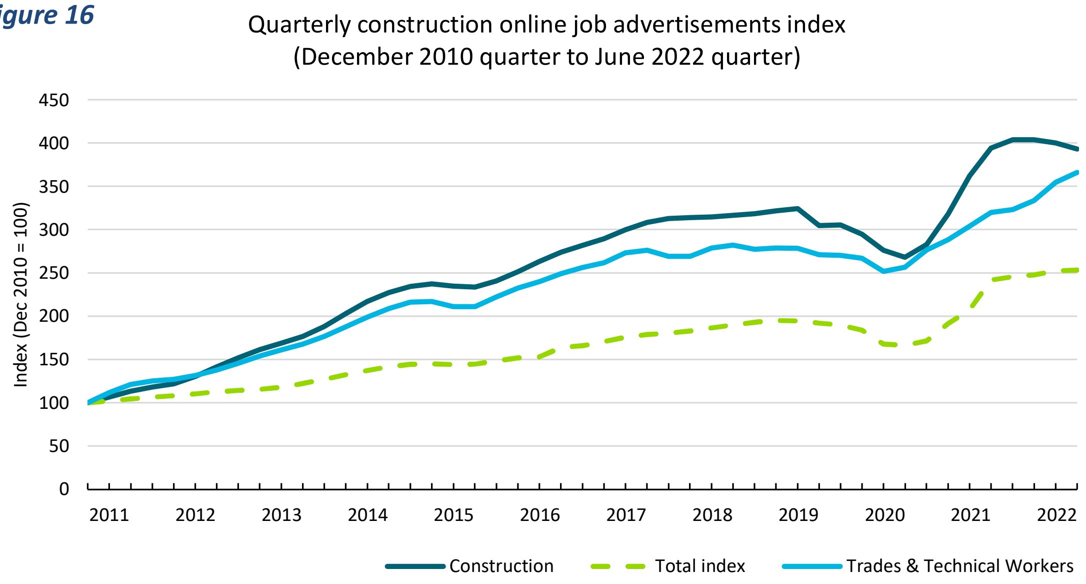
3.2.3. Workforce pipeline

Employment in the construction sector has been strong in the past decade, driven by population growth and the high demand for housing and infrastructure projects (including, for example, the Canterbury rebuild). Since the start of the COVID-19 pandemic, it has been one of the sectors with the greatest percentage increase in filled jobs [33]. Between June 2020 and 2022, the number of filled jobs in construction sector increased by 11 per cent, and was more than double the rate of growth compared with all industries [2].

The online job advertisements for the sector grew 47 per cent, when compared with June 2020 (refer to Figure 16). Construction job advertisements in the Bay of Plenty, Gisborne/Hawkes Bay, Northland, Otago/Southland, Marlborough/Tasman/Nelson/West Coast and the Waikato regions were above the national average for construction jobs in the June 2022 quarter [34].

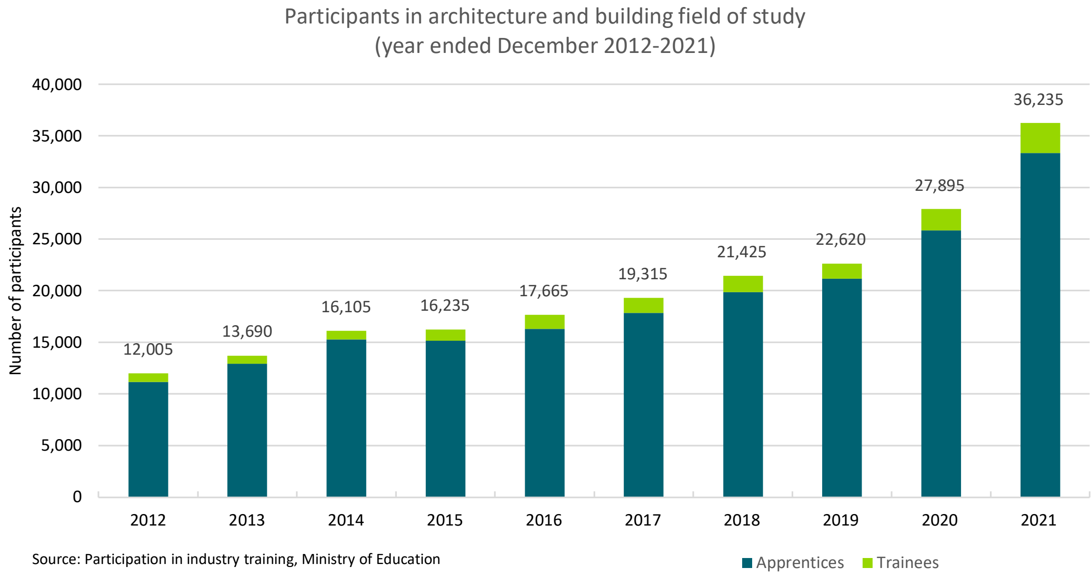
However, alongside the increase in job advertisements, Stats NZ's Business Operations Survey 2021 reported that around 90 per cent of construction businesses had experienced moderate to severe difficulties recruiting tradespersons and related workers (including apprentices). This was an increase from 74 per cent in the 2020 survey [35].

Figure 16



There is a strong pipeline of workers entering training for the construction sector. In the year ended December 2021, there were 36,235 learners in the field of architecture and building training (refer to Figure 17). Between 2012 and 2021, the total number of learners increased by 24,230, (more than 200 per cent). The sector also had the highest number of apprentices at 33,320 learners (42.5 per cent of the total number of 78,480 apprentices in 2021).

Figure 17

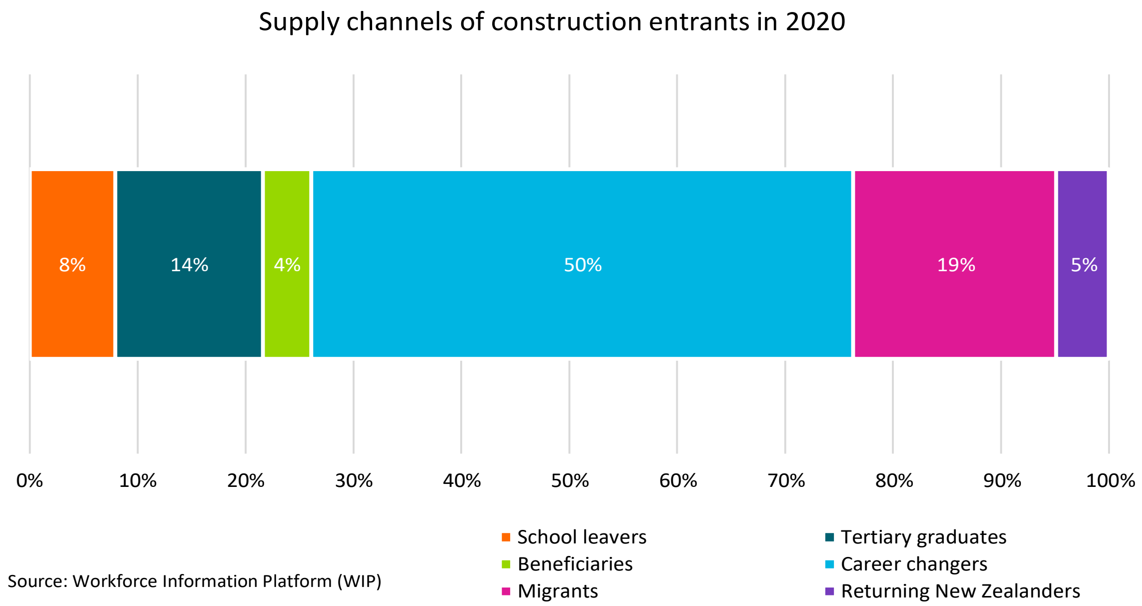


Source: Participation in industry training, Ministry of Education

Immigration plays a role in the construction workforce, with an estimated 7 to 10 per cent of the construction workforce being temporary migrants [36]. There has been a consistent number of construction-related work visas approved between the year ended June 2018 to June 2022, averaging about 8,900 visas approved per year. The most common occupations were: carpenters (33.9 per cent), scaffolders (7.9 per cent), builders' labourers (6.1 per cent) and steel fixers (5.6 per cent). About two-thirds (68 per cent) of visa applicants came from countries in the Asian continent [37].

Data from the Workforce Information Platform (WIP) reported that of the approximately 25,000 workers who entered the construction sector in 2020, half were changing their careers, while just under one quarter were either migrants (19 per cent) or returning New Zealanders (5 per cent) (refer to Figure 18) [38].

Figure 18



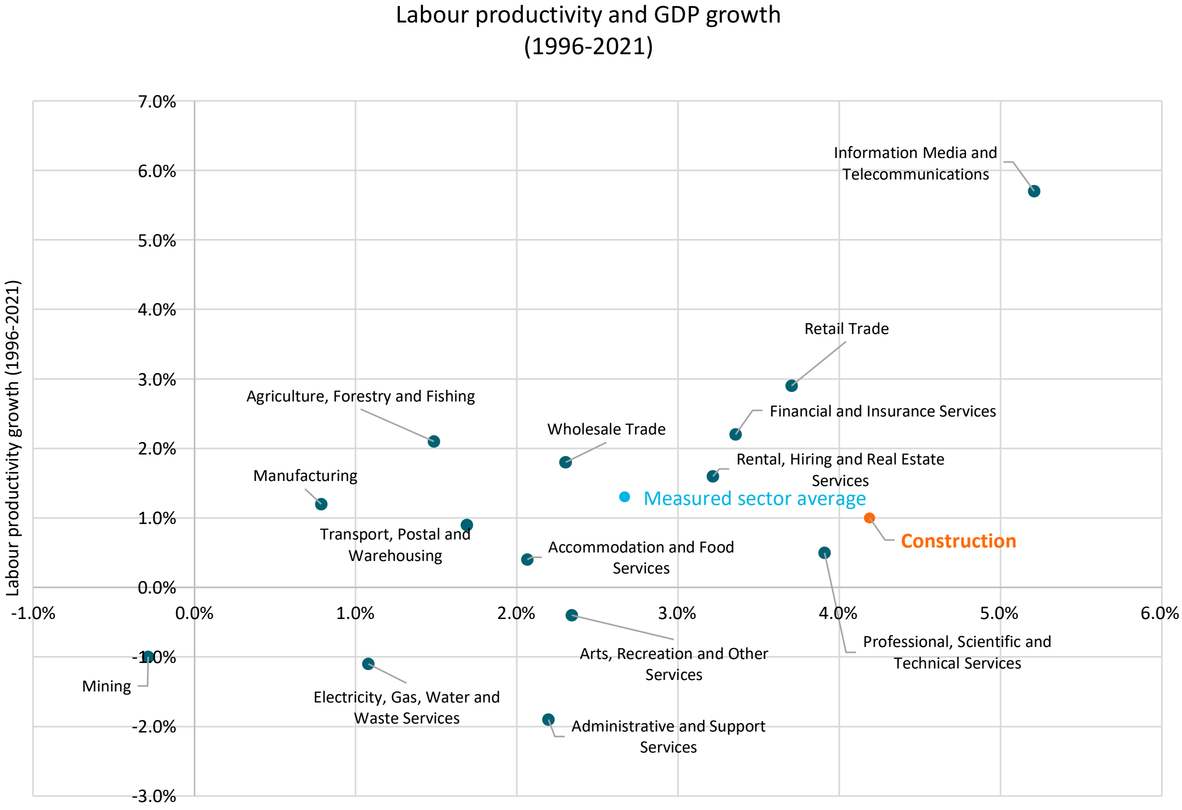
Source: Workforce Information Platform (WIP)

3.2.4. Labour productivity

Although the construction sector ranked second in terms of the compounded annual growth rate of GDP between 1996 and 2021, it was ranked eighth in terms of the compound annual growth rate of labour productivity (refer to Figure 19). Labour-productivity growth in construction averaged 1 per cent between 1996 and 2021[39].

Between the year ended March 2016 and March 2021, the sector's contribution to GDP grew 26 per cent (in terms of 2009/10 prices). However, the growth of labour productivity was below the all-industry average (refer to Figure 19).

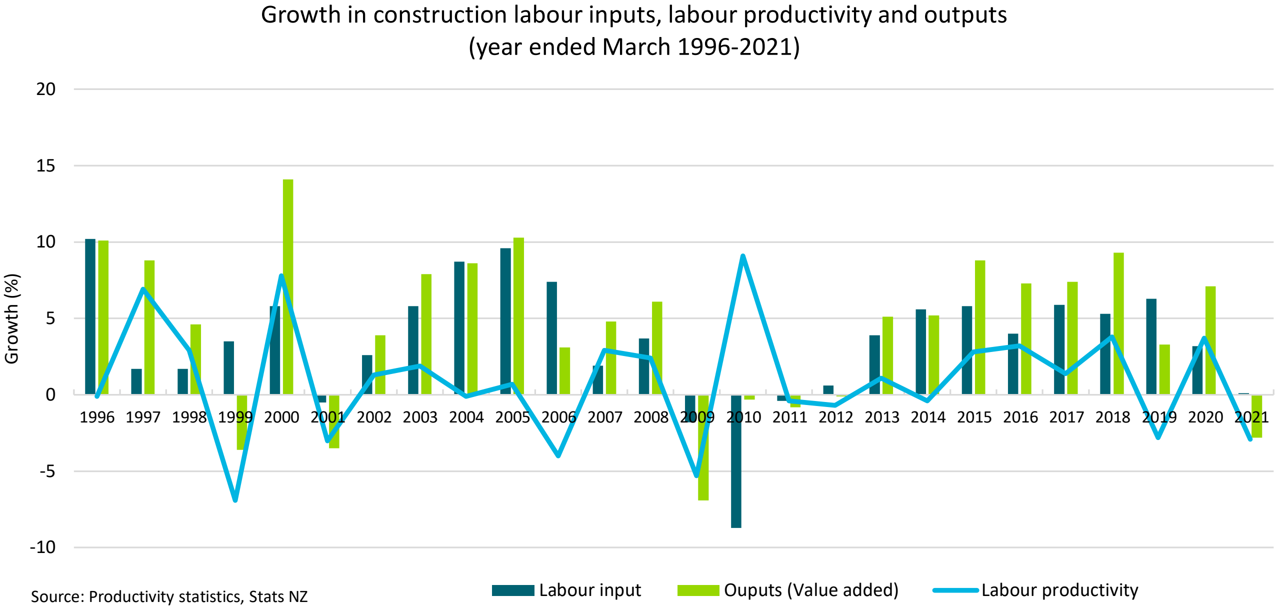
Figure 19



Source: GDP(P), volume series and productivity statistics, Stats NZ

The COVID-19 pandemic and its associated restrictions likely impacted labour productivity, which saw a decrease of 2.9 per cent between 2020 and 2021 (refer to Figure 20). However, this was less than the 5.3 per cent decrease in labour productivity between 2008 and 2009 during the 2008 Global Financial Crisis.

Figure 20



Source: Productivity statistics, Stats NZ

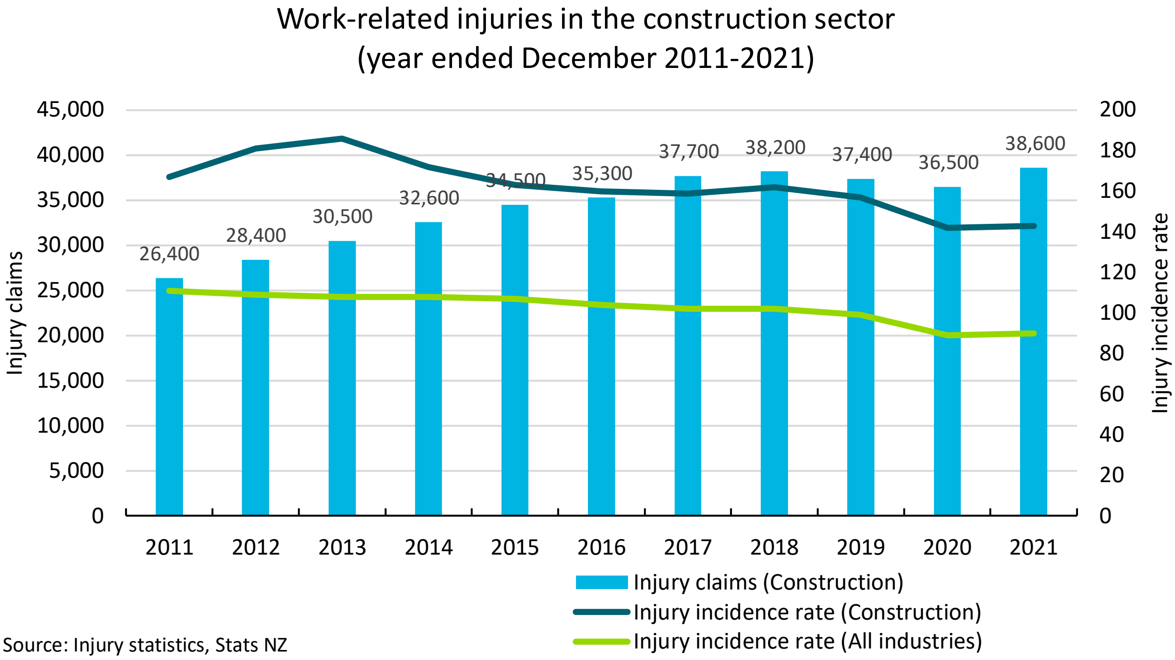
3.2.5. Health, safety and wellbeing

A total of 38,600 work-related injury claims were made by people in the construction sector in 2021 (up 5.8 per cent from 2020) (refer to Figure 21). This was the highest number of claims made across all industries, accounting for 17 per cent of all claims [40].

The injury incidence rate for the construction industry was 143 claims per 1,000 full-time equivalent (FTE) employees, compared with 90 claims per 1000 FTE for the all-industry average. This was the third highest incidence rate behind agriculture, forestry, and fishing (172 claims per 1000 FTE) and manufacturing (162 claims per 1000 FTE).

Nine construction-related fatal incidents were reported in the year ended December 2021, accounting for 17 per cent of the total number of work-related fatal claims.

Figure 21



Source: Injury statistics, Stats NZ

3.2.6. Occupational regulation

By July 2022, there were 27,346 licensed building practitioners (LBPs), and 32,409 licensed electrical workers in New Zealand [41].

For the year ended June 2022, 187 complaints were made against LBPs and non-LBPs. This was a decrease of 28.9 per cent from the number of complaints received for the same period in the year to June 2020, but a 10 per cent increase from the complaints received in the year to June 2021. The lower number of complaints received in the June 2021 year could potentially be due to building work being restricted during that time, in accordance with COVID-19 response measures.

In the year to June 2022, 100 complaints were made against registered electrical workers and non-registered electrical workers, compared with 126 complaints in 2020.

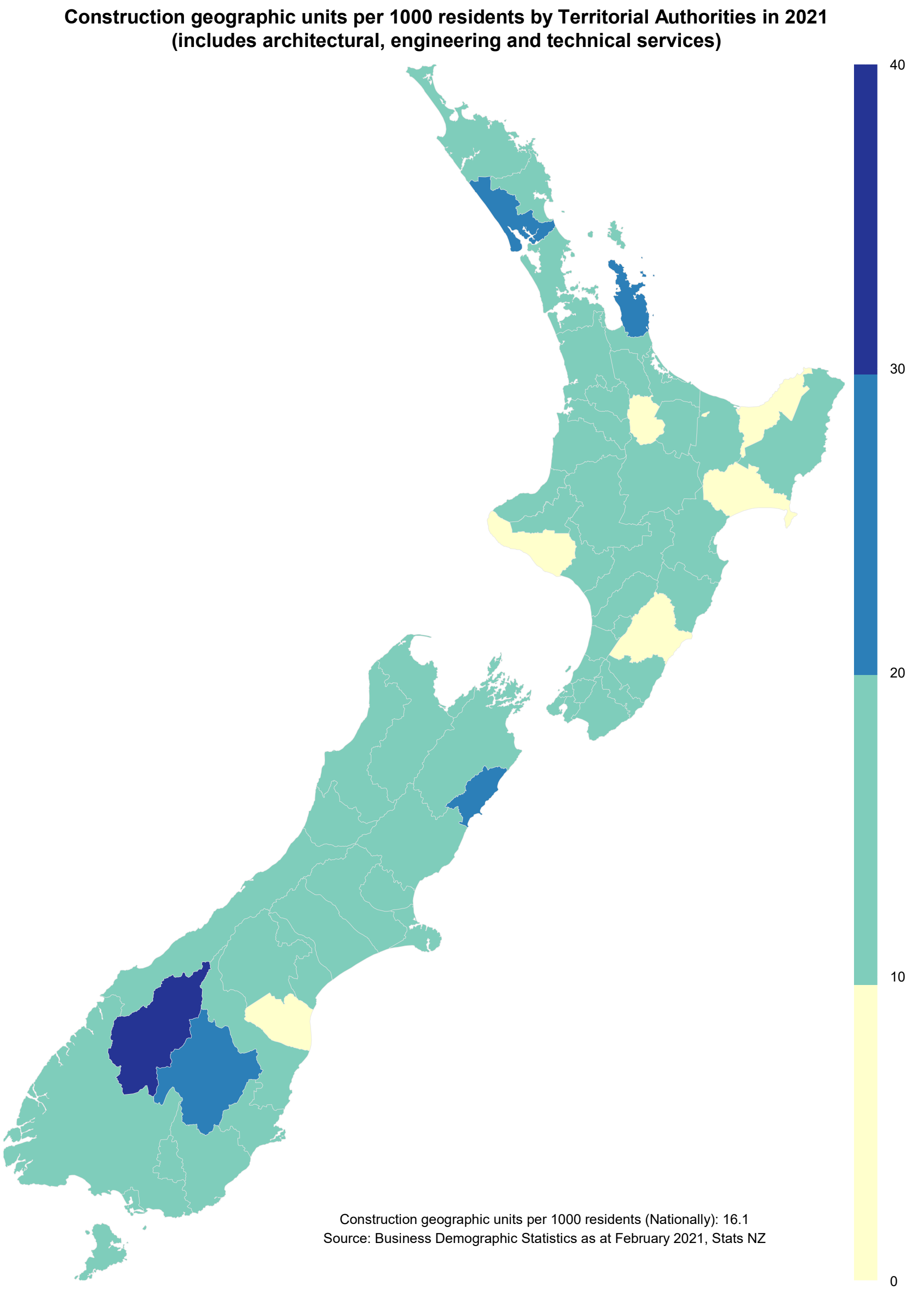
3.3. Building activity across Territorial Authorities

An overview of the geographic distribution of construction businesses, employees, and building consents across Territorial Authorities is outlined below.

3.3.1. By businesses

As at February 2021, there were 82,608 geographic units/locations/branches of construction businesses across New Zealand. This was a growth of 4 per cent (or 3,363 geographic units) since 2020 [42]. Queenstown-Lakes District Council had the highest number of geographic units per 1000 residents at 39, followed by Thames-Coromandel District Council (25.3), Kaikōura District Council (24.6), Central Otago District Council (23.7), and Kaipara District Council (20.4) (refer to Figure 22). The number of geographic units in the major Territorial Authorities were closer to the national average of 16.1 units per 1000 residents (i.e., Auckland City at 18.1, Wellington City at 11.6, Christchurch City at 17.9).

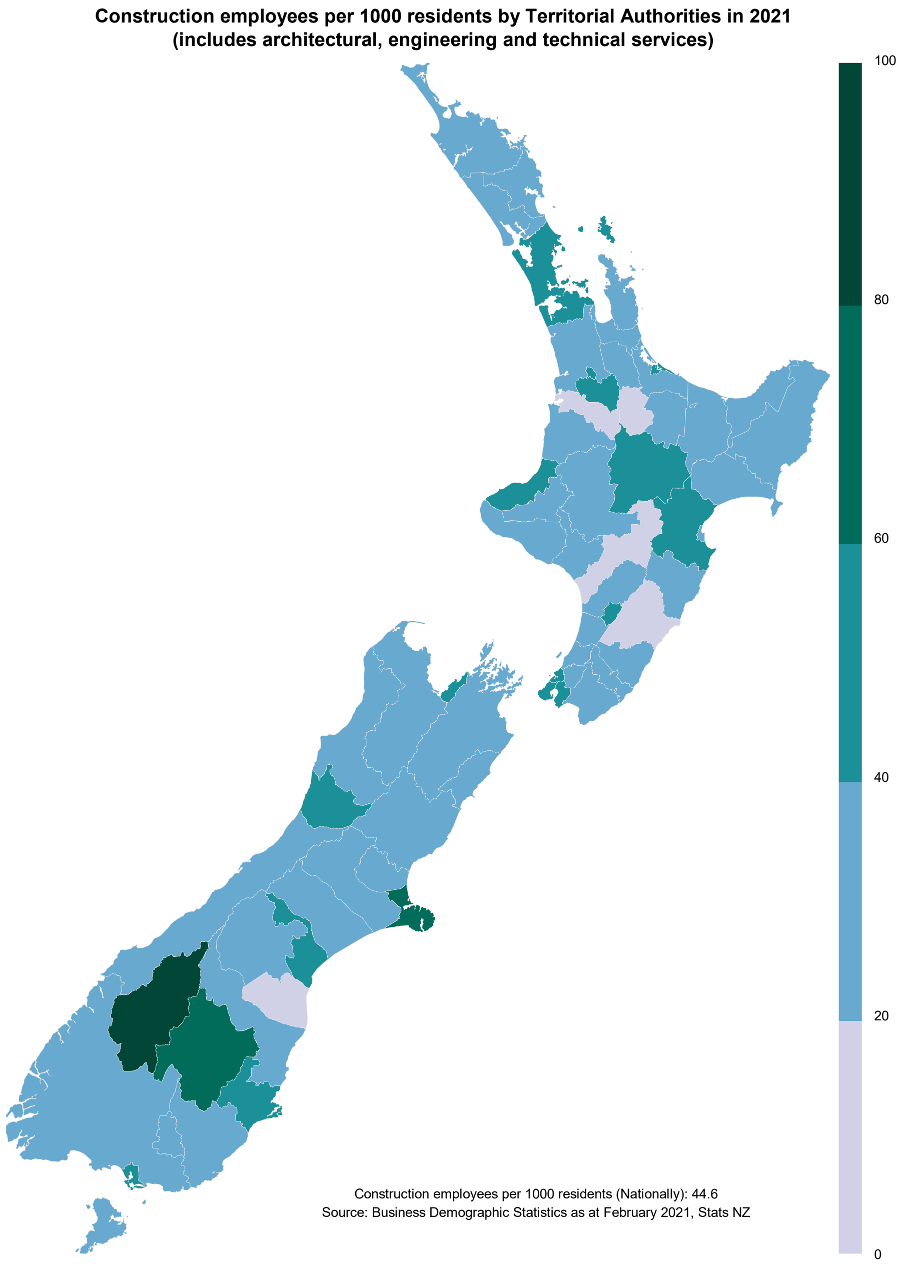
Figure 22



3.3.2. By employees

As at February 2021, Queenstown-Lakes District Council also had the highest number of construction workers at 82 employees per 1000 residents (refer to Figure 23) [42]. Other Territorial Authorities that also had a high number of construction employees per 1000 people included: Central Otago (68.1), Christchurch City (66.1), Hamilton City (57.9) and Tauranga City (55.9). Auckland City (47.4) and Wellington City (41.9) were closer to the national average of 44.6 construction employees per 1000 residents.

Figure 23



3.3.3. By building consents

The Queenstown-Lakes District Council had the highest number of dwellings at 26 consents per 1000 residents (compared to 9.6 nationally). Overall, Queenstown-Lakes District Council had the highest number of geographic units/locations/branches of construction businesses, construction workers and dwellings per 1000 residents in February 2021.

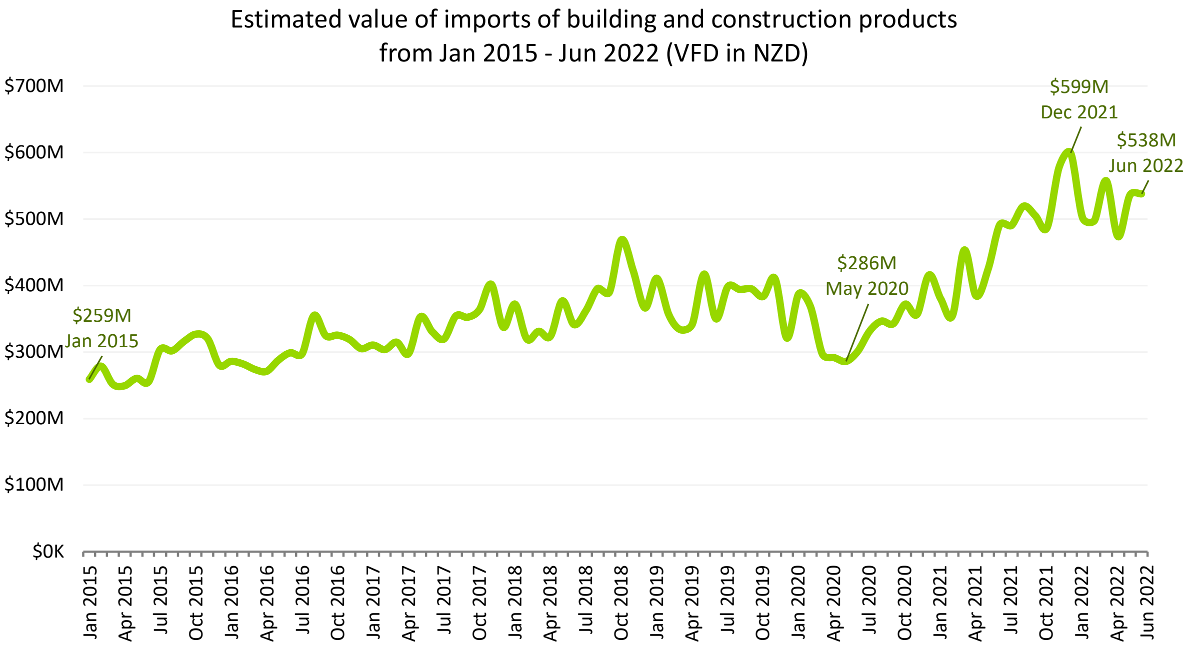
3.4. Building and construction product imports

3.4.1. Value of imports[3]

The import value of building and construction products has generally been on an upward trend since January 2015. Although it reached a low point of $286 million in May 2020 (due to COVID-19 pandemic restrictions, such as border closures and global shipping delays), a rebound was seen and an all-time high of $599 million was reached in December 2021 [43].

The monthly value of imports increased from $259 million in January 2015 to $538 million in June 2022 (refer to Figure 24) [43]. While the monthly figures showed some easing of import values, the annual import values showed an increasing trend. By year ended June 2022, the 12-month rolling total import value reached $6.28 billion compared with $4.65 billion in the year ended June 2021. This was an increase of 35 per cent or $1.63 billion.

Figure 24



Source: Overseas Merchandise Trade dataset, Stats NZ

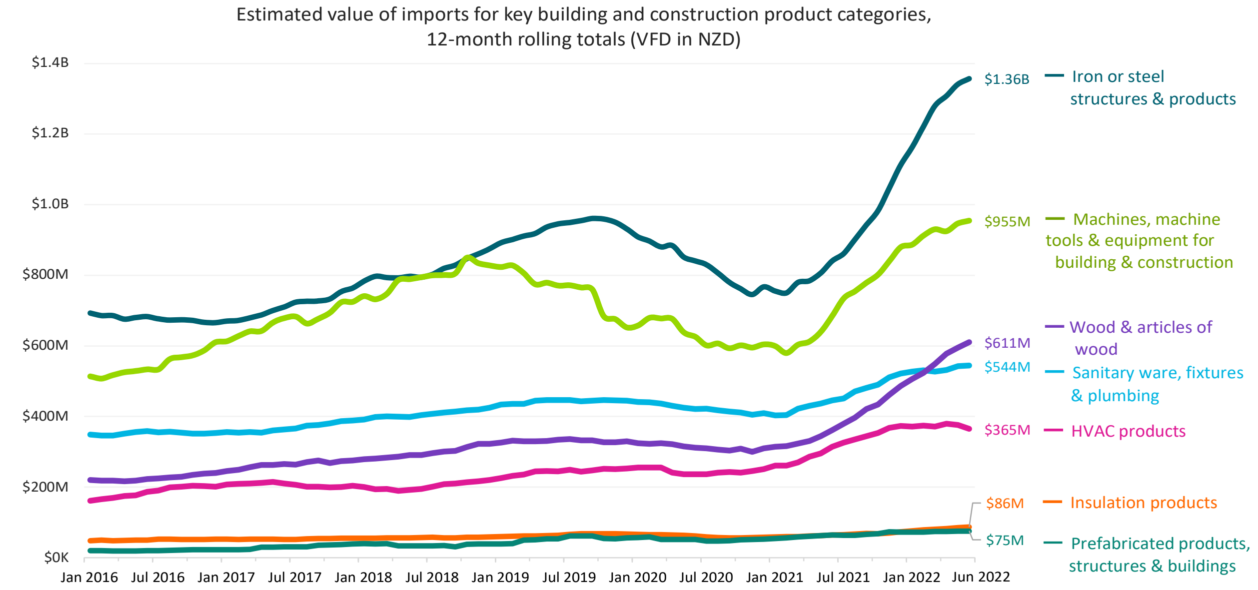
3.4.2. Types of products imported

Iron or steel structures and products and *machines, machine tools and equipment* made up the greatest proportion in the overall value of imported products. In the year ended June 2022, an estimated $1.36 billion worth of *iron or steel structures and products* were imported, an increase of $516 million (or 61 per cent) from the previous year. The import value of *machines, machine tools and equipment* reached $955 million in the year ended June 2022, exceeding its previous peak of $850 million in the year ended October 2018 [43].

Wood and articles of wood saw the largest annual percentage increase in the value of imported goods. In the year to June 2022, $611 million was imported, an increase of $250 million (69 per cent) compared with $361 million in the year ended June 2021 (refer to Figure 25) [43].

[3] This is measured as Value for Duty (VFD). VFD is the value of imports before the addition of insurance and freight costs and is expressed in NZD.

Figure 25

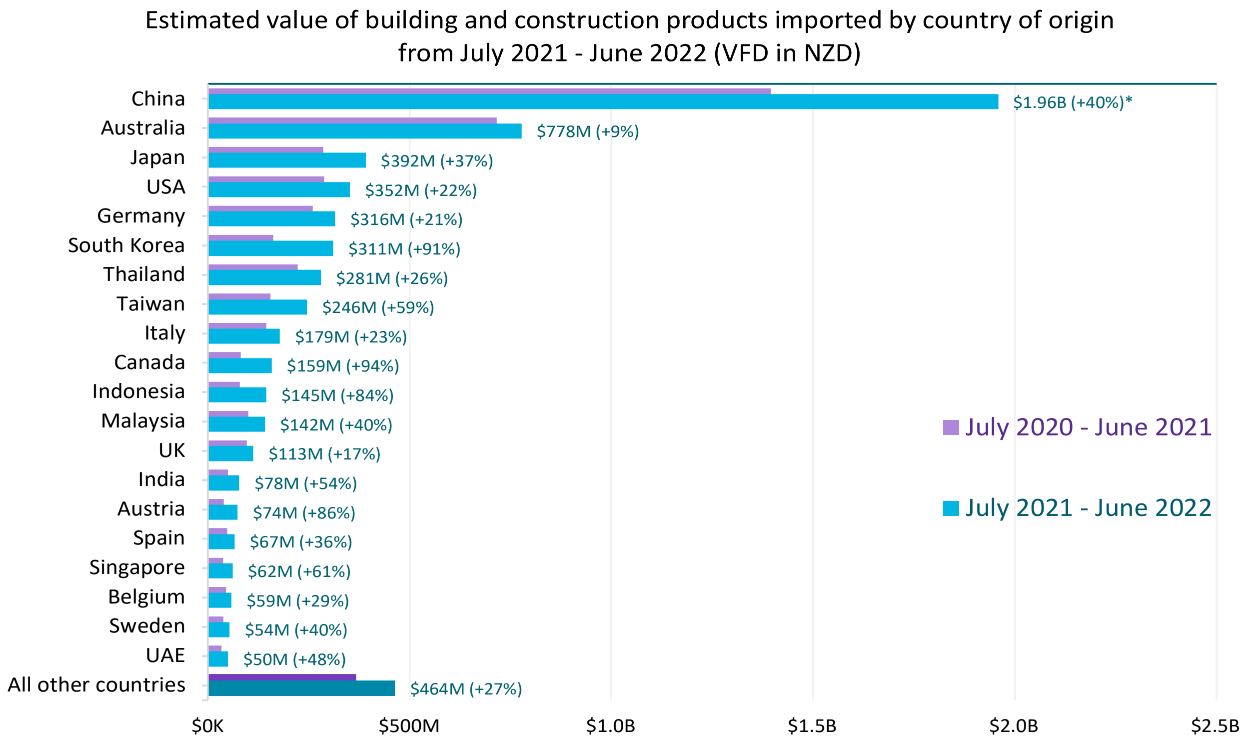


Source: Overseas Merchandise Trade dataset, Stats NZ

3.4.3. Country of origin of imported products

China was the country of origin for most imported building and construction products in the year ended June 2022, representing NZD $1.96 billion worth of products imported (refer to Figure 26). This was 40 per cent higher than in the year ended June 2021. Following China was Australia, with NZD $778 million of products imported, an increase of 9 per cent from the previous year [43].

Figure 26



Source: Overseas Merchandise Trade dataset, Stats NZ

*percentages shown are the change from July 2020 - June 2021 period

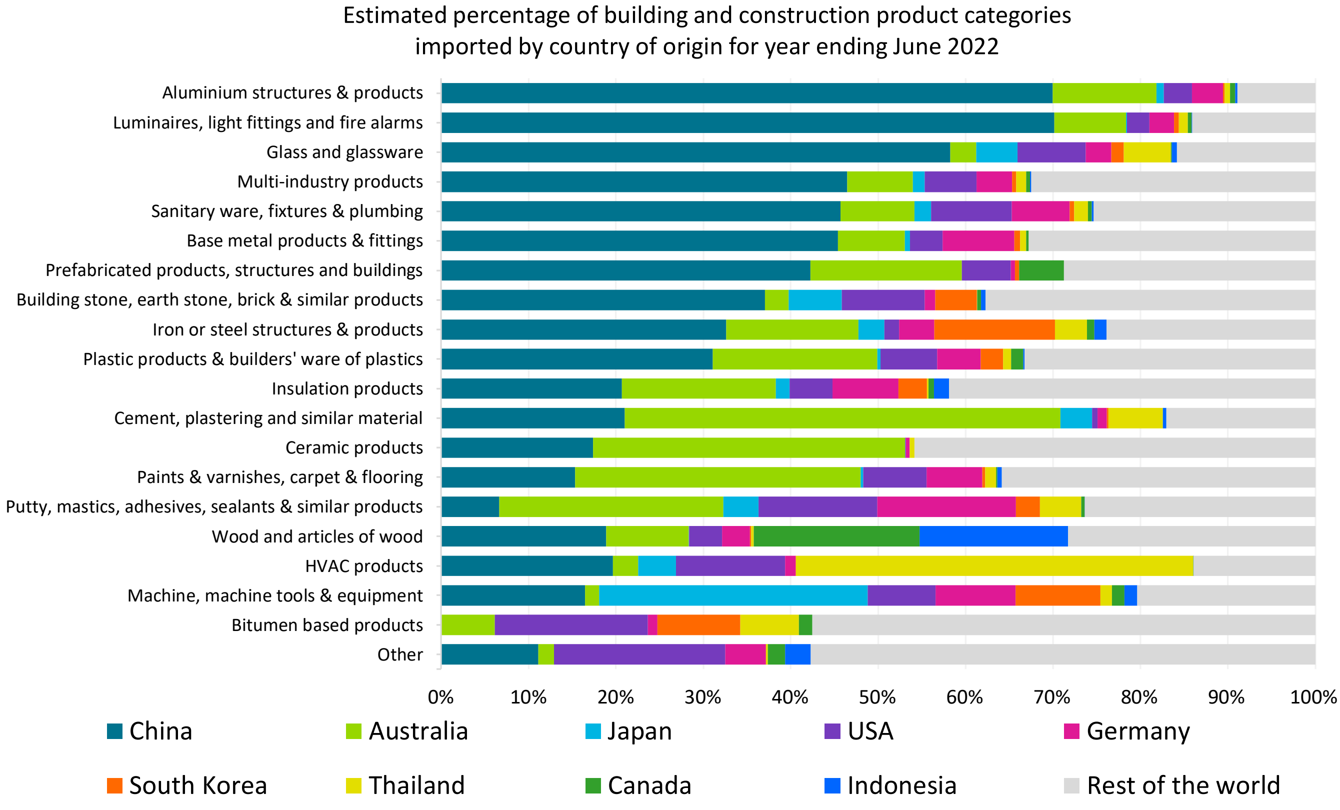
In terms of the types of products imported by country, China was the source for the majority of *aluminium structures and products* (70 per cent), *luminaires, light fittings and fire alarms* (70 per cent), and *glass and glassware* (58 per cent). In addition, it was the top country of origin for seven other product categories (refer to Figure 27) [43].

Other top countries of origin include:

> **Australia**: cement, plastering and similar material (50 per cent); ceramic products (36 per cent); paints and varnishes, carpet and flooring (33 per cent); and putty, mastics, adhesives, sealants and similar products (26 per cent)
> **Japan**: machine, machine tools and equipment (31 per cent)
> **Thailand**: Heating, Ventilation and Air Conditioning (HVAC) products (45 per cent)
> **Canada**: wood and articles of wood (19 per cent)

It is worth noting though that while the majority of total construction imports are from just a few countries, Figure 27 illustrates that New Zealand imports from a wide range of countries for all product categories.

Figure 27



Source: Overseas Merchandise Trade dataset, Stats NZ

4. Global trends in building design, technology, and materials

The construction sector is regularly changing and innovating, welcoming new trends in building design, technology and materials. In recent years, climate change, greater environmental awareness, increased health and safety awareness, and the need for increased efficiency and functionality, have been some of the key drivers behind these new trends.

This section provides highlights of current and emerging trends in building design, technology and materials. It is for this reason that a number of the topics covered in last year's Building and Construction Sector Trends Annual Report 2021 [44] (e.g., green buildings, prefabrication and Building Information Modelling (BIM)) have been excluded in this year's report. However, updates may be provided in future reports if there are further developments in these topic areas.

4.1. Trends in building design

4.1.1. Zero/Low carbon emission buildings

Following the Paris Agreement in 2015, various countries developed their own National Climate Action Plans to address climate change [45]. In 2021, the building and construction sector accounted for 37 per cent of global energy-related carbon dioxide emissions [46]. Building zero-emission buildings is one solution to reducing carbon emissions from buildings.

"*A zero carbon building is a highly energy efficient building that produces on-site, or procures, carbon-free renewable energy in an amount sufficient to off-set the annual carbon emissions associated with building operations*" [47]. A review of recent literature reported that "*maximizing operating efficiency and minimizing embodied carbon in buildings is one of the lowest cost pathways to significant emissions reductions*" and that it was possible to achieve this through existing "*systems, technologies and skills that already exist, and at costs that are in the range of conventional buildings*" [48].

The following trends and strategies are currently being used globally to reduce carbon emissions in the construction industry:

- Producing and using low/zero carbon emission materials in buildings [49-53]
- Avoiding or minimising the use of high carbon emission materials, such as cement and steel, or offsetting emissions from such materials [50, 54, 55]
- Designing and building more energy efficient buildings to reduce the operational emissions [48, 52, 56, 57]
- Taking advantage of the circular economy concept in design and construction [18, 53, 58]
- Decarbonising energy sources and using zero emission energy sources [59, 60]
- Refurbishing existing buildings as much as possible rather than demolishing and rebuilding [61, 62]
- Taking advantage of new construction methods and modern technologies [52, 63, 64].

The World Green Building Council estimated that there were approximately 500 net zero energy commercial buildings and 2,000 net zero energy housing units worldwide in 2016 [47], and that most of these buildings were in Europe, North America, Korea, Japan, China, India, and New Zealand [48].

According to a survey by the Royal Institution of Chartered Surveyors in 2021, approximately three-fifths of respondents reported that the occupier demand for green/sustainable commercial buildings had grown over the past twelve months [65]. In North America, the total number of zero energy projects grew by 15 per cent between 2019 and 2020 [66].

In New Zealand, the Government has recently introduced the Emissions Reduction Plan [18] and the Building for Climate Change programme [67]. Alongside these, changes in consumer demand and the sector have contributed to significant efforts in recent years to reach zero emissions in buildings [68-71]. The overall interest in green and sustainable buildings has also been increasing. One example of this are trends reported by the New Zealand Green Building Council (refer to Figure 1). Recent research suggests that the building and construction sector is in the early stages of transitioning to a net-zero carbon built environment [72].

***Table 1**. Trends in the New Zealand Green Building Council (NZGBC) data in the past year [73][4].*

	2020	2021	Percentage change
Green STAR[5] registrations [74]	21	54	157 per cent ↑
NABERSNZ[6] certifications [75]	53	72	36 per cent ↑
Homestar[7] registrations [76]	4755	6421	35 per cent ↑
Homestar Built Ratings	960	1688	76 per cent ↑

4.1.2. Retrofitting existing buildings

While changes are being made to have zero emissions in new buildings, the significant role of existing buildings in this journey cannot be neglected as "*the greenest building is... one that is already built*" [77]. To meet the Paris Agreement's 2050 carbon neutrality target, at least 20 per cent of the existing global building stock will need to be zero carbon ready by 2030 [78].

The types of retrofit required for climate change (known as *deep retrofit*) is substantially different from typical renovations. The Buildings Performance Institute Europe (BPIE) outlined that climate neutral retrofitted buildings needed to be [79]:

- Healthy and foster occupant well-being
- Part of the energy system infrastructure
- Highly energy efficient
- Circular in materials and use
- Fossil fuel free
- Resilient to climate risks.

While retrofitting existing buildings is a priority for developed countries, in developing countries, the focus is more likely to be on the pace of new construction [48]. Below are some examples of retrofitting plans from around the world (refer to Table 2).

[4] The data that is included in Table 1 was sourced from NZGBC.

[5] Green Star is a voluntary and holistic sustainability rating system for commercial buildings, fitouts and communities. This tool is created by the Green Building Council Australia and has been adapted for New Zealand [74].

[6] A NABERSNZ rating provides a simple, comparable, and independent measure of an office's operational performance. The rating shows a building's energy performance [75].

[7] Homestar is designed to be an independent rating tool for assessing the health, efficiency, and sustainability of homes across New Zealand. A rating is undertaken at the design stage (design rating) and once the project obtains practical completion (built rating) [76].

__Table 2.__ Examples of retrofitting plans from across the globe.

Australia
The Reliable Affordable Clean Energy for 2030 (RACE for 2030) consists of four programs. One program named RACE for Home is focused on making "*homes more comfortable while lowering their energy bills by developing and applying new energy technologies*" [80]. Based on the modelling, retrofitting one million existing Australian homes across five years could reduce the average home energy use and emissions by up to 9,000kWh and 5.8 tonnes CO_2 equivalent per year, and potentially create up to $55 billion in private finance investment opportunities [81].
Canada
Initiatives such as the Canada Greener Homes Initiative, CleanBC Better Homes and Home Renovation Rebate Program and the Energy Efficient Building Incentive Program are being offered by the Canadian federal and provincial governments. These programmes are designed to help homeowners make where they live more energy-efficient [82-84].
China
Since 2007, the central government established a fund to improve the energy efficiency of government offices and large-scale public buildings that are over 20,000 square meters [85]. Financial support to improve the energy efficiency of existing residential buildings was also introduced, and CNY 900 million allocated to 15 provinces and cities.
Germany
Through a collaboration with KfW Bank in 2011, the German Federal Ministry of Transport and the Building and Urban Development committed loans and grants of EUR €2.9 billion for the retrofit of residential buildings, including investments of EUR €3.9 billion, and securing employment for 52,000 people [86].
European Union
The European Green Deal was introduced in December 2019, and the Renovation Wave (an action plan within the Deal) was introduced in October 2020 [79, 87]. The aim of Renovation Wave was to at least double the renovation rates in the next ten years and to ensure that renovations led to higher energy and resource efficiency [88]. Through this Wave, it is anticipated that 35 million buildings will be renovated and up to 160,000 additional green jobs created in the sector by 2030 [88].

In addition to voluntary schemes and incentives, some countries also have mandatory policies for retrofitting existing buildings, and where the degree of renovation is cost dependent. Below are some examples [89]:

- **Brazil** – major renovations of federal buildings with a floor area of more than 500 m^2 are required to meet energy class A of the Brazilian building energy classification.
- **Canada** – a national energy code for alterations to existing buildings is being developed.
- **England and Wales** – the payback period for retrofits must not exceed 15 years.
- **Ireland** – the building code requires only *cost optimal* upgrades.
- **Italy** – existing buildings that undergo a major renovation must comply with Near Zero Energy Building requirements like new buildings.
- **England, Wales, Portugal,** and the **US** – heritage buildings are exempt from energy efficiency retrofits.

The importance of retrofitting existing buildings is highlighted in New Zealand's First Emissions Reduction Plan [18]. The Plan suggests introducing mandatory energy performance certificates for buildings, exploring incentive options and the expansion of the Warmer Kiwi Homes programme for decarbonising existing buildings. In its Zero Carbon Road Map, NZGBC recommended “*building owners to start certifying their existing buildings to zero carbon in 2020, and to have all their buildings zero carbon by 2030*” [90].

4.1.3. Medium-density housing

In the next 20 years, the total number of New Zealand households is projected to increase by 26.4 per cent from 1.8 million in 2018 to 2.3 million in 2043 [91, 92]. While expanding cities may not be sustainable nor environmentally friendly, housing intensification enables efficient use of existing land to increase housing supply.

As outlined earlier in Section 3.1.4 of this report, the number of building consents for multi-unit homes has increased significantly in the past decade, reflecting the growing demand for medium-density housing (MDH). A review of the literature by BRANZ in 2017 reported that there was increasing interest in the delivery of MDH in New Zealand [93].

While there are a wide range of definitions for MDH in New Zealand, MBIE has adopted the BRANZ definition of MDH: “*multi-unit dwellings of up to six storeys (above ground)*” [93]. Within this definition, there are three main categories [94]:

- 1 to 2 storey attached houses (e.g., duplexes, triplexes, semi-attached terraced houses)
- 2 to 4 storey attached houses (terraced houses)
- 3 to 6 storey apartments.

In recent years, BRANZ, MBIE, and the Ministry for the Environment have published information and guidance to facilitate MDH [94-96]. In 2021, the Resource Management Act 1991 was amended to require councils in New Zealand’s largest urban areas to adopt medium density residential standards (to boost housing supply and enable more types of housing) [97]. Accordingly, major city councils are now in the process of making changes to their District Plans and undergoing public consultation [98, 99].

4.1.4. Accessible buildings

According to the World Bank, one billion people (around 15 per cent of the world’s population) experience some form of disability, and is more prevalent in developing countries [100]. In New Zealand, 1.1 million (or 24 per cent of the population) were reported to have a disability in 2013 [101]. Having a disability may both be a permanent or a temporary condition.

Globally, there is an increasing trend to design buildings that are accessible for people with a disability. Being accessible means that “*a person with a disability is afforded the opportunity to acquire the same information, engage in the same interactions, and enjoy the same services as a person without a disability in an equally effective and equally integrated manner, with substantially equivalent ease of use*” [102].

Outlined below are examples of countries which have legislation on the accessibility requirements of buildings:

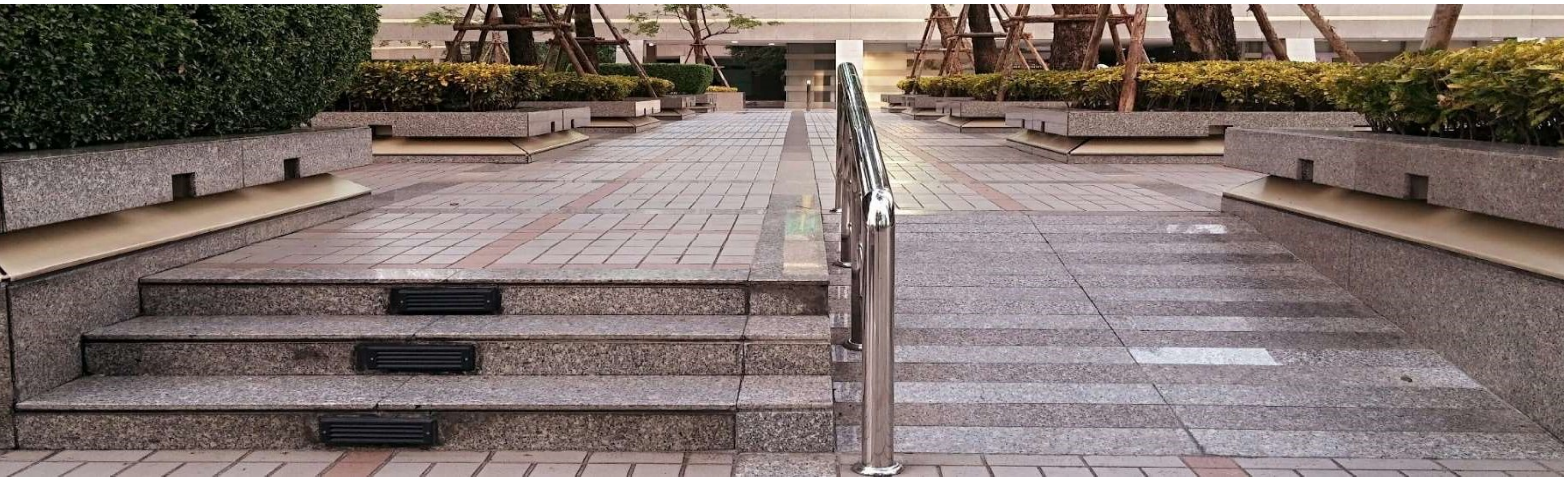
- **Canada** – the *Accessibility for Ontarians with Disabilities Act (2005)* is one of the most comprehensive examples of legislation that aims to develop, implement, and enforce accessibility standards in many types of buildings in Ontario by 1 January 2025 [103].
- **Singapore** – in March 2020, the Parliament of Singapore approved amendments to their Building Control Act to ensure buildings are more accessible [104]. Based on these new changes, all existing inaccessible commercial and institutional buildings, with a floor area of more than 500 sqm, which undergo any “*Additions and Alterations (A&A)*” work will be required to provide basic accessibility features (i.e., an accessible entrance, route, and toilet at the entrance level of the building) [104].

- **Sweden** – the Swedish Building Code has regulated the accessibility of public premises and workplaces for people with disabilities since 1966, and these regulations have been extended to residential buildings since 1976 [105].
- **UK** – Part M of the building regulation, which regulates *access and use of buildings,* was introduced in 2015 [106]. It categorised dwellings into: *visitable dwellings, accessible and adaptable dwellings, and wheelchair user dwellings*, and defined various levels of compulsory and optional accessibility requirements for each category [106].

In New Zealand, section 118 of Building Act 2004 states that buildings which "*members of the public are to be admitted"* are required to have "*reasonable and adequate provision by way of access, parking provisions, and sanitary facilities must be made for persons with disabilities who may be expected to (a) visit or work in that building; and (b) carry out normal activities and processes in that building*" [4]. This requirement applies to, but is not limited to, the building types that are mentioned in Schedule 2 of the Building Act 2004. In addition, various Building Code clauses [107] further define the scope of accessibility requirements, and NZS 4121:2001 provides a solution for situations that are within the scope of the Building Act 2004 [108].

Regarding residential buildings, 1 in 10 of disabled New Zealanders rated their housing as unsuitable for their needs, compared with 1 in 25 non-disabled people [109, 110]. The need for accessible housing is emphasised in the latest *Government Policy Statement on Housing and Urban Development* [111]. Kāinga Ora has committed to ensuring that at least 15 per cent of their new homes will meet universal design standards [112, 113]. Through their *Retrofit Programme,* 1500 existing homes will be retrofitted to be more energy efficient and accessible [114].

Universal Design[8], Life Span Housing[9], Inclusive Design[10], and Barrier-Free Design[11] are some of the key design approaches that take into account accessibility in the built environment [115-120]. Lifemark is the only accessible housing accreditation in New Zealand, and claims to represent the Universal Housing Design movement in New Zealand. In the past three years, there were 2682 Lifemark certified homes in New Zealand [121].



[8] *Universal Design* is the design and composition of an environment so that it can be accessed by all people regardless of their age, size, ability or disability [115].
[9] *Life Span Housing* accommodates changes in human ability over a person's lifespan, enabling the occupants to live and remain in their homes as long as possible [116].
[10] *Inclusive Design* is the design of mainstream products and/or services that are accessible to as many people as possible without the need for special adaptation or specialised design [117].
[11] *Barrier Free Design* describes the effort of removing physical barriers from the built environment for people with disabilities [117].

4.2. Trends in building technology

4.2.1. Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)

The adoption of virtual reality (VR), augmented reality (AR) and mixed reality (MR) is part of the growing digitization movement of the building and construction sector. These technologies enable clients to experience designed spaces before they are built, manage sites remotely, monitor health and safety; and enable collaborative working, training, and quality control [122, 123].

The definitions of VR, AR, and MR are as follows:

> **VR** – "*an artificial environment that is created with software and presented to the user in such a way that the user suspends belief and accepts it as a real environment*" [124]

> **AR** – "*an enhanced version of the real physical world that is achieved through the use of digital visual elements, sound, or other sensory stimuli delivered via technology*" [125]

> **MR** – a combination of both VR and AR.

Market analysis by Grand View Research reported that the value of the global VR market was USD $21.83 billion in 2021 and that this was expected to expand at a compound annual growth rate of 15 per cent from 2022 to 2030 [126]. Below are examples of how VR, AR, and MR are being used around the world (refer to Table 3).

Table 3. *Application of VR, AR, and MR technologies in the construction sector.*

NZ
Beca and Fonterra have partnered to develop a VR training and induction programme to improve health and safety in the NZ building sector (via an Accident Compensation Corporation (ACC) grant awarded as part of their injury prevention incentive programme) [127, 128].
UK
Oncor Reality combined high-resolution laser scans and photographs of clients' premises to develop fully explorable and interactive 3D environments. Using live or pre-recorded videos or photos, this technology enables project teams to inspect various parts of the project during the meeting from their preferred location. Oncor Reality claimed that this technology introduces time and cost savings against traditional onsite surveying, and allowed for precision planning of builds [129].
US
Industrial Training International has a Construction Hazard certification program that is fully delivered and assessed through VR Headsets [130].
The Wild launched a cloud-based, real-time collaboration platform which allows designers to work together on all stages of the design process, and present or review projects by connecting through a VR headset [131, 132]. The Wild claimed that their platform saved them $10,000 per project and 100+ days in preparing presentations, and gained them 50 per cent faster project approvals [132].
SRI International and Obayashi Corporation developed an AR system which captures 3D information of built rebar and digitally tie this to 3D Building Models [133]. Specifically, the technology enables identification of discrepancies between built structures and the building plan, and greater efficiencies in rebar inspection [133, 134].
Through a partnership between Microsoft and Trimble, users are able to use Trimble's XR10 hardhat, equipped with the Microsoft HoloLens 2, to visualise a 3D model hologram of a build within the real location, and collaborate in real time [135, 136]. Additionally, the AR technology enables installations to be verified and for building services to be priced more efficiently [137, 138].

Due to significant benefits of the VR, AR, and MR technology, governments around the world are making more investments in this field. Examples include:

- **Singapore** – as part of the *Construction Industry Transformation Map*, the Building and Construction Authority introduced the *Integrated Digital Delivery (IDD)* in 2017, with AR and VR technologies having a significant role in the digital design area [139, 140].
- **UK** – in 2018, the UK Government announced a £72 million investment in the *Core Innovation Hub,* which will support essential research and development in digital and offsite manufacturing technologies including AR and VR [141].

4.2.2. New energy sources for domestic buildings

The global energy crisis, limited fossil fuel resources, and increasing environmental awareness (of the impacts of fossil fuel usage) have encouraged scientists and governments from around the world to develop alternative clean and locally-generated energy sources. The application of hydrogen, sand batteries, and bladeless turbines are discussed below.

Hydrogen

In recent years, hydrogen has been suggested as an alternative energy source to natural gas. It can be used in domestic buildings in two ways: first, through its direct use (i.e., burning it for heating or cooking purposes); and second, through its usage in energy storage units [142]. The latter helps to store energy that is generated by renewable resources, such as solar and wind [143].

The process of burning hydrogen involves no greenhouse gas emissions, however, pure hydrogen is not readily available in nature and is produced through natural gas reforming, electrolysis, solar-driven or biological processes [144]. Generating hydrogen, therefore, may involve carbon emissions if renewable energy is not used in this process [145]. New Zealand is investigating *green hydrogen production* i.e., the use of renewable energy sources to produce hydrogen [146, 147].

Sand batteries

Researchers at Polar Night Energy in Finland installed the world's first sand battery which stores energy for months at a time and has 100 kW heating power and 8 MWh capacity [148, 149]. In this sand battery, green energy that is produced via wind turbines or solar panels is used for heating the battery's low-grade sand to up to 500°C [148]. The green energy that is stored during the summer can then be used during winter when energy is more expensive and producing green energy is more difficult [148]. Apart from CO_2 that is embedded in the construction of the heat storage unit, the system has no further carbon emission and is considered a clean energy source [149]. Residential buildings and grouped houses in a neighbourhood would be able to take advantage of this new technology.

Bladeless turbines

The wind energy sector has significant global growth in recent years [150]. However, despite some of the advantages of wind turbines, there are some challenges including high costs, location restrictions, noise and aesthetic pollution, and the negative impact on local wildlife [151, 152].

To address some of these challenges, a Spanish company is developing *Vortex Bladeless* which harvests wind energy without having any rotating blades. Instead, wind energy is harnessed when a cylinder fixed vertically with an elastic rod oscillates on a wind range, and electricity is generated through an alternator system [153]. The design of Vortex Bladeless was funded by the European Commission although the project is yet to be commercialised [154, 155].

Vortex Bladeless claims to be a greener wind alternative with fewer negative impacts on the environment and wildlife, is noiseless, lightweight, and can be placed near a house or over the roof [153, 156]. Tests suggest that it is able to generate electricity about 30 per cent cheaper than conventional wind turbines [154]. As a safe and noiseless wind turbine, this technology may be used near buildings and residential areas.

4.2.3. Wearable technologies

The application of wearable technology in the construction sector has grown significantly in recent years; and applies to "*any kind of electronic device designed to be worn on the user's body*" [157-159]. For example, it can be in the form of jewellery, accessories, medical devices, or clothing, and can be used in conjunction with other digital technologies.

The global wearable technology market was worth US $115.8 billion in 2021 and is expected to exceed US $380.5 billion by 2028 [160]. The benefits of this technology for the sector include: improved onsite safety, workplace communication and efficiency, resource planning and management, and compliance with regulation [159, 161, 162].

Below are some examples wearable technology available for the sector:

> Personal Protective Equipment (PPE) can be equipped with built-in sensors to track body movements and collect human physiology and biochemical data (e.g., heartbeat, body temperature, blood pressure), and track the user's location [157, 163-166]. The

information that is collected can then be combined with internet of things, artificial intelligence, and machine learning to detect worker health and safety (e.g., falls, fatigue, microsleeps, respiratory distress, presence of workers in hazardous zones) [161, 162, 165, 167-169].

> JLG and Kinetic developed a product that notified construction workers when they were within six feet of another worker when social distancing was required during the COVID-19 pandemic [158].
> Moodbeam is a silicone wristband which allows employees to self-report their mood. The data can then be collected and shared to make others aware of staff mental well-being [170].

However, despite the benefits of wearable technologies, there is concern about potential security and privacy issues associated with wearables, such as the amount of data collected, how long it is stored, the level of data processing and manipulation, accessibility of the data, and the risk of data misuse [171-173]. For this this reason, some countries have regulation around their usage. For example, under the European Union's General Data Protection Regulation (GDPR) framework, it is mandatory for wearable users to be aware of what data is being accessed by which app [174].

4.2.4. Digital twin

While it is important to monitor the performance of the build, it can be costly and sometimes unsafe to monitor the actual built object. With recent developments in BIM and data collection sensors, digital twin addresses this issue. Through this technology, an identical version of the built environment is created, enabling users to monitor the performance of buildings without the need to be physically present in the actual environment.

A digital twin is a *"virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making*" [175]. It acts as a repository of data that represents the past, the present, and simulates predicted futures [176].

In recent years, the use of a digital twin technology in the built environment has grown significantly. The global digital twin market was valued at US $6.75 billion in 2021 and is projected to grow to US $96.49 billion by 2029 [177]. An online survey by the Royal Institution of Chartered Surveyors (RICS) found that 21.5 per cent of construction professionals were currently using digital twin technology, and that 42.4 per cent were exploring its usage [178].

While a digital twin has mainly been used for the operation and maintenance phase of building, the built environment could also use this technology at all stages of a project (from design, construction, handover, post occupancy, through to the end-of-life [178]). However, some key challenges in using this technology include: data security and ownership issues, lack of common data standards and tools, and diversity in source systems [179].

Two examples of governments around the world using digital twins in their key projects are:

> **Singapore** – in February 2022, the world's first digital twin of an entire nation was completed. This will help Singapore respond to various national challenges including: climate change; the rollout of renewable energy; the national water resource management and planning; and coastal protection efforts [180].
> **European Commission** – as part of the Green Deal and Digital Strategy *Destination Earth* was initiated [181]. This is a "*digital model of Earth that will be used to monitor the effects of natural and human activity on our planet, anticipate extreme events and adapt policies*

to climate-related challenges”. As part of this project, digital twins on weather-induced and geophysical extremes and climate change adaptation will be available by 2024 [182].

Additionally, advancements in the implementation of digital twins in Australia and New Zealand are highlighted below.

> In 2019, the Australia and New Zealand Land Information Council (ANZLIC) developed the principles for spatially enabled digital twins of the built and natural environment in Australia [183].
> In July 2021, the Smart Cities Council (SCC) of Australia and New Zealand published the draft digital twin blueprint for public consultation. The document provided “*an overview of the opportunities to build a digital twin marketplace across the Australia New Zealand region*” [184].
> As part of the 2021 Australian Infrastructure Plan, Infrastructure Australia aims to ensure all federally funded infrastructure projects incorporate a digital twin within the next 10–15 years [185].
> Buildmedia is creating Wellington’s digital twin [186] which will “*help the community to understand the challenges at hand to make better decisions on how to plan for the future*” [187]. Wellington City Council was one of the 15 winners of the Bloomberg Mayors Challenge for this innovative project [187, 188].

4.3. Trends in building materials

4.3.1. Waste-based construction material

New Zealand's first Emissions Reduction Plan requires that "*by 2050, Aotearoa has a circular economy that keeps materials in use for as long as possible*" [18]. With that in mind, examples of waste-based construction materials are outlined below in Table 3.

Table 4. *Waste-based construction materials from around the word.*

Building waste
NZ – researchers from the University of Waikato are using building waste to produce new building products, such as alternatives to structural timber, cladding, fencing, and decking [189].
Plastics and packaging waste
Kenya – Green Pavers have been making building material such as roofing tiles and fencing posts from recycled waste plastic [190].
UK – researchers at the Queen's University Belfast have been exploring options for converting plastics waste to building materials since 2009 [191].
Global – a review of recent projects in this field concluded that waste-based plastic material could be successfully used in concrete bricks/pavement blocks, non-structural panels, temporary shelters, and low load-bearing structures such as partitions and decorative tiles [192].
NZ – saveBOARD upcycles packaging to produce building materials such as exposed internal linings, paperfaced internal linings, roofing substrates, rigid air brace boards, and ceiling tiles [193, 194]. SaveBOARD has less than 90 per cent of CO_2 compared to Plasterboard and Fibre Cement Board, and less than 80 per cent of CO_2 compared to Plywood [195].
Organic waste
Global – new sustainable construction materials have been developed from agricultural waste (e.g., corn husk, wheat/barley straw, rice husk, groundnut shells, sugarcane, and bamboo leaves). Products range from brick and masonry elements to green concrete, insulation materials, reinforcement materials, particleboards, and bio-based plastics [196]. A review of existing research concluded that using agricultural waste to manufacture construction materials brought cost and environmental benefits; improved the overall physical, mechanical, and thermal qualities of construction materials; led to reductions in greenhouse gas emissions and fossil fuel usage; and created new jobs [197].
Organic material
France – in 2019, a French architect showed how construction material could be fabricated from textile industry waste. Specifically, recycled clothes were mixed with glue and compressed into a mould to produce FabBRICK bricks. FabBRICKs have a unique visual appeal (as the bricks take on the colour of the recycled clothes/fabric), and have good mechanical/water/fire resistance, and acoustic/thermal insulating qualities. These bricks can be used for making both furniture and partition walls [198].

4.3.2. Sustainable reinforced concrete

"*After water, concrete is the most used man-made material on the planet*" [199]. Concrete's popularity is due to its strength, durability, fire resistance, resilience, safety and affordability, however, there are also concerns about the environmental impact of concrete [199, 200].

Following the Paris Agreement in 2015, scientists, manufacturers, and researchers around the globe have been looking at options to reduce the environmental impact of concrete. These include approaches such as low-damage design [201], corrosion protection [202], and strengthening existing structures [203] to reduce the life cycle carbon emission of concrete.

Reinforced concrete is when concrete is reinforced with steel bars. Applying the circular economy concept in the production, reusing and recycling of steel is also another strategy to reduce the environmental impacts of the manufacturing of reinforced concrete [204]. Along with these efforts, other innovative alternatives are briefly discussed below.

Hemp rebar
Researchers at the Centre for Architecture Science and Ecology at the Rensselaer Polytechnic Institute in New York invented hemp rebar as an alternative to ordinary steel. Preliminary results have found strength characteristics that were comparable with traditional steel while achieving a significant reduction in the carbon footprint [205]. However, whether this product is compatible with New Zealand's standards and seismic design approach remains to be seen and requires further research.

D5 Green concrete
D5 Green is a mineral-based mixture that includes natural pozzolans (pumice-like volcanic material that is common across the volcanic plateau of the central North Island in New Zealand) [206]. Concrete made with D5 Green reportedly reaches its character strength on day 7 (compared with day 28 for ordinary concrete), is waterproof, has up to 35 per cent greater strength, and reduces carbon emissions by up to 40 per cent [206, 207]. Additionally, when this product is used with supplementary cementitious materials "*cement content can be reduced by up to 50 per cent without impairing early or ultimate strength of concrete*" [207]. D5 Green concrete mixture was appraised by BRANZ [208].

Carbon-fibre reinforced concrete
Carbon-fibre reinforced concrete is one where the concrete is strengthened with carbon fibre yarn in a process of thermal decomposition called *pyrolysis* [209]. With this product, less concrete is used to protect the reinforcement elements in the new concrete and the outcome is a more sustainable, less material-intensive and is a lighter product. Compared to steel, carbon is four times lighter and has six times more load-bearing capacity [210]. In terms of architectural design, it is possible to design and build unusual and curved shapes with this thin reinforced concrete [210, 211]. To make the carbon fibre more environmentally friendly, scientists are currently developing bio-based carbon fibres that will have a significantly lower carbon footprint compared to petroleum-based carbon fibres [212].

The world's first carbon fibre-reinforced concrete building was initiated in Germany in 2017 [213]. Germany is accelerating the use of carbon fibre-reinforced concrete through significant research investment [213]. As an example, the project C^3 (Carbon, Concrete, Composite) is the largest research programme in the field of building construction within Germany [214, 215]. This project aims to replace traditional steel reinforced concrete with carbon reinforced concrete [214]. Further research is needed, however, before it can be determined whether this product is compatible with New Zealand's standards and seismic design approach.

5. Conclusion

The building and construction sector is a significant contributor to New Zealand's economy. It accounted for 6.7 per cent of total GDP for the year ended March 2022, and was the third largest employer, employing 295,300 people in the year ended June 2022.

Despite the ongoing challenges of the COVID-19 pandemic, the past year saw continued demand for residential housing, with the number of residential building consents reaching record-level highs. There was also steady growth in the workforce pipeline, due to increases in the number of domestic students enrolling in construction-related qualifications, and those changing their careers to work in the sector. The sector, however, continued to be impacted by the rising costs of construction and ongoing issues with the global supply chain.

Climate change is one of the key drivers shaping global trends and innovations in building design, technology, and materials. Related to this, decarbonisation and digitalisation are two key factors influencing these trends. The circular economy concept is also being introduced in the new generation of construction materials.

In the future, as these trends and innovations are further developed and embedded, they will enable the sector to be more environmentally friendly, less labour intensive, safer for workers, and more cost efficient and resilient. These are developments that New Zealand could well benefit from to ensure equitable outcomes for all.

6. Appendix A: Key sector statistics

		Year ended March	
		2021	2022
Gross Domestic Product (GDP)			
Real GDP (in 2009/2010 prices)	NZD millions	16,898	18,106
	annual % change	-2.8%	7.1%
Real residential investment (in 2009/2010 prices)	NZD millions	16,246	17,384
	annual % change	1.8%	7.0%
Real non-residential investment (in 2009/2010 prices)	NZD millions	6,642	6,909
	annual % change	-10.4%	4.0%
		Year ended June	
		2021	**2022**
Building consents and activity			
Residential dwelling consents	consents issued	44,331	50,736
	annual % change	17.9%	14.4%
▪ stand-alone houses	consents issued	24,532	23,913
	annual % change	10.8%	-2.5%
▪ multi-unit homes	consents issued	19,799	26,823
	annual % change	28.0%	35.5%
Value of total building work put in place	NZD$ millions	27,510	30,919
	annual % change	14.9%	12.4%
Residential building work put in place	NZD$ millions	18,537	21,222
	annual % change	21.3%	14.5%
Non-residential building work put in place	NZD$ millions	8,973	9,696
	annual % change	3.6%	8.1%
		Year ended June	
		2021	**2022**
Prices			
Consumers price index (CPI) – home ownership index	% change from the same quarter of the previous year	7.4%	18.3%
Producers price index (PPI) – construction input index		4.0%	13.1%
Producers price index (PPI) – construction output index		4.5%	12.7%
Wood and timber price index		13.8%	17.1%
Ready-mixed concrete index		6.5%	6.0%

		Year ended June		
		2021		2022
Labour market				
Employment (HLFS)	no. of employees	275,100		295,300
	annual % change	5.0%		7.3%
LCI salary and wage rates				
▪ construction sector	% change from the same quarter of the previous year	3.0%		4.2%
▪ all industries		2.1%		3.4%
QES average hourly earnings				
▪ construction sector	NZD	32.09		33.99
	% change from the same quarter of the previous year	4.2%		5.9%
▪ all industries	NZD	34.8		37.0
	% change from the same quarter of the previous year	4.0%		6.4%
		Year ended March		
		2020		**2021**
Labour productivity index				
▪ construction sector	annual % change	3.7%		-2.9%
▪ all industries	annual % change	0.9%		0.7%
		Year ended December		
		2020		**2021**
Health and safety				
Claims for work-related injuries	no. of claims	36,500		38,600
	annual % change	-2.4%		5.8%
Injury incidence rates				
▪ construction sector	claims per 1,000 FTEs	142		143
▪ all industries	claims per 1,000 FTEs	89		90

Source: Stats NZ

7. References

1. Statistics New Zealand. *Gross domestic product: March 2022 quarter*. 2022 [19/09/2022]. Available from: https://www.stats.govt.nz/information-releases/gross-domestic-product-march-2022-quarter/.
2. Statistics New Zealand. *Labour market statistics: June 2022 quarter*. 2022 [21/09/2022]. Available from: https://www.stats.govt.nz/information-releases/labour-market-statistics-june-2022-quarter/.
3. Statistics New Zealand. *Building consents issued: May 2022*. 2022 [29/09/2022]. Available from: https://www.stats.govt.nz/information-releases/building-consents-issued-may-2022/.
4. New Zealand Government, *Building Act 2004* Ministry of Business Innovation and Employment, Editor. 2004, New Zealand Government Wellington.
5. New Zealand Government. *History of the COVID-19 Alert System*. 2022 [15/08/2022]. Available from: https://covid19.govt.nz/about-our-covid-19-response/history-of-the-covid-19-alert-system/.
6. MinterEllisonRuddWatts. *A country divided: Alert Level differences and New Zealand's construction supply chain*. 2021 [15/08/2022]. Available from: https://www.minterellison.co.nz/our-view/a-country-divided-alert-level-differences-and-new-zealands-construction-supply-chain.
7. Harris, C., *Builders returning to work face prospect of not being able to get materials*, in *Stuff*. 2021, Stuff Limited: Wellington.
8. Ministry of Business Innovation and Employment. *Business Travel Register is now open*. 2021 [15/08/2022]. Available from: https://www.mbie.govt.nz/about/news/business-travel-register-is-now-open/.
9. Ipsos, *The COVID-19 pandemic and its impact on building system actors - Technical Report* 2021, Available from: https://www.mbie.govt.nz/building-and-energy/building/building-system-insights-programme/covid-19-impact-on-building-sector/. MBIE: Wellington.
10. New Zealand Government. *Border to reopen in stages from 27 February*. 2022 [15/08/2022]. Available from: https://www.beehive.govt.nz/release/border-reopen-stages-27-february.
11. New Zealand Government. *Fully open border and immigration changes speed up economic growth*. 2022 [15/08/2022]. Available from: https://www.beehive.govt.nz/release/fully-open-border-and-immigration-changes-speed-economic-growth.
12. Statistics New Zealand, *International Travel and Migration, Permanent & long-term migration by country of residence, occupation (ANZSOC minor) (Annual-Jun), Table reference: ITM306AA*. 2022, Statistics New Zealand: Wellington.
13. Shih, W.C., *Global Supply Chains in a Post-Pandemic World*, in *Harvard Business Review*. 2020, Harvard Business Publishing: Boston.
14. KPMG. *Six key trends impacting global supply chains in 2022: From logistics disruption, to workforce and labour*. 2022 [29/08/2022]. Available from: https://home.kpmg/sg/en/home/insights/2022/03/six-key-trends-impacting-global-supply-chains-in-2022.html.
15. Sachdeva, S., *Years more supply chain pain for construction*, in *Newsroom*. 2021, Newsroom: Wellington.
16. EBOSS, *Construction Supply Chain - Q3-2022 update*. 2022, EBOSS: Auckland.
17. Statistics New Zealand. *Annual inflation at 7.3 percent, 32-year high*. 2022 [29/08/2022]. Available from: https://www.stats.govt.nz/news/annual-inflation-at-7-3-percent-32-year-high/.
18. Ministry for the Environment Manatū Mō Te Taiao, *Te hau mārohi ki anamata Towards a productive, sustainable and inclusive economy: Aotearoa New Zealand's First Emissions Reduction Plan*. 2022, Ministry for the Environment Wellington.
19. Ministry of Business Innovation and Employment. *Emissions Reduction Plan released by Government*. 2022 [22/08/2022]. Available from: https://www.building.govt.nz/about-building-performance/all-news-and-updates/emissions-reduction-plan-released-by-government/.
20. Statistics New Zealand. *Household Labour Force Survey, June 2022 quarter*. 2022 [19/09/2022]. Available from: https://www.stats.govt.nz/information-releases/labour-market-statistics-income-june-2022-quarter/.
21. Statistics New Zealand. *New Zealand business demography statistics: At February 2021*. 2021 [19/09/2022]. Available from: https://www.stats.govt.nz/information-releases/new-zealand-business-demography-statistics-at-february-2021.

22. New Zealand Companies Office. *Latest company statistics*. 2022 [22/09/2022]. Available from: https://www.companiesoffice.govt.nz/insights-and-articles/latest-company-statistics/.
23. Statistics New Zealand. *Building consents issued: June 2022*. 2022 [5/10/2022]. Available from: https://www.stats.govt.nz/information-releases/building-consents-issued-june-2022/.
24. Statistics New Zealand. *Experimental building indicators: March 2022 quarter*. 2022 [19/09/2022]. Available from: https://www.stats.govt.nz/experimental/experimental-building-indicators-march-2022-quarter/.
25. Electricity Authority. *Market insights*. 2022 [19/09/2022]. Available from: https://www.emi.ea.govt.nz/.
26. Statistics New Zealand. *Value of building work put in place: June 2022 quarter*. 2022 [21/09/2022]. Available from: https://www.stats.govt.nz/information-releases/value-of-building-work-put-in-place-june-2022-quarter/.
27. Statistics New Zealand. *Business price indexes: June 2022 quarter*. 2022 [5/10/2022]. Available from: https://www.stats.govt.nz/information-releases/business-price-indexes-june-2022-quarter/.
28. New Zealand Infrastructure Commission Te Waihanga, *Te Waihanga: Infrastructure Quarterly - August 2022*. 2022, New Zealand Infrastructure Commission Te Waihanga,: Wellington.
29. Statistics New Zealand. *Consumers price index: June 2022 quarter*. 2022 [19/09/2022]. Available from: https://www.stats.govt.nz/information-releases/consumers-price-index-june-2022-quarter/.
30. Statistics New Zealand. *Producer prices increase in the June 2022 quarter*. 2022 [5/10/2022]. Available from: https://www.stats.govt.nz/news/producer-prices-increase-in-the-june-2022-quarter/.
31. Statistics New Zealand. *Annual wage inflation rises to 3.4 percent*. 2022 [5/10/2022]. Available from: https://www.stats.govt.nz/news/annual-wage-inflation-rises-to-3-4-percent/.
32. New Zealand Foreign Affairs and Trade, *Monitoring Global Supply Chains: April–June 2022 market report*. 2022, New Zealand Foreign Affairs and Trade,: Wellington.
33. Statistics New Zealand. *Employment indicators: June 2022*. 2022 [22/09/2022]. Available from: https://www.stats.govt.nz/information-releases/employment-indicators-june-2022/.
34. Ministry of Business Innovation and Employment. *Jobs Online*. 2022 [22/09/2022]. Available from: https://www.mbie.govt.nz/business-and-employment/employment-and-skills/labour-market-reports-data-and-analysis/jobs-online/.
35. Statistics New Zealand. *Business operations survey: 2021*. 2022 [22/09/2022]. Available from: https://www.stats.govt.nz/information-releases/business-operations-survey-2021.
36. Ministry of Business Innovation and Employment. *Construction Skills Action Plan 2021 (Q2 edition)*. 2021 [22/09/2022]. Available from: https://www.mbie.govt.nz/building-and-energy/building/supporting-a-skilled-and-productive-workforce/construction-skills-action-plan/.
37. Ministry of Business Innovation and Employment, *Migration Data Explorer*. 2022, MBIE: Wellington.
38. Workforce Information Platform (WiP). *Workforce Supply Channels*. 2020. Available from: https://wip.org.nz/supply-channels/.
39. Statistics New Zealand. *Productivity statistics: 1978–2021 – corrected*. 2022 [21/09/2022]. Available from: https://www.stats.govt.nz/information-releases/productivity-statistics-1978-2021/.
40. Statistics New Zealand. *Injury statistics – work-related claims: 2021*. 2022 [19/09/2022]. Available from: https://www.stats.govt.nz/information-releases/injury-statistics-work-related-claims-2021/.
41. Ministry of Business Innovation and Employment, *Licensed building practitioners dashboard, July 2022*, MBIE, Editor. 2022: Wellington.
42. Statistics New Zealand, *Geographic units by region and industry 2000-2021*. 2021, Statistics New Zealand: Wellington.
43. Statistics New Zealand and New Zealand Customs Service, *Overseas merchandise trade datasets (with MBIE analysis)*. 2022, Statistics New Zealand: Wellington.
44. Ministry of Business Innovation and Employment, *Building and construction sector trends annual report 2021*. 2021, Available from https://www.mbie.govt.nz/dmsdocument/16973-building-and-construction-sector-trends-annual-report-2021-pdf. MBIE: Wellington.
45. United Nations. *For a livable climate: Net-zero commitments must be backed by credible action*. 2022 [16/06/2022]. Available from: https://www.un.org/en/climatechange/net-zero-coalition.
46. United Nations Environment Programme, *2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. 2021, United Nations: Nairobi.

47. Laski, J. and V. Burrows, *From Thousands to Billions: Coordinated Action towards 100% Net Zero Carbon Buildings by 2050*. 2017, World Green Building Council: London.

48. Ürge-Vorsatz, D., et al., *Advances Toward a Net-Zero Global Building Sector.* Annual Review of Environment and Resources, 2020. **45**(1): p. 227-269.

49. Waldman, B., M. Huang, and K. Simonen, *Embodied carbon in construction materials: a framework for quantifying data quality in EPDs.* Buildings and Cities, 2020. **1**(1): p. 625-636.

50. Melton, P., *The Urgency of Embodied Carbon and What You Can Do about It*, in *Building Green*. 2018, BuildingGreen, Inc.: Brattleboro.

51. Trenga, B. *Importance of Reducing Embodied Energy in the Built Environment*. 2019 [17/06/2022]. Available from: https://www.buildings.com/sustainability-resilience/article/10185667/importance-of-reducing-embodied-energy-in-the-built-environment.

52. Avison Young Inc. *Ten Trends for a Zero Carbon World: 04. Zero in*. 2021 [16/06/2022]. Available from: https://avison-young.foleon.com/ten-trends/a-zero-carbon-world/zero-in/.

53. Pitman, K. *Lowering embodied carbon: five trends in building design and construction*. 2021 [17/06/2022]. Available from: https://www.rics.org/oceania/wbef/megatrends/urbanisation/lowering-embodied-carbon-five-trends-in-building-design-and-construction/.

54. S&P Global. *COP26: Five developed nations commit to support low carbon steel, cement sectors*. 2021 [17/06/2022]. Available from: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/110921-cop26-five-developed-nations-commit-to-support-low-carbon-steel-cement-sectors#:~:text=Steel%20and%20cement%20are%20among,the%20UK%20COP26%20Presidency%20said.

55. Fennell, P., et al. *Cement and steel — nine steps to net zero*. 2022 [17/06/2022]. Available from: https://www.nature.com/articles/d41586-022-00758-4.

56. Blesl, M., et al., *Role of energy efficiency standards in reducing CO2 emissions in Germany: An assessment with TIMES.* Energy Policy, 2007. **35**(2): p. 772-785.

57. Prada, M., et al., *New solutions to reduce greenhouse gas emissions through energy efficiency of buildings of special importance – Hospitals.* Science of The Total Environment, 2020. **718**: p. 137446.

58. Norouzi, M., et al., *Circular economy in the building and construction sector: A scientific evolution analysis.* Journal of Building Engineering, 2021. **44**: p. 102704.

59. Story, O. *WGBC sets new requirements for the construction sector to achieve total decarbonisation by 2050*. 2021 [17/06/2022]. Available from: https://www.climateaction.org/news/wgbc-sets-new-requirements-for-the-construction-sector-to-achieve-total-dec.

60. ENVIZI, *Electrification: Decarbonizing buildings through fuel switching*, in *Building analytics*. 2022, ENVIZI: Online

61. Ross, S., *Addressing climate change by retrofitting Canada's existing buildings*, in *Policy Opinions Politiques*. 2021, Policy Opinions Politiques: Montreal.

62. Royal Institution of Chartered Surveyors (RICS), *Retrofitting to decarbonise UK existing housing stock: RICS net zero policy position paper*. 2020, RICS: London.

63. Meggers, F., et al., *Reduce CO2 from buildings with technology to zero emissions.* Sustainable Cities and Society, 2012. **2**(1): p. 29-36.

64. Teng, Y., et al., *Reducing building life cycle carbon emissions through prefabrication: Evidence from and gaps in empirical studies.* Building and Environment, 2018. **132**: p. 125-136.

65. Zehra, K., *World Built Environment Forum Sustainability Report 2021*. 2021, Royal Institution of Chartered Surveyors (RICS): London.

66. New Buildings Institute, *2020 Getting to Zero Buildings List: Growth and trends for zero energy and zero carbon buildings*. 2020, New Buildings Institute: Portland.

67. Ministry of Business Innovation and Employment. *Building for climate change*. 2021 [17/06/2022]. Available from: https://www.mbie.govt.nz/building-and-energy/building/building-for-climate-change/.

68. Save Board. *Sustainable Building Material*. 2022 [17/06/2022]. Available from: https://www.saveboard.nz/.

69. Timber Design Centre. *The Timber Design Centre website*. 2022 [17/06/2022]. Available from: https://www.timberdesigncentre.co.nz/.

70. Heavy Engineering Research Association (HERA). *Zero carbon steel*. 2022 [17/06/2022]. Available from: https://www.hera.org.nz/sustainability/zero-carbon-steel/.

71. Quinn, J. *Local design and manufacture focused on zero energy building*. 2022 [1/08/2022]. Available from: https://sustainableengineering.co.nz/local-design-and-manufacture-focused-on-zero-energy-building/.

72. Phuong, T.B.T., et al., *Zero Carbon Building Practices in Aotearoa New Zealand.* Energies, 2021. **14**(15): p. 4455.

73. NZGBC, *Latest stats around Homestar, Greenstar and NABERSNZ rating certificates* MBIE, Editor. 2021, NZGBC.

74. New Zealand Green Building Council. *Green Star*. 2022 [21/09/2022]. Available from: https://www.nzgbc.org.nz/greenstar.

75. New Zealand Green Building Council. *Introduction to NABERSNZ*. 2022 [21/09/2022]. Available from: https://www.nzgbc.org.nz/NABERSNZ/What-is-NABERSNZ.

76. New Zealand Green Building Council. *Homestar*. 2022 [21/09/2022]. Available from: https://www.nzgbc.org.nz/homestar.

77. Elefante, C., *The Greenest Building Is... One That Is Already Built.* Forum Journal, 2012. **27**(1): p. 62-72.

78. International Energy Agency (IEA). *Buildings: A source of enormous untapped efficiency potential*. 2021. Available from: https://www.iea.org/topics/buildings.

79. Roscini, A.V., et al., *An action plan for the Renovation Wave: Collectively achieving sustainable buildings in Europe*, C. Milne and B. Jeffries, Editors. 2020, Buildings Performance Institute Europe (BPIE): Brussels.

80. RACE for 2030. *RACE for Homes*. 2021 [1/08/2022]. Available from: https://www.racefor2030.com.au/race-for-homes/.

81. Reliable Affordable Clean Energy for 2030 Cooperative Research Centre (RACE for 2030 CRC), *Pathways to scale: Retrofitting one million+ homes*. H2 Fast Track. 2021, New South Wales: RACE for 2030.

82. Govenment of Canada. *Canada Greener Homes Initiative*. 2022 [21/06/2022]. Available from: https://www.nrcan.gc.ca/energy-efficiency/homes/canada-greener-homes-grant/23441.

83. CleanBC Better Homes. *CleanBC Better Homes and Home Renovation Rebate Program*. 2022 [21/06/2022]. Available from: https://betterhomesbc.ca/rebates/cleanbc-better-homes-and-home-renovation-rebate-programs/.

84. City of Kimberley. *Energy Efficient Building Incentive Program*. 2022 [21/06/2022]. Available from: https://www.kimberley.ca/node/1754/incentive-programs-rebates#Energy%20Efficient%20Building%20Incentive%20Program.

85. Baker McKenzie. *Incentives for Green Retrofit*. 2022 [21/06/2022]. Available from: https://resourcehub.bakermckenzie.com/en/resources/global-sustainable-buildings-index/asia-pacific/china/topics/incentives-for-green-retrofit.

86. Kraft, G. *Example of incentive programmes for retrofits: the KfW in Germany*. 2015 [21/06/2022]. Available from: https://passipedia.org/planning/refurbishment_with_passive_house_components/example_of_incentive_programmes_the_kfw_in_germany.

87. European Commission. *A European Green Deal*. 2022 [21/06/2022]. Available from: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

88. European Commission, *Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty*. 2020, European Commission: Brussels.

89. Hinge, A. and F. Brocklehurst, *Building Energy Codes and Other Mandatory Policies Applied to Existing Buildings*. 2021, The International Energy Agency: Paris.

90. NZGBC, *A Zero Carbon Road Map for Aotearoa's Buildings*. 2019, NZGBC: Auckland.

91. Statistics New Zealand, *Subnational household projections, by household type, 2018(base)-2043*. 2021, Statistics New Zealand: Wellington.

92. Statistics New Zealand. *New Zealand households projected to climb half a million*. 2021 [15/07/2022]. Available from: https://www.stats.govt.nz/news/new-zealand-households-projected-to-climb-half-a-million/.

93. Bryson, K. and N. Allen, *Defining medium-density housing*. 2017, BRANZ: Judgeford.

94. Ministry of Business Innovation and Employment. *Introduction to medium-density housing*. 2022 [18/07/2022]. Available from: https://www.building.govt.nz/building-code-compliance/introduction-to-medium-density-housing/.

95. BRANZ. *Medium-density housing*. 2022 [18/07/2022]. Available from: https://www.branz.co.nz/mdh/.

96. Ministry for the Environment, *Ngā tohutohu hoahoa ā-motu mō te wharenoho mātoru-waenga: National medium density design guide*. 2022, Ministry for the Environment,: Wellington.
97. Ministry of Housing and Urban Development. *Enabling Housing Density*. 2022 [18/07/2022]. Available from: https://www.hud.govt.nz/urban-development/enabling-housing-density/.
98. Our Aukland. *Consultation closing on proposed changes to Auckland's planning rulebook*. 2022 [18/07/2022]. Available from: https://ourauckland.aucklandcouncil.govt.nz/news/2022/05/consultation-closing-on-proposed-changes-to-auckland-s-planning-rulebook/#:~:text=Following%20consultation%2C%20feedback%20will%20inform,the%20council's%20proposed%20plan%20change.
99. Wellington City Council. *Te Mahere ā-Rohe i Tūtohua: Proposed District Plan*. 2022 [18/07/2022]. Available from: https://wellington.govt.nz/your-council/plans-policies-and-bylaws/district-plan/proposed-district-plan.
100. The World Bank. *Disability Inclusion*. 2022 [22/06/2022]. Available from: https://www.worldbank.org/en/topic/disability#:~:text=One%20billion%20people%2C%20or%2015,outcomes%20than%20persons%20without%20disabilities.
101. Office for Disability Issues and Ministry of Social Development, *Briefing for Incoming Minister: Disability Issues*. 2017, Office for Disability Issues and Ministry of Social Development,: Wellington.
102. NC State University. *What Does Accessible Mean?* 2022 [5/10/2022]. Available from: https://dro.dasa.ncsu.edu/what-does-accessible-mean/.
103. Government of Ontario, *Accessibility for Ontarians with Disabilities Act 2005*, Government of Ontario, Editor. 2005, Government of Ontario: Ontario.
104. Building and Construction Authority (BCA). *Safer and more accessible buildings with new Building Control Act changes*. 2020 [27/06/2022]. Available from: https://www1.bca.gov.sg/buildsg-emag/articles/safer-and-more-accessible-buildings-with-new-building-control-act-changes.
105. Ministry of Ecological Transition and Territorial Cohesion, *Accessibility in OECD member countries*. 2022, Ministry of Ecological Transition and Territorial Cohesion: Paris.
106. Government of the United Kingdom. *Access to and use of buildings: Approved Document M*. Statutory guidance 2021 [23/06/2022]. Available from: https://www.gov.uk/government/publications/access-to-and-use-of-buildings-approved-document-m.
107. New Zealand Government, *Building Regulations 1992*, Ministry of Business Innovation and Employment, Editor. 1992, Parliamentary Counsel Office: Wellington.
108. Standards New Zealand, *NZS 4121:2001 Design for access and mobility: Buildings and associated facilities*. 2001, Standards New Zealand: Wellington
109. Statistics New Zealand, *Measuring inequality for disabled New Zealanders: 2018*. 2020, Statistics New Zealand: Wellington.
110. Statistics New Zealand. *The disability gap 2018*. 2020 [23/06/2022]. Available from: https://www.stats.govt.nz/infographics/the-disability-gap-2018/.
111. New Zealand Government and Ministry of Housing and Urban Development, *Government Policy Statement on Housing and Urban Development*. 2021, New Zealand Government and Ministry of Housing and Urban Development: Wellington.
112. Kāinga Ora. *New Kāinga Ora Accessibility Policy*. 2019 [27/06/2022]. Available from: https://kaingaora.govt.nz/news/new-kainga-ora-accessibility-policy/.
113. Kāinga Ora, *Accessibility Policy 2019-2022*, Kāinga Ora, Editor. 2019, New Zealand Government: Wellington.
114. Kāinga Ora. *Upgrades for more homes through Retrofit Programme*. 2020 [21/06/2022]. Available from: https://kaingaora.govt.nz/news/upgrades-for-more-homes-through-retrofit-programme/.
115. University of Cambridge. *Inclusive Design Toolkit*. 2017 [23/06/2022]. Available from: http://www.inclusivedesigntoolkit.com/whatis/whatis.html.
116. ASSA ABLOY. *Inclusive design: Inclusive design and accessible buildings for all*. 2020 [23/06/2022]. Available from: https://www.assaabloy.com/uk/en/solutions/topics/Inclusive-design.
117. Heiss, O., C. Degenhart, and J. Ebe. Barrier-Free Design: Principles, Planning, Examples. 2010: Birkhäuser.
118. Centre for Excellence in Universal Design. *What is Universal Design*. 2020 [23/06/2022]. Available from: https://universaldesign.ie/what-is-universal-design/#:~:text=Universal%20Design%20is%20the%20design,%2C%20size%2C%20ability%20or%20disability.

119. Kaup, M., *Life-Span Housing for Aging in Place: Addressing the Home as an Integrated Part of the Solution to Long-Term Care in America.* Seniors Housing & Care Journal, 2009. **17**(1): p. 101-113.

120. DeVol Design.Build.Remodel. *Barrier-Free Design*. 2022 [19/09/2022]. Available from: https://devoldbr.com/blog/barrier-free-design/.

121. LifeMark. *LifeMark website*. 2022 [23/06/2022]. Available from: https://www.lifemark.co.nz/.

122. Thomson, C., *5 benefits of embracing VR in the construction industry*, in *Embracing VR in the construction industry*. 2020, Correvate Ltd. : London.

123. Brooks, C. *How Virtual Reality Is Changing Construction*. 2022 [25/07/2022]. Available from: https://www.business.com/articles/how-virtual-reality-is-changing-construction/.

124. Adjia Technologies. *Virtual Reality*. 2020 [5/10/2022]. Available from: http://adjiatechnologies.com/about_vr.php.

125. Hayes, A. *Augmented Reality*. 2020 [25/07/2022]. Available from: https://www.investopedia.com/terms/a/augmented-reality.asp.

126. Grand View Research, *Virtual Reality Market Size & Share Report, 2022-2030*. 2022, Grand View Research: San Francisco.

127. Beca. *Fonterra VR Health and Safety Training Technology: Virtual Reality Training Tours*. 2022 [27/07/2022]. Available from: https://www.beca.com/what-we-do/projects/industrial/fonterra-vr-health-and-safety-training-technology.

128. ACC. *Using virtual reality to construct a safer workplace*. 2019 [27/07/2022]. Available from: https://www.acc.co.nz/newsroom/stories/using-virtual-reality-to-construct-a-safer-workplace/.

129. Oncor Reality. *Virtual Reality Remote Meetings and Site Inspections*. 2019 [26/07/2022]. Available from: https://oncorreality.com/virtual-reality-remote-meetings-and-site-inspections/.

130. Industrial Training International (ITI). *Construction Hazard Certification*. 2022 [25/07/2022]. Available from: https://www.iti.com/vr/construction-hazard-certification.

131. Civil + Structural Engineer. *The Wild launches cloud-based, real-time collaboration platform*. 2018 [25/07/2022]. Available from: https://csengineermag.com/the-wild-launches-cloud-based-real-time-collaboration-platform/.

132. The Wild. *VR Collaboration for the Building Industry*. 2022 [25/07/2022]. Available from: https://thewild.com/.

133. SRI International. *A modern approach to building inspections*. 2022 [26/07/2022]. Available from: https://www.sri.com/case-study/a-modern-approach-to-building-inspections-using-augmented-reality-and-mobile-technology-to-reduce-construction-overhead/.

134. SRI International, *Augmented Reality Solutions for Construction Inspection*. 2017, YouTube: Online.

135. Trimble. *Trimble and Microsoft Mixed Reality Partnership Spotlight*. 2020 [27/07/2022]. Available from: https://fieldtech.trimble.com/resources/customer-stories/trimble-and-microsoft-mixed-reality-partnership-spotlight.

136. Trimble. *Your Data. Your Work Site. Together at Last.* 2022 [6/10/2022]. Available from: https://fieldtech.trimble.com/resources/ftg-home/your-data-your-worksite-together-at-last?_gl=1*eppbmu*_ga*NDY1MTcyNDEuMTY1ODgxMDMwOA..*_ga_1TWB0X464Z*MTY2NTAwMzc1MC4zLjEuMTY2NTAwMzc1OS4wLjAuMA..

137. Trimble Buildings. *Miron Construction Levels Up Installation Verification and BIM Coordination Using Trimble's Augmented Reality Technology*. 2021 [27/07/2022]. Available from: https://fieldtech.trimble.com/resources/customer-stories/miron-construction-levels-up-installation-verification-and-bim-coordination-using-trimble-s-augmented-reality-technology.

138. Steciuk, T. *Price Building Services Avoids Costly Rework, Increases Productivity with Mixed Reality Technology*. 2021 [27/07/2022]. Available from: https://fieldtech.trimble.com/resources/customer-stories/price-building-services-avoids-costly-rework-increases-productivity-with-mixed-reality-technology.

139. Building and Construction Authority of Singapore. *Integrated Digital Delivery (IDD)*. 2017 [27/07/2022]. Available from: https://www1.bca.gov.sg/buildsg/digitalisation/integrated-digital-delivery-idd.

140. Hwang, B.-G., J. Ngo, and P.W.Y. Her, *Integrated Digital Delivery: Implementation status and project performance in the Singapore construction industry.* Journal of Cleaner Production, 2020. **262**: p. 121396.

141. The UK Government, *Virtual reality to revolutionise UK's construction sector*. 2018, The UK Government: London.

142. Clark, S., *Is hydrogen the solution to net-zero home heating?*, in *The Guardian*. 2020, Guardian News & Media Limited: London.

143. O'Neil, S. *Unlocking the Potential of Hydrogen Energy Storage*. 2019 [6/07/2022]. Available from: https://www.fchea.org/transitions/2019/7/22/unlocking-the-potential-of-hydrogen-energy-storage

144. The Office of Energy Efficiency & Renewable Energy. *Hydrogen Fuel Basics*. 2022 [6/07/2022]. Available from: https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics.

145. Early, C. *The race to decarbonise building heating*. 2021 [6/07/2022]. Available from: https://ww3.rics.org/uk/en/modus/natural-environment/renewables/the-race-to-decarbonise-building-heating---.html.

146. Green Hydrogen Coalition. *Green Hydrogen*. 2019 [3/08/2022]. Available from: https://www.ghcoalition.org/green-hydrogen#:~:text=Green%20hydrogen%20can%20be%20generated,ensure%20energy%20independence%20for%20decades.

147. New Zealand Government and ARUP, *A Vision for Hydrogen in New Zealand: Green Paper*. 2019, MBIE,: Wellington.

148. McGrath, M., *Climate change: 'Sand battery' could solve green energy's big problem*, in *BBC*. 2022, BBC: London.

149. Polar Night Energy. *Store Wind and Solar Power as Heat in Sand*. 2022 [6/074/2022]. Available from: https://polarnightenergy.fi/technology.

150. Lacal-Arántegui, R., *Globalization in the wind energy industry: contribution and economic impact of European companies.* Renewable Energy, 2019. **134**: p. 612-628.

151. Office of Energy Efficiency & Renewable Energy. *Advantages and Challenges of Wind Energy*. 2022 [7/07/2022]. Available from: https://www.energy.gov/eere/wind/advantages-and-challenges-wind-energy.

152. Korchinski, W., *The Limits of Wind Power*. 2012, Reason Foundation,: Los Angeles.

153. Vortex Bladeless. *How it works: First wind turbine without blades nor gears*. 2022 [7/07/2022]. Available from: https://vortexbladeless.com/technology-design/.

154. European Commission. *Wobbling in the wind: a bladeless alternative to turbines*. 2020 [7/07/2022]. Available from: https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/wobbling-wind-bladeless-alternative-turbines.

155. Vortex Bladeless. *About Vortex Bladeless SL*. 2022 [7/07/2022]. Available from: https://vortexbladeless.com/contact-us.

156. Vortex Bladeless. *Bladeless Wind Energy*. 2022 [7/07/2022]. Available from: https://vortexbladeless.com/.

157. Yasar, K. *Wearable technology*. 2022 [28/06/2022]. Available from: https://www.techtarget.com/searchmobilecomputing/definition/wearable-technology#:~:text=Wearable%20technology%20is%20any%20kind,clothing%20or%20elements%20of%20clothing.

158. Brown, A. *How wearable technology is used in construction*. Construction Technology 2021 [28/06/2022]. Available from: https://www.constructiontechnology.media/news/how-wearable-technology-is-used-in-construction/8013769.article#:~:text=By%20adding%20new%20technology%20to,improve%2C%20so%20does%20the%20technology.

159. Laurey, M., *5 Benefit of wearable technology for the construction industry*. 2021, Ving: Online.

160. Facts & Factors, *Wearable Technology Market Report 2022–2028*. 2022, Facts & Factors,: Pune.

161. SolePower. *Smart boot remote management platform*. 2022 [29/06/2022]. Available from: http://www.solepowertech.com/industrial.

162. WakeCap Technologies. *WakeCap Technologies website*. 2022 [29/06/2022]. Available from: https://www.wakecap.com/.

163. Wu, M. and J. Luo, *Wearable technology applications in healthcare: A literature review.* Online Journal of Nursing Informatics Contributors, 2019. **23**(3).

164. Merrill, M. *How Data From Construction Wearables Can Benefit Your Construction Business*. 2021. Available from: https://www.forconstructionpros.com/construction-technology/article/21940687/workmax-by-abouttime-technologies-how-data-from-construction-wearables-can-benefit-your-construction-business.

165. Lehmann, H. *Kenzen launches body heat sensor system for predictive, preventative worker safety*. 2020 [29/06/2022]. Available from: https://kenzen.com/kenzen-launches-body-heat-sensor-system-for-predictive-preventative-worker-safety/.

166. Al-Sahar, F., A. Przegalińska, and M. Krzemiński, *Risk assessment on the construction site with the use of wearable technologies.* Ain Shams Engineering Journal, 2021. **12**(4): p. 3411-3417.

167. Stannard, L., *6 Innovative Construction Wearables Reshaping Safety*, in *Think Big Blog*. 2020, BigRentz inc.: Irvine.

168. Lvivity. *Application of wearable technologies in different industries*. 2021 [28/06/2022]. Available from: https://lvivity.com/wearable-technologies.

169. SmartCap. *SmartCap website*. 2022 [29/06/2022]. Available from: http://www.smartcaptech.com/life-smart-cap/.

170. Bearne, S., *A wristband that tells your boss if you are unhappy*, in *BBC*. 2021, BBC: London.

171. Habibipour, A., A. Padyab, and A. Ståhlbröst, *Social, Ethical and Ecological Issues in Wearable Technologies*, in *Twenty-fifth Americas Conference on Information Systems*. 2019, Digitala Vetenskapliga Arkivet: Cancun.

172. Tomimbang, G. *Wearables: Where do they fall within the regulatory landscape?* 2018 [29/06/2022]. Available from: https://iapp.org/news/a/wearables-where-do-they-fall-within-the-regulatory-landscape/.

173. SOLGM and ALGIM, *Technologies for the 21st Century: Fit for the digital future*. 2015, SOLGM and ALGIM,: Wellington.

174. GlobalData Thematic Research. *Wearable Technology: Regulatory Trends*. 2021 [29/06/2022]. Available from: https://www.mining-technology.com/comment/wearable-technology-regulatory-trends/.

175. IBM. *What is a digital twin?* 2022 [7/07/2022]. Available from: https://www.ibm.com/topics/what-is-a-digital-twin#:~:text=A%20digital%20twin%20is%20a,reasoning%20to%20help%20decision%2Dmaking.

176. Royal Institution of Chartered Surveyors (RICS). *Digital twins from design to handover of constructed assets*. 2022 [8/07/2022]. Available from: https://www.rics.org/uk/wbef/home/reports-and-research/digital-twins-from-design-to-handover-of-constructed-assets/.

177. Fortune Business Insights, *Digital Twin Market, 2021-2028*. 2022, Fortune Business Insights,: Maharashtra.

178. Seaton, H., et al., *Digital twins from design to handover of constructed assets*. Jo FitzLeverton. 2022, London: RICS.

179. Shahzad, M., et al., *Digital Twins in Built Environments: An Investigation of the Characteristics, Applications, and Challenges.* Buildings, 2022. **12**(2): p. 120.

180. Lawton, G. *How Singapore created the first country-scale digital twin*. 2022 [11/07/2022]. Available from: https://venturebeat.com/2022/02/23/how-singapore-created-the-first-country-scale-digital-twin/.

181. European Commission. *Destination Earth*. 2022 [11//07/2022]. Available from: https://digital-strategy.ec.europa.eu/en/policies/destination-earth.

182. European Space Agency (ESA). *Destination Earth*. 2022 [11/07/2022]. Available from: https://www.esa.int/Applications/Observing_the_Earth/Destination_Earth.

183. Australia and New Zealand Land Information Council (ANZLIC), *Principles for Spatially Enabled Digital Twins of the Built and Natural Environment in Australia*, Australia and New Zealand Land Information Council, Editor. 2019, ANZLIC: Canberra.

184. Smart Cities Council (SCC), *Digital Twins for all: The Australia / New Zealand Digital Twin Blueprint*. 2021, Smart Cities Council (SCC),: Online.

185. Bushell-Embling, D., *All govt infrastructure projects to use a digital twin*, in *GovTech Review*. 2021, Westwick-Farrow Pty Ltd: New South Wales.

186. Buildmedia. *Wellington Digital Twin*. 2022 [11/07/2022]. Available from: https://buildmedia.com/work/wellington-digital-twin.

187. Local Government New Zealand (LGNZ). *Wellington's Digital Twin takes out top honours in Global Mayors Challenge*. 2022 [11/07/2022]. Available from: https://www.lgnz.co.nz/news-and-media/2022-media-releases/wellingtons-digital-twin-takes-out-top-honours-in-global-mayors-challenge/.

188. Wellington City Council. *Wellington wins global prize for innovation*. 2022 [11/07/2022]. Available from: https://wellington.govt.nz/news-and-events/news-and-information/our-wellington/2022/01/bloomberg-challenge#:~:text=Wellington's%20winning%20project%2C%20a%20Digital,how%20Wellington%20works%20and%20grows.

189. The University of Waikato. *Researchers make building materials from waste saving money and the environment*. 2021 [30/06/2022]. Available from: https://www.waikato.ac.nz/news-opinion/media/2021/researchers-make-building-materials-from-waste-saving-money-and-the-environment.

190. CGTN Africa, *Entrepreneur transforms plastic waste into construction materials*. 2019, YouTube: Online.

191. Cabrera, X. *Plastics could help build a sustainable future – here's how*. The Conversion, 2020.

192. Lamba, P., et al., *Recycling/reuse of plastic waste as construction material for sustainable development: a review.* Environmental Science and Pollution Research, 2021.

193. SaveBoard. *SaveBoard website: Sustainable Building Material* 2022 [4/07/2022]. Available from: https://www.saveboard.nz/.

194. SaveBoard. *Low Carbon Building Products*. 2022 [4/7/2022]. Available from: https://www.saveboard.nz/products.

195. SaveBoard. *SaveBoard website: Frequently Asked Questions*. 2022 [4/07/2022]. Available from: https://www.saveboard.nz/faq.

196. Maraveas, C., *Production of Sustainable Construction Materials Using Agro-Wastes.* Materials (Basel), 2020. **13**(2).

197. Kesh, D., *Can agro-waste serve as construction material?*, in *Planet Rescue 101: From Linear to Circular Economy* 2021, Planet Rescue: Online

198. DesignWanted. *From soft fabrics to solid walls: FabBRICK reinvents construction materials with recycled textile waste*. Design 2021 [1/07/2022]. Available from: https://designwanted.com/fabbrick-construction-materials-recycled-textile/.

199. Global Cement and Concrete Association (GCCA). *About Cement & Concrete*. 2022 [20/07/2022]. Available from: https://gccassociation.org/our-story-cement-and-concrete/.

200. Watts, J. *Concrete: the most destructive material on Earth*. 2019 [20/07/2022]. Available from: https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth.

201. Bianchi, S., J. Ciurlanti, and S. Pampanin, *Comparison of traditional vs low-damage structural and non-structural building systems through a cost/performance-based evaluation.* Earthquake Spectra, 2020. **37**(1): p. 366-385.

202. Constro Facilitator. *Corrosion Protection methods for Steel Reinforcement in Concrete*. 2021 [18/08/2022]. Available from: https://www.constrofacilitator.com/corrosion-protection-methods-for-steel-reinforcement-in-concrete/.

203. Motorwala, A. and J.B. Stephens, *Strengthening of Reinforced Concrete Structures*, in *Structure*. 2021, C3 Ink: Chicago.

204. World Steel Association. *Steel - The permanent material in the circular economy*. 2022 [21/07/2022]. Available from: https://worldsteel.org/circulareconomy/.

205. Rensselaer Polytechnic Institute. *Sustainable Building Through Hemp*. 2022 [21/07/2022]. Available from: https://news.rpi.edu/content/2022/01/26/sustainable-building-through-hemp.

206. Callaghan Innovation. *Customer stories: Cementing eco-friendly building*. 2022 [21/07/2022]. Available from: https://www.callaghaninnovation.govt.nz/customer-stories/cementing-eco-friendly-building#:~:text=The%20production%20of%20concrete%20contributes,as%20800kg%20of%20carbon%20emissions.

207. Neocrete. *D5 Green*. 2021 [21/07/2022]. Available from: https://www.neocrete.co.nz/ourproduct.

208. BRANZ, *Appraisal No. 1144 [2022] D5 Concrete Admixture*. 2021, BRANZ: Judgeford.

209. Dezeen. *The Cube will be "world's first building made of carbon concrete"*. 2021 [22/07/2022]. Available from: https://www.dezeen.com/2021/07/30/henn-tu-dresden-carbon-fibre-concrete-building/.

210. CARBOCON. *The Carbon Concrete Principle*. 2021 [22/07/2022]. Available from: https://www.carbocon.de/en/carbon-concrete/.

211. Tencom, *The World's First Concrete Building Reinforced with Carbon Fiber*. 2021, Tencom Limited Ohio.

212. Fairs, M. *Scientists developing bio-based carbon fibres being "showered with requests" for sustainable version of the wonder material*. 2021 [22/07/2022]. Available from: https://www.dezeen.com/2021/07/26/carbon-bio-based-carbon-fibres/.

213. Gardiner, G. *Carbon fiber-reinforced concrete accelerates in Germany*. 2020 [22/07/2022]. Available from: https://www.compositesworld.com/news/carbon-fiber-reinforced-concrete-accelerates-in-germany.

214. Technische Universitat Dresden. *C³ - Carbon Concrete Composite*. 2017 [22/07/2022]. Available from: https://tu-dresden.de/bu/bauingenieurwesen/imb/forschung/c3?set_language=en.

215. C³ - Carbon Concrete Composite. *The C³ project website*. 2022 [22/07/2022]. Available from: https://www.bauen-neu-denken.de/en/homepage/.

Te Kāwanatanga o Aotearoa
New Zealand Government

DDI 8299