Thermal
Tectonics.

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by

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Preface.

The ability of an architectural detail to translate and convey architecture's inherent meaning through materiality and craft is the foundation of tectonics, a term linked to architecture since it was expanded upon by Gottfried Semper in his essay The Four Elements of Architecture.

Over a century and a half later, the study and application of tectonics is still a fertile ground for architects to draw inspiration from. The introduction of new materials, production techniques, science, and design software each prompt a reinvestigation of this field and in turn inform the constructed expression of each generation of designer.

Recently, greater global awareness of Climate Change and the need to collectively reduce energy consumption has led to a greater interest in high performance buildings, which focus on operational efficiency, internal comfort, and the wellbeing of occupants.

In New Zealand, the construction industry is beginning to understand the need to design and construct our buildings differently, and consumers are beginning to demand greater thermal performance from their homes. Optional design standards that exceed the minimum requirements of our building code, such as Passive House, have significantly increased in popularity in recent years. In 2020 MBIE proposed significant changes to the building code that acknowledge the severity of our existing building stocks thermal performance shortcomings and set new performance targets which will require designers to think differently about the detailing of the external envelope in the near future.

New Zealand's traditional construction and detailing practices have defined the evolving expression of residential architecture in New Zealand. Our traditional platform framing is a familiar light tectonic language that has given designers a proven medium in which to explore their own architectural ideas.

The aforementioned changes will mean future designers must seek to find new ways to express their architectural intent within a tectonic language that is focused on thermal performance and sustainability, integrating to a greater degree the fields of building science and architecture. By examining the interplay between performance and poetics in the context of residential architectural detailing, the term 'Thermal Tectonics' emerges.

The thesis defines 'Thermal Tectonics' in the New Zealand context, and tests its application as a design strategy for residential architecture. The approach contrasts with previous design practices which often place performance as an outcome of post-design optimisation. Instead, performance is explored as a driving concept for architectural design through close attention to the expression of tectonic elements in the conceptual phase of the design process.

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01

Introduction.

1.1 RESEARCH QUESTION

How can a tectonic approach to energy efficient construction inform the design of architectural details and connections?

1.2 ABSTRACT.

This thesis examines high performance architectural tectonics through theoretical studies, design experiments, and through the design of two case study houses in Christchurch, New Zealand. The thesis focused on formulating a theoretical framework for a practice-focused, environmentally sustainable architecture by studying three key themes, specifically Architectural Tectonics, Contemporary Residential Architecture Detailing, and Energy Efficient Envelope Design.

The integration of these three fields was undertaken to address the role of architectural design as the construction industry transitions to a net-zero carbon emissions future.

Thermal tectonics takes a critical position towards the contemporary approach to residential architectural detailing, which increasingly intensifies the divergence between the tectonic expression of architectural junctions and the performance considerations of energy efficient envelope construction. This divergence results from a number of factors, including the increasing complexity of construction methods, the growing specialisation of building trades, and the increasing specialisation of architectural design.

The project aims to tilt the existing aesthetic traditions of New Zealand residential architecture towards a language that performs better thermally. The thermal tectonic approach to architectural design intends to re-integrate the tectonic and performance considerations of the external envelope through a system-based approach to architectural design.

Two case-study homes are developed through a tectonic framework that highlights the expressive potential of high performance construction systems. 'Four Peaks House' seeks to align a prefabricated SIP system with the vernacular typology of the Bach, developing a detail language that connects the building to place without the need for extensive low-performing glazing. 'Gallery House' explores the novel material of Hempcrete, demonstrating how exposing insulative materials can produce rich interior spaces.

The design research was conducted through a series of design-led experiments focused on the six key principles of the Thermal Tectonic framework; anatomy, tectonic-stereotomic, space, place, detail and intersection, representation and ornamentation.

This approach creates an explicit relationship between building elements and their thermal function, by using thermal simulation software to generate tectonic diagrams that describe how building elements are configured to express the thermal performance of a building. This provides architects with a critical tool for understanding how their design decisions can impact energy efficiency, while also allowing them to make design judgments that prioritise other factors such as aesthetic or material concerns. In addition, the research outcomes provide a direction for sustainable future practice that will ensure architectural ideas are translated into the high-performing language of our future built environment.

1.3 RESEARCH AIMS.

- 1 Investigate the key elements of Thermal Tectonics to develop a hybrid design workflow that equally considers thermal performance and tectonics within architectural design.
- 2 Analyse a range of architectural details from contemporary built projects to understand how thermal performance and tectonic architectural expression are interlinked.
- 3 Produce and evaluate alternative high performance architectural details in order to illustrate the design opportunities and limitations of environmentally motivated material selection.
- 4 Document the design process of two case study homes in Christchurch that express high performance construction systems through the framework of Thermal Tectonics.

1.4 THESIS METHODOLOGY.

The thesis approaches the research question and research aim, through design led research that utilises a range of combined research methods to address architectural design generation and appraisal. Groat and Wang suggest integrating a range of research methods provides “appropriate checks against the weak points in each, while simultaneously enabling the benefits to complement each other” (Groat and Wang 441).

From the beginning of the thesis, the research explored the interplay between thermal performance and tectonic expression, addressing design questions that arise from real-world residential design briefs, to inspire others to embrace the challenge of designing better performing homes within New Zealand’s established tectonic language.

In order to synthesise tectonic and performance thinking into an applicable design strategy, a design-led methodology was formed around an agile and iterative design workflow that would actively provide visual assessment of the performance impacts of design decisions at each stage of the design process (Niezabitowska 154). The design process was separated into six distinct stages that were informed by examining the relationships between key themes of tectonic theory and extracted principles of Passive House design. Chad Schwartz book, *Introducing Architectural Tectonics : Exploring the Intersection of Design and Construction* (2016) was a key text which greatly influenced the structure of the thermal tectonic design inquiries.

The six thematic approaches to thermal tectonic thinking were applied in the two projects undertaken in this thesis, and their appropriateness for different construction systems tested. Similarly to the tectonic methodology described by Edward Ford in his book *Five Houses, Ten Details* (2009), the premise of this process was that the study of a building’s tectonic assembly can be a mechanism for the exploration and expression of broader architectural concepts.

1.5 SIMULATION STRATEGY.

The thermal simulation software used was Therm, a steady state thermal simulation tool developed by Lawrence Berkeley National Laboratory (LBNL). The software is used to generate renderings that visually represent how various building elements impact energy efficiency through their placement and orientation within the envelope. This form of thermal simulation was selected as it is easily accessible to architects, and allows for incremental increases in simulation complexity, identified by Bleil de Souza and Knight as a key factor in the adoption of thermal simulation in wider architectural practice (88).

International studies have shown that in generic low performing timber framed buildings, thermal bridges are responsible for up to 36% of the total energy loss through the building envelope (Misiiopecki et al. 2). As standards governing the insulative properties of the external envelope raise the level of minimum performance of insulative materials, the proportion of heat loss attributed to thermal bridging will increase.

Thermal bridging analysis is an established feature of residential performance analysis in countries overseas. By providing visual feedback on temperature changes across the envelope and highlighting the impact of highly conductive materials, designers can identify and 'design out' problem areas through iterative design (Bleil De Souza and Knight 89).

1.6 CASE STUDY HOME OVERVIEW

The thesis focused on the design of two residential projects located in Canterbury, New Zealand. The author's previous experience of working in residential focused architectural firms in Christchurch was the catalyst for the research topic, and also provided foundational knowledge of typical architectural design processes to draw from.

Two residential design briefs received by the author provided vehicles through which the thesis explored the research question. The architectural outcomes of each case study aim to both satisfy the individual briefs of these projects, as well as the research objectives of the thesis, demonstrating the applicability of thermal tectonic thinking to architectural practice in New Zealand.

fig. 1.1. Map showing site location in Le Bons Bay from Google Earth, earth.google.com/web/.

CASE STUDY 1

FOUR PEAKS BACH

The first case study home was for a holiday house for a family of four, located in Le Bons Bay, Banks Peninsula. The clients inherited a section from relatives on a beach front, and were looking to build a weekend home for their family.

The key elements of the clients brief included:

One master bedroom

Separate bunk room for 2-3 children

Living room with wood fire

Kitchen with good connection to outdoor living space

Living room with views to the beach.

Small footprint, reflective of the client's previous experiences in older Baches. 80-100m2 max.

The family has a long connection with Le Bons Bay, and have been holidaying there for many years. The family appreciates both the character of houses in the area, and the wild landscape that surrounds the rural settlement. They suggested the house should fit into the character of the area, but be playful and contemporary at the same time.

fig. 1.2. Le Bons Bay in November 2018 from Schwede66. Le Bons Bay 960.
2018. Wikipedia Commons, https://commons.wikimedia.org/wiki/File:Le_Bons_Bay_960.jpg

fig. 1.3. Map showing site location in Fendalton, Christchurch from Google Earth, earth.google.com/web/.

CASE STUDY 2

GALLERY HOUSE

The second case study home investigated is a suburban home for a retired couple, located in Fendalton, Christchurch. The couple are looking to replace their family home after damage sustained in the Canterbury earthquakes of 2010 - 2011.

The house is required to be flexible enough to accommodate visiting family members, with a key design consideration to be the inclusion of a studio and gallery space for artwork to be displayed. The client's previous home was clad in oamaru stone, and both expressed a desire to retain a sense of mass and permanence to which they have become accustomed to.

The home should offer a variety of quiet, and contemplative spaces, as well as spaces connected to the established gardens and landscaping on site.

The key elements of the clients brief included:

One master bedroom

One separate guest rooms

Ample wall space for the display of artwork

Variety of living spaces, with an independant kitchen and dining space

Studio space that provides a retreat from the rest of the home

The clients indicated an appreciation of several early homes of Warren and Mahoney, and have described their dream home as being of a refined contemporary style. Another key concern expressed in the brief was that the home should not dominate or stand out on the street, over concern for damaging relations with the couple's long standing neighbours.

fig. 1.4. Fendalton site street frontage. Authors photograph

02

Literature Study.

2.1 LITERATURE STUDY OVERVIEW

The following chapter addresses the research objective: investigate the key elements of Thermal Tectonics to develop a hybrid design workflow that equally considers thermal performance and tectonics within architectural design. The chapter begins by addressing the industry context in which the research is situated, before examining the key themes of tectonic thinking, as well as design principles developed within Passive House to increase the thermal performance of the external envelope. Each section is first explored separately, with key strategies that have the potential to benefit the design section of the research identified. The chapter concludes with a reflection on interrelation of these ideas, and a synthesis of key principles into the proposed Thermal Tectonic design framework.

fig. 2.1. Diagram showing literature review scope

2.2 INDUSTRY RELEVANCE

2.2.1 A FRAMEWORK FOR THE FUTURE.

In recent years, the demands of sustainability and climate change have gone from an isolated issue within the architecture and construction industries to a central focus for future practice. New Zealand has committed to reaching net zero carbon emissions by 2050. This is an aspirational goal that has many implications for the building and construction sector. The industry currently accounts for around 20% of New Zealand's carbon emissions through the energy and carbon used in our buildings ("Transforming Operational Efficiency" 2).

MBIE has proposed two mitigation frameworks for reducing the impact our buildings have on the environment. The 'Whole-of-Life Embodied Carbon Emissions Reduction' framework targets the whole lifecycle of all components in a building, including materials and products, construction processes, as well as the processes at end of life of a building. The 'Transforming Operational Efficiency' framework aims to reduce the emissions directly related to the operation and running of our buildings, including heating, cooling, ventilation and lighting ("Transforming Operational Efficiency").

Central to both frameworks is the requirement for buildings to meet a new operational emissions cap. For this to happen, residential homes will need to reduce their need for heating and cooling, which currently accounts for between 30% - 40% of residential energy used in New Zealand (Study Report SR403 The Built Environment and Climate Change: A Review of Research, Challenges and the Future).

This will require significant changes to the way architects detail and construct the external envelopes of New Zealand homes, with a primary focus on increasing the thermal performance of these elements. This is highly important to consider in the design phase of a residential project, as a highly insulated envelope locks in good performance for the lifetime of a building.

2.2.2 A TIMBER TECTONIC HERITAGE

In New Zealand's relatively short history of construction, timber has dominated the tectonic expression of residential architecture. The dense native forests found around the country provided 19th century European settlers with an abundance of good quality timber that led to the adoption, evolution, and pervasiveness of timber construction systems. Light timber framing was found to be far more resistant to seismic forces than masonry, an ever present threat to buildings that was discovered quickly upon arrival to the new colony (Boarin et al. 69), and more recently reiterated by the 2010 and 2011 Christchurch Earthquakes.

By 1911, timber structures already accounted for 90% of all construction in New Zealand, cementing this materials place in New Zealand's architectural heritage. As industrialisation of the forestry sector increased, the ability to produce smaller dimensioned lumber at cheaper prices led to the development of balloon framing (Isaacs 98).

The key developments within this tectonic language were guided by the material itself. As the demand for housing grew, the availability of long lengths of timber which were essential to balloon framing decreased. The solution was to develop a system of construction which utilised smaller lengths of timber. Platform framing was the result, a system where the walls for each floor were framed separately and stacked on the floor joists at each level (Isaacs 99).

In the early 20th century the timber tradition began to integrate influences from Modernist movements internationally. Gradually the ornate carpentry of the 19th century villa was replaced with simplified roof structures and a greater variety of external cladding profiles (Hartley 53). By the 1950's a shift towards more robust forms and interconnected internal spaces gave rise to the exposed post and beam structures of the New Zealand Modernist expression (Hartley 79). While overseas commentators often lamented the "crude" nature of New Zealand's timber detailing, some acknowledged the truthful tectonic expression could provide a distinctly New Zealand architecture, embrative of international modern ideals, but distinctly of this place. Nikolaus Pevsner was one of these critics, although upon reflection suggested that "maybe that robustness of detail which strikes me as a little raw will one day be a valid expression of the New Zealand version of 20th Century architecture" (Clark 53).

Today, New Zealand's traditional light timber framing governed by NZS 3604:2011 allows for 'rapid and reliable' construction, and its popularity is reflected in its dominant 95% market share of all residential homes in New Zealand (Shelton and Beattie). Architects, Builders, and Councils are all highly proficient at designing within this system, with adaptations of standardised details which aim to provide a streamlined process for the design and consent of homes.

From the mid-90s and early 2000s, the country was severely affected by the 'leaky building crisis,' when over 42,000 homes, of primarily timber construction, were found to have significant weathertightness defects within the exterior envelope. The economic and health consequences were devastating to both the construction industry and homeowners. The crisis was attributed to the very low performance requirements of the New Zealand Building Code, as well as limited verification of newly introduced materials included in Building Consents (Boarin et al. 71).

Despite this event providing an alarming warning to the consequences of low performing housing stock, a similar attitude is adopted in the energy performance domain. Timber framed construction is 'lightweight' by nature, and clause H1 of the Building code requires very low minimum thermal resistance values that are far less than other developed nations with similar climates (Howden-Chapman et al. 3387). Boarin suggests the energy performance of our building stock today is comparable to that of the mid 60s Nord-European one (72).

New Zealand's timber tectonic heritage has had a significant positive influence on shaping the expression of New Zealand residential architecture, as well as a negative impact on the advancement of thermal performance in our homes. Developing high performance details that address the thermal weaknesses of timber construction, while retaining a connection to New Zealand's lightweight architectural heritage, is an important step towards raising the performance of our homes above minimum standards.

2.2.3 PASSIVE HOUSE IN NEW ZEALAND

In the simplest terms, a Passive House is a building designed to use minimal amounts of energy to provide heating and cooling. A passive House employs a highly efficient thermal envelope in conjunction with a ventilation system to provide healthy indoor temperatures and air quality. Instead of designing to a prescriptive acceptable solution, Passive House uses simple metrics to assess the homes performance and allows designers to use a range of strategies to meet these. The key metrics are:

- 1. An annual heating/cooling demand of no more than 15kWh/m² or peak heat load of 10W/m²**
- 2. No more than 0.6 air changes an hour as observed during a blower door test during construction.**

For comparison, an average 200m² NZ home can be expected to use 57kWh/m², based on energy consumption trends of New Zealand homes compiled from the last 10 years (James 118). Passive House therefore represents a major change from typical construction, with the majority of changes occurring in the construction external envelope.

The first certified Passive House project in New Zealand was completed in Auckland in 2012. Since then, there have been 24 fully certified homes completed around the country (Quinn 32). This is a small number compared to the total number of houses built each year, with Statistics NZ recording 37,010 new homes consented in 2019 (StatsNZ).

While it is widely acknowledged that achieving the Passive House standard will increase construction costs by approximately 10%, the generally slow uptake in adoption of higher performing construction systems reflects the reluctance of the construction industry to adapt to changing practices and demands from consumers. James, Nina Saville-Smith, Kay Saville-Smith and Isaacs suggest that despite widespread industry knowledge of the benefits of higher performance standards, accreditation schemes such as Passive house are “largely ignored by industry,” “despite evidence that there is consumer demand for performance not required under regulation” (14).

While not the subject of extensive study, the reluctance of designers to embrace higher performance standards in NZ can be compared to the previous experiences of the UK, which was in a similar position during a wider uptake of Passive House design between 2010 and 2016. The first certified Passive House in the UK was constructed in 2009, and by 2019 over 1000 had been constructed (Clarke and Marlow). In a 2016 report Passive House and Low Energy Buildings: Barriers and Opportunities for Future Development within UK Practice Adrian Pitts conducted a range of industry interviews to ascertain barriers to wider adoption of energy efficient design practices in the UK.

Underlying concerns were expressed by some designers that indicated negative attitudes from within the design industry towards more rigorous performance standards. One interviewee suggested many leading architects “did not want to be seen as concerning themselves with such a technical standard when their main reputation lay in more aesthetic fields” (Pitts 18). Another interviewee suggested that Passive House reflected a central European approach that did not align with processes in the UK, which Pitts described as “a non-technical barrier across country boundaries” (18).

Architect Rafe Maclean suggests that New Zealand needs to consider our buildings as future infrastructure, not as a pure commodity in the short term. “If we are going to build new buildings - which we are doing, constantly, let’s build them as best we can. Buildings that are both aesthetically pleasing, very energy efficient and extremely healthy to be in” (Home Magazine).

Maclean designed the first certified Passive House in the South Island in 2013, as well as the first NZIA awarded Passive House in Dunedin in 2019.

While energy savings, indoor air quality, and occupant wellbeing are often discussed when discussing the early Passive Houses in New Zealand, less discussion is given to how the novel construction systems used might impact the buildings visual appearance and formal composition. This does not necessarily indicate architects are not considering the tectonic formation of these buildings, but suggests that these emerging materials warrant more critical study. The realities of practice and the need to provide these buildings within budget, code, and time constraints have obviously been the first hurdles encountered in the adoption of higher performance construction techniques, and these early projects provide exemplary solutions that demonstrate that these standards are achievable within New Zealand.

However, this also indicates an opportunity exists for research into the tectonic expression of energy efficient construction systems. Further research in this field would assist architects in adopting higher performance construction as part of their design processes, and allow the discipline to focus upon delivering valid and attractive design expressions for these systems. New Zealand can be seen to be a position just behind other international communities, primed to adapt our industry for the adoption of more sustainable practices. Pitts concluded his study on the barriers and opportunities for low energy buildings in the UK with the following statement;

A key factor emerging from both the reviews carried out and from the interviews has been the potential opportunities for Passive House and low energy design professionals in the UK to try to exploit the opportunity to provide higher quality design as a means to generate business. It may be that energy efficiency and costs are the first attractants, but there is a much larger business potential in promoting the wider benefits. There is a risk that this will lead to a focus on richer clients able to afford higher levels of design, but this may also lead to aspirational attractions in the future for a wider range of the public (Pitts 18).

2.3 THERMAL PERFORMANCE

2.3.1 THERMAL PERFORMANCE AND THE NEW ZEALAND HOME

New Zealand's current regulations for operational efficiency address disparate elements of the building envelope, with simple measures such as the minimum R-Values for the insulation of roof, floor, and wall elements governing the majority of the envelope's thermal performance .

As BRANZ 'Exceeding the Minimum' research programme suggests, these minimum standards are often treated as targets by designers, instead of what they are - an accepted legal minimum. Meeting this minimum does not necessarily result in a well performing or comfortable home, and many homes built to these standards today will depend on expensive heating systems to maintain comfortable indoor temperatures.

Furthering this issue is the general public's lack of knowledge around the performance of their homes, and the expectations that a home built to the Building Code is a 'good' performing house. A Warm Homes Technical Report published by the Ministry for the Environment in 2005 estimated that around 10% of New Zealand's homes may have no insulation, while only around 71% have ceiling insulation, and 50% have wall insulation. Only 10% of our homes are fitted with double glazing - which is a minimum requirement in many other countries. The benefits of increased wall insulation, higher performing windows, and more energy efficient heating systems are often hard to quantify and convey to clients, who prefer to invest in the visible elements of their homes, such as bathroom fittings, exterior cladding, and extra rooms or space within their homes (BRANZ). This conclusion is reiterated by many industry professionals, who are actively advocating for changes in the way we think about the performance of our homes. Architect Joe Lyth suggests:

“In the New Zealand housing market, value is assessed on the square meterage, the stone counter tops, solid wood floors and shiny taps. These are compared to the same variables in the house next door. The health of a home, the quality of the building envelope, the quality of the interior environment and how it actually performs, barely even feature in the value assessment.” (2021)

This sentiment reveals a contradiction underpinning New Zealand's attitudes towards sustainable building practices. We want our homes to be healthy, but we don't recognise and reward them for being so. The reality is that a healthy home is not valued if it doesn't also look the part. The proposed changes to the New Zealand building code, summarised in section 2.2.1 represent a significant opportunity for the construction industry to re-focus and move towards a more sustainable and future-proof way of thinking about the design of our homes.

2.3.2 PASSIVE SOLAR vs PASSIVE HOUSE

Passive solar design is a sustainability strategy referenced often in the design of residential homes in New Zealand. Passive solar design relies on the local climate of a particular building to ensure the home is naturally warm in winter, and cool in summer. Key elements of passive solar design include the appropriate orientation and size of glazing, thermal mass, and insulation.

In the most general terms, passive solar aims to capitalise on the cyclical processes of a particular climate. Glazing is used to bring heat from the sun into a building, which is absorbed by heavyweight thermal mass materials, and released overnight to keep the space at a comfortable temperature. Insulation is the third element in this process, and aims to slow the flow of heat in and out of the house in order to maintain more constant temperatures internally.

A key text for sustainable passive solar design in New Zealand is *Designing Comfortable Homes* (Donn & Thomas 2010), which details extensively the interrelationship between glazing, thermal mass, and insulation. *Designing Comfortable Homes* provides code minimum, better practice, and best practice rules-of-thumb for use of each passive solar element. Published by the Cement and Concrete Association of New Zealand, the text focuses upon the use of thermal mass as a key passive design element, although it acknowledges “the interactions between these elements are complex, making it difficult to generalise about how much thermal mass to put into a house - more is not always better” (Donn and Thomas 22).

Passive solar can be seen to align with the design ethos of many architects within New Zealand, and is closely tied to the development of an appropriate New Zealand ‘vernacular’ architecture. Passive solar engages a building with its environment, incorporating natural ‘cues’ to inform the spatial arrangement of internal spaces in relation to the site.

A drawback of many passive solar processes is that while understanding the basic relationships between thermal mass, glazing, and insulation is straightforward, in reality these interactions are far more complex than can be accounted for in a single list of rules-of-thumb. A 2011 research paper by Studio Pacific in conjunction with Victoria University of Wellington simulated the thermal performance of 8 built residential projects designed between 2008 - 2010, and found that these recently designed architectural homes were using more energy than the typical Kiwi home to maintain comfortable indoor temperatures (Novak et al. 6). The research concluded the following:

“The relationship between a given design and the factors which can improve thermal performance appears to be dependent on a complex set of variables that cannot readily be simplified into universal ‘rules of thumb’ and this highlights the potential for this simulation process to aid the architect in the design of new residential buildings.”

(Novak et al. 8)

In contrast to passive solar, which might be called a climate-led approach to sustainability, Passive House takes a fabric-first approach, focusing on the performance of the thermal envelope. Passive house proponents are often critical of passive solar, as this approach is often not supported by energy modelling or simulation. Jason Quinn suggests “Solar passive is a guess and hope system, put some more windows towards the north and maybe it’ll be OK, maybe not” (2020).

The Passive House methodology assumes that indoor comfort is the primary goal, and seeks to achieve this by delivering a highly energy efficient external envelope. Before construction occurs, the building’s design is simulated for its predicted performance and must meet strict energy efficiency requirements.

Passive houses are still able to capitalise on the positive climatic conditions of a building through orientation and building form, but are more resilient to unfavourable climatic fluctuations through the high level of insulation achieved in the thermal envelope. Increased insulation was highlighted in both *Designing Comfortable Homes* and Studio Pacific’s research paper as the most significant factor contributing towards increased thermal performance.

When looking to the future of high performance residential architecture within New Zealand, both passive solar, and passive house strategies have validity and merit. However, the most appropriate response to our specific climatic conditions may lie somewhere in between. Site and climate may form the immediate drivers for building placement, glazing orientation, and spatial arrangement, but these may then be supplemented with strategies adopted from passive house design in order to ensure a highly energy efficient envelope is achieved as well.

2.4 TECTONICS.

2.4.1 TECTONIC CULTURE.

Buildings are constructed within the constraints of contemporary society. They are defined by current techniques, processes and materials, as well as ethics, values and meaning. Tectonics acknowledges that a building is simultaneously a product of material and cultural inputs, both in its conception and construction.

First proposed in the 19th century by Karl Botticher and Gottfried Semper, theories of tectonics initially looked to connect the underlying functional aspects of a building to its ornamented, visual facades (Schwartz, A Taxonomy of Architectural Tectonics 3). Botticher defined tectonics as the activity of forming a building, and linked the expression of elements - or details - to their appropriate practical functions.

“All decorative characteristics of the parts of built structure are perceptible demonstrations of their functions, essence, physiognomic beginning, development, turns, conclusions, and connections. In short, art is an explication of the organicism which connects the whole with its parts”

(Botticher, “Entwicklung der Formen” 328, translated by Mitchell Schwarzer in “Ontology and Representation in Karl Botticher’s Theory of Tectonics”).

Semper initially defined tectonics in terms of lightweight construction, and the tools used for its creation. He soon expanded upon this definition, connecting tectonics and culture more generally. In the book *The Four Elements Of Architecture* Semper offers a theory on the tectonic origins of architecture, based on an understanding of the primitive conditions of human society. The hearth, roof, enclosure and mound were presented as universal features of architecture. Each element was connected to a craft, respectively, ceramics and metalwork, carpentry, wall covering, and water and masonry work (Whyte 124). For Semper, tectonics was the use of specific materials and techniques to create a cultural expression. The elements of architecture shaped by hand were of most significance, crafted and assembled by people to form an architecture that reflects the values of particular community (Semper).

Important reinterpretations of tectonics were offered in the late 20th century by Kenneth Frampton and Marco Frascari. Frampton highlighted the artistic aspect of the term, describing tectonics as the poetics of construction - “the construction of buildings which in turn construct culture” (Leatherbarrow 98). In his book, *Studies in Tectonic Culture*, Frampton extracts the essential elements of tectonics. These are object, details, joint, material, construction, structure, and interaction. Frampton also indicated that tectonics should consider both local culture, and environmental issues (Frampton, *Studies in Tectonic Culture*).

Marco Frascari provides a similar unpacking of tectonics in his essay *The Tell the Tale Detail* in which he describes the concepts of ‘construction’ and ‘construing’. Construction relates to the physical assemblage of a building’s parts, while construing is about creating meaning through those parts. For Frascari, both of these features must be present in meaningful architecture, “(a)rchitecture is an art because it is interested not only in the original need of shelter but also in putting together spaces and materials in a meaningful manner” (Frascari 511).

Tectonic thinking therefore, does not only concern itself with conveying constructional logic, but with integrating culture and meaning. The assemblage of a building’s parts in physical materials reveals underlying narratives that tell a story of the time and place in which it was constructed. In today’s society, with heightened concerns for sustainability and the environmental impact of our built environment, tectonics offers a strategy to approach the design of high performance architecture in a way that elevates the established, empirically based, technical solutions to an art form that expresses these cultural values.

You say to brick,
“What do you want, brick?”
Brick says to you,
“I like an arch.”
if you say to brick,
“arches are expensive and I can
use a concrete lintel over an
opening. What do you think of
that, brick?”
Brick says:
“I like an arch.”

Louis Khan

2.4.2 MATERIALS, STRUCTURE, CONSTRUCTION

An important aspect of tectonics is the study of material agency - the nature of materials and the way in which they aggregate or come together in the creation of architecture. Tectonics suggests an understanding of materials is a precondition for the advancement of other architectural ideas, for example, spatial or formal ones.

In *Elements of Architecture: From Form to Place + Tectonics*, Pierre von Meiss states that “(t)he form and the space of architecture is defined by the character of materials and the imprint of their application” (247). A materials properties, structural configurations, and the corresponding methods of construction informs their expression, and the geometries of the architecture they are used within.

The notion of material agency links tectonic theory to the practice of architectural production. Frank Lloyd Wright described his thinking towards materials as a discovery of their unique tectonic potential:

“A stone building will no more be nor will it look like a steel building. A pottery, or terra cotta building, will not be nor should it look like a stone building. A wood building will look like none other, for it will glorify the stick. A steel and glass building could not possibly look like anything but itself. It will glorify steel and glass”.
Frank Lloyd Wright (1954).

Although not a new phenomenon, the introduction and adoption of new building technologies has throughout history prompted renewed interest in tectonic thinking and the capacity of materials to extend agency over architectural design.

The modernist movement was a significant period for the reconceptualisation of architectural tectonics. A connection can be drawn between the cultural values architects of the period wished to express, namely functionalism, and the proliferation of steel, glass, and reinforced concrete as preferred building materials with economical benefits.

While simplicity and removal of ornament were key overarching trends of this period, the use of new materials varied significantly between architects. Mies Van Der Rohe utilised the immaterial or transparent qualities of glass and steel to great effect in his works. Many of his architectural forms reflected the “Bekleidung” theory of Gottfried Semper, which separated the functions of structure and enclosure (Shih et al. 15).

Louis Khan took a contrasting approach to Mies in many of his works. Instead of focusing upon the immaterial qualities offered by new materials, Khan strongly emphasised the material expression of brick and concrete in his buildings. His architectural forms had a direct relationship to the qualities of the materials used and the structural

systems that correspond with these. Goldhagen suggests that Khan’s work “stresses process over finish, leaving traces of the human hand in the making of the building” (41).

Both attitudes have influenced the tectonic approach of contemporary architects, although Shih, Huang, and Kuo suggest the layered and complex nature of construction today has resulted in more complex relationships between the ontological and representational aspects of tectonic form (19). This observation reaffirms the merit of researching the tectonic expression of high performance construction systems, and suggests the design outcomes of the thesis have the potential to offer an original contribution to this field of study.

“Detailing should never be regarded as an insignificant technical means by which the work happens to be realised. The full tectonic potential of any building stems from its capacity to articulate both the poetic and the cognitive aspects of its substance . . . Thus the tectonic stands in opposition to the current tendency to deprecate detailing in favor of the overall image.”

Vittorio Gregotti

2.4.3 A TELL-THE-TALE DETAIL

An expressed detail bridges the gap between our perception of the building as a cohesive whole, and our perception of a building as an assemblage of parts (Ford 166). This duality is first formed within the architectural design process, where construction can dictate the form of a detail, and inversely the detail can also inform the narrative of construction.

Chad Schwartz uses the Greek Orders applied to a column as an example of the analysis that underpinned Botticher's ideas on ornament. The structural function of a column is straightforward. A beam above transfers gravity loads from the roof structure to the top of the column, where it is then transferred through its mass into foundations and then ground below. This structural action is reflected in the expression of the detail of the column as "the two points of primary transfer are also the points adorned with the most intricate elements of the design, highlighting or revealing the work underway below the surface" (Schwartz, A Taxonomy of Architectural Tectonics 2).

In this way, Botticher attempted to resolve the relationship between structure and ornament, identifying a key conceptual phase of design in which the constructional elements of the building are not only articulated and integrated, but elevated to what he described as Kunstform, or arts form. Schwartz explains Kunstform as "the exterior or visible description of the underlying mechanically necessary systems (Kernform)". (Introducing Architectural Tectonics : Exploring the Intersection of Design and Construction xxxi).

Tectonic thinking therefore, reveals that the architectural systems of a building are linked to the objective laws that govern its construction. It considers the properties of materials, the ways in which loads are transmitted and resisted by structure, and links the expression of individual elements to the commonality of their purpose, and ability to act and be perceived as a unified system (Pleshivtsev and Pakunova 3).

In 1975, Louis Kahn wrote the following lines in Light is the Theme:

**"The joint is the beginning of ornament
And that must be distinguished from
decoration which is simply applied.
Ornament is the adoration of the joint"** (43).

This view of ornament links closely to Botticher's ideas on tectonics, and proposes that ornament presents a way of understanding a building's assembly. Marco Frascari built on these concepts, suggesting architectural details are "minimal units of signification in the architectural production of meaning" (Frascari 500). Examining the evolution and application of tectonic theory reveals a strong correlation between the architectural detail and meaning production. A tectonic focus on the detail within the design phase of this research can therefore provide a vehicle through which alternative forms of construction can be approached. Greater understanding of high performance architecture may emerge from a focus upon the expression of individual connections.

2.5 THE THERMAL TECTONIC FRAMEWORK

The literature review undertaken in previous sections covered a broad array of topics from typical New Zealand timber framing, through to early theories on architectural tectonics. In order to translate the learnings from this study to the design of the two case study homes in the following chapters, a design framework was formulated to focus the design stages into several key thematic stages. This process aimed to extract key relationships between thermal performance and tectonic expression, firstly by focusing upon construction systems, then developing design strategies, then exploring the tectonic expression of each project. At individual stages various design tools are used to visualise the developing tectonic condition of each project.

TYPICAL RESIDENTIAL PROCESS

PROPOSED PROCESS

fig. 2.2. Diagram showing how the typical architectural design process is challenged to better integrate thermal performance considerations.

fig. 2.3. Diagram showing how the thermal tectonic framework is extracted to form a design process within the thesis.

ANATOMY

This design inquiry focused on the ‘anatomy’ of each project. The primary materials, components and systems of a building are critical factors in both the built expression of architecture, as well as in the expected thermal performance of the external envelope. The explorations undertaken in this phase focus upon considering high performing materials and construction systems as design drivers for tectonic expression.

TECTONIC + STEREOTOMIC

This design inquiry was focused on distilling the relationship between tectonic and stereotomic elements within the conceptual designs for each project. The aim was to identify the relationship between structural, and insulative components of the building and ensure the continuity of the thermal envelope early in the design process.

DETAIL + INTERSECTION

This design inquiry translated the tectonic systems to design details, in order to examine the tectonic implications of thermally led design processes at the smallest architectural scale. Key junctions in the thermal envelope were extracted and developed through an iterative workflow that integrated thermal simulation in Therm. This design inquiry explores how architects can approach consideration of thermal bridging within their design processes, as well as reinforcing Frascari’s idea of the ‘fertile detail’ in which a design detail can become a catalyst for conceptual development of an architectural scheme.

PLACE

This design enquiry explored the relationship between place, and tectonic form of each project. The literature review section revealed the industry perception that high performance construction systems were often perceived as unsuitable for the New Zealand context. By exploring each project’s tectonic relationship to place through modelling, this design inquiry looked to highlight aspects of the design that connected each building’s thermal tectonic expression to its surrounding context.

SPACE

This design inquiry examined the relationship between the human experience of each design, and the construction of the thermal envelope. The resulting imagery explores the spatial qualities of each design, focusing on moments in each project where the tectonic expression of the thermal envelope is most evident.

REPRESENTATION + ORNAMENTATION

This design inquiry unpacked the relationship between the actual construction, and the representational qualities of the cladding or ornamentation used to create each project’s aesthetic scheme. This process was used to explore the relationship between the thermal performance properties of each tectonic system, and the human scale experience of each project. Key detail areas are interrogated through the production of hybrid drawings combining aesthetic representation techniques with thermal simulation and 2D design details. This approach created an explicit relationship between building elements and their thermal function, and emphasised the capacity of tectonic elements to express the thermal performance of a building.

Precedent Studies.

“Just as the abundance of technical means is an embarrassment to us, even more so are we perplexed by the immense mass of historical knowledge, which increases daily. Every trend of taste is familiar to us, from the times of the Assyrian and Egyptian styles to the age of Louis XVI and beyond. We can do everything, we know everything except ourselves. ”

Gottfried Semper

3.1 NZIA AWARD WINNING HOME DETAIL STUDY

3.1.1 ANALYSIS PROCESS AND AIMS

The following chapter addresses the research objective: Analyse a range of architectural details from contemporary built projects to understand how thermal performance and tectonic architectural expression are interlinked. This particular study focused on assessing the relationship between thermal performance, and tectonic expression in award winning homes of the Canterbury region. Projects were selected from homes receiving NZIA local awards in the housing, and small architecture categories between 2015 - 2019. A total of 8 projects were examined with 2 - 3 key details from each being simulated to identify key thermal performance issues. Details are drawn from a vertical section of each project's external envelope, primarily focusing upon each building's relationship to the ground, treatment of openings, and interfloor or roof junctions.

3.1.2 SOURCING PRECEDENT MATERIAL

The study began by researching projects listed on the NZIA's website, and then approaching individual firms via email to explain the research aims and the intention to investigate the details of a particular project. Unfortunately, the timing of this corresponded with the country entering lockdown as a result of COVID19, and responses were minimal. To expedite the process the decision was made to approach Christchurch City Council, and to request the property files of each project. Finding the addresses of some projects proved difficult, and so 2-3 attempts at requesting property files were needed for some projects to find the correct property file.

The approved building consent drawings were then downloaded, printed, and hand drawing was then used to distil key details. These were then redrafted in Rhino, before being run in Therm through an associated Grasshopper plugin.

FIXED SKYLIGHT SECTION DETAIL.

JOINERY HEAD + SILL DETAIL.

FIXED SKYLIGHT SECTION DETAIL.

JOINERY HEAD + SILL DETAIL.

CILL/WINDOW SEAT DETAIL.

ROOF WALL JUNCTION DETAIL.

CILL/WINDOW SEAT DETAIL.

ROOF WALL JUNCTION DETAIL.

FIXED SHUTTER JAMB DETAIL.

WET AREA WALL DETAIL.

FIXED SHUTTER JAMB DETAIL.

WET AREA WALL DETAIL.

WINDOW + LOUVRE DETAIL.

WALL BASE DETAIL.

WINDOW + LOUVRE DETAIL.

WALL BASE DETAIL.

INTERNAL GUTTER DETAIL.

INTERNAL GUTTER DETAIL.

INTERNAL GUTTER DETAIL.

INTERNAL GUTTER DETAIL.

WINDOW HEAD + SILL DETAIL.

ROOF/WALL JUNCTION DETAIL.

WINDOW HEAD + SILL DETAIL.

ROOF/WALL JUNCTION DETAIL.

WINDOW SILL/SEAT DETAIL.

SLIDING DOOR JAMB DETAIL.

WINDOW SILL/SEAT DETAIL.

SLIDING DOOR JAMB DETAIL.

CONCRETE SLAB EDGE.

FIXED SKYLIGHT DETAIL.

CONCRETE SLAB EDGE.

FIXED SKYLIGHT DETAIL.

NZIA AWARD CITATION

“Hunkered down due to site covenants, this house has a bunker-like appearance evocative of the old gun emplacements located around the harbour. On entering, however, the feel of the house is completely different; what is offered are expansive views of the harbour, and a sense of lightness and airiness. The roof is an abstracted fractal form of the Black Rock headland itself; the circumference of the roof mirrors the lines of the bays of the harbour. The use of rock excavated from the site as cladding assists in keeping the house connected to its place; it is a house that is well grounded, both literally and figuratively, into its site.”

(NZIA, 2018)

NZIA AWARD CITATION

With a total absence of landscaping, Scrubby Bay takes the appearance of a simple arrangement of modest farm buildings set in an isolated bay. Until you notice the pool stretching out behind. The meticulously designed Annandale farmhouse / bach is composed of a pair of crisp eaveless forms with pitched roofs. Set side-by-side and precisely offset from each other, they contain lofty volumes that provide a counterpoint to the expansive views of the rugged Banks Peninsula landscape. While the massive central fireplace is constructed from rubble masonry, and thin strips of bluestone bring elegance shower, Scrubby Bay is overwhelmingly about the materiality of timber. The macrocarpa-lined interior, in particular, provides a rich sensory experience.

(NZIA, 2016)

NZIA AWARD CITATION

Post-earthquake, this home balances remembrance and reinterpretation within the footprint of its 1910 predecessor. The white, triple-gabled house sits confidently within the existing garden at the centre of the property. Symmetrical in both planning and form, the house is entered through an exaggerated central hall. The double-height space houses a sculptural spiral stair and connects the two ground floor wings. Familiarity is established through planning: functions are rehoused with a careful re-ordering of spaces allowing improved connections to the existing garden. A new-found flexibility is provided through a series of pocket doors, curtains and retractable windows, allowing for more intimate proportions which reference the former house and open new possibilities. The success of this house lies in its honest references to what was and its bold acceptance of change.

(NZIA, 2017)

3.1.3 PRECEDENT STUDY ANALYSIS

The details examined provided a rich source material on which to build upon in the design phase of the research, and reflected the tectonic diversity of residential architecture in the Canterbury region. The hypothesis beginning this study was that details would be resolved around the desired tectonic expression of the buildings interior and exterior surfaces, and that incorporation of energy efficiency features beyond code required insulation would be minimal. While this assumption was largely confirmed throughout the study, there were several interesting findings that demonstrated some architects are currently considering high performance detailing strategies into their own designs. Furthermore, some recurring features identified between details represented opportunities for designers to achieve higher performing details within the tectonic languages already being employed.

The selected details demonstrated little variation in materials used within the thermal envelope across the projects, with glass wool insulation being most commonly specified in conjunction with a building wrap or rigid air barrier. This was despite the highly diverse material expression of exterior and interior surfaces. Underfloor insulation was primarily polystyrene, either in sheet form or as part of a ‘pod’ type system. Only one of the projects assessed included active measures to reduce heat-loss through the slab perimeter.

Significant thermal bridging was identified in the majority of details assessed, as shown in the temperature graphs overlaid on details. Linear thermal bridges often occurred when different systems of construction met, for example the meeting of timber framed wall elements and concrete slab, or structural steel beams and a timber or hyspan rafter system.

The structural connections of externally mounted thermal control devices, such as louvres, and sliding screens were also the location of point thermal bridges. Typically these structural members were included within the thickness of the wall, or roof, displacing insulative materials in these areas to allow for uninterrupted lining of the internal surfaces.

Other elements of structure were deliberately positioned to be expressed. Roof structure was the most common structure that was detailed to be left exposed. Several projects also expressed ‘false’ rafters on the interior. This creates a tectonic condition where the true structure is hidden in order to provide a more consistent expression of structure on the interior. Interestingly, this misalignment between true structure and expressed structure actually exasperates thermal bridging, while actively concealing the issue. Concealed thermal bridges within the envelope are hidden from view, while the expressed structure on the interior implies that there is a layer of protection on top of the

structure that is not actually present.

This highlighted a larger trend within many of the selected details around material expression. The outward aesthetic features of many projects would suggest a type of construction that did not necessarily align with the actual construction system, even when exposing construction or structure was linked closely to the design intent for a particular project. This finding has a few implications. Firstly, it illustrates that modern construction has resulted in increasingly complex envelope constructions to meet the demands of weathertightness, thermal control, airtightness, and architectural expression. Secondly, the disconnect between actual construction and implied construction highlights that architects may be willing to incorporate new construction systems into their projects that offer a simpler, and more direct relationship between construction and tectonic expression.

The award-winning architecture examined demonstrated New Zealand Architecture is strongly focused on tectonic expression, and less concerned with addressing specific issues of thermal performance. This is despite growing research that New Zealand homes are thermally underperforming in many climate regions of New Zealand.

DESIGN PHASE

The following chapters summarise the design phase of the research, exploring the iterative development of the two case study homes through each thematic phase of the Thermal Tectonic Framework. Three chapters separate the preliminary design, developed design, and resolved design stages. Integrated throughout these chapters are the Thermal Tectonic design inquiries that allow key design decisions to focus upon thermal performance considerations. This structure mirrored the design process, as both projects were simultaneously developed throughout the course of the academic year. A benefit of this process was that it allowed cross comparison and discussion to occur between the two projects at significant phases, and allowed for consistent application of thermal performance consideration across the two projects.

04 PRELIMINARY DESIGN ANATOMY

05 DEVELOPED DESIGN TECTONIC + STEREOTOMIC DETAIL + INTERSECTION PLACE

06 RESOLVED DESIGN SPACE REPRESENTATION + ORNAMENTATION

Preliminary Design.

“The legacy of the essentialist approach to architecture, which elevates rationality (mainly in the lineaments of geometry) above matter, precludes the productive and rich capacity of matter to define or influence geometry.”

Reiser and Umemoto 74

4.1 ANATOMY

The following design inquiry focused on the ‘anatomy’ of each project. The primary materials, components and systems of a building are critical factors in both the built expression of architecture, as well as in the expected thermal performance of the external envelope. The explorations undertaken in this phase focus upon considering high performing materials and construction systems as design drivers for tectonic expression.

SYSTEM SIMULATION

Industry research into Passive House construction in New Zealand initially informed a selection of possible construction systems. Six construction systems that offered alternative thermal envelope solutions were explored in this phase. Each was modelled in Rhino, and simulated in Therm to obtain the expected R-Value. This figure was used to quickly gain an understanding of how materiality influenced the expected thermal performance of different construction systems.

EFFECTIVE R-VALUE
R3.2
1. PLASTER RENDER ON BACKING BOARD
2. 90mm MINERAL WOOL INSULATION
3. 200 SERIES CONCRETE BLOCKWORK

EFFECTIVE R-VALUE
R3.6
1. PLASTER RENDER ON BACKING BOARD
2. 100mm CAVITY EPS INSULATED BLOCK
3. CAST IN SITU CONCRETE
4. INTERNAL LINING

EFFECTIVE R-VALUE
R3.6
1. PLASTER RENDER ON BACKING BOARD
2. 200mm CAVITY EPS INSULATED BLOCK
3. 200mm CAST IN SITU CONCRETE
4. INTERNAL LINING

EFFECTIVE R-VALUE
R2.8
1. 100mm RAMMED EARTH
2. 90mm EPS INSULATION
3. 100mm RAMMED EARTH

EFFECTIVE R-VALUE
R1.8
1. PLASTER RENDER ON BACKING BOARD
2. 90mm MINERAL WOOL INSULATION
3. 300mm RAMMED EARTH

EFFECTIVE R-VALUE
R2.6
1. 300mm RAMMED EARTH
2. 90mm MINERAL WOOL INSULATION
3. 90mm TIMBER FRAMING
4. INTERNAL LINING

4.2 SYSTEM SELECTION

SIMULATED WALL SECTIONS

**STRUCTURALLY
INSULATED PANELS**

HEMPCRETE

For Four Peaks Bach, SIP panels were identified as the preferable construction system. SIPs offer a high R-Value, indicated by the undertaken Therm simulations, and provided a modular framework from which to approach the design. This was consistent with the desire for Baches to be simple structures, largely influenced by, and exposing their tectonic configuration.

For Gallery House, hempcrete was selected as a construction material. The brief for this home asked for solidity, largely informed by the client's preference for early Warren & Mahoney homes. Hempcrete returned higher expected R-Values than both insulated concrete blockwork and rammed earth, the other 2 stereotomic construction systems tested. Hempcrete also offers a similar surface aesthetic to rammed earth, due to the stratification created by its construction process.

USE FULL PANELS OR
SIMPLE FRACTIONS

MINIMISE PANEL CUTS

ELIMINATE LINTELS
WITH FULL HEIGHT
WINDOWS

UTILISE INSULATED
SPACE FROM ROOF
PANELS

4.3 FOUR PEAKS HOUSE

STRUCTURALLY INSULATED PANELS

SIP's panels are by nature a modular system, and this geometrical condition was identified as a key factor that would influence the design of the Le Bons Bay Home.

By working with the module size of a panel, and aiming to minimise waste through offcuts, a clear organisational system could be reflected in the tectonic expression of the building. Interestingly, the 1200mm width of panels relates to a standard timber framing module of 600mm. While this relationship is not necessarily expressed in either system, it could be explored further in order to create a visual articulation of the underlying logic of the material, providing a connection to vernacular construction methods.

Other design opportunities identified within this system of construction included the ability of panels to not only perform the function of a wall, but also roof and floor elements as well. This makes SIP's a total building system and minimises the need for various other systems to be included in the design of the external envelope. Analysis of contemporary construction details in chapter 3 revealed that the meeting of different systems in junctions such as roof to wall, and wall to floor were often the location of significant thermal bridging, as the structural and insulative components became misaligned due to the connection conditions present. By utilising SIPs for the full building envelope a consistent thermal envelope condition could be more easily maintained.

Furthermore, when SIPs are used for roof and floor elements, the structural properties of the panel allow for the option to remove lintels above openings in the walls. Lintels are commonly a location of significant thermal bridging, and are difficult to address in timber framed walls where the structural and insulative components of a wall are positioned within the same layer of the external envelope.

Similarly, the structural properties of roof panels allows for interior space to be increased to the full height of the thermal envelope. The extra space created when using a gable or raised roof form could be utilised as a loft space, or be used to create a more voluminous interior double height space.

While SIPs are typically hidden between the exterior cladding and internal linings, the use of OSB or plywood as the structural lining also raises the possibility of exposing the interior surface of the panel. This would both reduce labour and cost in interior finishes, but will need to be considered in conjunction with the fixing of panels, which are typically nailed along the edges of joints. The ability of SIPs panels to be manufactured to specification from different suppliers would allow for different interior surfaces to be explored.

FOUR PEAKS BACH

PRELIMINARY PLANNING

4.4 GALLERY HOUSE

HEMPCRETE

As designers continue to add more insulation to buildings in order to meet lower energy requirements, the volume of insulative material used in buildings will only increase. Hempcrete provides a renewable, sustainable and high performing material with several benefits over more traditional insulative materials.

Hempcrete fits well with conventional New Zealand framing techniques, and although the installation of this material may be a novel process for a builder, it does not require significant changes to the way framing is approached. The construction techniques of hempcrete actually benefit the timber framing significantly, providing Passive House comparable air tightness, and minimal thermal bridging at key envelope junctions. While not a structural material, hempcrete also offers some level of structural bracing to framing members, and international precedents have been able to reduce the spacing and size of structural elements when the strength properties of hempcrete are considered (Magwood 2016).

Hempcrete construction also simplifies the construction process significantly, forming the insulation, water proofing, air barrier, and internal lining layers of the envelope in one material.

The surfaces can be left exposed on the interior of the building, reducing the need for additional internal linings, and also creating opportunities to experiment with texture, colour, and different expressions of stratification as a result of the construction process. Externally, the surface of hempcrete forms an ideal surface for plastering - with no additional mesh needed.

Hempcrete differs from many insulative materials in that it is extremely well suited to deal with humid indoor conditions. The porous structure of the mix exposes a large surface area of the plant fibre, which is able to absorb moisture from within a building. The high pH level of the lime binder also gives the mix antifungal and antimicrobial properties, meaning the absorbed moisture will not develop into mould.

The preliminary study also revealed some limitations of the material. Firstly, the need to build formwork for each layer of mix to be poured around the framing means that straight sections of walls will inherently be more efficient to build. Reducing corners was therefore considered in order to minimise the need for custom formwork for specific corner conditions.

Secondly, the porous structure of hempcrete requires the top plate of walls to be protected from water egress, and so Hempcrete design guides suggest wide eaves are crucial for the longevity of this construction material. The eave detail therefore has added significance within this construction system, and could be developed into a formal element that expresses the protective function of the roof.

GALLERY HOUSE

PRELIMINARY PLANNING

4.5 PRELIMINARY PLANNING OUTCOMES

Comparison of the thermal performance properties of each system were used to inform a sketching led exploration around the design of each case study home. The modularity of SIP panels was a strong geometrical tool that assisted in the development of a variety of floor plan arrangements very quickly. Three unique conceptual designs emerged, driven by possible envelope details for a variety of cladding options. Timber, profiled metal, and stone were explored, each responding to the modularity of the SIP panel in different ways. Timber was considered the preferable option, providing texture and colour to the exterior form. Each floor plan offered some functional benefits however, and these would be synthesised in the following design stage.

In contrast to SIP's, the plastic nature of hempcrete mixture gives it the ability to be formed to any shaped formwork, a common property among stereotomic construction systems.

This meant that the floorplanning for this home was less rigorously informed by the material, although consideration of a thicker thermal envelope did factor into the early design. The thicker envelope steered the design towards the development of a complimentary roof form, of a different tectonic language. This was intended to prevent the design becoming overly monolithic, and losing a sense of residential scale.

4.6 PRELIMINARY DESIGN REFLECTION

Although we may like to believe our homes are made of purely natural materials, the realities of modern construction demand far more complicated assemblies. In high performance construction, these complicated assemblies often result in thicker envelopes with exterior surfaces ambivalent to the functions and materials contained within them. Many of these materials have not been asked the same questions as more established materials such as stone or wood have, and so the expression of the final architecture does not always reflect the inherent properties of the construction materials used. Selecting and investigating construction systems in the preliminary design phase revealed several key considerations which not only will assist in resolving specific details later in the research, but also to identify qualities and conditions that can be used as design drivers going forward.

Both systems of construction explored have the potential to be used as exposed surfaces on the interior of the building, removing the need for plasterboard linings - which hides the wall assembly and creates a tectonic expression in the interior that is ambivalent to the construction systems used. By considering the properties of these sustainable materials before design commenced, this condition became a driving factor in the resultant designs and contributed immensely towards the architectural concept for each project.

Both systems also can be seen to retain some connection to traditional timber framing, with SIP modules conforming to standard stud framing modules, and hempcrete providing the ability to be packed around any arrangement of wall framing selected. This commonality was considered important when selecting the systems, as it allowed previous experience gained designing in timber framing to be applied to the design.

05

Developed Design.

5.1 DEVELOPED DESIGN OVERVIEW

The preliminary design phase successfully analysed a range of high performance construction systems in order to facilitate the generation of architectural concepts for both case study homes. The developed design phase looks to advance the resolution of both projects. Firstly by developing a tectonic language reflective of the selected construction systems, then by exploring a key 'fertile detail' of each project that could spur further resolution of the projects tectonic expression. This detail was used as a catalyst to explore tectonic relationship to place, as well inform the spatial experience of the resolved designs in the following stage.

“These gravitational opposites, the immateriality of the frame and the materiality of the mass, may be said to symbolise the two cosmological opposites to which they aspire: the sky and the earth”

Frampton, Rappel à L'ordre: The Case for the Tectonic 24

5.2 TECTONIC + STEREOTOMIC

The following design inquiry was focused on distilling the relationship between tectonic and stereotomic elements within the conceptual designs for each project. The aim was to identify the relationship between structural, and insulative components of the building and ensure the continuity of the thermal envelope early in the design process. Initially diagramming was used as a strategy to explore the interaction between structure and insulative components, Secondly the study focused on the construction/assembly sequencing of each selected system and how this might inform further development of each design.

SIP PANEL ASSEMBLY

5.3 FOUR PEAKS HOUSE

SIP PANEL ASSEMBLY

SIP panels are typically joined through the ‘sandwiching’ of a framing member between the ends of panels along each vertical junction. Thermal simulation through Therm was used to compare the thermal performance of this typical arrangement, to the alternative arrangement of using an insulated spline made of a smaller section of SIPs panel. For ease of fixing, it was assumed the equivalent framing members were moved to the inside face of the panel.

For comparison, a standard timber framed wall with glass fibre insulation was also simulated. The initial results were as expected, with the SIP wall sections providing higher R values then the equivalent timber framed walls. The impact of structural members in the wall was larger than expected however. In the 4.8m sections of wall - equating to four SIP standard modules and containing 3 panel connections - removing the framing members increased the R Value by around 25%. This meant that a 110mm thick wall with spline connections performed almost identically to a larger wall section of 160mm with timber studs.

Diagramming shown on the previous page reflects the design thinking resultantant from this inquiry, where 3 tectonic, stereotomic relationships were explored. The hidden structure diagram shows structural members placed between panels, while the exposed structure diagram shows structure positioned either on the exterior, or interior joint of the SIP panel - with an insulated spline closing the gap between the panels. Independent structure, envisioned as a portal frame separated from the SIP to support the roof, was also explored - although the ability to use the insulated splines in this configuration was likely to be negated, as the panels would be weak along junctions without a structural member to be fixed too.

5.4 FOUR PEAKS BACH

DEVELOPED TECTONIC SYSTEM

The tectonic and stereotomic inquiry of SIP's led to the development of a tectonic strategy for the Four Peaks house, utilising a thinner SIP panel, with internally exposed structure for the wall and roof sections. This strategy maximised the performance of the external envelope, while also creating an internal expression of structure that would have otherwise been concealed within the wall assembly. This strategy also had the added benefit of aligning structural members with panel joints - meaning that the issue of exposed fixings on the interior surface identified in the 'Anatomy' discussion previously was negated, and the interior surface of the SIP could be more justifiably left exposed.

GALLERY HOUSE

HEMPCRETE ASSEMBLY

AUTHOR'S EXPLORATION OF
CONSTRUCTING A HEMPCRETE 'BLOCK'

5.5 GALLERY HOUSE

HEMPCRETE ASSEMBLY

While the tectonic and stereotomic relationship of Four Peaks House and its SIP assembly centred around the exposure of structure as an architectural strategy, the use of hempcrete prompted investigation of an inverse relationship, and suppression of the building’s primary structure as a driver for design. As hempcrete is self-supporting only, thicker wall sections require additional framing to ensure the stability of the wall profile, as well as to assist in the erection of shuttering to support the hempcrete mixture during its curing period.

Thermal simulation through Therm was used to compare two hempcrete thickness options, firstly single stud, and secondly, double stud options were explored. Again, timber framed wall sections were presented alongside these options for comparison. The single stud options performed similarly to the timber framed wall sections, with hempcrete offering little to no thermal performance improvements in this configuration. The 400mm thick double stud options were significantly higher performing however, and the position of framing members within the wall profile had little effect on the expected R-Value.

A 400mm wall section is not uncommon within many examples of European high performance buildings, but is not typically found in the New Zealand context. Further development of design details will have to address the termination of this wall element at window and door junctions, possibly highlighting the thickness in a way that suggests retreat and protection within internal spaces. The figure on the opposite page details a possible construction method for this type of double stud wall, based on techniques described in Chris Magwoods book, Essential Hempcrete Construction: The Complete Step-by-Step Guide (2016). The book highlighted the ability of hempcrete to be exposed on the interior surface of the wall section, while suggesting the exterior surface be plastered in a lime mix to protect it against the elements. In this configuration, no expression of structure is evident, and both surfaces are monolithic in appearance. While this could have been selected as the final expression of the stereotomic system, it was decided that the exterior surface should provide some indication of the structural system, and so the shuttering to the exterior of the wall is offset from the external framing line through the inclusion of vertical metal channels. This created vertical articulation of the timber studs on the exterior finish, providing some modulation of this surface, and implying structure through repetition of this detail along the length of the wall.

- 1. Timber framing on concrete footing. Steel brackets fixed to vertical studs to hold shuttering.
- 2. Shuttering fixed to frame through steel brackets progressively up wall.
- 3. Shuttering filled with hemp lime mix and tamped down in 150mm strata.
- 4. Second level of shuttering fixed and filled with hemp lime mix and tamped down.
- 5. Hempcrete self supporting and shuttering removed after 24hr dry time. Steel brackets exposed.
- 6. Hempcrete left for 4-8 weeks to naturally cure before lime render applied to exterior surface.

5.6 GALLERY HOUSE

DEVELOPED STEREOTOMIC SYSTEM

The tectonic and stereotomic inquiry of hempcrete construction for Gallery House prompted the selection of a double stud framing system, with a 400mm wall profile. At this point of the design process, the configuration of the roof remained unresolved. While SIP panels offer a solution for both the wall and roof envelope, a secondary roof system is needed for hempcrete construction. As highlighted in the previous 'Anatomy' section, the preliminary design aimed to use this distinction between elements as a key design feature. The tectonic enquiry reiterated this observation, although did not provide a significant step towards resolution of this project's tectonic configuration.

“Architecture is an art because it is interested not only in the original need of shelter but also in putting together spaces and materials in a meaningful manner. This occurs through formal and actual joints. The joint, that is the fertile detail, is the place where both the construction and the construing of architecture takes place”

Frascari 511

5.7 DETAIL + INTERSECTION

The following design inquiry translated the tectonic systems to design details, in order to examine the tectonic implications of thermally led design processes at the smallest architectural scale.

Key junctions in the thermal envelope were extracted and developed through an iterative workflow that integrated thermal simulation in Therm. This design inquiry explores how architects can approach consideration of thermal bridging within their design processes, as well as reinforcing Frascari's idea of the 'fertile detail' in which a designed detail can become a catalyst for conceptual development of an architectural scheme.

1:10 SCALE MODEL MAKING

1:10 scale physical models were constructed in order to explore various configurations of the tectonic language for each project explored in the 'Tectonic and Stereotomic' inquiry. These models were an intermediate step between construction systems, and specific envelope details.

The physical models for Four Peaks House explored various configurations of a timber rainscreen on the external surface of the SIP's, as well as connections between panels at roof and wall, wall and floor, and corner wall junctions.

Exploration of the roof to wall junction was the focus of physical modelling for Gallery House, as this was identified in both the 'Anatomy' and 'Tectonic and Stereotomic' design inquiries as an area requiring further resolution.

5.8 FOUR PEAKS BACH

SLIT WINDOW

The development of a fertile detail for the Le Bons Bay house focused on the integration of a window into the structure of the SIP panel modules. Various configurations of window sizes and positions within the SIP panels were firstly explored, followed by a short evaluation of different window suites. A typical aluminium suite positioned at the line of the cladding, followed by an aluminum suite positioned on the centre line of the wall, and also a timber composite suite were all simulated for comparison.

The developed window detail for the Le Bons Bay house became a slit window, spanning the height of the wall panels, and positioned between panels along each elevation of the building. The developed window focuses on achieving higher thermal performance through several key considerations. A timber composite glazing suite was selected, as it offered significantly higher R-Values than an aluminium suite. This was positioned to align with the centre of the wall panel, allowing the insulation layer of the thermal envelope to be continued on both sides of the window frame.

From an architectural perspective, this detail aims to negate the need for large expansive glazing elements in the project, instead focusing the concept for the window detail on capturing specific views of the project's coastal environment. This concept also forms a relationship with the SIP panel construction system. The slit window is positioned between full width panels, and capitalises on the SIP's ability to use the roof panel as a lintel, thus reducing thermal bridging by negating the need for additional framing elements around the window.

5.9 GALLERY HOUSE

FLYING EAVE DETAIL

The suppression of structure resulting from the 'Tectonic and Stereotomic' investigation of hempcrete in the previous section led to the conceptualisation of an eave detail that looked to further enhance the monolithic expression of the developing architectural scheme.

The development of this detail focused on addressing the linear thermal bridge of the top plate connection, as well as the continuity of the insulation layer at the junction of roof and wall systems. Various roof structures were explored, including roof truss systems, as well as skillion roof systems that included exposed rafters to the interior of a warm roof with rigid insulation.

In order to protect the hempcrete walls from water ingress at the top plate, as well as to formally balance the mass of thick exterior walls, a wide eave form for the building was explored. The developed eave detail achieves higher thermal performance by using a raised heel truss to allow ceiling insulation to overlap the wall profile.

The concept of pulling the gutter back from the eaves assisted in creating a seamless junction between wall and roof and the continuous eave aimed to conceptually separate the building from the ground plane and suggest protection from the elements.

5.10 PLACE

The following design enquiry explored the relationship between place, and tectonic form of each project. The literature review section revealed the industry perception that high performance construction systems were often perceived as unsuitable for the New Zealand context. By exploring each project's tectonic relationship to place through modelling, this design inquiry looked to highlight aspects of the design that connected each building's thermal tectonic expression to its surrounding context.

SITE STUDY

THE FOUR PEAKS BUILDING FORM EMERGED FROM
A STUDY OF BACH FORMS, WITHIN THE MODULE
CONSTRAINTS OF A SIPS SYSTEM.

5.10.1 FOUR PEAKS SITE RESPONSE

The developed design of Four Peaks Bach aspired to form a visible connection to the Le Bons Bay context by incorporating design features demonstrated by the humble New Zealand Bach typology. The first key move made was the separation of internal spaces into two complementary forms, in order to allow the architecture to be read as a collection of small sheds along the coast. The twisted roof form of the building is conceived as an abstracted gable, again referencing the surrounding buildings along the coast. This formal move is emphasised by the continuous wrapping of the timber rainscreen, designed to age and weather as the building settles into the muted colours of the surrounding tussock and beach dunes.

GALLERY HOUSE

STREETSCAPE STUDY

GALLERY HOUSE SITS QUIETLY AMONG ITS
NEIGHBOURS

5.10.2 GALLERY HOUSE SITE RESPONSE

Gallery house sits within a suburban context in one of Christchurch's oldest neighbourhoods, facing onto a traffic dominated street edge. The surrounding buildings are mostly single story villas, with a variety of gable hip roof forms visible from the street. Gallery house aspires to sit quietly among its neighbours, with a simple pavilion roof floating over its thick rendered exterior walls. While appearing as a single story structure in keeping with the scale of the neighbourhood, this roof form actually conceals a mezzanine level study. This one-and-a-half storey concept was informed by international Passive House designs, and reduced the internal volume of the house from a full two storey structure.

Resolved Design.

6.1 RESOLVED DESIGN OVERVIEW

For the final stage of design, the thesis aspired to focus again on the more intangible, thermal tectonic expression of each project. Each project was documented through a variety of representational modes, exploring in more depth the experiential qualities inherent in the emergent tectonic languages developed for each project. The production of these drawings concluded the design phase, and facilitated the final reflection on the architectural outcomes of a design process led by the thermal tectonic framework.

6.2 SPACE

The following design inquiry examined the relationship between the human experience of each design, and the construction of the thermal envelope. The resulting imagery explores the spatial qualities of each design, focusing on moments in each project where the tectonic expression of the thermal envelope is most evident.

FOUR PEAKS BACH

RESOLVED DESIGN

1. 60x20 thermally modified radiata pine roof + upper wall cladding
2. 30mm treated timber battens
3. Torch on membrane on external PUR insulation and timber purlins
4. 215mm SIP roof panel with joists within spline
5. Vertical opening panels with external lintel
6. 165mm SIP wall panel with spline connection
7. ULEB woodburner with triple-flued wall penetration
8. 30mm cavity battens on building wrap for lower cladding

9. 180mm vertical rusticated timber weatherboard cladding
10. 2 layer EPS underfloor insulation between and below joists
11. External louvres hung on top mounted track
12. Subfloor framing with timber pile foundations
13. Double glazed skylight above kitchen
14. Timber decking between living modules
15. Double Glazed timber slit windows between panels
16. Custom steel channel to form gutter and louvre support

GALLERY HOUSE

RESOLVED DESIGN

“The lines, the marks on the paper, are a transformation from one system of representation to another. They are a transformation of appropriate signs with a view to the predicting of certain architectural events, that is, on one hand the phenomena of construction and the transformation by the builders, and on the other hand, the phenomena of construing and the transformation by the possible users”

Frascari 507

6.3 REPRESENTATION + ORNAMENTATION

The resolved design inquiry unpacked the relationship between the actual construction, and the representational qualities of the cladding or ornamentation used to create each project's aesthetic scheme. This process was used to explore the relationship between the thermal performance properties of each tectonic system, and the human scale experience of each project. Key detail areas are interrogated through the production of hybrid drawings combining aesthetic representation techniques with thermal simulation and 2D design details. This approach created an explicit relationship between building elements and their thermal function, and emphasised the capacity of tectonic elements to express the thermal performance of a building.

FOUR PEAKS BACH

THERMAL TECTONIC MANIFESTATIONS

WALL
140mm THERMALLY
TREATED TIMBER
CLADDING
30mm CAVITY BATTENS
ON ADHESIVE BACKED
BUILDING WRAP
165mm SIP WALL PANEL
WITH PLYWOOD FOR
EXPOSED INTERNAL
FINISH
90mm EXPOSED INTERNAL
FRAMING CENTRED ON
PANEL JOINTS

GALLERY HOUSE

THERMAL TECTONIC MANIFESTATIONS

ROOF
2 LAYER MEMBRANE ON
150MM WARM ROOF SYSTEM
TO FALLS.
18mm PLYWOOD DECK
400mm I-BEAM TIMBER
JOISTS @ 400 CRS WITH
CELLULOSE INSULATION.
VAPOUR CONTROL LAYER.
20mm CEILING BATTENS.
TIMBER CEILING LINING WITH
WHITEWASHED FINISH.

WALL
2 LAYER LIME RENDER TO
CONCRETE GREY ROUGH
FINISH.
50mm STEEL CHANNELS (TO
SUPPORT SHUTTERING).
140mm EXTERNAL FRAMING.
400mm HEMPCRETE MIX
140mm INTERNAL FRAMING
WITH 30mm COVER
EXPOSED HEMPCRETE
INTERIOR FINISH

Conclusion.

7.1 DESIGN PROCESS SUMMARY

The design phase documented the conceptual design process of two case study homes in Canterbury, New Zealand. Each was developed through an iterative design process guided by key design inquiries framed in the thermal tectonic design framework.

The preliminary design phase focused on the anatomy of each project. The early phase of the research highlighted a variety of high performance construction systems available in New Zealand, and indicated that embracing new materials could provide a rich source of design inspiration for architects. Louis Khan, and Frank Lloyd Wright's attention to material agency informed this phase, and considering the systems of construction early in the design process was critical in developing architectural concepts that had a direct relationship to the qualities of the high performance systems of SIP's and hempcrete.

In the developed design phase, the tectonic and stereotomic design inquiry distilled key relationships between structural, and insulative components of the building envelope. This was used as a strategy to design-out repetitive thermal bridges caused by primary structural members, as well as to develop a design language that informed further development of each project's architectural expression.

The detail and intersection inquiry drew on Frascari's idea of the fertile detail, and iteratively developed a key architectural junction for each project. Thermal simulation was used to minimise further point thermal bridges, while modelmaking was used to gain a greater understanding of the constructability, and possible aesthetic expression of each junction. The process of resolving a construction detail early in the design process was useful in summarising the thermal performance considerations of previous explorative design inquiries, steering each design towards a more resolved tectonic language.

The place inquiry addressed a common misconception towards high performing construction systems, which are often perceived as unconnected to New Zealand's tectonic heritage. Reflecting on the macro image of each project led to the development of visual identities that responded through scale and materiality to the local context of each project.

In the resolved design phase, a closer attention to architectural expression was made through focusing upon the representational aspects of the thermal envelope. This process was informed by Bottchier's tectonic theory of Kunstform, which suggests the visual appearance of architecture should reflect the underlying functional aspects of construction. This highlighted moments of each design where previous performance considerations such as material selection, thermal bridging, and continuity of the thermal envelope had generated novel tectonic outcomes.

7.2 DESIGN PROCESS LIMITATIONS

Throughout the design process, simulation was used as a tool to guide design development. The scope of the thesis did not allow for testing of different methods of thermal simulation, or a rigorous analysis of full building thermal performance. Thermal performance considerations were primarily focused upon the integration of a more continuous and effective insulation layer that mitigates thermal bridging and heat loss in each project. This strategy was deemed valid in response to New Zealand's internationally low energy efficiency requirements, and consistent with recommendations made in MBIE's Transforming Operational Efficiency framework.

Similarly, while constructability and structure were considered during the design process, the specific design details and structural configurations would require further testing to ensure their feasibility in real world applications. If the thesis were to continue, constructing large scale details to be tested in real world conditions would have been a direction worth pursuing.

7.3 CONCLUSION

As New Zealand continues to strive for a Net-Zero Carbon future, adopting new ways of thinking about the detailed design of the exterior envelope is critical in ensuring that architects can meet higher thermal performance standards, while maintaining agency in the design process. New Zealand's traditional timber construction and detailing practices have defined the evolving expression of residential architecture in New Zealand, but this lightweight tectonic language has significant thermal performance issues. Low minimum performance standards in the New Zealand building code have resulted in a building stock of cold and damp houses.

A tectonic approach to energy efficient construction was used in order to demonstrate how architects can design higher performing buildings, and develop tectonic expressions that are directly drawn from, and reflect the properties of high performance construction systems. Through a series of interlinked design inquiries, the research demonstrates the applicability of a design process which considers thermal performance and tectonic expression as equally important. The final two design outcomes, Four Peaks Bach, and Gallery House, serve as evidence that thermal performance, and tectonic expression are not mutually exclusive pursuits. The tectonic qualities of alternative high performance construction systems offer many compelling expressions for sustainable architecture that can contribute to the evolution of New Zealand's architectural heritage.

The research began with a parallel review of literature concerning tectonic theory and high performance construction. The literature review provided the basis for a design framework from which the relationship between tectonics and thermal performance could be addressed. Analysis of key detail areas of NZIA award winning homes from the Canterbury region revealed that thermal performance is often not a priority in tectonic expression of many architectural homes. The results suggested that key junctions were often designed around the aesthetic qualities sought for the exposed interior and exterior surfaces, and little consideration was given to improving thermal performance beyond minimum standards.

In the design phase of the research, the thermal tectonic framework was integrated into a typical design work-flow of two residential projects through six key design inquiries. These studies were spread throughout the preliminary, developed, and resolved design phases of the research. The thematic focus of each inquiry allowed for thermal performance to be addressed iteratively through various design mediums, which assisted in resolving each project to a high degree of tectonic detail.

By binding the reasoning for aesthetic features of the architecture to thermal performance, the research recognises the potential of architecture to be a vehicle to convey cultural ideas. The thermal tectonic framework was a critical tool for producing architectural outcomes in which the built form, tectonic expression, and construction processes align and promote sustainable future-focused architecture. Thermal Tectonics contributes to the growing discussion of thermal performance issues within the New Zealand architectural community. It is intended that the framework developed is flexible enough to be applied to a range of projects in the industry, and could serve as a tool for forward-thinking architects looking to adopt higher performing construction practices in their own work.

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