University of Southern Queensland

Faculty of Engineering and Surveying

Analysis of Australian building code relevant to the use of decommissioned shipping containers as housing

A dissertation submitted by

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ABSTRACT

This dissertation examined how decommissioned shipping containers could meet Australian building code for Class 1a housing to provide a potential solution to the current housing supply shortage in Australia with consideration to the nation's climate targets. An explanatory case study of decommissioned shipping containers as residential housing, through document analysis of the National Construction Code (2022), the Queensland Development Code and Bundaberg Regional Council policies was undertaken to develop a reasonable interpretation of how national, state and local building codes relate to the use of decommissioned shipping containers as residential housing. The case study research was used to evaluate how decommissioned shipping containers can meet the national, state government and local council building codes for residential housing in Australia.

The research interpretation found that ISO shipping containers were capable of meeting all examined sections of the National Construction Code, Queensland Development Code, and Bundaberg Regional Council policies with suitable modifications. It was also found that shipping containers decommissioned due to errors in labelling, door handle and locking mechanisms, or forklift pockets and rail corner protector recesses would be suitable for use as housing. The study further establishes the minimum modifications to an ISO shipping container required for its repurposing as housing. It also suggests changes to the analysed building codes which may facilitate the use of decommissioned shipping containers as Class 1a housing.

These findings establish the legality of using decommissioned shipping containers as Class 1a housing in ideal circumstances according to the most recent Australian building codes. This study also aids the wider construction field by providing a baseline for housing requirements in Australia. It further serves as an entry point for additional research into the field of repurposing decommissioned shipping containers to use as any class of housing in the Australian context.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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NOMENCLATURE AND ACRONYMS

The following abbreviations have been used throughout the text:

ABCB	Australian Building Codes Board
AS	Australian Standard
BCA	Building Code of Australia
BRC	Bundaberg Regional Council
FRL	Fire Resistance Level
IICL	The Institute of International Container Lessors
ISO	International Organisation for Standardisation
NASH	National Association of Steel-Framed Housing
NCC	National Construction Code
NHFIC	National Housing Finance and Investment Corporation
NZS	New Zealand Standard
QDC	Queensland Development Code
QLD	Queensland
TEU	Twenty-Foot Equivalent Unit
WELS	Water Efficiency Labelling and Standards

CHAPTER 1

INTRODUCTION

The State of the Nation's Housing 2022-23 report stated that:

> "*Australia's housing markets…are now at an inflection point. At a time of returning migration, they are contending with a perfect storm of high inflation and interest rates, slowing supply and record low vacancy rates…The short to medium term is likely to be dominated by a cyclical downturn in new supply, at a time of strong population growth. This is likely to see household formation outpace new supply for several years, with adverse flow on effects for affordability.*"
>
> (National Housing Finance and Investment Corporation's 2023: ii)

1.1 Outline of the study

The above statements suggest the immediate need for additional housing supply in Australia, particularly affordable housing. Innovative approaches to increasing housing supply are required. The repurposing of already existing structures, which can act as affordable residential housing, can meet this need. Shipping containers currently provide an inexpensive alternative to conventional housing on a small scale in many countries, including Australia (Zafra et al: 2021; Dhongde & Anagal: 2020; Ishan et al: 2019; Cameron: 2019). Previous research has not investigated the possibility of expanding the small scale use of shipping containers for residential housing to decommissioned shipping containers. Decommissioned shipping containers are those deemed unsuitable for their original purpose and presently, these are mainly recycled as scrap metal in Australia (Tiger Containers: 2021). When compared to Australia's net zero emissions target by 2050 (Australian Government Department of Industry, Science, Energy and Resources: 2021), this represents a loss of the embodied energy used to produce the steel relative to repurposing these decommissioned shipping containers for housing. As a result, this research project aimed to explain how decommissioned shipping containers can meet national, state and local building standards and be used as a potential housing solution in Australia aligning with national emissions targets.

An explanatory case study of decommissioned shipping containers as housing, through document analysis of the National Construction Code (2022), the Queensland Development Code and Bundaberg Regional Council policies was undertaken to develop a reasonable interpretation of how national, state and local building codes relate to the repurposing of decommissioned shipping containers as residential housing.

The scope and purpose of this study is detailed in 1.4 Scope.

1.2 Introduction

Australia has entered a 'housing crisis', in which individuals and families are experiencing difficulty in finding affordable housing (National Housing Finance and Investment Corporation: 2023; Queensland Council of Social Service: 2021; Local Government Association of Queensland: 2022; Bennett: 2022). Additionally, Australia has pledged to produce net zero emissions by 2050 (Australian Government Department of Industry, Science, Energy and Resources: 2021). These factors suggest a social environment favouring housing that is inexpensive and with a low environmental footprint (Queensland Audit Office: 2022; Doyle: 2021; Queensland Government: 2017). Shipping container housing, which is cost-effective and has lesser environmental impact than conventional housing, could address these issues (Huard: 2019; Ishan et al: 2019; Brandt: 2011). There were approximately 37 million shipping container TEUs in use world-wide in 2018 (Song 2021), and this number historically increases by 10% annually (Figure 1.2.1). As shipping containers are typically removed from service when damage is noted (Hoffmann et al: 2020), using these decommissioned shipping containers for housing instead of scrap metal would further reduce cost and environmental footprint in Australia, however it would be necessary to ensure that such housing meets Australian building code.

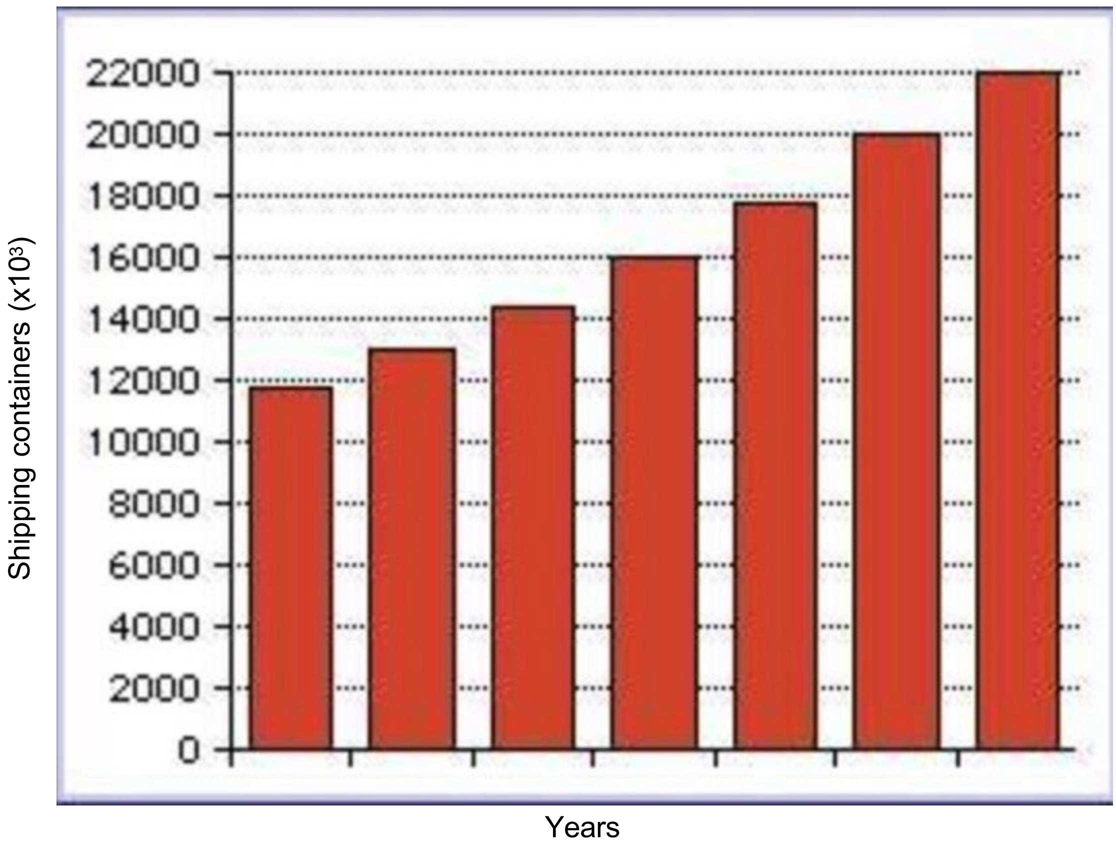


Figure 1.2.1: The number of shipping containers in use worldwide shows growth of approximately 10% per year from 1999 to 2005 (derived from The Institute of International Container Lessors: 2005)

1.3 The Problem

Despite decommissioned shipping containers being low cost (refer to 2.4.2), readily available (refer to 2.5.4) and typically recycled as scrap metal (refer to 2.5.4), there is little standardisation of the condition of shipping containers when they are deemed no longer fit for their original purpose. This makes their suitability as housing stock that is compliant with the National Construction Code (refer to 2.6.1) unknown. The use of decommissioned shipping containers for housing is unlikely to become widely accepted in Australia if used shipping containers cannot meet the NCC.

Other effects of using decommissioned shipping containers for housing in Queensland specifically include their need to comply with the Queensland Development Code (refer to 2.6.2), and with local council regulations. To analyse example effects of using decommissioned shipping container housing at a local council level, a document analysis of how such housing relates to the Bundaberg Regional Council policies (refer to 2.6.3) was done.

1.4 Scope

This qualitative case study research was comprised of identifying the problems and needs in assessing the viability of utilising decommissioned shipping containers for residential housing in Australia (refer to Appendix A). The NCC was the chief secondary data source analysed to ascertain how current national building code relates to decommissioned shipping containers. Purposive non-probability sampling was enacted to include the QDC as the state building code to be analysed to identify aspects related to the use of decommissioned shipping containers as housing at a state level. The researcher further used judgment sampling to include the Bundaberg Regional Council policies as the local council building code to be examined to identify areas related to decommissioned shipping container housing at a local level. Benefits and drawbacks of using decommissioned containers for housing in Australia were identified and suggestions made for their modification to meet Australian standards. Alterations to the NCC that could facilitate decommissioned shipping container housing were proposed.

1.4.1 Research objectives

This research aimed to solve the existing and perceived emerging suite of problems in relation to using decommissioned shipping containers as residential housing that meets national building code to address Australia's housing supply (refer to 2.2) in line with stated climate goals (defined in 2.3).

The research project was to safely and ethically assess the viability of using decommissioned shipping containers for housing purposes in line with the NCC, QDC and BRC Planning Scheme to address the Australian housing situation and help meet the emissions target (Appendix A) (Appendix B) (Appendix C).

The research question to be answered was: *How can decommissioned shipping containers comply with Australian building code to enable their use as residential housing in Australia?*

The hypothesis was that decommissioned shipping containers can meet Australian building standards for residential housing, possibly with modifications to the shipping container or changes to the building code. This hypothesis was investigated through interpretive document analysis of the NCC, QDC and BRC policies to determine if that is the case or not, and to identify what modifications to the used shipping containers could be made or what changes to the building code could facilitate the use of decommissioned shipping containers as housing.

The objectives of the research were to:

1: Produce a reasonable interpretation of Australian building code (NCC, QDC and BRC policies) which relates to the use of decommissioned shipping containers as housing.

2: Conduct an interview with a member of the Bundaberg Regional Council to determine implications for the use of shipping containers as housing imposed by a local council.

3: Identify the benefits and downsides of decommissioned shipping container housing as relevant to the interpretation of Australian building code.

4: Suggest how decommissioned shipping containers may be modified, if necessary, to meet the interpretation of Australian building code.

5: Suggest changes to Australian building code which may facilitate the use of decommissioned shipping containers as housing.

1.4.2 Research methodology

The research methodology was divided into four subparts, the first two being the background research, comprising of:

(a) Reviewing of relevant literature relating to the use of decommissioned shipping containers as housing, grouped under:
  (i) Australian Housing Supply
  (ii) Australia's Climate Goals

(iii) Shipping Container Housing
(iv) Shipping Container Specifications
(v) Australian Building Codes

(b) Defining the scope of the research and planning the design of the research

The second two subparts of the research were data collection and interpretation of findings, and evaluation comprised of:

(c) Document analysis and interpretation of Australian building code, as it relates to the use of shipping containers as housing, specifically:
(i) National Construction Code (NCC)
(ii) Queensland Development Code (QDC)
(iii) Bundaberg Regional Council (BRC) policies

(d) Linear-analytic examination of the results and evaluation of the findings to determine the viability of using decommissioned shipping containers as housing by:
(i) Identifying modes and effects of failure that cause shipping containers to be decommissioned, and determining if and how these can be managed to meet the baseline standard interpreted for an ISO 40ft shipping container to satisfy the building code
(ii) Evaluating the benefits and downsides of using decommissioned shipping containers as housing
(iii) Suggesting structural modifications that would enable decommissioned shipping containers to meet Australian building code
(iv) Suggesting changes to Australian building code that could facilitate the use of decommissioned shipping containers as housing

1.5 Conclusions

This dissertation aimed to assess the legality of using decommissioned shipping containers for housing purposes aligned with the NCC, QDC and BRC policies, with consideration of the current Australian housing situation and climate goals.

The research was expected to result in a reasonable interpretation of the National Construction Code, Queensland Development Code and the Bundaberg Regional Council policies as they relate to the use of decommissioned shipping containers as housing. Also, it was to identify benefits and downsides of using such housing according to the interpretation of these building codes, and to suggest how decommissioned shipping containers could be modified or Australian building codes altered to facilitate used shipping container housing.

A review of literature for this research identified that shipping container housing was cost effective (refer to 2.4.2) and had reduced environmental impacts compared to conventional housing (refer to 2.4.3), however a knowledge gap was evident around using decommissioned shipping containers as housing (refer to 2.5.4), likely due to the unpredictable nature of damaged items making it difficult to determine whether or not the used shipping containers comply with Australian building codes.

The outcomes of this study will be used for the design of modifications to decommissioned shipping containers to enable their use as affordable, green, residential housing to address increasing housing demand. Further, the outcomes of the study will inform any changes to the National Construction Code, the Queensland Development Code and the Bundaberg Regional Council policies required to facilitate the use of decommissioned shipping containers as residential housing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature to establish the need to address the housing supply situation in Australia, in line with Australia's climate goals, through using decommissioned shipping containers as residential housing that can comply with Australian building code. It establishes the importance of researching the use of decommissioned shipping containers for housing that can meet the National Construction Code due to the low cost of construction, rapid construction time and low environmental impact of this type of housing compared to conventional housing.

After verifying the technical specifications of shipping containers in literature, this chapter ascertains the need to interpret and evaluate the National Construction Code, Queensland Development Code and Bundaberg Regional Council policies as they relate to decommissioned shipping container housing to determine the viability, benefits, drawbacks and practicality of using such housing.

The research question investigated was: How can decommissioned shipping containers comply with Australian building code to enable their use as residential housing in Australia?

2.2 Australian Housing Supply

The Australian Bureau of Statistics (2021) found that 10,852,208 private dwellings were counted in Australia on the most recent census night, with 70% of these separate houses, 13% townhouses and 16% apartments. The National Housing Finance and Investment Corporation (2023) found that more than 1.8 million new households will likely form across Australia in the next ten years, with approximately 184,500 net new houses built this financial year, before net new constructions fall to around 127,500 next financial year. The *State of the Nation's Housing Report 2022-23* (NHFIC: 2023) suggested slowing national supply and greater household formation would lead to a shortfall of 106,300 dwellings over the next five years. NHFIC (2023) also reported an expected shortage of apartments and multi-density buildings available to rent nation-wide over the next five years, and gave a conservative estimate of approximately 377,600 households in housing need, with 331,000 facing rental stress, 577,400 having less acute renting pressure and 46,500 Australian households homeless. It was also noted that housing supply was being affected by rising construction cost (NHFIC: 2023).

Evidently, the latest data suggests an urgent need for increased housing supply over the next decade to alleviate rental stress on Australian households. Use of decommissioned shipping containers that comply with Australian building code for residential housing could be part of meeting this need.

2.2.1 Housing supply in Queensland

The CEO of the Queensland Council of Social Service (2021, n.p.) noted that "Queensland is facing a housing crisis….with 26,400 families on social housing waitlist, and …people facing homelessness for the first time in their lives". The *Covid-19 Rental Housing and Homelessness Impacts:an initial analysis* report found in 2021 that 2-bedroom unit rents on the Sunshine Coast, Mackay and Rockhampton increased between 2.6% and 4.3%, while 3-bedroom house rents in Gladstone, Rockhampton, Caboolture and Hervey Bay increased between 2.9% and 4% (Queensland Council of Social Service: 2021). In Southeast Queensland, all 12 local government areas had the largest rental increases in Australia in the last financial year, with rental rises of 30% or greater (NHFIC: 2023).

The Queensland Housing Strategy 2017-2027 reported that Queensland will need an extra 380,000 houses by 2027 for the growing population and affordable rental houses (Queensland Government: 2017), with the Queensland Housing Summit Outcomes Report reinforcing this by noting that only 1.9% of housing is affordable to minimum wage earners (Queensland Government: 2022).

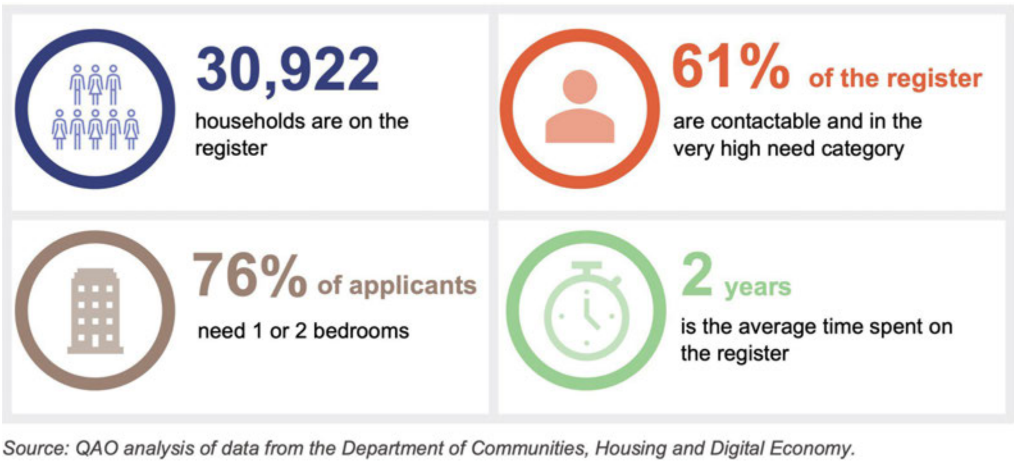


Figure 2.2.1: Profile snapshot of social housing applicants in Queensland (Queensland Audit Office: 2022)

The Queensland Premier stated that "every Queenslander should have access to a safe, secure and affordable home that meets their needs" (Palaszczuk 2023, n.p.). She announced a doubling of the Housing Investment Fund to $2 billion for 5600 affordable houses; an improved planning framework for Southeast Queensland to accelerate housing delivery; a plan to develop 38 Local Housing Action Plans with local councils; and a Housing Opportunities Portal for proposals that can deliver more houses, plus extra Modern Methods of Construction contracts (Palaszczuk 2023).

Clearly, additional housing supply in Queensland is needed, particularly affordable housing, and an interest in new, alternative housing solutions is apparent. Decommissioned shipping container homes that meet the Australian and Queensland building codes could address this need. It is also possible that a similar situation exists at a state level in other Australian states and that research into how decommissioned shipping containers can meet Queensland building code could be relevant generally to how decommissioned shipping containers could be used as housing compliant with state legislation in other states.

2.2.2 Housing supply in the Bundaberg Regional Council (BRC) area

The Member of Parliament for Burnett stated that "the housing crisis (is) continuing to hit the region hard" (Bennett: 2022, n.p.). He noted that nearly 600 people in the Bundaberg and Burnett electorates were on the very high need waiting list for social housing in 2021, with the average waiting time in the region nearly two years and the situation now worse (Bennett: 2022). The Local Government Association of Queensland (2022) launched a campaign encouraging community answers of workable solutions to the housing situation.

It is obvious that increased housing supply is needed in the Bundaberg Regional Council area, and real community solutions welcomed. Decommissioned shipping containers that can meet local building regulations for residential housing could form part of the solution and it is possible that research into how this could occur may be able to be extrapolated to other council areas within Queensland and in interstate localities.

2.3 Australia's Climate Goals

In 2021, the Australian Government made a whole-of-economy plan to achieve net zero emissions by 2050, and reduce emissions across the country by 85% (Australian Government Department of Industry, Science, Energy and Resources: 2021). The national plan aims for zero-energy residential buildings in Australia and the use of low emissions technologies in new and existing buildings (Australian Government Department of Industry, Science, Energy and Resources: 2021).

Low emission housing solutions, which could include decommissioned shipping containers that are compliant with Australian building code for residential houses, will be required to reach the net zero emissions target by 2050, justifying the research.

2.4 Shipping Container Housing

The present social environment favours housing that is both inexpensive and has a low environmental footprint. Shipping container housing is known to possess both these traits (Huard: 2019; Ishan et al: 2019; Brandt: 2011). Nduka et al (2018, p.350) concluded that: "Future studies should be targeted on qualitative study … on maintenance challenges of shipping container house", supporting a building code analysis explicitly related to shipping container housing. Dhongde & Anagol (2020 p.181) found that it was "amply demonstrated that housing using upcycled containers can be explored in practice as a viable option" and Bernardo et al (2013, p.629) noted that papers on structural elements of building with reused shipping containers are rare, with most literature focussed on architectural aspects, validating research into the use of decommissioned shipping containers specifically for housing. Brandt (2011, p.10-11) tabulated strengths and weaknesses of various features of shipping container housing, suggesting possible adaptions to counteract downsides (Figure 2.4.1)

Table 2.4.1: Table of strengths and weaknesses of features of shipping container housing and possible adaptations to address identified weaknesses (Brandt: 2011, p.10-11)

Feature	Strengths	Weaknesses	Adaption
Strength & Durability	Designed to carry heavy loads, and can thus support multiples of their own self-weight. They are also designed to resist harsh environments while being transported on ocean going vessels, trucks, and trains.	Strength is compromised when shell is modified, and containers are not built to carry loads such as large roofs. While they do resist the affects of harsh environments, they are vulnerable to degradation caused by natural elements.	Reinforcement modifications can be installed such as metal or wood framing to support the modifications to the container. Containers also can be treated and sealed to resist the deterioration of materials and occasional maintenance can be performed as well, such as de-rusting and painting.
Modularity	Container's cell-like structure is suitable for layout systems with small rooms, which can be joined together.		
Transportability	Containers conform to standard shipping sizes allowing them to be easily transported by ship, truck, or rail.	Transportability	Containers conform to standard shipping sizes allowing them to be easily transported by ship, truck, or rail.
Availability	Widely Available	Site, trade agreements, and the current need for containers can alter the availability of containers.	

Cost	Used containers are available at a cost that is low compared to a finished structure built by other labor-intensive means such as brick and mortar.	The cost of the container can increase depending on the prices of raw materials used such as steel.	
Temperature		Shipping containers are made from steel which conducts heat very well. In areas of extreme temperature variations, the interior of the container can become uncomfortable for the use of human occupancy	By insulating the container, and installing HVAC systems, the interior environment can become comfortable for any environment.
Labor	Units are pre-formed so labor is directed at modification rather than creation or assemblage	Modifying containers requires welding and cutting skills, which are considered to be a specialized labor, which adds to the construction cost.	Shipping containers can be shipped with each module prefabricated so that a limited amount of skilled labor is required to assemble the parts.
Construction Site		Maneuvering containers around a construction site generally requires the assistance of a crane or forklift.	Containers can be easily oriented on the site as needed.

Giriunas et al (2012, p.48) noted that "many shipping containers used for non-shipping applications are modified from their original design, and guidelines for safely using these containers for building applications do not exist." The literature clearly denotes that shipping containers are used across the world for housing purposes, though little published research is available on building guidelines associated with using any type of shipping container as housing. This research project could address the knowledge gap around using decommissioned shipping containers for housing in the Australian context through detailed analysis of how their use fits into the National Construction Code.

2.4.1 History

Forty years ago, Reiger & Engel (1983) reported on the experience of installing over 500 modular, mobile units in Victoria. They found that small, modular housing was financially viable, but that community perception and local regulations requiring many modifications were the main impediments to its widespread use. Other authors have since supported this finding (Steinhardt et al: 2013; Boafo et al: 2016; Ganiron: 2016; Lacey et al: 2018).

Following this widely-accepted historical perspective on modular housing in general, shipping containers as specific building modules gained traction initially for their use in post-disaster relief, as well as for temporary mining and military operations due to their transportability and deployment speed (Pena & Schuzer: 2012; Grant: 2013; Hong: 2017; Cameron: 2019). The use of shipping containers for residential housing was formalised in 1987 when a patent for a 'Method for converting one or more steel shipping containers into a habitable building at a building site and the product thereof' was submitted by Phillip C. Clark (Blanford & Bender 2020).

Using shipping containers as residential housing has occurred in several countries, for reasons ranging from financial hardship and disaster relief to housing for the elderly (Cameron: 2019; Dhongde & Anagal: 2020; Ishan et al: 2019; Zafra et al: 2021).

The use of decommissioned shipping containers for housing has occurred in some countries for around 20 years, triggered by accumulated shipping containers at ports, with examples in Australia (Bernardo et al: 2013). To guarantee safety in the reuse of shipping containers for housing, necessary works, including disinfection, cleaning, strengthening of connections and openings, surface preparation and painting, should occur in factories before transportation to the site to prevent issues during on-site construction (Bernardo et al: 2013). Bernardo et al (2013) concluded that building codes could be used by structural engineers to verify the safety of elements of shipping containers, but that some verifications were problematic, requiring assumed simplifications and adoption of particular construction details. However, Bernardo et al (2013) concluded that, overall, the reuse of shipping containers for building was feasible.

Literature supports the possibility of using shipping containers generally for housing, with limited evidence on the use of decommissioned shipping containers for this purpose. A gap in knowledge around how decommissioned shipping containers particularly, fit into building codes in many countries, including Australia, is evident.

2.4.2 Costs

Relevant literature cites the financial benefits of using new shipping containers for building over traditional housing materials. Ishan et al (2019) reported that housing costs in Sri Lanka could be reduced up to 60% by using shipping containers rather than traditional housing methods. Huard (2019) also reported that the cost of building a shipping container apartment of US$140 000 to be significantly lower than the cost of a traditional house build.

Similarly, a cost reduction of approximately 50% was reported by Thanekar et al (2022) in a study from India that analysed the value of using shipping containers decommissioned after 8-10 years, and then used as housing for a further 15-20 years. Bernardo et al (2013) also noted that in times of economic decline, when fewer goods are transported by sea and an oversupply of shipping containers accumulate at ports, a market for construction using decommissioned shipping containers becomes available, and Gateway Containers (2020a: n.p.) in Brisbane suggest that "millions of empty shipping containers go unused after a single trip because it is cheaper to sell them than it is to ship them back to their place of origin", making the cost benefit of using decommissioned shipping containers for residential housing evident.

The cost benefits of using shipping containers, including decommissioned shipping containers, for housing are well established, giving validation to this research project into how used shipping containers can comply with Australian building code for use as residential housing.

2.4.3 Environmental impacts

Literature consistently reported the lowered environmental impact of shipping container homes over traditional housing (Juschka: 2007; Abrasheva et al: 2012; Ling et al: 2014, Carey: 2014; Islam et al: 2016; Elrayies: 2017; Huard: 2019). With one 12 metre shipping container house recycling around 3.57 tons of steel (Cameron: 2019), upcycling shipping containers, with few modifications, to make housing would be considered environmentally-friendly construction. Kristiansen et al (2020) found that shipping container housing in China was associated with a 23% saving on electric energy for heating, however, Elrayies (2017) reported concerns that the energy required to make shipping containers habitable, including for thermal performance, sandblasting, window cutting and transportation fuel, impacted their environmental footprint.

Interest in using shipping containers for residential housing due to the reduced environmental footprint compared to conventional housing construction has been increasing, with environmental impact assessments, public opinion studies, thermal property and ventilation measurements, and models for complete housing units within shipping containers being undertaken (Abrasheva et al: 2012; Carey: 2014; Boafo et al: 2016; Dhongde & Anagal 2020). Further, Dhongde & Anagal (2020, p.175) noted the "huge burden on (the) environment … of embodied energy" in dumped shipping containers, supporting the environmental benefit of reusing decommissioned shipping containers as homes.

However, the steel exterior of shipping containers offers poor thermal performance (Blanford & Bender: 2020), with an uninsulated shipping container possibly leading to inhabitants suffering up to 5000 discomfort hours per year (Elrayies: 2017), making added insulation essential and increasing environmental impact. Further, shipping containers are vulnerable to surface condensation and interstitial condensation, which can damage insulation (Grant: 2013), making insulation of shipping containers challenging.

The literature supports the reduced environmental impact of using any type of shipping container for housing due to the savings made in embodied energy. However, some environmental effects related to modifications needed to make shipping containers suitable as houses, particularly insulation requirements, were noted. Though no literature specific to the impacts of decommissioned shipping containers as housing was found, the published literature supported the lowered environmental impacts of shipping containers as housing generally. It could therefore be understood that this research project into how decommissioned shipping containers can meet building code in Australia for use as a low-environmental impact housing option is supported.

2.4.4 Construction time

Numerous authors cited the efficiency and reduced overall construction schedule of modular housing generally, including shipping container housing (Lacey et al: 2017; Ganiron: 2016; Hong: 2017). The main reasons reported for using shipping containers as housing were their ability to be quickly and inexpensively manufactured and erected (Zhang et al: 2014; Hong: 2017; Uchechukwu: 2020). A study from Nigeria found that industry professionals stated that speed of construction was a primary enabler to the use of shipping containers as housing (Nduka et al: 2018). Grant (2013) also noted that when building prison cells, using shipping containers roughly halved deployment time compared to traditional methods, and a shipping container house product, 'Future Shack', uses prefabrication to fully erect the building in 24 hours (Helsel: 2001).

No articles specifically addressing construction time for repurposing decommissioned shipping containers as housing were found, however the general reduced construction time for pre-fabricated housing can be implied, and as such, using decommissioned shipping containers for houses could facilitate moving people into homes more quickly than if traditional housing methods were used. This justified the research project into how decommissioned shipping containers can meet Australian building code and help achieve this outcome.

2.4.5 Public Perception

Shipping container housing is generally poorly perceived by the public. This is consistently identified as an inhibiting factor to the use of shipping containers as housing in a variety of countries and cultures (Nduka,et al: 2018; Ishan et al: 2019). One factor contributing to this perception is the historical and continuing use of shipping containers as disaster relief housing, in prisons and to house low income individuals (Grant: 2013). Further, negative media attention, including on "illegal housing…where immigrants were found living in shipping containers" (Sully & Moore: 2014), impacts public views. Steinhardt et al (2013) also noted that both negative and positive perceptions exist within the building sector itself, with Giriunas et al (2012) stating that some in the industry, including designers and architects, view aesthetics, efficiency and economics as important, while other industry specialists, including engineers, believe that structural considerations should drive how shipping containers can be used for housing.

Agencies addressing homelessness have expressed concerns that using shipping containers for housing may not meet community standards. Beavis (2018) reported one expert as stating:

> *"We need to make sure that it's a quality product, it meets regulation standards, it meets community standards, especially if the Government is being asked to sponsor these different models. We really need to have those checks and balances put in place."*
>
> *Patty Chugg (Executive Officer Shelter Tasmania)*

However, individuals building luxury homes using shipping containers are gaining positive public interest in the media, online and onsite (Gateway Containers: 2020c), affecting public perception.

Figure 2.4.5.1: Luxury shipping container home at 8 Jaora Street, Graceville that sold for $1.5m (E Place Real Estate in Gateway Containers: 2020c)

Literature presents conflicting views around the public's perception of shipping container housing. From an industry perspective, this research project into how decommissioned shipping containers can comply with Australian building standards could address some of the issues raised around regulation and standards.

2.4.6 Trends

There is consensus amongst authors that interest is growing in using shipping containers for housing (Abrasheva et al: 2012; Bernardo et al: 2013; Ling et al: 2020; Kristiansen et al: 2020; Blanford & Bender: 2020; Risnandar & Primasetra: 2021). This option is increasingly being researched as a potential self-sufficient housing solution, with studies on environmental impact particularly, including the effect of mechanical insulation compared to natural ventilation

(Kristiansen et al 2020). Boafo et al (2016) concluded that monitored data on occupants' comfort and public perception of such constructions is required. However, researchers agree that limited clear guidance or regulatory policy applicable to design, construction and performance of innovative building types exists (Lacey et al: 2017; Steinhardt et al: 2013; Boafo et al: 2016; Giriunas et al: 2012). This may be changing, with Longreach Regional Council (2022) proposing a major amendment to its Planning Scheme titled: *Topic 6. Tiny Houses and Liveable Shipping Container Conversions*.

Longreach Regional Council explicitly considering formally addressing shipping container housing in its Planning Scheme provides additional validation to the research project. With this Queensland local government area proposing guidelines around the use of shipping containers as housing, there is justification for research into how such housing using decommissioned shipping containers can comply firstly with the NCC and QDC building codes, and then with local regulations.

2.5 Shipping Container Specifications

Shipping containers are freight containers intended for intercontinental traffic, known as ISO shipping containers, after the *ISO668:2020 - Series 1 freight containers* document, which specifies their classification, external dimensions, minimum internal and door opening dimensions and ratings (International Organisation for Standardisation: n.d.). The shipping container was "designed to withstand harsh weathering and heavy loading over long distance transportation" (Ling et al: 2020, p.1). There are various models of shipping containers, including general purpose, open top and refrigerated containers, with the most common being general purpose containers for dry cargo. The Institute of International Container Lessors (2005) reported that one-third of shipping containers worldwide were the 20ft general purpose model, and two-thirds of containers were the 40ft general purpose model. These models consist of one front face, one door face, two sides, the roof and the base (Figure 2.5.1).

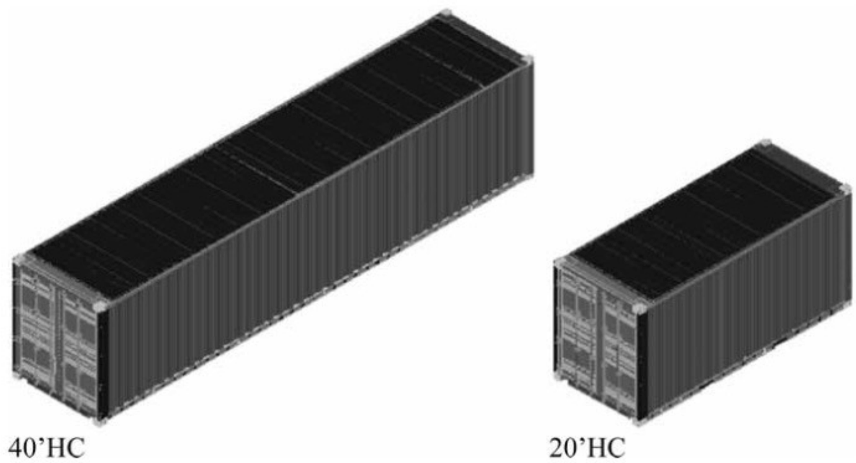


Figure 2.5.1: Image showing the general elements of the 40ft and 20ft general purpose shipping containers (Bernardo et al: 2013)

Using the literature to direct the study, it was determined that the research would focus on how the 40ft decommissioned general purpose ISO shipping container model can comply with Australian building code for residential housing due to this model being the most common worldwide.

2.5.1 History

In the late 1950s, a trucking company in the USA sought an inexpensive alternative to moving cargo and put loaded trailers onto a World War Two tanker, beginning containerisation (The Institute of International Container Lessors: 2005). Containers were then designed for different cargo, including dry and refrigerated goods, and ports built facilities to transfer these containers to trucks and trains in an intermodal system. In 1967, the International Maritime Organisation studied the safety of containerisation, resulting in the joint United Nations / International Maritime Organisation adoption of the *1972 Convention for Safe Containers*, which set out acceptable testing and strength requirements for containers (International Maritime Organization: 2019). Container sizes were standardised by the International Organisation for Standardisation in the *Freight Containers ISO Standards Handbook* to enable stacking and to facilitate loading and unloading across continents. *ISO 668 series 1 - freight containers,* the IICL-5 guide for container inspection and the Unified Container Inspection and Repair Criteria for steel general purpose containers comply with the *1972 Convention for Safe Containers,* its annexes I and II and amendments (Alshaar: 2015). Containerisation has become a world-wide, intermodal transportation system moving a volume of more than 100 million units of cargo each year in a fleet of over 22 million shipping containers (The Institute of International Container Lessors: 2005). Today, more than 95% of global trade occurs through shipping containers (Abrasheva et al: 2012).

Using the literature, it was determined that the research project would define decommissioned shipping containers to be ISO 668 series 1 freight containers that are deemed for any reason to no longer meet the IICL-5 guide for container inspection. As such containers no longer comply with the *1972 Convention for Safe Containers,* its annexes I and II and amendments which are internationally recognised as the standard for sea-worthy containers, it was decided that shipping containers not able to satisfy IICL-5 criteria would be classed as ‘decommissioned’ for the purposes of the research project.

2.5.2 Structural integrity

Shipping containers offer a strong starting point for creating a structurally sound residential building, due to the inherent strength of such a building system (Bernardo et al: 2013; Blanford & Bender: 2020, Ling et al: 2020). As shipping containers are built to ISO and International Convention for Safe Containers specifications, data on technical specifications is stated in the ISO documentation or provided by the manufacturer (Ling et al: 2020). Figure 2.5.2.1 provides the technical specifications of the two most common shipping container models - the 20ft and 40ft, general purpose shipping container models.

Model	Length (m), internal/external	Width (m), internal/external	High (m), internal/external	Self-weight (kg)	Load capacity Total (kg)	Load capacity Surf. (kg/m^2)	Capacity Volume (m^3)
20'HC	5.9/6.0	2.34/2.40	2.71/2.89	2300	28,000	867.63	37.41
40'HC	12.0/12.2	2.34/2.40	2.71/2.89	2300	36,000	1229.51	76.10

Figure 2.5.2.1: Technical specifications of the 20ft and 40ft shipping container models (Bernardo et al: 2013)

According to Bernardo et al (2013), ISO standards require each shipping container to be able to support 6 or more maximum-loaded other containers. The exact load testing requirements are shown in Figure 2.5.2.2.

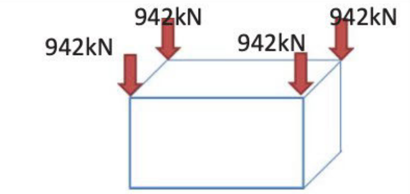
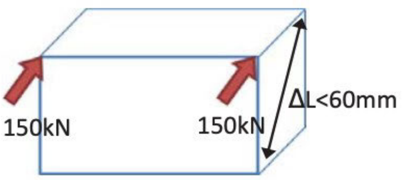
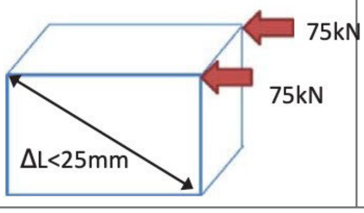
Testing	Loading	Permissible Criteria: Deflection under load	Permissible Criteria: Residual Deformation
Staking		Corner Post: 4mm Bottom Side Rail: 4mm Cross Member: 6mm	Corner Post: 2mm Cross Member: 3mm
Rigidity (Transverse)		End Frame: 60mm	End Frame: 10mm
Rigidity (Longitudinal)		Side Frame: 25mm	Side Frame: 7mm

Figure 2.5.2.2: Standard Testing Requirement for ISO Shipping Containers (Ling et al: 2020)

To support these loads, shipping containers are designed with the front and sides made of load-bearing steel plates of thicknesses between 1.6 - 2mm, the door made of two leaves of 4 - 6mm thick steel held within a frame and connected by two hinges, and a base of 28mm thick plywood inside a steel grid of cross members and two bottom side rails (Figure 2.5.2.3). These components are connected by continuous welds. Such design results in loading capacities as outlined in Appendix D.

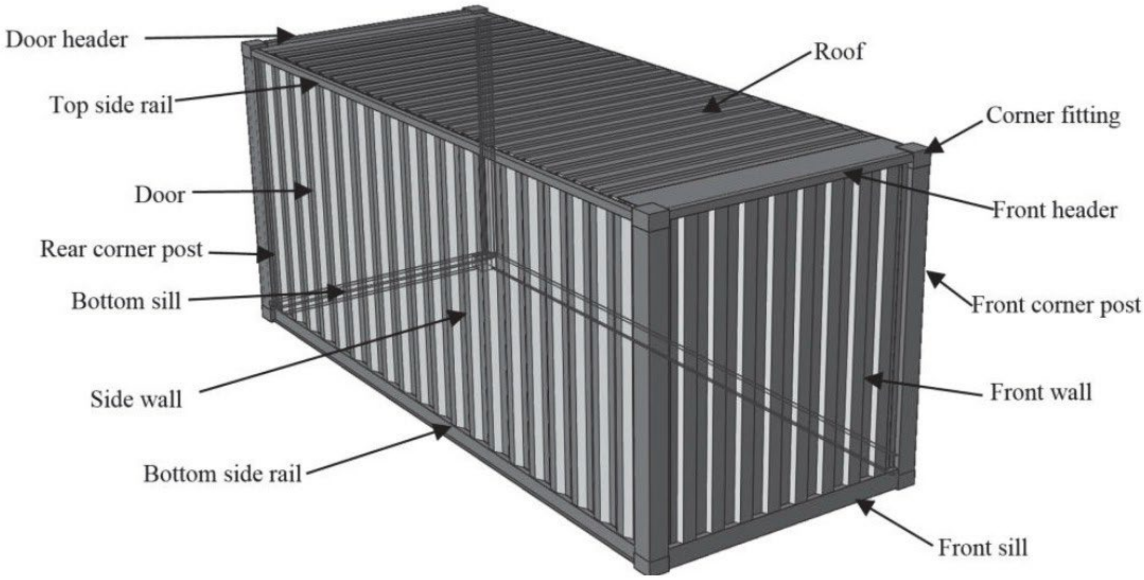


Figure 2.5.2.3: Front view image showing the main structural elements of an ISO shipping container (Ling et al: 2020)

Structural components are made of CORTEN-A steel (ASTM A242) with a yield strength (fy) of 343.23MPa and an ultimate strength (fu) of 480.53MPa and an elongation of 22% (Ling et al: 2020). This weathering steel has a layer protecting against rust from atmospheric conditions (Ling et al: 2020). Fittings are made of a casted weldable steel SCW49 (ASTM A216) with yield strength, ultimate strength, and elasticity of 274.58MPa, 480.53MPa, and 20% respectively (Ling et al: 2020). Giriunas et al (2012, p.51) listed the specifications for all the ISO 20ft metal container components as: Density = 7.85 E 10^9 tonne/mm3, Young's Modulus (E) = 200 E 10^3MPa (N/mm^2), Poisson's Ratio = 0.3, yield stress = 275 N/mm^2 for corner fittings, 285 N/mm^2 for inner rear corner posts, and 343 N/mm^2 for all other components.

Shipping containers are deemed seismically stable, suggesting utility in earthquake-prone areas (Dhongde & Anagal: 2020). However, the roofs of shipping containers are not as structurally sound as the walls, which can cause challenges in snowy regions (Cameron: 2019). Bernardo et al (2013) found this is emphasised when cutting the sides to add windows, doors, and other fixtures that cause the container to lose structural integrity. Giriunas et al (2012, p.56) confirmed this loss of structural integrity when they made eight different modified computer simulation models of a 20ft shipping container where the rear doors were replaced with a wall (Figure 2.5.3.1). When the modified models were subjected to five different loading scenarios, it was found that the end walls were the strongest load resisting component for axial loads, followed by the sidewalls, with the roof providing minimal structural value. They also concluded that end walls were the strongest for transverse loads, and sidewalls the strongest load resisting component for longitudinal loads. Bernardo et al (2013) found such structural integrity loss can be accounted for by adding vertical supports on both sides of the fixture. Giriunas et al (2012) found the original ISO container model to be the strongest in every loading scenario tested, and noted that extra reinforcement is usually given to modified shipping containers due to their structural strength being unknown when modified. Giriunas et al (2012) also stated that the reinforcement limits, as well as modification properties and foundation requirements of shipping containers used for non-shipping purposes are also mainly unknown.

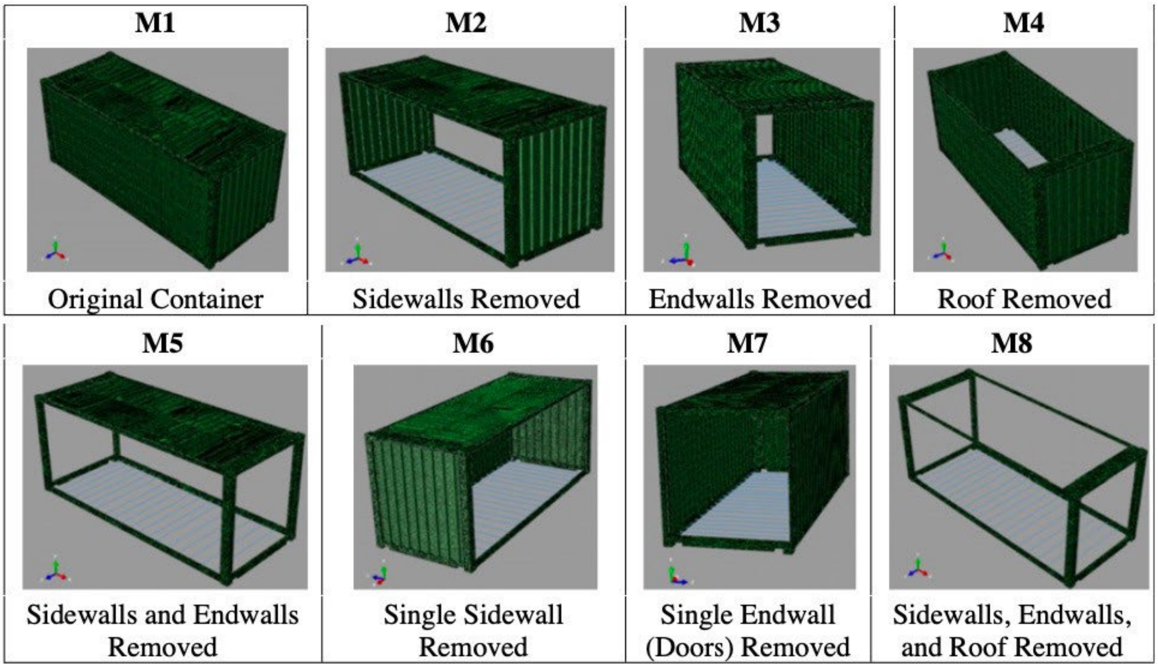


Figure 2.5.3.1: 20ft ISO shipping container modifications applied by Giriunas et al (2012, p. 54)

The limited literature around structural aspects of shipping containers that are used for purposes other than their intended manufacture, such as housing, was used to plan the research methodology. With comprehensive data available for ISO standard shipping containers, it was determined that a case study research methodology examining the case of how an ISO standard 40ft shipping container can meet Australian building code standards for domestic housing, through document analysis of the NCC, QDC and BRC policies, would provide a baseline that decommissioned shipping containers would need to reach to enable their use as a safe housing alternative.

2.5.3 Modes and effects of failure

The Institute of International Container Lessors (2022) listed 81 components of shipping containers which may suffer one of 31 damage types, causing the shipping container to be decommissioned. Among these damages, some can be repaired at low cost and effort, such as seized hinges requiring lubrication, loose components requiring re-securing, or the container requiring relabelling (The Institute of International Container Lessors: 2022). While such damages should result in a shipping container being decommissioned, they can be easily rectified, thus may result in the shipping container being reinstated into service and therefore unavailable for use as housing.

However, other damages are more costly to repair, and thus more likely to result in the permanent decommissioning of the shipping container. Out of 636 potential damages identified by The Institute of International Container Lessors (2022), two distinct categories of damage were apparent - physical damage and chemical damage (Appendix E).

Physical damages, such as cracks, dents, or nonconforming components, are typically able to be repaired through a combination of straightening, welding, and replacement of sections or the entirety of the component (Appendix E).

Chemical damages, such as contamination, corrosion / rust, or oil stained components, are typically able to be repaired through a combination of steam cleaning, water washing, and chemical cleaning of the component, however sometimes replacement is deemed a suitable solution (Appendix E).

The resulting effects of these modes of failure can largely be interpreted as a need to repair, rather than a reduction in structural stability, given that there are prescribed repairs for each mode of failure (Appendix E). This suggests a slight increase in both cost and resources used, relative to the option of not repairing shipping containers before they are converted into housing, impacting the environmental and cost benefits.

After document analysis of the NCC, QDC and BRC policies has occurred to establish a baseline level at which ISO standard 40ft shipping containers can be used as residential houses, the research project will analyse the modes by which these standard shipping containers are deemed to fail and the effects of these. This will inform how shipping containers decommissioned for specific reasons can be repaired or modified to reach the baseline standard set for domestic housing in Australian building code.

2.5.4 Decommissioned shipping containers

The useful lifespan of a shipping container that was designed and built to ISO standards to carry heavy loads in marine environments is about 12-15 years (Bernardo et al: 2013, Tiger Containers: 2021). Risnandar & Primasetra (2021) reported that in the USA alone, there were more than 5 million unused shipping containers, and Abrasheva et al (2012) reported that up to 3 billion TEU (6m) shipping containers are produced each year, with up to 1.5 billion TEU containers considered decommissioned each year. Following the pandemic, Tan (2022) reported that the worldwide reduction in global container demand resulted in shipping companies ‘giving away’ containers to counter crowded storage depots, making them easily available for reuse.

After decommissioning, shipping containers are generally graded. To determine the most suitable reuse for end-of-life shipping containers, suppliers grade decommissioned shipping containers firstly according to what international standard they meet, and then with an A, B, C or D rating within that category (Table 2.5.4).

Figure 2.5.4.1: Major grades of used shipping containers and repurposing suitability (Gateway Containers: 2020b)

	General Appearance	Dents & Scratches	Superficial rusting on exterior or interior	Understructure	Valid CSC	Meets ISO	Suitability
Grade A							
IICL	Very Good	Minor	Minor	Good	Yes	Yes	Transport / Storage
CW	Very Good	Minor to Medium	Minor to Medium	Good	Yes	Yes	Transport / Storage
WWT	Very Good	Minor to Medium	Minor to Medium	N/A	No	Generally	Storage
Grade B							
IICL	Good	Minor to Medium	Minor to Medium	Good	Yes	Yes	Transport / Storage
CW	Good	Medium	Medium	Good	Yes	Yes	Transport / Storage
WWT	Good	Medium	Minor to Medium	Good	No	Possibly	Storage
Grade C							
CW	Mediocre	Medium to heavy	Medium to heavy	Good	Yes	Yes	Transport / Storage
WWT	Mediocre	Medium to heavy	Medium to heavy	N/A	No	Possibly	Storage
Foodstuff							
IICL	Very Good	Minor	Minor	Good	Yes	Yes	Transport / Storage
CW	Very Good	Minor to Medium	Int / Minor - Ext Minor to Medium	Good	Yes	Yes	Transport / Storage
WWT	Very Good	Minor to Medium	Int / Minor - Ext Minor to Medium	N/A	No	Generally	Storage

Note: IICL= The Institute of International Container Lessors inspection rated; CW=Cargo Worthy; WWT=Wind and Water-tight

Decommissioned shipping containers that have a valid *Convention for Safe Shipping Containers* serial plate, meaning that they meet IICL-5 international inspection and leasing standards, are labelled as 'IICL'; those that no longer comply with IICL-5 standards but retain acceptable strength and appearance are labelled as 'Cargo Worthy'; containers that are no longer cargo worthy due to extensive denting and repairing, but remain both wind and watertight are labelled as 'Wind and Watertight'; and containers that have major internal and external damage over much of the container are labelled 'As Is' (Gateway Containers: 2020b). An A-Grade can be given to decommissioned shipping containers labelled IICL, Cargo Worthy and Wind and Watertight of overall very good quality in strength and appearance, with 80% of the sides unblemished and some marks, scratches, dents or surface rust (Gateway Containers: 2020b). Used containers labelled IICL, Cargo Worthy or Wind and Watertight can be given a B-Grade if their overall strength and appearance is good, with approximately half the sides unblemished, widespread surface rust and some repair patches, while Cargo Worthy and Wind and Watertight decommissioned containers can be given a C-Grade if extensive repairing and blemishes are evident (Gateway Containers: 2020b). Suppliers rarely deal in D-Grade 'As Is' containers.

A shipping container used for building can be referred to as an Intermodal Steel Building Unit (Bernardo: 2013). Shipping containers of A and B grade meet IICL-5 standard and are deemed suitable for reuse as housing (Tiger Containers: 2021). Ling et al (2020, p.1) stated that shipping containers made for harsh marine cargo-carrying are "very durable and suitable for housing purpose" on land and Bernardo et al (2013, p.645) ultimately concluded that "the feasibility of this construction system based on the use of refurbished shipping containers as construction modules for buildings should be recognised". However, published data on shipping containers used for housing or other non-shipping purposes is uncommon, and published articles on the structural modelling and analysis required for such repurposing is even more difficult to find (Giriunas et al: 2012).

With an established knowledge gap around the use of decommissioned shipping containers generally, and for housing specifically, likely due to the unpredictable nature of used products, this research project aims to identify the modes by which shipping containers are deemed 'decommissioned' and how these might impact the ability of such decommissioned shipping containers to meet Australian building standards for residential housing.

2.6 Australian Building Codes

Historically, building regulatory systems in Australia rested with State and Territory governments, with little consistency of standards and some states passing regulatory powers onto municipal councils (NCC: 2023). In 1965, States and Territories established the Interstate Standing Committee on Uniform Building Regulations and an Australian Model Uniform Building Code was released in the 1970s (NCC: 2023). However, large variations between state provisions remained until 1988, when the first Building Code of Australia was released (NCC: 2023). The Australian Building Codes Board was established in 1994 and it converted the Building Code of Australia into a performance based document adopted nation-wide by 1998 (NCC: 2023). In 2003, an annual amendment cycle with an operational date of 1 May each year was agreed and by 2011, the Building Code of Australia and the Plumbing Code of Australia had joined to become the National Construction Code (NCC: 2023). The printed publication was moved to a free online version in 2015, with a 3-year amendment cycle beginning in 2016 (NCC: 2023).

Giriunas et al (2012, p. 48), in the context of the United States, reported: "Currently, guidelines for safely using shipping containers for building applications do not exist." This literature review found no guidelines in existence in the Australian context either. Giriunas et al (2012) also noted that building code regulations for using shipping containers for building applications are mostly unknown, while Nduka et al (2018) and Bernardo et al (2013) also noted the need for further research into how shipping containers as housing meet building code.

An explanatory case study with document analysis of the National Construction Code (2022), the Queensland Development Code and Bundaberg Regional Council policies can develop a reasonable interpretation of how national, state and local building codes relate to the repurposing of decommissioned shipping containers as residential housing.

2.6.1 National Construction Code (NCC)

The NCC is a uniform set of technical provisions for building and provides minimum standards for all aspects of new buildings and new building work in existing buildings in Australia (NCC: 2023). It currently consists of NCC 2022 Volume One - Building Code of Australia Class 2 to 9 (multi-residential, commercial, industrial and public) buildings and structures; NCC 2022 Volume 2 - Building Code of Australia Class 1 (residential) and Class 10 (non-habitable) buildings and structures; and NCC Volume Three - Plumbing and drainage for all classes of buildings (NCC: 2023). The NCC 2022 became operational on 1 May 2023 and has mobile and tablet options and integration with Computer-Assisted Drawing software (NCC: 2023).

The NCC covers Class 1 - 10 buildings and structures, with Class 1a being a detached house, row house, terrace house, town house or villa unit, Class 1b being a boarding house, guest house or hostel for 12 or fewer people or used for short-term holiday accommodation, Class 2 being a building with more than one dwelling, Class 3 being a temporary residential building, Class 4 being a residence within a commercial building, Class 5 being an office building, Class 6 being a retail shop building, Class 7 being a storage building, Class 8 being a laboratory-type building, Class 9a being a public healthcare building, Class 9b being a public assembly building, Class 9c being a public residential care building and Class 10 being non-habitable structures (NCC: 2023).

The NCC uses seven clause types - G (governing requirements), P (performance requirements), D (deemed-to-satisfy provisions), C (clauses in a specification), O (objectives), F (functional statements) and V (verification methods) (NCC: 2023). G and P clauses are mandatory; C clauses can be mandatory or optional; D clauses are optional, but used to meet P clauses; O and F clauses give guidance and V clauses are used in conjunction with experimental data (NCC: 2023).

Initial overview of the NCC found that no volume or section directly addressed IICL-5 standard shipping containers or decommissioned shipping containers used for building applications, supporting a methodology for this research that encompasses document analysis of the NCC in relation to how ISO shipping containers used for residential buildings fit into the NCC.

After overviewing the volumes of the NCC, it was determined that NCC Volume One - Building Code of Australia Class 2 to 9 (multi-residential, commercial, industrial and public) buildings and structures would be excluded from the research, due to 83% of housing in Australia being made up of Class 1 buildings (inferred from ABS: 2021). It was also decided that NCC Volume Three - Plumbing and drainage for all classes of buildings would be excluded from the research, as this volume chiefly focuses on plumbing, which is generally available post-construction.

Further, it was also determined that this research project would exclude Class 1b, Class 3 and Class 4 buildings as defined in the NCC, because the aim of this research is to solve the problems in relation to using decommissioned shipping containers as residential housing to address current housing supply issues, and these forms of building are of temporary residential or small-scale nature. It was decided to also exclude Class 5 , 6, 7 and 8 buildings, as these cover structures for non-residential purposes and as such, do not address the aim of the project. Class 9 buildings were excluded as the Class 9 group covered aged care facilities or non-residential buildings. Class 10 buildings were also excluded, as they are not habitable and thus, do not contribute to the project aim. Class 2 structures were excluded as it was determined that a separate study should be undertaken into how decommissioned shipping containers relate to residential apartment housing that makes up 16% of Australian housing (ABS: 2021).

It was determined that the research will cover G and P clauses that are mandatory, D clauses which give a pathway to P clauses and C clauses which can be mandatory or optional. This research project will not cover O and F clauses, which provide guidance only, or V clauses which use experimental data.

2.6.2 Queensland Development Code (QDC)

The Queensland Development Code places Queensland-specific building standards in one document, consisting of Mandatory parts, Non-mandatory parts and Pending parts, and covers matters additional to the NCC (Queensland Government: 2023). However, should a discrepancy exist between the NCC and the QDC, the QDC prevails to the extent of the discrepancy (Queensland Government: 2023). It contains default standards that apply unless local governments have alternative standards in their planning schemes, as well as sample standards for local councils to consider putting in planning schemes (Queensland Government: 2023).

The QDC comprises of MP 1.1 (detached housing on lots under 450m^2), MP 1.2 (detached housing on lots over 450m^2), MP 1.3 (duplex housing), MP 1.4 (a building near infrastructure), MP 2.1 (fire safety in a low-cost accommodation building), MP 2.2 (fire safety in a residential care building), MP 2.3 (fire safety in a detention centre), MP 2.4 (buildings in bushfire-prone locations), MP 2.5 (external cladding), MP 3.1 (a floating building), MP 3.2 (a tent), MP 3.3 (temporary buildings), MP 3.4 (swimming pools), MP 3.5 (a building in flood-prone locations), MP 3.6 (Commonwealth Games residences), MP 3.7 (farm buildings), MP 4.1 (sustainability), MP 4.2 (water tanks), MP 4.3 (water tanks in commercial buildings), MP 4.4 (buildings near transport routes), MP 5.1 (work buildings), MP 5.2 (personal appearance service buildings), MP 5.3 (retail meat buildings), MP 5.4 (childcare buildings), MP 5.5 (private health buildings), MP 5.6 (farm workers' residences), MP 5.7 (residential services buildings), MP 5.8 (work buildings), MP 5.9 (buildings in cyclonic locations), MP 6.1 (fire safety installations) and Pre 2007 MP 2.3.

The overview of the Queensland building code found that it does not explicitly state how it applies to the use of shipping containers, either ISO standard or decommissioned. The research to be conducted would address this gap in knowledge by enacting purposive, non-probability sampling to include this state building code for document analysis to identify aspects related to the use of decommissioned shipping containers as housing at a state level.

It was decided that only the QDC Mandatory parts would be included in this research, as the other parts are presently non-compulsory. From this overview of the Mandatory parts of the QDC, it was determined that MP 1.4, MP 2.3, MP 2.4, MP 3.1, MP 4.4 and MP 5.9 would not be included in the study, as these are location-based regulations, with the documentary analysis required to determine how decommissioned shipping containers fit within state housing regulations generally, rather than location specifically. MP 3.4, and MP 4.2 were excluded, as these cover building aspects that are usually available post-construction. MP 3.2, MP 3.3 and MP 3.6 were not included due to these sections covering temporary buildings. MP 3.7, MP 4.3, MP 5.1, MP 5.2, MP 5.3, MP 5.4, MP 5.5 and MP 5.8 were not part of the research either, as they are related to buildings for commercial purposes, rather than for residential accommodation. Further, MP 1.3, MP 2.2, MP 5.6 and MP 5.7 were not within the scope of the research, as they relate to buildings that are not Class1a buildings. Pre 2007 MP 2.3 was excluded, as it has since been superseded by MP 2.3.

2.6.3 Bundaberg Regional Council (BRC) Planning Scheme

The Bundaberg Regional Council Planning Scheme provides guidance for development in the district. It commenced with Version 1.0 in 2015 under the Sustainable Planning Act 2009, with the current BRC Planning Scheme (Version 6.1) taking effect on 12 May 2023 (BRC 2023).

It consists of Parts 1 9, with six schedules and two appendices. Part 1 is about the planning scheme; Part 2 comprises the state planning provisions; Part 3 is the strategic framework; Part 4 has the local government infrastructure plan, Part 5 has Tables of Assessment Version 5.0 effective 10 February 2020; Part 6 has zoning; Part 7 contains local plans; Part 8 has overlays and Part 9 covers Development codes Version 5.0 effective 10 February 2020 for the assessment given in Part 5 (BRC 2023). Schedule 1 contains definitions; Schedule 2 has mapping; Schedule 3 covers the local government infrastructure plan maps; Schedule 4 gives notations under legislation; Schedule 5 designates premises for development and Schedule 6 gives policies. Appendix 1 is the index and Appendix 2 contains amendments (BRC 2023).

The BRC Planning Scheme includes standards modelled and modified from the QDC, with the standards in the BRC Planning scheme being applied when standards different to the QDC are given (BRC 2023).

An initial review of the current BRC Planning Scheme found no explicit or implicit guidelines for any type of shipping container housing stated, suggesting that research into how decommissioned shipping containers as residential houses can fit into local council regulations is needed. As such, BRC policies, rather than the BRC Planing Scheme, were selected through purposive non-probability sampling to be the local government building regulations to be analysed.

2.7 Conclusions

The aim of this chapter was to validate research into the use of decommissioned shipping containers for residential housing aligned with the NCC, QDC and BRC requirements to address the current housing situation and climate goals in Australia.

This literature review firmly established a shortage of residential housing supply across Australia, in Queensland and within the Bundaberg Regional Council area, and verified Australia's net zero emissions target by 2050. The literature endorsed the use of shipping containers for housing, both historically and presently, due to the low cost of construction, rapid construction time and low environmental impact, compared to conventional housing, however, concern was raised about the thermal performance of shipping containers that could make insulation of shipping container homes necessary, adding cost and environmental burden. It was found that in spite of generally poor public perception of shipping container houses, some positive public interest is occurring, and a trend towards greater use of container housing was established.

A knowledge gap relating to the use of decommissioned shipping containers for residential housing became evident. The impacts of using shipping containers as housing were clearly cited in published literature, but a dearth of data around using decommissioned shipping containers for this purpose was obvious. Research detailed the lifespan of ISO shipping containers and the extent that these are decommissioned worldwide annually. Yet, limited published research was available on how such used shipping containers can meet building codes to be safely repurposed as residential housing in any country, including Australia.

The historical development of containerisation led to standardised technical specifications for shipping containers, and there was consensus within the literature about their structural integrity due to this standardisation. It was found that 81 components in shipping containers are subject to failure, with 31 damage types that can cause shipping containers to be decommissioned identified (The Institute of International Container Lessors: 2022). Physical and chemical damages were the main modes of failure of shipping containers, with effects of these being interpreted as a need to repair, rather than a reduction of structural stability (Appendix E). There was agreement within the literature of the viability of using decommissioned shipping containers as housing, yet guidelines on how to safely do that were not evident, likely due to the unpredictable nature of the used products. The NCC, QDC and BRC Planning Scheme were found to lack explicit mention of the use of ISO or decommissioned shipping containers for housing.

From the literature, it became evident that an explanatory case study of decommissioned shipping containers as housing, through document analysis of the National Construction Code (2022), as well as the Queensland Development Code and Bundaberg Regional Council policies, selected through purposive non-probability sampling as the state and local building codes to be included, can develop a reasonable interpretation of how national, state and local building codes relate to the repurposing of decommissioned shipping containers as residential housing in Australia. It was also decided which sections of the NCC and QDC and BRC policies were to be excluded from the research due to their irrelevance to how shipping containers can be used for residential housing that addresses Australia's housing supply issues.

This chapter reviewed relevant literature, and confirmed the need to interpret and evaluate Australian building code as it relates to decommissioned shipping container housing to determine the legality, benefits, drawbacks and implementation of such housing in Australia to assist in addressing the current housing supply problem, in line with stated climate goals. Research methodology to achieve this will be discussed in the following chapter.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

The use of decommissioned shipping containers for housing is unlikely to become widely accepted in Australia if such a solution to the present housing supply issue cannot meet relevant NCC, state and local council regulations. Considering this, the research project comprised an explanatory case study of decommissioned shipping containers as housing, through document analysis of the National Construction Code (2022), the Queensland Development Code and Bundaberg Regional Council policies to develop a reasonable interpretation of how national, state and local building codes relate to using decommissioned shipping containers as residential housing. Linear-analytic examination of the results occurred, with evaluation of the findings used to determine the legality of using decommissioned shipping containers as housing in Australia. Modes and effects of failure that cause shipping containers to be decommissioned were identified to determine if, and how these can be managed to meet the baseline standard interpreted for an ISO 40ft shipping container to satisfy Australian building code. Benefits and drawbacks of using decommissioned shipping containers as housing were then suggested. Structural modifications to decommissioned shipping containers to make them compliant with the interpretation of the Australian building code, should they be repurposed for residential housing, were proposed. Further, changes to the NCC, QDC and BRC policies were suggested to facilitate the use of decommissioned shipping containers for residential housing in Australia to address housing supply.

3.1 Resources

Few resources were necessary for this project. The primary requirement was a computer and stable internet connection to access the Australian building codes (NCC, QDC and BRC policies) and Australian Standards (AS 1562.1, AS 2047, AS/NZS 2728, AS 4055).

Ample time to analyse the information in these comprehensive documents needed to be allocated for thorough document analysis of the NCC, QDC and BRC polices to occur. Transportation to the interview with the BRC representative was arranged.

3.2 Scope

Previous research identified a lack of guidance on using decommissioned shipping containers for residential housing, and requirements to make these a legal, residential housing solution in Australia. Limited published data was available on how modes of failure that cause ISO shipping containers to be decommissioned can be repaired or the container modified so they can be safely used as residential housing. The literature established a need for guidelines on how decommissioned shipping containers relate to baseline safety standards for domestic housing across the world. Previous research has not investigated how decommissioned shipping containers can fit into the national, state and local building codes to enable their use as residential housing in Australia.

With the research question being: *How can decommissioned shipping containers comply with Australian building code to enable their use as residential housing in Australia?,* it was determined that decommissioned shipping containers would be defined as ISO 668 series 1 freight containers that are deemed for any reason to no longer meet the IICL-5 guide for container inspection. As these containers no longer comply with the *1972 Convention for Safe Containers,* its annexes I and II and amendments, which are internationally recognised as the standard for sea-worthy containers, it was decided that shipping containers not able to satisfy IICL-5 criteria would be classed as decommissioned for the purposes of the research project.

From the literature reviewed on shipping container specifications, inclusion and exclusion criteria for the research project were determined. It was decided that the case study research would focus on the 40ft decommissioned, general purpose, ISO shipping container model. Open top and refrigerated models were excluded due to their impracticality for housing, and the 20ft general purpose model was determined to be structurally similar to its 40ft counterpart, but less commonly used. Therefore, the 40ft general purpose model was deemed the most suitable for inclusion in the study, as its larger size and greater prevalence make it more suitable for repurposing as permanent residential housing.

As the research was seeking to determine how decommissioned shipping containers can comply with Australian building code, it was decided that national building code, state building code and local building code would all need to be included for analysis. As such, the National Construction Code, the Queensland Development Code and Bundaberg Regional Council policies were included as the secondary data sources for interpretive document analysis. The NCC was included due to it being the overarching, Australia-wide building legislation. The QDC was selected through purposive, non-probability sampling as the state building code to be analysed because the Queensland building code can be considered representative of state building legislation in Australia. BRC policies were included, again through purposive, non-probability sampling, as the local building code to be reviewed, as this local council documentation was considered representative of local building legislation in Australia.

With the research aiming to determine how decommissioned shipping containers can be used as residential housing, it was determined that sections of any of the included Australian building codes not related to residential housing would be excluded.

The NCC 2022 Volume 2 - Building Code of Australia Class 1 (residential) and 10 (non-habitable) buildings and structures was included in the scope of this research. It was determined that NCC 2022 Volume One - Building Code of Australia Class 2 to 9 (multi-residential, commercial, industrial and public) buildings and structures would be excluded from the research, due to 83% of housing in Australia being made up of Class 1 buildings (inferred from ABS: 2021). While it is possible that the NCC 2022 Volume Three (Plumbing Code of Australia) could provide further insights into potential difficulties of using decommissioned shipping containers for residential housing, it was deemed outside the scope of the research, as this volume chiefly focuses on plumbing, which is generally available post-construction (Table 3.2.1).

Further, it was also determined that sections of the NCC covering on-site preparation and masonry components would be excluded from the study, due to their irrelevance to the design of a shipping container being used as housing.

Also, sections of the NCC that referred to AS4100 were considered outside the scope of the research, as it was determined that the compliance of shipping containers with AS4100 was worthy of a seperate study.

Within the NCC Volume Two, four of the seven clause types were included- governing requirements (G), which are mandatory; performance requirements (P), which are mandatory; deemed-to-satisfy provisions (D) which are optional, but provide a pathway to meet performance requirements; and clauses in a specification (C), which may be mandatory or optional. The remaining three clause types were excluded from the study - Objectives (O) and functional statements (F) were excluded as they provide guidance only, and verification methods (V) were excluded from the research, as these clauses use experimental data if the structure meets performative requirements (Table 3.2.1).

Further, within the NCC 2022 Volume Two, it was determined that the research would exclude Class 1b (a boarding house, guest house or hostel for 12 or fewer people or used for short-term holiday accommodation), Class 3 (temporary residences) and Class 4 (a residence within a commercial building) buildings, because the aim of the research was to solve the problems in relation to using decommissioned shipping containers as residential housing to address the current national housing supply issues. It was decided to also exclude Class 5 , 6, 7 and 8 buildings, as these cover structures for non-residential purposes and so, do not address the aim of the project. Class 9 buildings were excluded as they are not residential buildings or covered aged care facilities and Class 10 buildings were also deemed outside the scope of the research, as they are not habitable and thus, do not contribute to the project aim. Class 2 (a building with more than one dwelling) buildings were excluded, as it was decided that a separate study would be required to determine how decommissioned shipping containers could be used as residential apartments (Table 3.2.1).

Also, any clause within the NCC Volume One and Volume Two that can be satisfied through the physical location of the decommissioned shipping container, as opposed to the attributes of the container itself, was considered to be satisfied by default, as any house in an acceptable location would meet such clauses. Thus, location-dependent clauses, such as those which only apply to structures in certain wind regions or within a specified distance of a wave break were excluded from the analysis unless a direct conflict of location was evident.

The QDC Mandatory parts were included in the scope of this research. While it is possible that the QDC Non-mandatory parts and Pending parts could provide additional insights into potential difficulties of using decommissioned shipping containers for residential housing, these were deemed outside the scope of the research due to them being non-compulsory at present (Table 3.2.1).

Within the QDC Mandatory Parts, it was decided that MP 1.4, MP 2.3, MP 2.4, MP 3.1, MP 4.4 and MP 5.9 would not be included in the study, as these are location-based regulations, and the document analysis was to determine how decommissioned shipping containers fit within state housing regulations generally, rather than location specifically. MP 3.4, and MP 4.2 were excluded, as these cover building aspects that are usually available post-construction. MP 3.2, MP 3.3 and MP 3.6 were not included due to them covering temporary buildings. MP 1.3, MP 2.2, 3.7, MP 4.3, MP 5.1, MP 5.2, MP 5.3, MP 5.4, MP 5.5, MP 5.6, MP 5.7 and MP 5.8 were not within the scope of the research either, as they relate to buildings that are not Class 1a residential buildings. Pre 2007 MP 2.3 was excluded, as it has since been superseded by MP 2.3 (Table 3.2.1).

The BRC Planning Scheme 2015 Version 5.0 effective 10 February 2020 was excluded from the study, since it neither explicitly nor implicitly provides any guidance regarding shipping container housing. The BRC Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy was included, as it directly impacts the use of shipping containers as housing in the local council area.

Benefits and downsides of using decommissioned shipping containers as long-term, residential housing were within the scope of the research. While there are likely benefits and drawbacks of using decommissioned shipping containers as temporary housing, these was deemed outside the scope, as the aim of the research was to address the current housing supply situation.

Structural modifications to decommissioned shipping containers to have them comply with Australian building code were also within the scope of this research. Aesthetic modifications were not considered, unless these were mandatory and required structural modification.

Changes to the NCC, QDC and BRC policies, in the form of additional wording that could facilitate decommissioned shipping container housing as a viable housing solution, were within the scope of the research. Deletions were not considered.

Though a more broad look into using decommissioned shipping containers as non-residential structures may lead to more widespread use for commercial or industrial practices, in turn perhaps improving public acceptance of decommissioned shipping container residential housing, the primary justification for this research was the current housing situation within Australia, and as such, non-residential uses of decommissioned shipping containers were deemed outside the justifiable scope of the research project.

Table 3.2.1 : Inclusion and exclusion criteria of the documents included for document analysis

	Included	Excluded	Reasoning
NCC - Volume 1		X	The Building Code of Australia Class 2-9 structures
NCC - Volume 2	X		The Building Code of Australia Class 1 structures
NCC - Volume 3		X	The Plumbing Code of Australia - Generally available post-construction
NCC - Building Classifications	Class 1a		Covers permanent residential housing
NCC - Building Classifications		Class 1b, Class 2, Class 3, Class 4, Class 5, Class 6, Class 7, Class 8, Class 9, Class 10	Cover temporary residential housing or residence in commercial building, non-residential or inhabitable buildings, requires separate study
NCC - Clauses	Governing requirements (G), performative requirements (P), deemed-to-satisfy provisions (D), clauses in a specification (C)		Mandatory or lead to mandatory clauses or can be mandatory
NCC - Clauses		Objectives (O), functional statements (F), verification methods (V)	For guidance only or determined with experimental data
NCC - Other		Site preparation, masonry components	Irrelevant to shipping container design
QDC - Parts	Mandatory parts		Compulsory
QDC - Parts		Non-mandatory parts, Pending parts	Non-compulsory at present
QDC - Mandatory parts	MP 1.1, MP 1.2, MP 2.1, MP 2.5, MP 3.5, MP 4.1, MP 6.1		Cover Class 1a buildings

	Included	Excluded	Reasoning
QDC - Mandatory parts		MP 1.3, MP 1.4, MP 2.2, MP 2.3, MP 2.4, MP 3.1, MP 3.2, MP 3.3, MP 3.4, MP 3.6, MP 3.7, MP 4.2, MP 4.3, MP 4.4, MP 5.1, MP 5.2, MP 5.3, MP 5.4, MP 5.5, MP 5.6, MP 5.7, MP 5.8, MP 5.9, Pre 2007 MP2.3	Cover location-based regulations or aspects available post-construction, temporary or commercial buildings or a superseded part
BRC Policies	Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy		
BRC Policies		Planning Scheme - all parts	

3.3 Methodology

3.3.1 Research question

The research question posed was: *How can decommissioned shipping containers comply with Australian building code to enable their use as residential housing in Australia?*

3.3.2 Aim of the research

The aim of the research was to assess the viability of using decommissioned shipping containers for housing purposes in line with the NCC, QDC and BRC policies, considering the current Australian housing situation and climate goals.

The hypothesis was that decommissioned shipping containers can meet Australian building standards for residential housing, possibly with modifications to the shipping container or changes to the building code.

This hypothesis was investigated through interpretive document analysis of the NCC, QDC and BRC policies to determine if that is the case or not, and to identify what modifications to the used shipping containers could be made or what changes to the building code could facilitate the use of decommissioned shipping containers as housing.

3.3.3 Research objectives

To achieve the aim, the following objectives were decided:

Objective 1: To produce a reasonable interpretation of Australian building code (NCC, QDC and BRC policies) which relate to the use of decommissioned shipping containers as housing

Objective 2: To conduct an interview with a member of the BRC to determine implications for the use of shipping containers as housing imposed by a local council

Objective 3: To identify the benefits and downsides of decommissioned shipping container housing as relevant to the interpretation of Australian building code as determined in Objective 1

Objective 4: To suggest how decommissioned shipping containers may be modified, if necessary, to meet the interpretation of Australian building code as determined in Objective 1

Objective 5: To suggest changes to Australian building code which may facilitate the use of decommissioned shipping containers as housing

3.3.4 Literature review and planning

The research methodology was divided into four subparts, the first two being the background research, comprising of the literature review and planning of the research.

Korstjens & Moser (2017, p.274) stated that "the SPIDER tool (sample-phenomenon of interest-design-evaluation-research type)… can support the process of formulating research questions for original studies". This method was used to develop the research question: *How can decommissioned shipping containers comply with Australian building code to enable their use as residential housing in Australia?* The sample to be investigated was 'Australian building code'; the phenomenon of interest was 'decommissioned shipping containers'; the design was an explanatory case study with content analysis of the NCC, QDC and BRC policies; the evaluation was the researcher's interpretation of if and how decommissioned shipping containers can comply with building regulations for housing and the research type undertaken was qualitative. From the research question developed, a broad literature review of related published articles was done.

A literature review to identify current knowledge and empirical knowledge gaps around the topic (Korstjens & Moser: 2017), as well as to justify the research issue was conducted. The purpose of the review was to connect the study to literature that supports the need for this research, and place the study within previous published works (Rocco & Plakhotnik: 2009).

The database search strategy involved using Google Scholar, Science Direct, SCOPUS, Informit, the ICE Virtual Library and the ASCE Library. Keywords used were: shipping container, house, home, housing, used shipping container, decommissioned shipping container, Australia, building code (Appendix F).

The literature review explored themes relevant to the research question posed and was grouped under five headings:

(i) Australian Housing Supply
(ii) Australia's Climate Goals
(iii) Shipping Container Housing
(iv) Shipping Container Specifications
(v) Australian Building Codes

Research into how decommissioned shipping containers relate to residential building code in Australia was found to be necessary to address the present housing supply situation and stated climate goals in Australia, and to fill the knowledge gap around compliance of decommissioned shipping container housing with national, state and local building codes.

The literature was used to design the research methodology and to plan the project, including defining the scope and determining a suitable research method. It was decided that qualitative research would be undertaken, as this focuses on detailed investigation within a specific context (Lapan et al: 2012; Yin: 2014). A theoretical framework with an interpretive perspective was taken to gain understanding of the relationship between the phenomenon of interest, decommissioned shipping containers, and Australian building codes (Lapan et al: 2012; Korstjens & Moser: 2017). The method decided upon was case study research, defined by Lapan et al (2012, p.243) as "an investigative approach used to thoroughly describe complex phenomena ….in ways to unearth new and deeper understanding of these phenomena". Case study research into ISO shipping containers deemed as failing their intended purpose can uncover new understanding of how these decommissioned shipping containers can meet building code for use as residential housing.

Lapan et al (2012) noted that case study research involves careful defining and specification of the elements and portions of the case at the centre of the study using the research question posed to produce the detailed data needed to answer the question. Thus, the research question: *How can decommissioned shipping containers comply with Australian building code to enable their use as residential housing in Australia?* provided the limits for the research. It was decided that an explanatory, intrinsic single-case study of how decommissioned shipping containers only relate to current Australian building code could answer the question, maintaining focus on the case at hand.

Yin (2014) noted that case study research allows for in-depth examination of a specific case to elucidate overlooked details of a phenomenon for thoughtful understanding of the phenomenon, however, this understanding is generally not transferable to another context. A qualitative case study was planned to capitalise on published data about ISO shipping containers and their modes of failure, to apply this information to the case of how decommissioned shipping containers can meet Australian building code for repurposing as domestic housing. Through research on how ISO 40ft shipping containers can meet Australian building standards, a baseline can be obtained, to which the modes of failure that cause such shipping containers to be decommissioned can be applied, thus closing the knowledge gap on if and how decommissioned shipping containers can meet national, state and local building codes for residential housing. It was not expected that the understanding gained from this case study would be transferrable to other contexts.

3.3.5 Analysis and evaluation

The research methodology was divided into four subparts, the second two being data collection and interpretation, and evaluation of the findings.

It was determined that data would be collected through a theoretical, desktop document analysis and interpretation of Australian building code, as it relates to the use of shipping containers as housing, specifically, the 2022 National Construction Code, the Queensland Development Code and Bundaberg Regional Council policies. Bowen (2009, p.27) defined document analysis as "a systematic procedure for reviewing or evaluating documents…requir(ing) that data be examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge". Document analysis as a data collection method is especially applicable to case study research, and is useful for specialised qualitative research (Bowen: 2009; Yin: 2014). As this case study research involved an interpretive inquiry of highly specialised, qualitative research, explanatory document analysis was an appropriate data collection method. This research project utilised the advantages of document analysis, including efficiency and cost-effectiveness of information-gathering, lack of obtrusiveness and reactivity from the researcher within the research process, and exactness and coverage of the information in the documents (Bowen: 2009). However, limitations of the method, including possible lack of detail in documents not intended for research purposes, and an incomplete collection of documents possibly suggesting biased selection (Bowen: 2009; Yin: 2014), were noted. The documents analysed for this project were not created for research, but were considered to contain enough detail to achieve the aim of the study, as they are the source documents. However, the collection of documents was incomplete, with only one state building code and one council building scheme analysed. Thus, a degree of selection bias was present, as the state and local government documents included for analysis were chosen at the researcher's discretion.

Bowen (2009, p. 32) stated that the content analysis to be done "entails a first-pass document review, in which meaningful and relevant passage of text or other data are identified". The researcher is to identify relevant information from irrelevant text when interpreting the data in document analysis. Thus, this project involved the researcher selecting, appraising and synthesising the data in the analysed documents, and organising this collected data into categories. As such, the researcher was the subjective interpreter of the meaning in the data, so there is uncertainty in the method and risk of research bias due to a single researcher's interpretive analysis.

The NCC, QDC and BRC policies were the secondary data sources analysed for interpretation of how current national building code relates to using decommissioned shipping containers for residential housing. The NCC (Volume Two) was analysed with regards to Class 1 structures intended for long term housing; the QDC (Mandatory Parts) were analysed with relation to building provisions specific to Queensland in addition to the NCC, as any inconsistency between the NCC and the QDC requires the QDC to prevail (Queensland Government: 2023) and the BRC Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy was analysed with relation to building provisions specific to one local council. Though local government Planning Schemes may contain standards alternative to the QDC and in such cases, the alternative standards of the local government apply (Queensland Government: 2023), there was no explicit not implicit guidance relating to the use of shipping containers as housing in the BRC Planning Scheme, thus the Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy was analysed instead, as it implicitly impacts shipping containers as housing in the selected local government area. A supporting interview with a BRC representative was conducted to ensure best interpretation of the local regulations (Appendix G).

Document analysis was performed by dividing the NCC, QDC and BRC policies into segments, and interpreting if and how the properties of ISO 40 ft shipping containers, according to relevant literature on a newly-constructed standard shipping container, met the minimum requirements of each segment to provide a baseline that decommissioned shipping containers would need to reach to enable their use as a safe housing alternative in Australia. "Case study research uses descriptions of programs (documents) … to construct a complete portrayal of a case for interpretation and possible action" (Lapan et al: 2012). Also, Korstjens & Moser (2018) noted that content analysis gives a descriptive summary, while Lapan et al (2012) noted that an interpretive case study report adds explanation to the descriptive summary. This interpretive case study research focused on identifying the problems and needs in utilising decommissioned shipping containers for residential housing in Australia to determine if such a housing option was feasible. As such, the above building codes were described and interpreted in relation to minimum requirements and these requirements were then compared to relevant literature on ISO 40ft shipping containers to determine if a newly-constructed, standard 40ft shipping container inherently meets the requirements, or requires modification to meet Australian housing standards. If new 40ft shipping containers innately met the requirements outlined in the analysed segment, an 'IM' classification was given. If modifications were necessary to fulfil the requirements of that segment, an 'MR' classification was given. If it were not possible to modify standard 40ft shipping containers to meet the requirements outlined in that particular segment of the code, an 'NP' classification was given. For cases where an MR rating was given, the nature of the modifications required were outlined. For cases where an NP rating was given, alterations to the applicable building codes, which may allow newly-constructed shipping containers to meet the standard, were suggested.

Table 3.3.5.1: Sample table which was used to summarise the building code analysis

Section	Code	Explanation
H1D7	MR	Installation of a roofing fixture complying with Part 7.2 of the ABCB Housing Provisions
H1D8	MR	Installation of proprietary windows and window frames designed to meet AS2047
H2D6	IM	-

Following the descriptive summary and interpretive explanation made during the document analysis process, linear-analytic examination of the results occurred, and evaluation of the findings was used to determine the viability of using decommissioned shipping containers as housing by:

(i) Identifying modes of failure that cause shipping containers to be decommissioned, and analysing these to determine if, and how each impact can be managed to meet the baseline standard interpreted for an ISO 40ft shipping container to satisfy each of the analysed segments of the NCC, QDC and BRC policies
(ii) Identifying and evaluating the benefits and downsides of using decommissioned shipping containers as housing, based on the mode of failure that deemed the shipping container no longer cargo worthy
(iii) Suggesting structural modifications that would enable shipping containers decommissioned due to each mode of failure to comply with Australian building code
(iv) Suggesting alterations to the NCC, QDC and BRC policies, in the form of additional wording, that could facilitate the use of decommissioned shipping containers for residential housing use

Reporting of the evaluation of findings occurred to ascertain issues and needs in the decommissioned shipping containers themselves and within Australian building code related to using decommissioned shipping containers as a long-term housing solution. The report answered the research question and also compared the study findings to other findings within literature. Yin (2014) suggested that a major application for a case study is as the primary evaluation method where the phenomenon being evaluated is the main case. This case-based research was the primary evaluation method with decommissioned shipping containers used as housing being the main case.

The linear-analytic examination process ends with conclusions being reached, implications for the issue being discussed, and conclusions for further research being suggested (Yin: 2014). After evaluating the findings, conclusions were reported, implications for using decommissioned shipping containers as housing were addressed and suggestions for further research were made.

3.4 Risk Assessment

3.4.1 Risk register

A risk assessment with reference number 2422 was created on SafeTrak to quantify the identifiable risks associated with the research and approval for the the project was granted (Appendix B).

3.4.2 Research consequences and ethics

This research did not involve studies on humans or animals, and as such, no physical or psychological damage resulted from the project and human ethics approval was not required (Appendix C). The research was not performed in collaboration with any group, and the researcher did not have any financial or personal investments in the field of research, and as such does not stand to benefit from any particular outcome of this research. All research was performed using information available to the public and was conducted in such a way that no issues with legality or transparency could arise.

The research promoted sustainability and the researcher demonstrated integrity, practised competently and exercised leadership throughout the project.

3.5 Project Timeline

The Project Specification detailed the intended timeline and key tasks for the research (Appendix A). It is of note that the phases were defined and divided in such a way as to allow each phase to be completed before the subsequent phase began, largely preventing the need for concurrent activities.

3.6 Quality Assurance

In considering the quality of case study research, Yin (2014) noted the importance of readability, credibility and confirmability. In this case study research, readability was addressed through the addition of summary tables to complement the descriptive summary and interpretation; credibility was somewhat addressed, as the interview with a BRC representative quality-assured the single researcher's interpretation of the included local council planning scheme (Appendix G), but no similar process existed for the researcher's interpretation of the state and national code; confirmability was addressed through the use of academic literature and international standards, where possible, to enable minimum requirements of the Australian building code to be compared to the best available literature on technical specifications of ISO shipping containers through the reproducible method of document analysis, though with only the sole researcher's interpretation. Gammelgaard (2017) suggested that quality case-based research needs transferability, where the result can be analytically generalised; truth value, where coding procedures, iteration and refutation are established; and traceability, where open transparency of the research process is evident. In this case study research, transferability was mostly addressed, as the results can be analytically generalised by readers attending to each section of the analysed documents to garner how the interpretation was reached; truth value was somewhat addressed, with coding procedures included, iteration somewhat addressed (Appendix H), but refutation of the process was less established; traceability was present within the clear data collection guidelines given, the validity of the purposive, non-probability sampling method chosen and the justified inclusion and exclusion criteria provided.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 National Construction Code (NCC) Analysis

This analysis covered Volume Two (the Building Code of Australia) of the 2022 National Construction Code, which came into effect on May 1, 2023.

The section notation within the NCC takes the form of X1Y1, whereby the first letter denotes the section, the first number denotes the part of that section, the second letter denotes the clause type, and the second number is the clause number within each part.

4.1.1 Volume One - Section A

Though Volume One was generally excluded from the study, section A6G2 provided the definition used throughout the study. Section A6G2 defines Class 1a structures as detached dwellings, or dwellings separated by a fire resisting wall.

4.1.2 Volume One - Section S1

Though Volume One was generally excluded from the study, section S1C2 provided necessary guidance on fire resistance. According to S1C2, acceptable fire resistance is met if the building is determined to achieve the FRL in accordance with AS 4100 and AS/NZS 4600 for steel structures.

4.1.3 Volume Two - Section H1

According to H1P1, structures must perform adequately when subjected to expected loads, including dead and live loads, time-dependant effects, and loads caused by the environment, such as wind, water, earthquake, termite and thermal effects. The five percentile characteristics of materials should be used to determine structural resistance, and allowance should be made for construction activities, material types, site characteristics, inherent accuracy, and dimensional fluctuations caused by atmospheric conditions. Finally, glass installations must be designed to minimise injury to people if broken, and to minimise breakage chance by adhering to durability standards and markings for visibility.

The QLD amended H1P2, as well as the amended H1D10, both specify that buildings in flood areas in Queensland are governed by the Building Act 1975 and Development Code 3.5 - Construction of buildings in flood hazard areas. The Building Act 1975 describes the administrative responsibilities involved, and further suggests that the Queensland Development Code is the authoritative document for structural design of buildings in flood areas in Queensland. The QDC section MP3.5 contains 4 performative requirements, with Class 1a structures being required to fulfil performative requirements 1, 2, and 3. The first performative requirement states buildings must be designed so as to resist floatation, collapse, or significant movement from flood actions, as well as to safeguard users of the building from injury or illness, up to the extent of the defined flood level provided by the local council. Similarly, the second requirement states utilities associated with a building, excluding an electrical meter, must be designed to reduce the effects of a flood on these utilities. The fourth performative requirement states customer dedicated subsections of the building must not be affected by a flood up to the defined flood level. All these requirements can be met through choosing an elevated construction site, therefore these do not necessarily impact shipping container performance.

According to the QLD amended H1P3, termite protection must be designed to protect primary building elements, which are any load-bearing elements, for the lesser of 50 years or the design life of the building, and must be designed to minimise the risk of damage, and to enable maintenance to the degree necessary. However, all load-bearing elements within a shipping container are formed from steel, and thus inherently resistant to termite damages.

According to H1D1 and H1D2, the performative requirements H1P1 and H1P2 are fulfilled if the house is constructed in accordance with any combination of provisions H1D3 - H1D11 and Section 2 of the ABCB Housing Provisions.

According to H1D7, performance requirement H1P1 is met for metal sheet roofing if it is designed in accordance with Part 7.2 of the ABCB Housing Provisions. ISO standard 40ft shipping containers do not inherently meet the roofing standards due to roof pitching requirements. However, adding a roofing fixture designed to meet Part 7.2 of the ABCB Housing Provisions to a shipping container would allow it to meet these requirements. Therefore, shipping containers are able to meet roofing requirements with structural modification in the form of an attached fixture.

Additionally, H1P1 is met for metal sheet wall cladding if it is designed in accordance with AS1562.1. This standard requires preprinted and organic film or metal laminate products to conform to the requirements of AS/NZS 2728. To comply with this standard, an appropriate layer of paint as determined by the standard would need to be added to the shipping container wall cladding.

According to H1D8, performance requirement H1P1 is met if glazed assemblies such as windows located in an exterior wall are installed so as to comply with AS2047 and Part 8.2 of the ABCB Housing Provisions, so long as the building falls within the geometric limits outlaid in AS4055. These requirements specify that the distance from the ground level adjacent to the building to the underside of the eaves is less than 6m, while the distance from the ground level to the highest point on the roof is less then 8.5m. The width of the building should not exceed 16m, and the length should not exceed five times its width. The roof pitch should not exceed 35°. ISO standard 40ft shipping containers fall within these geometric limits.

So long as installed windows have been designed to meet AS2047, the windows themselves will satisfy the requirements. However in addition to this, since shipping container walls are load-bearing, the window must designed such that its frame can carry a load equivalent to the load which would have been carried by the portion of the steel wall removed in order to install the window. Part 8.2 of the ABCB provisions, states that structural loads must not be transferred to glass elements, and that a minimum of a 10mm gap should exist between the top of a load-bearing window frame and the glass. These factors could, however, be included in the window design without further modifying the shipping container. Therefore, while structural modification of shipping containers is necessary to install a window, no structural modification to the container beyond this is necessary to meet glazing requirements.

Therefore, all elements of H1P1 which were included in this study were determined to be either innately met by shipping containers, or met with some structural modification to the container. In addition to this, all elements of both H1P2 and the QLD amended H1P3 could be met by a shipping container without structural modification.

4.1.4 Volume Two - Section H2

H2P1 specifies that surface water from rainfalls of 5% annual exceedance probability must not damage the building, and must be disposed of in a way that avoids damage or nuisance to other properties. Rainfall from a 1% annual exceedance probability must not cause surface water to enter the building.

H2P2 specifies that roofs and walls should prevent unhealthy or dangerous conditions or loss of amenities to occupants, and should prevent undue dampness or deterioration of building elements. Similarly, H2P3 specifies that moisture from the ground must be prevented from causing these outcomes.

H2P4 concerns drainage from swimming pools, which are unnecessary to constitute a house, and therefore outside the scope of this study.

According to H2D1, performance requirements H2P1, H2P2, and H2P3 are deemed to be satisfied if the structure complies with H2D2 to H2D8.

H2D6 (4) specifies that H2P1 is satisfied for walls so long as they are compliant with H1D7.

H2D7 specifies that H2P2 is satisfied for weatherproofing and glazing so long as these building elements are designed according to H1D8.

According to H2D8, this section does not apply to metal sheet roofing designed in accordance with H1D7. Therefore, H2D8 is addressed through the earlier satisfaction of H1D7.

Therefore, all elements of H2P1 and H1P2 which were included in this study were determined to be innately met by shipping containers. No elements of H1P3 were within the scope of the study.

4.1.5 Volume Two - Section H3

H3P1 requires that Class 1 buildings within 900mm of the allotment boundary, or within 1.8m of another building, excluding associated Class 10 buildings, be protected from fire spread from a design heat flux of 92.6kW/m^2 for 60 minutes such that the fire has a 1% or lower chance of spreading.

H3P2 requires that occupants receive automatic warning of smoke with an efficacy and reliability each greater that 95% to allow for evacuation with consideration made for building function, occupant characteristics, as well as fire load, intensity, hazards, and characteristics.

H3D1 specifies that H3P1 and H3P2 are met when H3D2 to H3D6 are complied with.

H3D6 states that H3P2 is satisfied for smoke alarms and evacuation lighting if the building complies with Part 9.5 of the ABCB Housing Provisions. This section specifies that in Class 1a buildings, smoke alarms should be located in accordance with Part 9.5.2 and 9.5.4, as well as specifies that smoke alarms should be interconnected where more than one alarm is used in a dwelling. Additionally, 9.5.1c uses ambiguous language, stating that smoke alarms must "be powered from the consumer mains source where a consumer mains source is supplied to the building" (NCC 2022, p.547). This could be interpreted that smoke alarms are only required to be connected to the consumer mains source if the Class 1a building is connected to the consumer mains source, or alternatively that smoke alarms must be powered directly from the point of connection to the consumer mains source. Neither interpretation necessitates additional modifications to shipping container design. Part 9.5.2 specifies that in single storey Class 1a buildings, smoke alarms must be installed in any hallway associated with a bedroom. Part 9.5.4 lists installation requirements, including that smoke alarms must be 300mm or more from any corner junction of the wall and ceiling. Part 9.5.3 and Part 9.5.5 addressed Class 1b buildings, which fall outside the scope of this study. These clauses indicate that shipping containers are able to meet these requirements with modifications, since standard shipping containers do not have smoke alarms installed.

4.1.6 Volume Two - Section H4

H4P1 requires that water should not penetrate behind fittings or linings, or into concealed spaces wet areas, so as to maintain structural integrity of the building and amenity of occupants. H4P2 requires that rooms should be of a height which does not interfere with their intended function. H4P3 requires laundering and food preparation facilities, as well as a sanitary compartment (toilet), to be included in Class 1 buildings, and must be located in convenient locations. H4P4 requires habitable rooms contain windows providing an average daylight factor of 2% or more, and that artificial lighting must provide luminance of 20 lux or more suited to the function of the building. H4P5 requires that ventilation provide outdoor air to provide adequate air quality to residents, and that contaminated air must be disposed of such that it does not create nuisance or hazard for residents or owners of other property. H4P6 requires that walls have a spectrum adaption term of 45 or more, that walls separating wet areas from habitable rooms must insulate against generated sound so as to prevent illness or loss of amenity to occupants, and that sound insulation must not be compromised by pipes or other service elements. H4P7 requires that vapour and condensation must be managed to minimise impact on the health of occupants in Class 1 buildings.

H4D1 states that H4P1 to H4P7 are satisfied so long as H4D2 to H4D9 are fulfilled.

H4D2 states that H4P1 is satisfied for wet areas so long as Parts 10.2.1 to 10.2.6, and 10.2.12 of the ABCB Housing Provisions are met. Part 10.2.1 requires structural components in wet areas to be protected by a waterproofing system which complies with Parts 10.2.2 to 10.2.6. Part 10.2.2 requires shower floor areas, including any hobs and step-downs, to be waterproof. The walls, including any junctions, must also be waterproof to a minimum height of 1800mm above the floor substrate. In addition to this, walls within 40mm of either side of junctions must be waterproof, as must penetrations within the shower area. Part 10.2.3 further adds that within a room containing a shower, the flooring outside the shower area must be water resistant if using concrete materials, or waterproof if using timber materials, and the junctions between the wall and floor must be waterproof in both instances additionally. 10.2.4 discusses areas adjacent to baths and spas without showers - however, these structures are unnecessary in buildings where a shower is present, and thus fall outside the scope of this study. 10.2.5 outlines that walls joining to a water vessel such as a sink must be water resistant to a height of 150mm above the vessel if the vessel is within 75mm of the wall, or waterproof if the vessel is fixed to the wall, while tap and spout penetrations must be water resistant or waterproof. It additionally requires that in laundries and water closets, floors and wall/floor junctions must be water resistant. Part 10.2.6 states that a waterproofing system required to be waterproof must use the materials nominated in part 10.2.8, or those required to be water resistant must use a combination of the materials nominated in 10.2.9 and 10.2.10. These sections list the materials which are acceptable to be used for areas required to be waterproof and water resistant as per clauses 10.2.2 to 10.2.5. Part 10.2.12 requires that where a floor waste (floor drain) is used, a continuous fall from the floor plane to the waste of between 1:50 and 1:80 must be used.

H4D3 states that H4P1 is satisfied for materials and installation of wet area components and systems if Parts 10.2.7 to 10.2.32 of the ABCB Housing Provisions are met. Part 10.2.7 reaffirms 10.2.6 by stating that materials in wet areas forming a waterproofing system must use materials from Part 10.2.8 and 10.2.9. Similarly, Part 10.2.11 states that wall and floor substrate materials in wet areas must comply with 10.2.9, while Part 10.2.13 states that wall and floor surface materials in wet areas must comply with 10.2.10. Part 10.2.14 requires that shower areas be designed as enclosed or unenclosed, and must contain a floor waste, and contain one of a step-down, hob, or level threshold complying with 10.2.15, 10.2.16, or 10.2.17, respectively. To proceed, it was decided that an enclosed shower with a level threshold would be chosen as the sample to study, since other shower types would not be compliant as the sole shower within the building due to Clause H8D2. Part 10.2.17 specifies that a waterstop must be installed such that the vertical leg finished at least 5mm above the floor level where a shower screen is installed, and additionally specifies that the junction where the waterstop intersects the wall must be waterproof. 10.2.21 requires that where a screed (layer between finished surface and structural base) is used together with a waterproof membrane, the membrane can be installed either above the tile bed or above the screed. 10.2.22 specifies that at the time a membrane is applied, the surface it is applied to must be clean, dust free, and be free of indentations and imperfections. 10.2.23 requires that penetrations for taps, shower nozzles, or similar structures be waterproofed by sealing with sealants or proprietary flange systems. This section also requires the spindle housing of tap bodies to be removable to enable the replacement of the washer without damaging the seal, and for all penetrations in surface or substrate materials resulting from mechanical fixings or fastenings to be waterproof. 10.2.24 requires that perimeter flashings for wall/floor junctions have a vertical leg extending 25mm above the finished floor level except across doorways, and have a horizontal leg of 50mm. It also requires that when the substrate and surface materials are both water resistant, a waterproof sealant must be installed at the substrate wall/floor junction. Vertical flashings must extend a minimum of 1800mm above the floor level. 10.2.25 requires that membranes must be applied over the whole shower area floor and no less than 1800mm above the finished floor level on the vertical face of the shower area wall. 10.2.26 requires that wall sheeting substrates with external membrane systems must be waterproof to prevent capillary action, and that all edges of water resistant plasterboard which may be affected by water and moisture must be waterproofed.
10.2.27 requires that bond breakers be installed at the wall/wall, wall/floor, and hob/wall joints where the membrane is bonded to the substrate, and that these bond breakers must be compatible with the flexibility class of the membrane used. 10.2.28 requires that the membrane for showers with a waterstop extend to the top of the finished floor, or if under a framed shower screen, must extend at least 5mm above the tile surface. 10.2.29 requires a drainage flange set into the floor

substrate or tile bed be installed with the waterproofing membrane terminating at the flange to provide a waterproof connection for non-preformed shower areas not using concrete as the floor substrate. 10.2.30 requires that the drainage riser (floor waste pipe) is connected to the shower tray with a waterproof joint for preformed shower bases, or with a membrane to form a permanent waterproof seal to the drainage riser or drainage flange for other shower trays. 10.2.31 falls outside the scope of this study, as it only applies to door jambs where the bottom of the door jamb finishes below the floor tiling, which are not required. Finally, 10.2.32 requires that for enclosed showers with a level threshold, shower screens must be mounted on, or incorporate, an inverted channel positioned over the top of the waterstop which defines the shower area.

H4D4 states that H4P2 is satisfied for room heights so long as the room complies with Part 10.3 of the ABCB Housing Provisions. This section outlines the minimum room heights for habitable rooms, kitchens, corridors, bathrooms, and other spaces in homes. The maximum minimum room height is 2.4m. Since 40ft shipping containers have an internal height of 2.71m, an unmodified shipping container innately fulfils the height requirements for all rooms.

H4D5 states that H4P3 is satisfied for facilities where Part 10.4 of the ABCB Housing Provisions is met. 10.4.1 specifies that Class 1 houses must contain a kitchen sink and facilities for the preparation of cooking food, as well as either a bath or a shower, a wash tub with space for a washing machine in the same room, a closet pan (toilet), and a wash basin. While these facilities can be detached from the main building (shipping container), they must be set aside only for the occupants' use. At a minimum, this means that a shipping container house is not required to contain these facilities, however, to keep these facilities separate in a traditionally built structure would call into question the necessity of using a shipping container at all. As such, while it is recognised that this option is available as a baseline minimum, using this option would not satisfy the justification for this study. 10.4.2 requires that doors to sanitary compartments slide, open outwards, or be easily removed from the outside unless a clear space of 1.2m is available between the closet pan and the doorway.

H4D6 states that H4P4 is satisfied for lighting where Part 10.5 of the ABCB Housing Provisions is met. 10.5.1 requires that each room must contain either a wall window with an area excluding framing or other obstructions of 10% of the floor area of the room, or a similarly measured roof light of 3% of the floor area of the room. Wall windows must face the sky or a similarly open area including verandahs or carports, while roof lights must be open to the sky. Of these options, the wall window was chosen to be investigated further since the roof light may require modifications for the roofing fixture required by H1D7. Furthermore, any window facing an adjoining allotment must be at least 900mm from the boundary. 10.5.2 requires that bathrooms, shower rooms, airlocks and laundries must contain artificial lighting of one light fitting per $16m^2$ if natural lighting in accordance with 10.5.1 is not available.

H4D7 states that H4P5 is satisfied for ventilation where Part 10.6 of the ABCB Housing Provisions is met. This section outlines the requirements for ventilation, one being that each room must contain a window which can be opened with a ventilating area of 5% or more of the floor area. Additionally, it requires that sanitary compartments do not open directly into a kitchen or pantry unless the access is through another room or the sanitary compartment contains mechanical ventilation.

4.1.7 Volume Two - Section H5

H5P1(a) requires that walking surfaces must have safe gradients. H5P1(b) additionally sets requirements for stairways and ramps, however no stairway or ramp is necessary to constitute a house, therefore these sections fall outside the scope of the study.

H5P2 outlines the situations in which fall prevention barriers are required and the performance expected of these barriers. However, the minimum fall height which requires a barrier is a 1m fall through an opening (excluding windows) in the external wall or roof, or a 1m fall due to a sudden change in the building level. Since shipping containers do not have openings in the wall nor sudden changes in the building level, this requirement is satisfied by default.

H5D1 states that H5P1 and H5P2 are satisfied by complying with H5D2 and H5D3.

H5D2 states that H5P1 is satisfied for stairway and ramp construction where Part 11.2 of the ABCB Housing Provisions is met. 11.2.1 explains the terms used, 11.2.2 sets requirements for stairway construction, 11.2.3 sets requirements for ramp construction, 11.2.4 sets requirements for slip resistance of stair treads, ramps, and landings, and 11.2.5 sets requirements for landings. Since no stairway, ramp, or landing is necessary, none of these sections apply. 11.2.6 only applies to doorways where the threshold is 230mm above the adding surface, and thus, shipping containers innately meet all requirements of H5D2.

H5D3 states that H5P2 is satisfied for barriers and H5P1(b)(i) is satisfied for handrails where Part 11.2 of the ABCB Housing Provisions is met. Since no handrails are present in shipping containers, this section is innately satisfied.

4.1.8 Volume Two - Section H6

H6P1 requires that the total heating, cooling, and thermal energy loads do no exceed the respective load limits in specification 44.

H6P2 outlines the minimum energy efficiency required of room heating, room cooling, water heating, and lighting systems. H6P2 also requires that domestic services - including heating, cooling, pool pumps, water heating, and renewable energy systems, but excludes cooking facilities - must facilitate efficient use of energy appropriate to the building location, domestic service type, usage, and location, and the energy source used.

H6D1 states that H6P1 and H6P2 are satisfied by complying with H6D2.

According to H6D2, H6P1 is satisfied for thermal performance by complying with Parts 13.2 to 13.5 of the ABCB Housing Provisions. H6P2 is satisfied for building energy usage by complying with Parts 13.6 to 13.7 for a building with a total floor area less than 500m^2, which a 40ft shipping container meets.

Part 13.2 requires that insulation must achieve a minimum R-value dependant on the climate zone. Since this section requires choosing a climate zone, climate zone 2 was selected since this is the climate zone in which Bundaberg belongs (NCC: 2022, p.171), allowing for the greatest consistency between the analysis of differing codes. The minimum roof insulation R-value which must be achieved for climate zone 2 for buildings with pitched roofs and horizontal ceilings is detailed in Table 13.2.3c. Table 13.2.3c specifies that for roofs with an under-roof insulation of R-value 0.5 or higher, and for all listed solar absorptance values (SA $\leq$ 0.64), the minimum R-value for ceiling insulation is 2.5. Furthermore, for metal-framed roofs such as the one proposed earlier, thermal bridging must be accounted for by adding 0.5 to the R-value derived previously, for a minimum R-value of 3. Additionally, insulation of an R-value of 0.2 must be installed between any metal roof purlins and the metal sheeting of the roof. The minimum wall insulation R-value for lightweight wall construction in climate zone 2 is determined by adding an R-value of 0.3 to the R-value found using Table 13.2.5c. In this table, for walls between 2.7 and 3m tall where overhang is between 600m and 900mm, the minimum wall insulation R-value is 1.5, for a total of 1.8 required. To address thermal bridging in lightweight metal-framed walls, Table 13.2.5t must be complied with, which requires that a continuous insulation with an R-value of 0.3 be installed either inside or outside the frame. Further, the outer walls must have an additional thermal break using a material with an R-value of 0.2 installed at all points of contact between the external cladding and the metal frame. 13.2.6 requires that floor insulation is determined using Table 13.2.6a for floors over an unenclosed space. This table imposes a minimum floor insulation R-value of 2 for climate zone 2. Table 13.2.6j must be used for metal framed suspended floors, which requires that this R-value be changed to 3.

Part 13.5 requires ceiling fans to be installed in all bedrooms and habitable rooms for houses in climate zone 2. A total of two ceiling fans would be required in a 40ft shipping container house under the assumption that the bedroom was separated from an adjoining habitable room.

Part 13.6 requires that net energy usage of the house does not fall above a specified amount, however the calculation for net energy usage subtracts energy supplied by on-site photovoltaics. Therefore, by supplying a sufficient amount of on-site photovoltaic energy, this section can always be met without modification to the shipping container.

Part 13.7.2 additionally requires that insulation for central heating water piping and cooling ductwork must be able to withstand the temperature effects of these systems, and be protected from sunlight. Further, 13.7.3 requires that this insulation have an R-value of 0.4 when inside an unventilated wall, or of 0.6 for climate zone 2 when outside the building. 13.7.7 requires that heated water systems are designed and installed in accordance with Part B2 of the NCC Volume 3.

4.1.9 Volume Two - Section H8

H8P1 requires that the building includes a step-free pathway to the dwelling entrance, at least one level and step-free entrance door from this pathway, internal doors and corridors which facilitate unimpeded movement on the entrance level, a sanitary compartment on the level of entry, a shower which facilitates independent access and use, and for all walls for rooms containing a sanitary compartment, shower, or bath to facilitate future installation of grab rails or similar mobility assistance structures.

H8D1 states that H8P1 is met by complying with H8D2.

H8D2 requires that Class 1a dwellings must comply with the ABCB Standard for Livable Housing Design (Australian Building Codes Board: 2022). Part 2 of this standard requires that at least one entrance must have a clear opening width of 820mm, with the sill height being not more than 5mm if the sill is rounded or bevelled. 40ft ISO shipping containers innately meet both these requirements. Part 3 requires that at least one entrance must have a clear opening width of 820mm, with the sill height being not more than 5mm if the sill is rounded or bevelled. It additionally requires that corridors have a clear width of 1000mm. Part 4.1 requires a sanitary compartment to be on the entry level of the building. Part 4.2 requires the toilet pan to have no fixed obstruction 450mm to either side, and a circulation space of 1200mm in front of the toilet pan. Part 5.2 requires at least one shower in the building to be hobless and step-free. Part 6 requires wall reinforcement to be provided where a shower, bath, or toilet is located and the walls are not deemed able to support a grab rail without this additional reinforcement. This reinforcement is required within a fixed area relative to the length and width of these structures.

Part H8 takes effect from October 1, 2023 in all states, except Tasmania, where Part H8 takes effect from October 1, 2024.

4.1.10 NCC - Excluded sections

The following codes were used to describe sections of the NCC excluded during the document analysis:

NM = not mandatory

L = can be satisfied by location regardless of structure

NSC = no structural changes required

AS4100 = refers to AS4100

OS = otherwise outside the scope of the study

Table 4.1.10.1: Sections of the NCC excluded from the study during the document analysis with their exclusion code and brief description of reason behind exclusion

Section	Code	Reason
QDC MP3.5 Performative Requirement 3	NSC	Addresses valves in drains, which do not impact shipping container structure
H1D3	OS	Addresses site preparation
H1D4	OS	Addresses footings and slabs
H1D5	OS	Addresses masonry structures
H1D6	AS4100	Requires framing to be designed in accordance with AS4100
H1D9	L	Does not apply to domestic housing outside areas subject to seismic activity
H1D11	NM	Addresses framed decks and balconies, which are unnecessary to constitute a house
H1D12	OS	Addresses piled footings
H2D2	NM / NSC	Addresses drainage, however drainage systems are both not required by the NCC and exclusively require site work which does not impact the dwelling
H2D3	OS	Addresses footings and slabs
H2D4	OS	Addresses masonry components
H2D5	OS	Addresses subfloor ventilation, which is entirely composed of groundwork
H2D6 (1) - H2D6 (3)	NM	Addresses roof drainage, however roof drainage systems are not required by the NCC
H3D2	NM	Lists combustible materials which may be used wherever a non-combustible material is required
H3D3	L / NM	Refers to Part 9.2 of the ABCB Housing Provisions. 9.2.1 and 9.2.2 provide direction and explanatory information only, while 9.2.3 is non-mandatory if the structure is adequately located. Parts 9.2.4-9.2.8 concern the presence of a Class 10a structure, however such a structure is not required by the NCC to constitute a house. 9.2.9 and 9.2.10 address encroachments and roof lights, which are similarly not required.

H3D4	L	Refers to Part 9.3 of the ABCB Housing Provisions. 9.3 addresses separating walls and floors, which are not non-mandatory if the structure is adequately located
H3D5	L	Refers to Part 9.4 of the ABCB Housing Provisions. 9.4 addresses garage-top dwellings, which are non-mandatory if the structure is adequately located
ABCB 10.2.15, 10.2.16, 10.2.18 10.2.19, 10.2.20	NM	Addresses step-down showers, hobbed showers, unenclosed showers, preformed shower bases, and baths and spas, thus are unnecessary since enclosed showers with a level threshold were addressed instead
H4D8	L	Refers to Part 10.7 of the ABCB Housing Provisions. This section addresses sound insulation, however the section only applies if the dwelling is adjoined to a Class 1 building or a Class 10a building.
H4D9	NM / L	Refers to Part 10.8 of the ABCB Housing Provisions. This section addresses condensation management. 10.8.1 addresses pliable building membranes in external walls, which are not required. It also addresses insulation layers in climate zones 4, 5, 6, 7, and 8 - however the NCC was analysed considering only climate zone 2. 10.8.1 also addresses separation requirements between water control layers and water sensitive materials, however shipping containers do not use any water sensitive materials. 10.8.2 addresses exhaust systems, however these are non-mandatory. 10.8.3 addresses roof ventilation, however only applies in climate zones 6, 7, and 8.
ABCB 13.3	NSC	Addresses thermal properties of glazing, however this does not impact the shipping container's construction, only the thermal requirements imposed on the installed windows.
ABCB 13.4	NM	Addresses chimneys, flues, roof lights, as well as windows, doors, ceilings, walls, and floors in conditioned spaces, and evaporative coolers. Neither conditioned spaces nor evaporative coolers are required.
ABCB 13.7.4	NM	Addresses heating and cooling ductwork
ABCB 13.7.5	NM	Addresses electric resistance space heating
ABCB 13.7.6	NM	Addresses artificial lighting
ABCB 13.7.8	NM	Addresses swimming pool heating and pumping
ABCB 13.7.9	NM	Addresses spa pool heating and pumping
H7	NM / L	Addresses swimming pools, heating appliances, buildings in alpine areas, buildings in bushfire prone areas, and private bushfire shelters
ABCB Livable Housing Design Part 1	NSC	Addresses access paths
ABCB Livable Housing Design Part 2.3	NSC	Addresses landing area dimensions
ABCB Livable Housing Design Part2.4	NSC	Addresses weatherproofing, which is deemed satisfied if H2D2 is satisfied. H2D2 does not impact the construction of the dwelling

4.1.11 Summary of NCC analysis

Table 4.1.11.1: Addressed sections of the NCC and summary of general changes required

Section	Code	Explanation
H1D7	MR	Installation of a roofing fixture complying with Part 7.2 of the ABCB Housing Provisions Appropriate (as determined by AS/NZS2728) Painting of external wall cladding
H1D8	MR	Installation of proprietary windows and window frames designed to meet AS2047
H2D6	IM	-
H2D7	IM	-
H2D8	IM	-
H3D6	MR	Installation of interconnected smoke alarms in each hallway associated with a bedroom
H4D2, H4D3, H4D5	MR	Installation of proprietary bathroom, laundry, toilet, and kitchen models designed to meet Parts 10.2.1 to 10.2.32 as well as 10.4.2 of the ABCB Housing Provisions and Part 4 of the ABCB Standard for Livable Housing Design
H4D4	IM	Modifications to comply with other sections should not reduce room height by more than 300mm
H4D6 H4D7	MR	Installation of wall windows of 10% the floor area in each room, which open to provide 5% the floor area as ventilation space, alongside any necessary support bracing to maintain structural stability.
H5D2	IM	-
H5D3	IM	-
H6D2	MR	Installation of insulation of determined R-values in roof fixture, walls, and floor. Ceiling fans must be installed in habitable rooms in accordance with Part 13.5 of the ABCB Housing Provisions. Installation of solar panels to offset energy usage so as to comply with Part 13.6. Installation of heat and light resistant insulation of determined R-value for heated water piping and cooling ductwork.
H8D2	MR	Designation of clear opening at entrance door, clear space around toilet pan, installation of hobless, step-free shower, installation of compliant wall reinforcement at shower, bath, and toilet.

4.2 Queensland Development Code (QDC) Analysis

Where discrepancies between the NCC and the QDC arise, the QDC states that "Under section 35 of the Building Act, if a part of the QDC is inconsistent with the BCA, the QDC part prevails to the extent of the inconsistency" (Queensland Government: 2023).

Similar to the NCC, the QDC contains performative requirements labelled with a P, however unlike the NCC, the QDC assigns an associated acceptable solution to satisfy these performative requirements, labelled with an A. As such, this section will address only the associated acceptable solution, A, to each performative requirement.

4.2.1 Mandatory Parts 1.1 - 1.2

Within the QDC, MP1.1 addresses lots under 450m^2 while MP1.2 addresses lots of 450m^2 or more. The contained sections cover the same topics, though with different required values. In both instances, P4/A4 requires that building height is no greater than 8.5m, or no greater than 10m if the lot slope is 15% or more. 40ft shipping containers innately meet these height requirements, however this limits the maximum potential height of the roof fixture.

4.2.2 Mandatory Part 2.1

MP2.1 addresses fire safety in budget accomodation buildings, stating "***Budget accommodation building*** means the definition in the application of this code" (Queensland Government: 2023). The application section then states "This code is the fire safety standard applicable to budget accommodation buildings as prescribed by Part 3 of Chapter 7 of the *Building Act 1975*." (Queensland Government: 2023). Viewing Part 3 of Chapter 7 of the Building Act 1975 did not reveal any definition of the term budget accomodation building. However, further analysis found that section 216 of Part 1 of Chapter 7 of the Building Act 1975 defines budget accomodation buildings, and explicitly states that this definition excludes Class 1a buildings (State of Queensland: 2022). Therefore, MP2.1 was excluded from the study during the document analysis.

4.2.3 Mandatory Part 4.1

P1/A1 of MP4.1 require that energy usage must comply with Parts 3.12.1 to 3.12.4 of the BCA2010 (Volume 2). This has since been superseded by the NCC 2022, and therefore by satisfying section H6 of Volume 2 of the NCC 2022, P1/A1 is satisfied. Similarly, P3/A3 can be satisfied through complying with Part 3.12.5.5 of *BCA* 2010 (Volume 2). P5/A5 require a hot water system to be supplied to the building using any type of heater. P6/A6 require shower roses to have a minimum 3 star WELS rating. P7/A7 require toilet cisterns to have a dual flush function with a minimum 4 star WELS rating and to be compatible with the toilet bowl. P8/A8 require that tap ware with a minimum 3 star WELS rating be installed in all laundry tubs, kitchen sinks, and basins.

4.2.4 Mandatory Part 6.1

MP6.1 addresses commissioning and maintenance of fire safety installations. This part explicitly states that Class 1a buildings are excluded. Therefore, MP6.1 was excluded from the study during the document analysis stage.

4.2.5 QDC - Excluded sections

The following codes were used to describe sections of the QDC excluded during the document analysis:

L = can be satisfied by location regardless of structure

NSC = no structural changes required

OS = otherwise outside the scope of the study

Table 4.2.5.1: Sections of the QDC excluded from the study during the document analysis with their exclusion code and brief description of reason behind exclusion

Section	Code	Reason
MP1.1 P1 and A1	L / NSC	Describes road setback requirements
MP1.1 P2 and A2	L / NSC	Describes side and rear setback requirements
MP1.1 P3 and A3	L	Sets percentage of lot which must not contain buildings or structures roofed with impervious materials
MP1.1 P5 and A5	L	Describes window and balcony requirements when within 1.5m of rear or side lot boundary
MP1.1 P6 and A6	L	Describes wall setback requirements from side and rear boundaries
MP1.1 P7 and A7	L / NSC	Describes structure exclusion zones for lots with 2 road frontages
MP1.1 P8 and A8	L / NSC	Describes space requirements allocated to parking cars
MP1.1 P9 and A9	L / NSC	Describes dwelling outdoor living space requirements
MP1.2 P1 and A1	L / NSC	Describes road setback requirements
MP1.2 P2 and A2	L / NSC	Describes side and rear setback requirements
MP1.2 P3 and A3	L	Sets percentage of lot which must not contain buildings or structures roofed with impervious materials
MP1.2 P5 and A5	L	Describes window and balcony requirements when within 1.5m of rear or side lot boundary
MP1.2 P6 and A6	L	Describes wall setback requirements from side and rear boundaries
MP1.2 P7 and A7	L / NSC	Describes structure exclusion zones for lots with 2 road frontages
MP1.2 P8 and A8	L / NSC	Describes space requirements allocated to parking cars

MP1.2 P9 and A9	L / NSC	Describes dwelling outdoor living space requirements
MP2.1	OS	Review of standard revealed it did not apply to Class 1a buildings
MP2.5	NSC	Applies only to aluminium composite panels
MP4.1 P2 and A2	OS	Applies exclusively to Class 2 buildings
MP4.1 P2 and A2	OS	Applies exclusively to Class 2 buildings
MP4.1 P9 and A9	NSC	Describes electricity sub-meter installation requirements
MP4.1 P10 and A10	NSC	Describes electricity sub-meter location requirements
MP4.1 P11 and A11	NSC	Describes electricity sub-meter labelling requirements
MP4.1 P12 and A12	OS	Describes end of trip requirements (vehicle storage and locker, determined if required by local government) for commercial buildings
MP6.1 P1 and A1	OS	Describes post-construction fire safety installation maintenance requirements
MP6.1 P2 and A2	OS	Describes fire safety administrative requirements

4.2.6 Summary of QDC analysis

Table 4.2.6.1: Addressed sections of the QDC and summary of general changes required

Section	Code	Explanation
MP1.1 P4 and A4	IM	-
MP1.2 P4 and A4	IM	-
MP4.1 P1 and A1, MP4.1 P3 and A3	MR	Satisfied by satisfying H6 of Volume 2 of the NCC 2022
MP4.1 P5 and A5	MR	Installation of a hot water system required
MP4.1 P6 and A6	MR	Shower roses must have a 3 star WELS rating
MP4.1 P7 and A7	MR	Toilet cisterns must have a dual flush function and a 4 star WELS rating
MP4.1 P8 and A8	MR	Tap ware in laundry tubs, kitchen sinks, and basins must have a 3 star WELS rating

4.3 Bundaberg Regional Council (BRC) Policy Analysis

Similar to the QDC, the BRC policy document reviewed contains performative outcomes labelled with a PO, and assigns an associated acceptable outcome to satisfy these performative outcomes, labelled with an AO. These requirements are categorised into tables.

4.3.1 Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy

Section 4.0 of this policy states that building work listed in Tables 4.1 and 4.2 may have an adverse effect on the amenity or likely amenity of the locality, or may stand in conflict with the character of the locality. Table 4.1 then lists steel clad housing used as a Class 1a building to be referable to Council if located on any residential lot other than a rural residential zoned lot of 4,000m^2 or more. This table further lists shipping containers other than those used as a Class 1a building as referable to Council. This section suggests that shipping containers used as housing require additional aesthetic design to meet the council standards.

Table 5.5 PO1 states that steel-clad construction to be used as Class 1a buildings must not adversely impact the amenity or aesthetics of the locality, must maintain the intended or prevailing character of the locality, and must not have the appearance of a shed. AO1.1 and AO1.2 combined then state for all proposed steel-clad Class 1 buildings other than a shed which is converted to a Class 1a building, no acceptable outcome is provided. While this does not prevent shipping containers from being used as housing, it does not provide any clear means by which a shipping container house may meet Table 5.5 PO1.

The following codes were used to describe the performative outcomes of the BRC policies excluded during the document analysis:
L = can be satisfied by location regardless of structure
NSC = no structural changes required
OS = otherwise outside the scope of the study

Table 4.3.1.1: Performative outcomes of the BRC policies excluded from the study during the document analysis with their exclusion code and brief description of reason behind exclusion

Section	Code	Reason
Table 5.1	L / NSC	Addresses carport road frontage setback requirements
Table 5.2	NSC	Addresses domestic outbuilding (shed and garage) requirements
Table 5.3	NSC	Addresses Aerial, Antenna, Satellite Dish, Mast, and Tower requirements
Table 5.4	NSC	Addresses wind turbine requirements
Table 5.6	OS	Addresses shipping containers and railway carriages used for purposed other than housing
Table 5.7	OS	Addresses rebuilding or removal of a Class 1a building

4.4 Modes and Effects of Decommissioning

As stated in the literature review (refer to 2.5.3), The Institute of International Container Lessors (2022) has developed a comprehensive list of potential damages which result in a shipping container being decommissioned.

Among the items which may cause decommissioning are Approved Continuous Examination Program markings, height and width caution markings, customer and owner logos, high cube stripes, height markings, mass markings, the consolidated data plate, marking single digit, serial number and check digit, size and type marking, and United Cargo International decal, amounting to 13 unique components and 78 modes of decommissioning. All these components and damage types, while necessary for the intended usage of shipping containers, do not impact the shipping container's ability to function as a home. Further, removing or otherwise concealing these components, could aid decommissioned shipping container homes in passing local government aesthetics assessments, and as a result, shipping containers decommissioned for these reasons could be more suitable for housing purposes than in-service ISO containers.

A further 15 unique components and 109 modes of decommissioning are related to the door handle and locking mechanisms. As with labels, removing these mechanisms would likely be required to pass local government aesthetics assessments. Additionally, 6 unique components and 55 modes of decommissioning are related to the forklift pocket and rail corner protector recess, and an extra 2 components and 16 modes of failure relate to container lashing (securing during transit). These components are necessary when transporting goods, however have no impact on such decommissioned shipping containers used as housing.

While many modes of decommissioning would be costly to repair, and if not repaired would significantly impact or even prevent the shipping container from complying with building regulations, there are some modes of decommissioning which minimally impact, do not impact, or even positively impact a shipping container's ability to comply with building regulations.

Table 4.4.1: Summary of components and modes of decommissioning, including the approximate percentage which does not impact the use of shipping containers as housing

Component type	Unique components	Modes of failure
Safety and use markings	13	78
Door handle and locking mechanisms	15	109
Forklift pocket and rail corner recess	6	55
Total not impacting use as housing	34	242

All other types	47	394
Percentage not impacting use as housing	**42%**	**38%**

Of the components and modes of failure outlined by The Institute of International Container Lessors (2022), 38% of modes of failure would have positive or no significant effect on the ability of shipping containers decommissioned due to those failure modes to meet construction standards compared to ISO shipping containers. Shipping containers with any of the remaining 62% of modes of decommissioning could either be excluded from use for housing purposes, or be repaired using the IICL prescribed methods (The Institute of International Container Lessors: 2022) in order to return these containers to a standard condition that would make them suitable for repurposing as housing.

4.5 Benefits and Drawbacks

From this research, several benefits of using decommissioned shipping containers as housing could be drawn. The first is that the innate properties of shipping containers supply a standardised module which can be easily adapted to housing, and also allows for mass production through fabrication plants. This allows shipping containers to provide many of the benefits of both modular and prefabricated homes, which means decommissioned shipping containers can be relatively easily adapted to meet construction code requirements.

Decommissioned shipping containers as housing excel as a short term and environmental housing solution, since they situationally allow a waste product to be quickly repurposed with minimal embodied energy usage for repairs. This niche closely aligns with the current Australian housing climate in which supply of houses is not meeting demand, while environmental regulations are simultaneously being enforced, further slowing housing supply.

However, decommissioned shipping containers suffer from the drawback of being less optimised as a long term housing solution compared to alternatives such as prefabricated housing, which offers identical benefits of being comparatively inexpensive and quick to assemble, while simultaneously providing structures specifically designed for use as housing, instead of converting an existing structure. This intentional design for housing allows prefabrication to develop more specialised models compared to shipping containers, thus further minimising cost, environmental footprint, construction speed, or any combination of these factors.

4.6 Necessary Modifications to Shipping Containers

Modifications to several elements of the shipping container would be required. The areas requiring modifications were generalised into 3 categories - the roof, the walls and floors, and wet areas.

4.6.1 Roofing modifications

To comply with building codes, a roofing fixture complying with Part 7.2 of the ABCB Housing Provisions would need to be developed then attached to the shipping container. This roof fixture would contain insulation of the appropriate R-value as determined through H6D2 of the NCC. Additionally, electrical wiring installed in the roofing fixture, with appropriate penetrations through the roofing fixture and original shipping container roof, would be required to attach and supply power to the ceiling fans in each habitable room required by Part 13.5 of the ABCB Housing Provisions, and smoke alarms in each hallway associated with a bedroom to comply with H3D6 of the NCC. Solar panels should be attached to this roofing fixture to further enable the shipping container to meet energy usage requirements outlined in Part 13.6 of the ABCB Housing Provisions.

4.6.2 Wall and flooring modifications

On the external wall cladding, a layer of paint complying with AS/NZS 2728 would need to be applied. Within the walls, water pipes and electrical cabling would be required to deliver water and electricity from the connection point to relevant amenities. A hot water system should be included in the home's design to comply with MP4.1 P5 of the QDC. This system could remain outside the shipping container, with the only modifications to the shipping container being the penetrations required for water from the system to connect to the necessary outlets. Additionally, walls must also contain windows compliant with AS2047 with a minimum area of 10% the floor area of the room being serviced by the window, and should open to provide 5% of this floor area as ventilation space in order to fulfil H1D8, H4D6, and H4D7 of the NCC, and to better fulfil aesthetics requirements from local governments. These windows should be designed to minimise energy usage in accordance with H6D2 of the NCC, and should be installed alongside any support bracing necessary to maintain the structural integrity of the container, since shipping container walls are load-bearing. Similarly, the original shipping container doors should be fixed closed since shipping container doors are load-bearing. For use to enter and exit the building, a door of thermal regulation compliant with H6D2 of the NCC, and width, sill height and clear space compliant with H8D2 of the NCC should be installed. Similar to the roof, both walls and floors must contain insulation of the appropriate R-value with allowance for additional insulation for heated water piping as determined through H6D2 of the NCC. An internal wall and floor layer designed to seperate the occupant from structural and insulation components would additionally need to be installed. This installed floor layer and floor insulation should not reduce the height from the new floor layer to the roof below 2400mm in order to maintain compliance with H4D4.

4.6.3 Wet area modifications

Designated wet areas compliant with H4D2, H4D3, and H4D5 of the NCC would need to be installed. For the laundry and bathroom, these would most easily be achieved through installing a proprietary model designed to meet these standards alongside Part 4 of the ABCB Standard for Livable Housing Design. The primary features this proprietary model should include are a hobless, stepless shower, a toilet pan with adequate clear space, wall reinforcement if deemed necessary in the designated area near the toilet pan and within the shower area, waterproofing measures compliant with H4 of the NCC installed in the floor, wall, and at penetrations, and devices complying with a 3 star WELS rating for shower roses, laundry tubs, and other basins, and a 4 star WELS rating for the toilet cistern. Such a model would comply with H4D2, H4D3, H4D5, and H8D2 of the NCC, as well as MP4.1 P6, P7, and P8 of the QDC. A kitchen area with adequate space for food preparation, a sink with a 3 star WELS rating, and a means for cooking food such as a stove top, as well as waterproofing measures compliant with H4 of the NCC would meet all wet area requirements for non-bathroom and laundry areas.

4.7 Recommended Changes to National Construction Code (NCC)

The National Construction Code 2022 does not uniquely prohibit the use of shipping containers as housing. However, section H8D2 notably enforces accessibility requirements which will impose a significant additional upfront cost to new home developments. Further, since these changes are designed for low-mobility individuals who constitute approximately 13.6% of the population (Australian Bureau of Statistics: 2018), and these changes do not contribute to the longevity nor structural integrity of the house, it is likely that individuals constructing a home with these features will not benefit from these features until a long period of time has passed, and potentially may never benefit from these features. While not uniquely impacting decommissioned shipping container housing, H8D2 does disproportionately impact affordable housing, which is, by its nature of being affordable, chosen to minimise upfront costs.

To make the NCC more accommodating of shipping container houses, it is recommended that H8D2 be modified from a section which applies to all newly constructed housing, to a section which outlines requirements for accessible housing. Such an alteration would maintain clear requirements for houses designed for use by low mobility individuals, while not requiring that people with other needs adhere to these standards.

4.8 Recommended Changes to Queensland Development Code (QDC)

The QDC does not uniquely, nor disproportionately, obstruct the use of decommissioned shipping containers as housing. To facilitate the use of decommissioned shipping containers as housing, it is recommended to maintain the current QDC regulations.

Another route through which the QDC could facilitate decommissioned shipping containers as housing could be to enact the recommended modifications to the NCC (refer to 4.7), since the QDC prevails where inconsistencies exist between the NCC and the QDC.

4.9 Recommended Changes to Bundaberg Regional Council (BRC) Policies

The BRC Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy does not provide clear guidance on how steel framed housing can pass an aesthetics assessment. A clearly defined set of mandatory criteria, such as the removal, modification, or concealment of certain shipping container components could provide a clearer goal for individuals and companies seeking to produce shipping container housing. If the original policy were intentionally vague, then the policy could be implemented such that the defined set of mandatory criteria were a minimum, thus container houses meeting these criteria would not be guaranteed approval in all situations.

CHAPTER 5

CONCLUSIONS

5.1 Introduction

This study addressed all five stated research outcomes, and provided an answer to the research question. Through the analysis of current Australian building codes, it was determined that 40ft ISO shipping containers require modifications to be compliant with Australian code, and that some modes of decommissioning do not inhibit the use of a decommissioned shipping container as housing compared to an ISO certified shipping container.

These results advance the field of shipping container housing research by providing an analysis of modes of decommissioning with respect to Australian construction codes. Analysis of decommissioned shipping containers is rare due to the difficulties involved with standardising used products, and addressing housing in relation specifically to Australia's environmental goals and housing situation is a recent topic, thus this pioneering research investigates an original topic.

Several critical points can be drawn from this research for individuals pursuing shipping container or decommissioned shipping container housing in Australia. The first is to determine critical locality information, such as the wind and climate zone of the prospective construction location, as well as if the construction location is in a bushfire, flood, earthquake, or other zone subject to heightened restrictions. The second would be to either arrange a meeting in preparation for design or a review during design with the local council body to determine the expectations that local council may have specifically of shipping container housing. The final point would be to use the typical design choices of conventional housing to direct modifications for shipping container houses.

5.2 Conclusions

The outcomes of the five research objectives are addressed below.

1. A reasonable interpretation of the NCC, QDC and BRC policies was produced, and the relation of this interpretation to decommissioned shipping containers used as housing was stated.

2. An interview with a Bundaberg Regional Council representative was conducted for quality assurance purposes, which confirmed the implications and interpretation produced from the research to be accurate.

3. The primary benefit of decommissioned shipping containers as housing was identified to be their reduced environmental impact stemming from being a reused product. The primary downside was identified to be the nonspecialised nature of decommissioned shipping containers repurposed as housing, since more specialised alternatives may offer greater overall benefits.

4. Three categories of modifications to decommissioned shipping containers that would be needed for their use as residential housing were identified - roofing, walls and flooring, and wet areas. Specific modifications within these categories which may allow used shipping containers to comply with construction codes were suggested.

5. Changes to H8D2 of the NCC, such that the clause only applies to housing for mobility impaired individuals, was suggested to reduce upfront housing costs, thus making shipping container houses generally, and decommissioned shipping container houses specifically, more able to serve as affordable housing. It was suggested that the QDC either did not change, or enacted the changes suggested for the NCC in place of the NCC enacting these changes. Changes to Table 5.5 PO1 of the BRC Amenity and Aesthetics, and Building Work Involving Removal or Rebuilding Policy to give more clarity as to council aesthetic expectations of steel-clad housing were suggested.

5.3 Limitations and Recommendations for Further Research

As qualitative research "places more emphasis on the study of phenomena from the perspective of insiders" (Lapan et al: 2012, p.3), the methodology used in the study limit its findings to the author's interpretation. Further, Lapan et al (2012) noted that the outcomes of qualitative research are seldom generalised beyond the study setting, with this particularly applicable to case study research, where a single phenomenon is studied in-depth. As such, the final results of this research are limited in application to the Bundaberg Regional Council area of Queensland, Australia. The analysis of the NCC is limited in use to Australia, except where state-specific clauses of the NCC would supersede the analysed sections. The analysis of the QDC is limited in use to Queensland. Additionally, all results are limited in application to the time period for which the edition of each analysed construction code is enforced.

Further research into the areas excluded from this study, including studies of the ability of decommissioned shipping containers to meet the requirements outlaid in Volume 1 and Volume 3 of the 2022 NCC, as well as research into the compliance of ISO shipping containers with AS4100, could be performed. A study into how decommissioned shipping containers relate to Class 2 structures (buildings with more than one dwelling) could reproduce the methodology of this research and expand knowledge of this topic to residential apartment housing.

A study on the financial viability of decommissioned shipping containers as housing could also be warranted, as modifications required for their repurposing as housing may cause such shipping containers that are modified to houses to become more costly than a standard house construction.

More comprehensive research into the effects of specific modes of decommissioning of shipping containers could verify the review in this research and inform the viability of shipping containers with these modes of decommissioning as a housing solution.

A reproducibility study of this dissertation could also strengthen its reliability and expose flaws in the research methodology.

Additionally, since the NCC receives updates over time, this research could be repeated for any changed or new sections in future editions of the NCC.

APPENDIX A - Project Specification

ENG4111/4112 Research Project

Project Specification

For: David Riggs

Title: Analysis of Australian building code relevant to the use of decommissioned shipping containers as housing

Major: Civil Engineering

Supervisor: Steven Goh

Enrolment: ENG4111 - ONL S1, 2023
ENG4112 - ONL S2, 2023

Project aim: To investigate the viability of using decommissioned shipping containers for housing purposes as outlined in the National Construction Code with consideration to the current Australian housing situation and climate goals.

Programme: Version 1, 22/02/2023

1: Produce a reasonable interpretation of Australian building code which relates to the use of decommissioned shipping containers as housing.

2: Conduct an interview with a member of the Bundaberg Regional Council to determine implications for the use of shipping containers as housing imposed by a local council.

3: Identify the benefits and downsides of decommissioned shipping container housing as relevant to the interpretation of Australian building code.

4: Suggest how decommissioned shipping containers may be modified, if necessary, to meet the interpretation of Australian building code.

5: Suggest changes to Australian building code which may facilitate the use of decommissioned shipping containers as housing.

Project Plan

Task \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Access the National Construction Code (NCC)	■																																	
Arrange interview with Bundaberg Regional Council (BRC)	■	■																																
Identify modes and effects of shipping container failure			■	■	■	■	■	■	■	■	■																							
Analyse NCC to determine viability of shipping containers as housing												■	■	■	■	■																		
Identify modifications to shipping containers																	■	■	■	■														
Identify modifications to building code																					■	■	■	■	■									
Interview with BRC																										■								
Evaluate information from interview																										■	■	■	■					
Report Writing		■				■	■	■	■	■	■			■	■	■		■	■	■			■	■	■			■	■	■	■			
Report finalisation																																■	■	
Presentation of results																																	■	■

Communications to supervisor will be performed by email upon the completion of each task.

Project Resources:

For adequate completion of the project, access to the following Australian Standards will be required:

- AS3600
- AS3959
- AS1668.2
- AS4100
- AS/NZS4100
- AS/NZS2327
- AS/NZS1170.2

During the course of the project, Australian Standards related to those in the list above may be required in addition to the above list. No access to materials, facilities, or data sets is anticipated to be necessary for project completion

Supplementary material:

Accessing the National Construction Code: Completed

Arranging interview with Bundaberg Regional Council: Completed

Identifying modes and effects of shipping container failure: Partially completed as part of the literature review performed during the ENG4110 Assignment 3

Analysis of National Construction code to determine viability of shipping containers as housing: Partially completed as part of a preliminary analysis performed prior to semester starting

APPENDIX B - Risk Assessment and Approval

Risk Assessment 2422 has been **APPROVED**.

Reference Number: 2422

Risk Assessment Name: Honours Project Risk Assessment

Risk Approver: Steven Goh approved this Risk Assessment for the following reason(s) "desktop study with minimal risks and expsoure to potential hazards"

Restricted: No

Next Steps (NEW in SafeTrak):

- This Risk Assessment will automatically be moved into the *Risk Register* tab and will have a status of *Live*. It will now be visible to everyone, except if it is marked as restricted.
- **NEW!** Where there are Proposed Controls (Actions), update the percentage complete within the Risk Assessment. Once this reaches 100%, the Proposed Controls (Actions) will be closed and moved to the Existing Controls (Actions).
- **NEW!** Risk Assessments **can** be modified in SafeTrak, including amendments to risks and Proposed Controls (Action). Any changes will re-trigger the approval process.
- **NEW!** SafeTrak will automatically set a review date based upon the current risk with the Control Measures (Actions) in place. This risk assessment due date can be found in the WHS Risk Register > *Next Review Date* column. A SafeTrak alert will be issued 14 days prior to this date.

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Help & Support

Contact the USQ Safety Team for any enquiries:
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w: USQ Safety Central for Staff and Students
p: +61 7 4631 2627

PLEASE DO NOT REPLY TO THIS EMAIL - THIS IS AN AUTOMATED SERVICE

APPENDIX C - Human Ethics Exemption

Original Communication to supervisor

Dear Steven,

In my project specification, I had described an interview with a Bundaberg Regional Council representative to gather information about local laws relating to the use of decommissioned shipping containers as housing. I have arranged this interview for May 17.

From the Project Progress Report Guidelines, any interviews require USQ Human Ethics approval, which can occur either via approval from the USQ ethics committee or with a written statement endorsed by my supervisor. I have provided the list of questions to be asked during the interview, which the interviewee has received and agreed to answering, as well as a written statement. If you consider the contents of the interview questions to pose negligible intrusion or risk to the interviewee, would you be able to provide your endorsement for my written statement?

Thank you for your guidance.

Regards,

David Riggs
[redacted]

No results or findings from any interview held for the purposes of completing the project titled "Analysis of Australian law and building code relevant to the use of decommissioned shipping containers as housing" will be published externally. All interviews to be held for this project involve negligible intrusion or risk to participants.

As a result, the USQ Human Ethics committee requirements have been considered and approval has been determined to not be required for the activity being undertaken

Student Signature: [redacted]

Supervisor Signature:

Supervisor endorsement

David, as long as the “data” of the interviews are not used in your research, that should be fine. As professional we do talk to and seek advice on many things, not all interactions with a human subject will need ethics clearance. In this case, if the interview I assume is meant to direct your research and do not form part of the collecting data/evidence, then it should not require ethics clearance.

Happy to endorse on the provision that the above description is valid. This email should suffice as endorsement.

APPENDIX D - Summary of Shipping Container Strengths

Table 11. Design strengths for profiles (gross sections)

Profile	N_{Rd} (kN)	$M_{Rd.y}$ (KN m)	$M_{Rd.z}$ (KN m)	$V_{w.Rd.z}$ (kN)	$V_{b.Rd.z}$ (kN)	$V_{w.Rd.y}$ (kN)	$V_{b.Rd.y}$ (kN)
DCP	1188.8	14.98	36.98	73.79	59.10	429.71	–
$FH^{20'HC}$	206.06	3.65	3.65	52.09	46.00	–	–
$FS^{40'HC}$	206.06	3.65	3.65	52.09	34.30	–	–
$TSR^{20'HC}$	206.06	3.65	3.65	52.09	56.00	–	–
$TSR^{40'HC}$	206.06	3.65	3.65	52.09	56.00	–	–
$FS^{20'HC}$	393.76	12.38	4.57	41.23	41.00	37.62	32.50
FCP	929.25	27.51	29.75	196.41	126.00	222.45	193.00
$BSR^{40'HC}$	342.95	11.21	2.66	111.50	113.80	–	–
$BSR^{20'HC}$	316.00	11.83	1.07	117.19	104.25	–	–
BCM1	248.02	8.55	1.33	76.68	70.67	–	–
BCM3	242.41	0.46	4.64	–	–	–	–
BCM4	191.12	8.11	1.32	73.43	74.20	–	–

Table 12. Design strengths for profiles (effective sections)

Profile	$N_{t.Rd}$ (kN)	$N_{c.Rd}$ (kN)	$M_{c.Rd.y}$ (kN m)	$M_{c.Rd.z}$ (kN m)	e_{Ny} (mm)	e_{Nz} (mm)	$V_{w.Rd.z}$ (kN)	$V_{b.Rd.z}$ (kN)	$V_{w.Rd.y}$ (kN)	$V_{b.Rd.y}$ (kN)
DS	531.4	522.5	16.27	11.93	0.2	1.5	118.0	92.5	157.5	140
$DH^{40'HC}$	795.6	612.4	19.29	14.52	40.9	10.7	146.1	90.3	147.6	0
$DH^{20'HC}$	802.4	587.1	21.36	13.82	57.0	11.9	147.6	136.0	172.9	127
$FH^{40'HC}$	537.4	236.3	6.27	2.52	94.1	20.6	51.4	60.0	72.1	46.3
BCM2	285.4	260.9	8.83	1.51	4.5	4.8	76.7	113.0	–	–
BCM5	279.8	255.3	8.37	1.50	4.5	4.7	73.4	–	–	–
BCM6	536.6	510.8	17.11	9.41	1.4	4.3	119.2	99.0	–	–
FP	995.5	414.4	15.44	184.7	–	–	153.4	93.0	–	–

Table 13. Design strengths for sheets

Sheet	$N_{t.Rd}$ (kN/m)	$N_{c.Rd}$ (kN/m)	$M_{Rd.z}$ (kN m/m)	$V_{w.Rd}$ (kN/m)	$V_{b.Rd}$ (kN/m)
Few	761.79	588.32	98.55	61.62	60.66
$sw_{1/3}^{40'HC}$	659.52	594.35	–	–	–
$sw_{1/3}^{20'HC}$	659.88	622.01	–	–	–
$sw_2^{40'HC}$	528.26	391.12	–	–	–
$sw_2^{20'HC}$	528.42	411.87	–	–	–

(Bernardo et al: 2013, pp.16-17)

These tables were calculated using dead loads of:

Self-weight of structural steel = 7850 kN/m^3; self-weight of plywood: 0.70 g/cm^3; equivalent self-weight of partitions = 1.1 kN/m^2; cladding siding external walls = 5.4 kN/m; floor and roof coat = 1.0 kN/m^2 (Bernardo et al: 2013)

And live loads of:

Live load on roofs (terrace): 2.0 kN/m^2 ($\psi_i = 0$); live load on floors: 2.0 kN/m^2 ($\psi_0 = 0.4$; $\psi_1 = 0.3$; $\psi_2 = 0.2$); snow: 1.7 kN/m^2 ($\psi_0 = 0.6$; $\psi_1 = 0.3$; $\psi_2 = 0$); earthquake: based on a dynamic analysis with response spectrum seismic loading ($\psi_i = 0$) (Bernardo et al: 2013)

APPENDIX E - Modes and Effects of Failure

Damage Code	Damage type	Appropriate repairs
Bowed	Physical	Straightening, replacement
Broken / Split	Physical	Replacement
Consequential / Combined damage	Physical	Straightening, replacement, welding
Cracked	Physical	Straightening, replacement, welding
Cut	Physical	Straightening, replacement, welding
Dent / Bent	Physical	Straightening, replacement
Existing manufacturing defect	Physical	Surface prep and painting, replacement, welding
Gouged / Scratched	Physical	Surface prep and painting
Holed	Physical	Straightening, replacement, welding
Improper / Nonconforming repair	Physical	Straightening, welding, surface prep and painting, replacement
Missing / Lost	Physical	Replacement
Misuse (Physical)	Physical	Straightening and welding, replacement, welding
Not within ISO dimensions	Physical	Straightening and welding, replacement, welding
Remove for access	Physical	Removal and refitting after repairs
Burned	Chemical	Surface prep and painting, reconditioning / refurbishment, replacement
Contaminated	Chemical	Surface prep and painting, steam cleaning, water washing, chemical cleaning, replacement
Corroded / Rusty	Chemical	Surface prep and painting, replacement, welding
Dirty	Chemical	Steam cleaning, water washing, chemical cleaning, sweeping
Misuse (Chemical)	Chemical	Steam cleaning, chemical cleaning, replacement
Odour	Chemical	Steam cleaning, water washing, chemical cleaning
Oil Saturated	Chemical	Steam cleaning, water washing, chemical cleaning
Oil stained	Chemical	Steam cleaning, water washing, chemical cleaning
Rotted	Chemical	Replacement

Derived from The Institute of International Container Lessors: 2022.

Note: Repairs can be performed on the entire component, an appropriate section of the component, or can be inserted alongside the component.

APPENDIX F - Search Log

Date	Approach	Tool Used	Keywords	Search Statement	Results	Comments
20 July, 2022	Initial overview: shipping container housing	Google Scholar	Shipping container, house, home, housing	“Shipping container” AND House OR Home OR Housing	21,800	Broad search related to shipping container housing
15 April, 2023	Initial overview: decommissioned shipping container housing	Google Scholar	Used shipping container, house, home, housing	“Used shipping container” AND House OR Home OR Housing	77	Broad search related to used shipping container housing
15 April, 2023	Initial overview: decommissioned shipping container housing	Google Scholar	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container” AND House OR Home OR Housing	1	Broad search related to decommissioned shipping container housing
20 July, 2022	Iteration 1: Refine to shipping containers for houses specifically	Google Scholar	Shipping container, house, home, housing	“Shipping container house” OR “shipping container home” OR “shipping container housing”	748	Refined to shipping container usage specifically for housing. Full text of articles of relevance were downloaded and reviewed.
15 April, 2023	Iteration 1A: Refine to decommissioned shipping containers for houses specifically	Google Scholar	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing”	0	Refined to decommissioned shipping container usage specifically for housing. Did not match any articles.
20 July, 2022	Iteration 2: Refine to Australian context	Google Scholar	Shipping container, house, home, housing, Australia	“Shipping container” AND House OR Home OR Housing AND Australia*	8,850	Broad search related to shipping containers as houses with mention of the Australian context
15 April, 2023	Iteration 2A: Refine to Australian context	Google Scholar	Decommissioned shipping container, house, home, housing, Australia	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia*	1	Broad search related to decommissioned shipping containers as houses with mention of the Australian context. Same article as above.
20 July, 2022	Iteration 3: Refine to use of shipping container housing in Australia	Google Scholar	Shipping container, house, home, housing, Australia	“Shipping container house” OR “shipping container home” OR “shipping container housing” AND Australia*	218	Refined to shipping container usage specifically for housing and some relationship to the Australian context. Full text of new articles of relevance were downloaded and reviewed.
15 April, 2023	Iteration 3A: Refine to use of decommissioned shipping container housing in Australia	Google Scholar	Decommissioned shipping container, house, home, housing, Australia	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing” AND Australia*	0	Refined to decommissioned shipping container usage specifically for housing and some relationship to the Australian context. Did not match any articles.
20 July, 2022	Iteration 4: Refine to include building code	Google Scholar	Shipping container, house, home, housing, Australia, building code	“Shipping container” AND House OR Home OR Housing AND Australia* AND “building code”	190	Broad search related to building code associated with shipping containers as houses in Australia. Full text of new articles of relevance were downloaded and reviewed.
15 April, 2023	Iteration 4A: Refine to include building code	Google Scholar	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia* AND “building code”	0	Broad search related to building code associated with decommissioned shipping containers as houses in Australia. Did not match any articles.
20 July, 2022	Iteration 5: Refine to shipping container housing and Australian building code	Google Scholar	Shipping container, house, home, housing, Australia, building code	“Shipping container house” OR “shipping container home” OR “shipping container housing” AND Australia* AND “building code”	28	Refined to specifically shipping container housing related to building code and a mention of Australia. Full text of new articles of relevance were downloaded and reviewed.
15 April, 2023	Iteration 5A: Refine decommissioned shipping container housing and Australian building code	Google Scholar	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing” AND Australia AND “building code”	0	Refined to specifically decommissioned shipping container housing related to building code and a mention of Australia. Did not match any articles.
15 April, 2023	Initial overview: shipping container housing	Science Direct	Shipping container, house, home, housing	“Shipping container” AND House OR Home OR Housing	14,088	Broad search related to shipping container housing
15 April, 2023	Initial overview: decommissioned shipping container housing	Science Direct	Used shipping container, house, home, housing	“Used shipping container” AND House OR Home OR Housing	14,137	Broad search related to decommissioned shipping container housing
15 April, 2023	Initial overview A: decommissioned shipping container housing	Science Direct	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container” AND House OR Home OR Housing	14,077	Broad search related to decommissioned shipping container housing
15 April, 2023	Iteration 1: Refine to shipping containers for houses specifically	Science Direct	Shipping container, house, home, housing	“Shipping container house” OR “shipping container home” OR “shipping container housing”	19	Refined to shipping container usage specifically for housing. Full text of new articles of relevance were downloaded and reviewed.
15 April, 2023	Iteration 1A: Refine to decommissioned shipping containers for houses specifically	Science direct	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing”	0	Refined to decommissioned shipping container usage specifically for housing. No results found.
15 April, 2023	Iteration 2: Refine to Australian context	Science Direct	Shipping container, house, home, housing, Australia	“Shipping container” AND House OR Home OR Housing AND Australia*	10,107	Broad search related to shipping containers as houses with mention of the Australian context
15 April, 2023	Iteration 2A: Refine to Australian context	Science Direct	Decommissioned shipping container, house, home, housing, Australia	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia*	10,096	Broad search related to decommissioned shipping containers as houses with mention of the Australian context
15 April, 2023	Iteration 3: Refine to use of shipping container housing in Australia	Science Direct	Shipping container, house, home, housing, Australia	“Shipping container house” OR “shipping container home” OR “shipping container housing” AND Australia*	13	Refined to shipping container usage specifically for housing and some relationship to the Australian context. Full text of new articles of relevance were downloaded and reviewed.
15 April, 2023	Iteration 3A: Refine to use of decommissioned shipping container housing in Australia	Science Direct	Decommissioned shipping container, house, home, housing, Australia	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing” AND Australia*	0	Refined to decommissioned shipping container usage specifically for housing and some relationship to the Australian context. No results found.
15 April, 2023	Iteration 4: Refine to include building code	Science Direct	Shipping container, house, home, housing, Australia, building code	“Shipping container” AND House OR Home OR Housing AND Australia* AND “building code”	9,776	Broad search related to building code associated with shipping containers as houses in Australia.
15 April, 2023	Iteration 4A: Refine to include building code	Science Direct	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia* AND “building code”	9,765	Broad search related to building code associated with decommissioned shipping containers as houses in Australia.
15 April, 2023	Iteration 5: Refine to shipping container housing and Australian building code	Science Direct	Shipping container, house, home, housing, Australia, building code	“Shipping container house” OR “shipping container home” OR “shipping container housing” AND Australia* AND “building code”	8	Refined to specifically shipping container housing related to building code and a mention of Australia. Full text of new articles of relevance were downloaded and reviewed.

15 April, 2023	Iteration 5A: Refine to decommissioned shipping container housing and Australian building code	Science Direct	Decommissioned shipping container, house, home, housing, Australia, building code	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing" AND Australia* AND "building code"	0	Refined to specifically decommissioned shipping container housing related to building code and a mention of Australia. No results found.
16 April, 2023	Initial overview: shipping container housing	SCOPUS	Shipping container, house, home, housing	"Shipping container" AND House OR Home OR Housing	128	Broad search related to shipping container housing
16 April, 2023	Initial overview A: decommissioned shipping container housing	SCOPUS	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container" AND House OR Home OR Housing	0	Broad search related to decommissioned shipping container housing. No documents were found.
16 April, 2023	Iteration 1: Refine to shipping containers for houses specifically	SCOPUS	Shipping container, house, home, housing	"Shipping container house" OR "shipping container home" OR "shipping container housing"	6	Refined to shipping container usage specifically for housing. Full text of new articles of relevance were downloaded and reviewed.
16 April, 2023	Iteration 1A: Refine to decommissioned shipping containers for houses specifically	SCOPUS	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing"	0	Refined to decommissioned shipping container usage specifically for housing. No documents were found.
16 April, 2023	Iteration 2: Refine to Australian context	SCOPUS	Shipping container, house, home, housing, Australia	"Shipping container" AND House OR Home OR Housing AND Australia*	6	Broad search related to shipping containers as houses with mention of the Australian context. No new articles of relevance were found.
16 April, 2023	Iteration 2A: Refine to Australian context	SCOPUS	Decommissioned shipping container, house, home, housing, Australia	"Decommissioned shipping container" AND House OR Home OR Housing AND Australia*	0	Broad search related to decommissioned shipping containers as houses with mention of the Australian context. No documents were found.
16 April, 2023	Iteration 3: Refine to use of shipping container housing in Australia	SCOPUS	Shipping container, house, home, housing, Australia	"Shipping container house" OR "shipping container home" OR "shipping container housing" AND Australia*	34	Refined to shipping container usage specifically for housing and some relationship to the Australian context. No new articles of relevance were found.
16 April, 2023	Iteration 3a: Refine to decommissioned shipping container housing in Australia	SCOPUS	Decommissioned shipping container, house, home, housing, Australia	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing AND Australia*	0	Refined to decommissioned shipping container usage specifically for housing and some relationship to the Australian context. No documents were found.
16 April, 2023	Iteration 4: Refine to include building code	SCOPUS	Shipping container, house, home, housing, Australia, building code	"Shipping container" AND House OR Home OR Housing AND Australia* AND "building code"	1	Broad search related to building code associated with shipping containers as houses in Australia. Same article as above.
16 April, 2023	Iteration 4A: Refine to include building code	SCOPUS	Decommissioned shipping container, house, home, housing, Australia, building code	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing" AND Australia* AND "building code"	0	Broad search related to building code associated with shipping containers as houses in Australia. No documents were found.
16 April, 2023	Iteration 5: Refine to shipping container housing and Australian building code	SCOPUS	Shipping container, house, home, housing, Australia, building code	"Shipping container house" OR "shipping container home" OR "shipping container housing" AND Australia* AND "building code"	1	Same article as above.
16 April, 2023	Iteration 5A: Refine to decommissioned shipping container housing and Australian building code	SCOPUS	Decommissioned shipping container, house, home, housing, Australia, building code	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing" AND Australia* AND "building code"	0	No documents were found.
16 April, 2023	Initial overview: shipping container housing	Informit	Shipping container, house, home, housing	"Shipping container" AND House OR Home OR Housing	214,237	Broad search related to shipping container housing
16 April, 2023	Initial overview A: decommissioned shipping container housing	Informit	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container" AND House OR Home OR Housing	214,259	Broad search related to decommissioned shipping container housing
16 April, 2023	Iteration 1: Refine to shipping containers for houses specifically	Informit	Shipping container, house, home, housing	"Shipping container house" OR "shipping container home" OR "shipping container housing"	3	Refined to shipping container usage specifically for housing. New items of relevance were perused.
16 April, 2023	Iteration 1A: Refine to decommissioned shipping containers for houses specifically	Informit	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing"	0	Refined to decommissioned shipping container usage specifically for housing. The search did not return any results.
16 April, 2023	Iteration 2: Refine to Australian context	Informit	Shipping container, house, home, housing, Australia	"Shipping container" AND House OR Home OR Housing AND Australia*	185,275	Broad search related to shipping containers as houses with mention of the Australian context
16 April, 2023	Iteration 2A: Refine to Australian context	Informit	Decommissioned shipping container, house, home, housing, Australia	"Decommissioned shipping container" AND House OR Home OR Housing AND Australia*	185,275	Broad search related to decommissioned shipping containers as houses with mention of the Australian context
16 April, 2023	Iteration 3: Refine to use of shipping container housing in Australia	Informit	Shipping container, house, home, housing, Australia	"Shipping container house" OR "shipping container home" OR "shipping container housing" AND Australia*	3	Same items as above
16 April, 2023	Iteration 3A: Refine to use of decommissioned shipping container housing in Australia	Informit	Decommissioned shipping container, house, home, housing, Australia	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing" AND Australia*	0	The search did not return any results.
16 April, 2023	Iteration 4: Refine to include building code	Informit	Shipping container, house, home, housing, Australia, building code	"Shipping container" AND House OR Home OR Housing AND Australia* AND "building code"	770	Broad search related to building code associated with shipping containers as houses in Australia. New items of relevance were perused.
16 April, 2023	Iteration 4A: Refine to include building code	Informit	Decommissioned shipping container, house, home, housing, Australia, building code	"Decommissioned shipping container" AND House OR Home OR Housing AND Australia* AND "building code"	770	Broad search related to building code associated with decommissioned shipping containers as houses in Australia.
16 April, 2023	Iteration 5: Refine to shipping container housing and Australian building code	Informit	Shipping container, house, home, housing, Australia, building code	"Shipping container house" OR "shipping container home" OR "shipping container housing" AND Australia* AND "building code"	3	Same items as above
16 April, 2023	Iteration 5A: Refine to decommissioned shipping container housing and Australian building code	Informit	Decommissioned shipping container, house, home, housing, Australia, building code	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing" AND Australia* AND "building code"	0	The search did not return any results.
17 April, 2023	Overview: Decommissioned shipping container housing	ICE Virtual Library	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container" AND House OR Home OR Housing	24,213	Broad search related to decommissioned shipping container housing.
17 April, 2023	Iteration 1A: Refine to decommissioned shipping containers for houses specifically	ICE Virtual Library	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing"	0	Refined to decommissioned shipping container usage specifically for housing. The search did not match any publications.
17 April, 2023	Iteration 2A: Refine to Australian context	ICE Virtual Library	Decommissioned shipping container, house, home, housing	"Decommissioned shipping container" AND House OR Home OR Housing AND Australia*	0	Refined to decommissioned shipping container usage specifically for housing. The search did not match any publications.
17 April, 2023	Iteration 3A: Refine to use of decommissioned shipping container housing in Australia	ICE Virtual Library	Decommissioned shipping container, house, home, housing, Australia	"Decommissioned shipping container house" OR "decommissioned shipping container home" OR "decommissioned shipping container housing" AND Australia*	0	The search did not match any publications.

17 April, 2023	Iteration 4A: Refine to include building code	ICE Virtual Library	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia* AND “building code”	10,693	Broad search related to building code associated with decommissioned shipping containers as houses in Australia.
17 April, 2023	Iteration 5A: Refine to decommissioned shipping container housing and Australian building code	ICE Virtual Library	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing” AND Australia* AND “building code”	0	The search did not match any publications.
17 April, 2023	Overview: Decommissioned shipping container housing	ASCE Library	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container” AND House OR Home OR Housing	37,036	Broad search related to decommissioned shipping container housing.
17 April, 2023	Iteration 1A: Refine to decommissioned shipping containers for houses specifically	ASCE Library	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing”	0	Refined to decommissioned shipping container usage specifically for housing. The search did not match any publications.
17 April, 2023	Iteration 2A: Refine to Australian context	ASCE Library	Decommissioned shipping container, house, home, housing	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia*	19,337	Broad search related to decommissioned shipping containers as houses with mention of the Australian context.
17 April, 2023	Iteration 3A: Refine to use of decommissioned shipping container housing in Australia	ASCE Library	Decommissioned shipping container, house, home, housing, Australia	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing” AND Australia*	0	The search did not match any publications.
17 April, 2023	Iteration 4A: Refine to include building code	ASCE Library	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container” AND House OR Home OR Housing AND Australia* AND “building code”	19,337	Broad search related to building code associated with decommissioned shipping containers as houses in Australia.
17 April, 2023	Iteration 5A: Refine to decommissioned shipping container housing and Australian building code	ASCE Library	Decommissioned shipping container, house, home, housing, Australia, building code	“Decommissioned shipping container house” OR “decommissioned shipping container home” OR “decommissioned shipping container housing” AND Australia* AND “building code”	0	The search did not match any publications.

NB: Search statements in Science Direct were made covering all years, article types and publication titles in the Engineering subject area with Open access and open archive. Search statements in SCOPUS were made within ‘Article title, Abstract, Keywords’ covering all years, subject areas, document types and status of publication. A filter to search ENGLISH ONLY was applied. No country limits were applied unless stated.

APPENDIX G - Questions for BRC Representative

Are there any standards the Bundaberg Regional Council requires of all residential housing beyond the minimum standards put forward by national and state laws and code, and if so, what are they?

Do any of these standards change with location such as by postcode or in the sea turtle sensitive area?

Are there any standards the Bundaberg Regional Council applies specifically to shipping containers repurposed as houses, and if so, what are they?

Are there any time frames or other limitations placed on the use of shipping containers as temporary housing?

Would the limitations to the number of dwellings allowed by the Bundaberg Regional Council on a single lot of land be different if one or more of the dwellings were temporary?

Are there any structural or aesthetic requirements imposed by the Bundaberg Regional Council regarding shipping container housing, such as requiring windows or using a door separate to the in-built shipping container door, etc?

Does the Bundaberg Regional Council place any limitations on:

- The dimensions of houses?
- The number of residents allowed in a house?
- The number of kitchens, bathrooms, laundries, etc in a house?
- Environmental impact of houses, such as requiring insulation or meeting water efficiency goals?

Would any of these standards be different for existing houses versus newly constructed houses?

Is there anything else you feel would be relevant when constructing shipping container houses in the Bundaberg Regional Council region?

APPENDIX H - Preliminary Document Analysis Notes

NCC Volume 1

From A6
Classes: 9c (aged care), do not care about 1b since it is boarding houses only
Aged care: Designed to both Class 9a and 9c
School dorms: Class 3 (some with workers' quarters such as mine accommodation)
Apartments: Class 2 (one building, multiple dwellings)
Houses: Class 1a (one building, one dwelling)
1a 2? 3 9a 9c harsher requirements

From A2
Determine criteria for performance measurement through A5
Performance solution: Proves beyond doubt that criteria is met through scientific analysis
Deemed to Satisfy: Expert judgment says it is OK

From A3
NCC is always subject to state laws and never surpasses state laws
From A4
NCC always takes priority over any documents it references (same for ABCB)

From A5
Materials and construction methods must have one of: Code Mark Australia certificate of conformity, certificate of accreditation, a certifying body's certificate, a report from an accredited laboratory, a report from a professional engineer or a product technical statement.

From B1
Glazing = windows, doors, other fixed openings. Must adequately withstand regular use, extreme or regularly repeated actions, not sustain damage to the structure beyond what is expected if a portion is locally damaged.

Must resist: Permanent and imposed loads, wind, earthquake, snow, liquid pressure, groundwater, rainwater and earth pressure actions, differential movements, time effects (creep, shrinkage), thermal effects, ground movements from swelling, shrinking, freezing, landslip, subsidence and site works, as well as construction activity and termite actions.

Structural resistance determined using 5th percentile of strength adjusted for construction activities, type of material, site characteristics, testing accuracy, actions from settling of foundations, and from dimensional changes due to temperature, moisture, shrinkage, creep.

Glass must break safely, be durable and marked to reduce the odds of people walking into it.

Check B1D4 QLD and B1D6 QLD
WA Part B2: Not applicable

From S1
S1 (2a) has a list of tables with fire resistance requirements.
Can be designed in accordance with AS/NZS 2327, AS 4100, AS/NZS 4100 (steel structures) or AS 3600 (concrete)

From S3
Fire hazard properties are to be determined AS/NZS 1530.3, AS 1530.4 and Specification 7 (later in NCC)

Specification 2 is not checked yet.

From S4

Building roofs in a wind region C or D zone according to AS/NZS 1170.2 must remain in position in spite of any permanent distortions or damages to the sheet or fastenings when subjected to the pressures outlined in Table S4C2

Schedule 3: Take note of point 7, rest is irrelevant

Schedules 4, 5, 6, 8, 9, 10 and 11 are irrelevant.

Section I is irrelevant.

NCC Volume 2

QLD adjustments
H1P1: Building act 1975 and Development code 3.5
H1P3: Termite protection must last 50 years
H1D3: Compliance with part 3.4 or ABCB mean both the above are met.
H1D6: Timber roof trusses (see page)
H1D10: As stated in H1P1
H3: H3P1 is met if H3D2 as well as 9.2 – 9.4 of ABCB are met
H3P2: Check H3D6
H4: H4P1 is satisfied if designed to meet 10.2, 1.02.1 – 10.2.6 and 10.2.12 of ABCB
Note that for single-bathroom houses, complications arise so see rule H4D3
H4P2 is satisfied if designed to 10.3 of ABCB
H4P3 is satisfied if designed to 10.4 of ABCB
Check H4D5 however due to cross-volume complications
H4P4 is from 10.5 of ABCB
H4P5 is from 10.6 of ABCB OR ventilation installed according ot AS1668.2
H4P6 is from 10.7 of ABCB
H4P7 is from 10.8 of ABCB
H7P7 and H7D2: Swimming pools, not needed
H7D4: See page
Primary building elements are defined as any part of the building designed to take building loads, or any door jamb, window frame, architrave or skirting
H8: Must access door without steps, must have a toilet, must have a shower?
H8P1e): Ask if interpretation is correct. Can call BRC Mon – Fri
H7: H7F1 – H7F3 and H7P1 – H7P4 are irrelevant in QLD, same with H7P6
H7P5 (building in bushfire areas) is met if designed to AS3959 OR NASH standard – Steel Framed Construction in Bushfire Areas
Specification 4: May be unnecessary. Find HDH, CDH, DGH and Tr from BOM website, perform calcs for Bundaberg
H6: To meet H6P1, comply with 13.2 – 13.5 of ABCB
To meet H6P2, comply with 13.6 – 13.7 of ABCB
H5: H5P1 means any level-floor, single storey building is fine
H5P2 is fine for level, single storey buildings
Otherwise comply with 11.3 of ABCB

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