STRAW INTO GOLD

A LOW CARBON APPROACH TO CHRISTCHURCH’S HOUSING NEEDS

EXPLANATORY DOCUMENT
A Research Project submitted in partial fulfillment of the requirements for the degree of Masters of Architecture (Professional).
Unitec Institute of Technology, 2016

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"Once there was a miller who was poor, but who had a beautiful daughter. Now it happened that he had to go and speak to the king, and in order to make himself appear important he said to him, "I have a daughter who can spin straw into gold."

And when the girl was brought to him he took her into a room which was quite full of straw, gave her a spinning-wheel and a reel, and said, "Now set to work, and if by tomorrow you have not spun this straw into gold, you must die."

There sat the poor miller’s daughter, and for the life of her could not tell what to do, she had no idea how straw could be spun into gold.

And the story continues that the miller’s daughter does the impossible and, with the help of Rumpelstiltskin, spins the straw into gold.

This project is about turning straw into gold, without the help of Rumpelstiltskin.
ABSTRACT

Climate change is one of the biggest problems facing mankind, and the contribution the built environment makes to the problem is immense. Architecture can play an important role in the survival of the global environment. If materials and methods that are environmentally sustainable are utilised, then architects can do their part in addressing the pressing issue.

This project explores low carbon architecture that uses local, renewable, bio-based materials. Bio-based materials like timber and straw are an abundant, and in the case of straw, under utilised building material. Each year in Canterbury alone, 310,000 tonnes of straw is burned as waste. This presents an opportunity to turn what is seen as waste into a valuable resource; turning straw into gold.

Out of the destruction caused by the 2011 Christchurch Earthquake comes an urgent need for new housing and an opportunity for change and innovation. The aim is to address the urgent need for housing by using prefabricated straw and timber panels to form a sustainable, medium density housing development in the centre of Christchurch.
AUTHENTICITY
This explanatory document has been prepared by myself,
Ryan Pringle as partial fulfilment of the requirements of
Unitec Master of Architecture programme (Professional), 2016.

I declare that all work in this document is my own unless otherwise stated.

Ryan Pringle
1396879
ACKNOWLEDGEMENTS

Thanks firstly to Min, thanks for letting me annoy you over the last couple of years and for being the best Supervisor there could be.

Thanks to all of my family and Melissa for looking after me and offering encouragement when the going got tough.

And to Patt; I'll miss you. Always

This is for all of you.
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1.0 INTRODUCTION
1.1 BACKGROUND & OUTLINE

Climate change is one of the biggest problems facing mankind, and the contribution the built environment makes to the problem is immense. Buildings and cities continue to be built using materials sourced from a global supermarket of building products, products that travel thousands of kilometers to get to their point of use. This fact alone means that the embodied energy associated with construction globally is huge.

The design outcome of this project is based around the introduction of low carbon alternatives to contemporary methods of construction into an urban environment. Prefabricated panels made from low carbon materials are proposed for a community based housing development. The project is intended to fit into the existing and proposed urban framework of the Christchurch central city and help address the city’s housing shortage. Furthermore, the project sets a precedent for the use of low carbon materials, such as straw and timber, as a relevant, renewable and local building products in urban environments around New Zealand.
1.2 RESEARCH QUESTION

How can low carbon materials be used to provide a sustainable medium density housing model for Christchurch?
1.3 AIMS & OBJECTIVES

The current energy and resource use of buildings is unsustainable and current patterns of development suggest that without change this will only get worse. Thus the predominant aim for this project is focused around the best way to introduce low carbon materials into an urban, built environment in order to reduce the contribution that New Zealand cities make to climate change.

Key objectives are:

1. Investigate the use of local, low-carbon materials such as straw and timber in an urban environment.

2. Design a plausible architectural example of the use of low carbon materials at scale.

3. Design a prototype medium density housing development for inner-city Christchurch.

Refer to the chapter 6.1, Design Brief for design specific details and objectives
1.4 SCOPE & LIMITATIONS

This research project looks at how straw can be integrated in an urban housing prototype using contemporary prefabrication methods. The project aims to create a design that helps to remove the rural stereotype associated with the use of straw.

Every attempt has been made to design a plausible construction system. Some advice from specialist engineers has been sought, however the structural design is not fully developed.

Each individual dwelling in the medium density housing development is not designed in detail. One block is selected and designed at a micro scale. The two designed dwelling types are standard across the whole scheme, so most of the design decisions made are consistent across all dwellings.

The site is located in central Christchurch, where the design outcome has the greatest potential for interaction and influence. A key part of this project is about integrating the new development into existing and proposed attractions and features of the city. However Christchurch, especially the central city, is in a constant state of change, plans are changing all the time. For the purposes of this project the it is assumed that the buildings existing on the chosen site remain, with the exception of the partially built international rental car precinct, which had not been started at the beginning of this research project. Refer to the Future Plan section in chapter 5.4 of this document for further explanation.
1.5 METHODOLOGY

This research project is based around exploring the connection between straw as a building material and its application in an urban environment. Two main design methodologies have been used: research for design and research by design.

Architectural solutions have developed via a cyclical combination of these processes. The process began with an analysis of existing knowledge, assessing what was required for the project, and devising an approach to address the problem. The research based component was completed in tandem with design and directly linked to a study of Christchurch and its post-earthquake needs to ensure that design ideas and solutions would improve the city. The design is based around relevant information and proposed plans which mean that the project is based around a ‘real world’ approach to sustainable urban occupation in the city.

A review of literature using online and book based research provided a basis of information for appropriate precedents that exemplify the objectives that are to be achieved. These precedents were then analyzed to influence positive design decisions. This led to research by design that involves a creative process of further analysis which led to establishing a design approach that fulfils design aims and objectives and ultimately leads to an architectural proposition.

Design exploration is in the form of 2 and 3 dimensional sketching, modelling, urban master planning, diagramming and detailed drawings. Modelling is an important part of this process as it allows an understanding of existing construction techniques which then influence the approach towards first designing an appropriate wall system and then applying this to a housing development.

A combination of all methods of architectural research and design allows for an architectural resolution to the problem.
2.0 CONTEXT
2.1 THE GLOBAL ISSUE

The greatest issues facing mankind are the degradation of the Earth’s natural environment and climate change. Continual population growth means there is ever increasing pressure on the resources that are available, and with the population now over 7.4 billion people, these resources are dwindling. Over 50% of the world’s population now live in an urban environment. This urbanization is only expected to increase, as population grows to reach an anticipated 10 billion people by 2050. As a result of this rapid urbanization, cities must change and evolve. Contemporary buildings and urban developments are major contributors to the environmental crisis, so how these buildings are designed is a central challenge for the immediate future.

Architects therefore have the power to influence the direction of a green agenda, and have a responsibility to make decisions that take the long term viability of the planet into consideration. Buildings and urban development are large contributors to the environmental crisis, by way of high operational energy, and the high embodied energy in it's material make up. They play a central role in providing humans with the basic needs of shelter and security and also transform the environment and shape cultures. However, the built environment also contributes significantly to determining a sustainable future.

In ‘The Ten Shades of Green’, Peter Buchanan writes, “Sustainable developments, cultures, lifestyles, are those that do not overtax the resources and regenerative capacities of the earth, thus leaving for future generations as much of natures bounty and beauty as we enjoy now”. New means of doing this are becoming available, through features such as solar power, water retention and smarter passive design but as it stands, cities continue to be built using materials with very high embodied energy, namely steel and concrete. Design choices need to be made with sustainability as the main driver and, as the design changes, the materials used also change. A key part of this is being able to no longer depend on non-renewable resources and respect the regenerative properties of the earth and live within these cycles. Concrete and steel originate from materials that are extracted from the earth, and are unsustainable. Natural materials that are regenerative, such as timber and straw, need to be used more as they fit within the natural, sustainable limits of the earth, where use of these materials gives nature a chance to repair. While architecture alone cannot make the world sustainable, building with nature is a good starting point.

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Figure 2-01. Smog over Beijing city
2.2 THE NEED FOR LOW CARBON

For centuries people have constructed dwellings out of materials that were available in their immediate environment. More commonly these materials were stone, earth, timber, other plant-based materials and even ice. However with greater urbanization and the need to provide housing for the increasing populations, non-renewable, high carbon materials are being used in alarming and unsustainable quantities.

Low carbon materials have low embodied energy. This is defined as the total energy inputs consumed throughout a product’s life cycle and can be looked at as either cradle-to-gate or cradle-to-site. All figures used here are cradle-to-site in order to obtain an overall embodied energy figure. Embodied energy is net carbon emissions per tonne of material. Both timber and straw have negative embodied CO₂ because of their ability to sequester carbon. This will be further discussed in 2.3, Bio-Based Materials.

Approximately 50% of timber is carbon, thus 1kg of timber contains 0.47kg of carbon which equates to 1.32kg of carbon dioxide (CO₂). 1kg of straw stores 1.66kg of CO₂. In comparison concrete and steel have high embodied CO₂ per kg thus a high amount of CO₂ is involved in the production of the material. Concrete has an embodied CO₂ amount of 0.16kg of carbon dioxide per 1kg of concrete, and steel 1.77kg per 1kg. Both of these materials have much greater embodied energy than bio-based materials. Thus maximising high carbon sequestering materials such as timber and straw is a very effective way of reducing the net carbon emissions of a building.

Figure 2-02, Igloo’s were built using the materials that the Inuit had available.

Figure 2-03, Apartment buildings are needed in Hong Kong to house the large population.

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6 David Clark, Dan Bradley, ’Embodied Carbon of Steel vs Concrete Buildings”, (Cundall Johnston and Partners LLP: 2013), 4
7 Andrew Alcorn, ’Global Sustainability and the New Zealand House’, (Victoria University: 2010), 317
Buchanan et. al have carried out an important study, "The Carbon Footprint of Multi-Storey Buildings Using Different Construction Materials" which shows that multi-storey buildings using timber have considerably lower CO₂ than their concrete and steel counterparts. The figure 2-04 shows that of the four buildings in the study the TimberPlus building has a negative carbon footprint, due to carbon sequestration. Andrew Alcorn defines sustainability as "meeting the needs of the present without annual carbon dioxide emissions exceeding what the planet can absorb", and in this context the negative carbon footprint of the example building suggests that this is sustainable.

If timber can be used in conjunction with other bio-based materials, straw for instance, there is the potential to further reduce the carbon footprint of the built environment.

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9 Andrew Alcorn, "Global Sustainability and the New Zealand House", (Phd diss. Victoria University, NZ: 2010), 311
2.3 BIO-BASED MATERIALS

Bio-based materials are materials derived from plants, plants that grow via the process of photosynthesis where energy from the sun is used to convert $\text{CO}_2$ from the atmosphere into other compounds. These include carbon which is stored, or sequestered, in the plant and oxygen which is released into the atmosphere. The process of photosynthesis also ensures that plant based materials can continue to be produced using only the energy from the sun, in other words they are renewable.

Bio-based materials originate from a range of sources often depending on what is locally available. In the last 150 years, timber has been the predominant building material\(^\text{10}\) of use but materials such as straw and bamboo are also relevant building products but are hugely undervalued. Figure 8-01 in Appendix A compares the qualities of bio-based materials found in New Zealand. The table also includes steel and concrete, in order to compare these widely used products in terms of sustainability.

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2.4 STRAW AS A LOCAL MATERIAL

Location is critical in determining how sustainable a building can be. The ability to utilise materials that are sourced locally is fundamental for low-carbon architecture. Yet in the global market economy materials manufactured in Asia or Europe are easily accessible to the local building industry in New Zealand, and these materials must travel huge distances between the point of manufacture and the point of use. Transport is the second largest consumer of energy after buildings, and much of this is due to the international movement of materials. By the time these materials arrive on a building site they already have a significant carbon footprint. Using materials that can be sourced locally not only reduces a building's carbon footprint but also allows a place-based solution that contributes to the local community and economy.

Canterbury is an important grain growing area, and produces 70% of all arable crops in New Zealand. Large amounts of straw are produced as a by-product of grain production, and much of it is currently burnt in the paddock. This abundant, raw resource is located in close proximity to Christchurch meaning there is only a short distance to travel from the source to the site, thus reducing the carbon footprint of the final building material.

Utilising local and renewable materials is...
not just about reducing the city’s carbon footprint, it also increases its resilience. The Christchurch Resilience Challenge is an initiative the Christchurch City Council launched following the earthquakes, with an aim of creating a more resilient future.\(^{13}\) The concept of resilience relates to sourcing locally, and is based around the capacity of communities and cities to adapt and grow, no-matter what stresses or shocks they experience. The use of locally sourced materials plays a part in resilience as it ensures an accessible building product in times of disaster, or in the future when non-renewable building materials are scarce. In particular a locally sourced building product allows a future response to any challenges that the city may face, such as earthquakes and climate change.

Figure 2-07 indicates the main straw and timber producing regions of New Zealand. It shows the proximity of Christchurch to both the timber growing areas of the northern and central South Island and the straw producing areas on the east coast. It also shows the appropriateness of these materials for use in Christchurch. Refer to figures 8-02,03,04 in this document for a detailed diagram of grain growing regions.

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\(^{13}\) Resilient Christchurch, “Greater Christchurch Preliminary Resilience Assessment”, 2015, page 6
3.0 STRAW CONSTRUCTION
3.1 WHAT IS STRAW?

As mentioned previously, straw is a by-product of grain production. People will often confuse hay and straw, believing they are one in the same, which they are not. Straw is the tubular, stalk part of the cereal plant between the grain head and the roots. The upper portion of cereal crops such as wheat, barley, oats, rice or rye is harvested and taken for processing and sale. The dried, lower half of the crop left behind is straw.14 Hay on the other hand is a product in its own right. It is grass that is cut before going to seed, when the plant still contains all of its nutrients. This is then dried and used as feed for farm animals. Hay is a lot higher in organic matter than straw meaning that it is less appropriate for building. Both hay and straw are harvested by a baling machine and turned into bales. Bale sizes and shapes differ around the world depending on the baler that is used, but the standard bale size used for straw bale construction in New Zealand and much of the world is 900-1000mm in length, 450mm wide and 350mm deep.15

Straw has many uses that include; fertiliser, animal bedding, building material or as a bio-fuel, however generally it is an underused material.

The chemical composition of straw varies according to type but is generally made up of:
- Cellulose, which provides the tensile strength and structure of the plant.
- Hemicellulose, which acts as a structural adhesive to bind the fibers together.
- Lignin, which binds the chemical elements together.
- Silica, which gives the fibres a greater resistance to moisture and decay.16

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15 Ibid., 29.
16 Bruce King et al., Design of Straw Bale Buildings: The State of the Art. (San Rafael, CA: Green Building Press, 2006), 2

Figure 3-01, Cereal crop types where straw is the by-product
3.2 THE HISTORY OF STRAW BUILDING

Straw has been used as a building material or component of building, for hundreds of years, beginning in the Paleolithic Era when humans were nomadic and materials of abundance and ease of use were important. As an insulator, loose straw has been used throughout history, but it was not until the invention of the baling machine that straw bales could be formed easily and tirelessly. The practice of building with bales first began in the 1890’s in Nebraska, United States of America, where settlers had limited access to traditional building materials. The owners of these homes appreciated their low-cost and fast construction time. The super-insulation provided by the thick straw bale walls, ensured that their occupants were warm in the winter and cool in the summer. Many straw bale homes and buildings of this era still remain and are used to this day. The oldest of these being the Burke house in Alliance, Nebraska, built in 1903.

However, improvements in infrastructure, namely rail transport, meant that areas, especially in the Southwest of America where straw building had once flourished, now had greater access to timber for building and building with straw bales was abandoned.

In the 1960’s people began to doubt the superiority of science and technology, especially through the Cold War and Vietnam War. After the oil crisis of the 1970’s, “a passive, back-to-the-land movement began, oriented towards a more ecologically minded lifestyle and self-sufficiency”. Low carbon building materials, like straw, began to be experimented with in a counter-culture movement. Popularity slowly grew as more buildings were built and workshops were held. People began to write about straw bale, in books and journals which increased the awareness and use. Many viewed the movement with scepticism as many of the buildings were built without building consents. Through the 1980’s and early 90’s many worked hard to prove the material capabilities of straw in buildings through extensive testing, leading to state building codes being established, and in more recent times, a nation wide building code in the United States.

3.3 STRAW IN NEW ZEALAND

It was not until grain was introduced and cultivated in the mid 1800’s that straw became available in New Zealand. An article on the 5th of April 1887 from the Grey River Argus, titled “A Straw House” addresses a rise in popularity of straw as a building material overseas. It is evident that the people of New Zealand were aware of the use of straw in this manner but possibly due to a lack of expertise, it had yet to catch on. Research into the origins of the baling machine in New Zealand has found that in the early 1900’s, straw was being baled using early versions of a baling machine, but wasn’t being used for construction. It is more than likely it was being used as stock feed and bedding as a substitute for hay in the winter months.

It wasn’t until the late 20th century when the Straw revival occurred in the U.S.A that straw bale construction began in New Zealand. As a result of worldwide events, as mentioned in section 3.2, people were more aware of the need for environmental protection. New Zealanders responded with a passive movement which resulted in such events as nuclear free New Zealand, the Save Manapouri campaign, and also the revival of natural, or low carbon, building. As people sought passive alternatives to typical construction methods, natural materials and straw were the appropriate option. It wasn’t until 1995 that New Zealand’s first straw bale building was completed in Marlborough by Peter Kundycki, a landscape architect and urban designer.

Since this, straw buildings have continued to be built. Graeme North, architect and founding Chairman of the Earth Building Association of New Zealand (EBANZ) estimates that there are between 200 and 300 straw bale buildings in New Zealand currently.

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Figure 3-03, New Zealand’s first straw bale house
Photo by Min Hall
3.4 Benefits of Straw

A straw bale wall system consists of stacked straw bales (on a foundation) with a plaster render on the interior and exterior. Refer to section 3.7 Straw Bale Construction Methods for a more indepth description of wall systems. The following benefits are consistent with all straw bale wall systems:

High Insulative Properties:

Straw bale have good insulative properties. In New Zealand a value of R5.6 for a 350 or 450mm thick wall with the bales on edge or flat is accepted by Territorial Authorities and is based on laboratory testing in the USA.26 This value depends on many factors, such as orientation of the bale, whether it is on edge or laid flat, type of straw, and thickness of the bale. For the purposes of this project, the R-values of 0.25 M°C/W for every 25mm when the bale is laid flat, and 0.35 M°C/W for when the bale is laid on its edge have been used.27 The mass that is gained from the plaster render on the inside and outside also helps to increase the thermal performance of the wall.28 Currently in New Zealand the minimum insulation value for a standard timber framed wall is R2.2. Clearly a wall with an R-value of 6 is going to greatly out perform this wall.

Permeability:

The permeability of a fully plastered straw bale wall means that while any airflow through is restricted, water vapour is allowed to pass through the wall.29 Vapour permeability ensures that the moisture passes through the wall and does not remain in the wall where it can cause the straw to rot. When the straw is plastered externally with earthen or lime plasters, water vapour is allowed through the wall but any direct water or rain is kept out by this rainscreen. Internal plaster also helps to regulate internal humidity by absorbing excess airborne moisture.30

Ease of Construction:

The methods of straw bale construction are something that can be learned easily, allowing inexperienced and unskilled people the opportunity to build their own houses.31 Using traditional methods of construction, straw bales are effectively building blocks. More contemporary methods have been oriented towards panelisation.

26 Accepted values based on laboratory testing at Oak Ridge National Laboratory, USA 1998. Bruce King et al., Page 193
27 Worked out based on the Insulative Co-efficients of straw and the thickness of the bale
30 Bruce King et al., Design of Straw Bale Buildings: The State of the Art. (San Rafael, CA: Green Building Press, 2006), 33
Seismic Resistance:

A straw bale wall is flexible and absorbent of seismic movement. In load-bearing straw bale systems, walls are compressed to load bearing capacity meaning that they cannot compress any further under more loading.\(^{32}\) Non-load bearing systems rely on timber to bear the load with the straw being infilled and not bearing any load. The wide footprint of a straw bale wall, helps to spread the loads that are are applied during an earthquake and the flexibility of the material means that forces are absorbed rather than resisted.\(^{33}\) The plaster on the inside and outside of the wall also act as a diaphragm resisting the lateral loads created by the seismic event.\(^{34}\)


\(^{33}\) Ibid., 16

\(^{34}\) Bruce King et al., *Design of Straw Bale Buildings: The State of the Art.* (San Rafael, CA: Green Building Press, 2006), 35
3.5 COMMON CONCERNS

Fire Safety:
Naturally, fire is a big concern when building with a flammable material. Loose straw on its own has no natural fire resistance properties but because the bales are so tightly packed and compressed, oxygen cannot easily enter into the bale to fuel the fire. The plaster, when applied to the straw, is a poor conductor of heat which restricts the flow of oxygen to the straw and acts as a barrier against fire. A plastered straw bale wall has been proven to have a fire resistance of F90, a 90-minute fire rating during fire testing.\(^{15}\)

Moisture:
It is first essential to ensure that bales with a low moisture content of less than 20 percent\(^{16}\) are selected for use and are protected from the elements during construction and prior to the roof being erected. In the wall system, the plaster plays an important role in moisture control, protecting the straw from direct contact. It also allows water vapour to pass through the wall to ensure that a dew point does not form on the interior of the wall and create condensation due to high temperature differentials.\(^{37}\)

Decaying occurs in humid or warm conditions where a moisture level is sustained, allowing the growth of mould and fungus. By ensuring that only vapour permeable materials are used, the straw is able to dry if it gets wet.\(^{38}\)

Pests:
Another concern that arises is the issue of insects and rodents. It has been found that the straw is too dense for rodents to chew on, and as a food source, there is no nutritional content. However rodents, like mice, do enjoy small warm spaces so plaster is essential to provide a barrier against access to the straw. In terms of insects, as long as the wall is kept dry and there is no excessive moisture there is no appeal to insects.\(^{39}\)

Building Codes:
In New Zealand there is very little local information on the performance and moisture resistance of straw bale construction. There are currently no straw bale standards in the Building Code, meaning that the only way to get this approved is through alternative methods. This is an involved process with local Councils. Straw builders have also moved to using a timber frame and infilling with straw, to create an easier route through the permit process. While the current building codes are an issue, work is being completed by people around New Zealand aimed at creating a set of guidelines that will make the consent process much simpler.

\(^{15}\) Bruce King et al., Design of Straw Bale Buildings: The State of the Art. (San Rafael, CA: Green Building Press, 2006), 175
\(^{16}\) Ibid., 140
\(^{37}\) Bruce King et al., Design of Straw Bale Buildings: The State of the Art. (San Rafael, CA: Green Building Press, 2006), 134
\(^{38}\) Ibid., 133
3.6 THE BURNING OF STRAW

Stubble burning is the removal of the remaining stems of the cereal crop after harvest, through burning. It is regarded traditionally as an important method of removing chaff, straw and other crop residues before the planting of the next crop and is believed to be the best way of returning nutrients to the soil, weed management and reducing disease. The consequence of this process is the direct pollution of the environment. This process has been banned in England since 1992, and continues to be in many other countries. A 2013 review of the practice by Environment Canterbury found that baling and removing cut straw after harvest gives many of the same benefits as burning does, but without the pollution. A change to this tradition of burning straw would allow a greater availability of straw as a building material and help to change the perception of straw as a waste material.

40 Foundation for Arable Research, "Review of the role and practices of stubble burning in New Zealand" Environment Canterbury Regional Council, 2013, 13
41 Ibid., 9
Figure 3-05, Grain growing areas of Canterbury with growing and straw producing figures

- 94,000 hectares of cereal crop grown
- 41,000 hectares of crop burned
- 44% of all straw produced, burned
- 310,000 tonnes of usable straw burned
3.7 STRAW BALE CONSTRUCTION METHODS

Throughout the history of straw bale construction many methods have been tried, based on the technologies of the time and often the materials available. There is a progression of development beginning with the simple Nebraska method, and in more recent times moving towards prefabricated straw bale systems. Analysis of existing systems gives an understanding of the benefits of each and how these can be combined and adapted to benefit a new prefabricated system.
NEBRASKA LOAD-BEARING METHOD

The Nebraska method is a load-bearing system where the roof loads are transmitted to the foundations through the stacked straw bales. The quick and simple construction of this system meant that it was popular in the early days of straw bale construction, before timber was introduced into the system as the load-bearing component. The bales are stacked and pinned together using timber or steel spears. An essential part of this system is that the walls and bales are pre-stressed, which is usually achieved with a bond beam on top of the bales and then connected to the foundations with tension ties. The roof structure is then fixed directly on top.

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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<tbody>
<tr>
<td>- Structural simplicity</td>
<td></td>
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<tr>
<td>- Short construction time</td>
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<tr>
<td>- System performs well in seismic events due to the ductility of the straw</td>
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<tr>
<td>- Especially low carbon footprint due to abundance of straw</td>
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<tr>
<td>- Construction process and simplicity allows for community involvement</td>
<td></td>
</tr>
<tr>
<td>- Uninterrupted thermal envelope because of continuity of straw</td>
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<tr>
<td>- Economical method of construction</td>
<td></td>
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<tr>
<td>- Less load-bearing capabilities than if timber was used</td>
<td></td>
</tr>
<tr>
<td>- System relies on plaster and the bales being pinned together for stability and bracing</td>
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</tr>
<tr>
<td>- Walls must be erected prior to roof, meaning there is potential for the bales to get wet during construction.</td>
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<tr>
<td>- Authorisation by local planning authority is difficult</td>
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<tr>
<td>- Multi-storey construction is possible but difficult</td>
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</tbody>
</table>

Figure 3-06, Top Right: 1:10 scale model of the Nebraska method.
Figure 3-07,08, Bottom Right: Examples of straw bale construction using this method.
Figure 3-09, These small pictograms indicate the main points taken from the precedent analysis and modelling.

Figure 3-10, Sectional Perspective of the Wall System

- **Timber Box Beam** allows the roof to fix to the walls and helps to support and distribute the load of the roof.
- **Base Plaster Layer**
- **Render** for an aesthetic finish. Lime plaster is best for the exterior as it is the most robust and flexible and allows vapour permeability.
- **To provide compression on bales, straps are tied around the bottom plate and box beam and tensioned until bales are compressed to appropriate level.**
- **Timber Box Beam is filled with straw to provide a continuous thermal envelope.**
- **Interior Clay or Lime Plaster layers to protect the straw bales from moisture and also allow water vapour to pass through the wall.**
- **Straw bales stagger bonded and typically fixed together with reinforcing steel or Hazel pins.**
- **Timber Bottom Plate creates an uplift for the straw bales to sit on to separate the bales from contact with any moisture.**
TIMBER FRAMED LIGHTWEIGHT METHOD

The lightweight method is a wall system method that uses the structural properties of both timber and straw as the load-bearing component. Typically timber posts are notched into the centre, interior or exterior of the straw bales (model displays posts centrally placed) at intervals and either side of openings. This eliminates all potential thermal breaks created by having the timber structure on the outer face of the straw. As with the Nebraska method, a timber bond beam is needed to tie the walls together and support the lateral loadings. However, the timber fixes directly to the bond beam creating a stable structural system and giving constant compression on the bales.

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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</thead>
<tbody>
<tr>
<td>- Roof can be raised prior to wall erection so the bales are protected from rain</td>
<td></td>
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<tr>
<td>- Utilises the structural properties of straw in collaboration with the properties of the timber frame</td>
<td></td>
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<tr>
<td>- Timber posts as structural members means less likelihood of thermal breaks because of insulative cover behind posts</td>
<td></td>
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<tr>
<td>- Fixing of timber bond beam to the timber studs allows for greater structural integrity</td>
<td></td>
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<tr>
<td>- Enables two storey construction</td>
<td></td>
</tr>
<tr>
<td>- Authorisation by local planning authority is difficult although easier than load-bearing method</td>
<td></td>
</tr>
<tr>
<td>- Notching timber posts into straw is tedious work, especially if placed centrally in wall</td>
<td></td>
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<tr>
<td>- Longer building process because of the need to erect and support the timber structure before bales are stacked</td>
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Figure 3-11, Top Right: 1:10 scale model of the Timber Framed Lightweight Method
Figure 3-12,13, Bottom Right: Examples of straw bale construction using this method.
Figure 3-14, These small pictograms indicate the main points taken from the precedent analysis and modelling.

- **Figure 3-15, Sectional Perspective of the Wall System**

  - **Timber Box Beam**: Allows the roof to fix to the walls and helps to support and distribute the load of the roof.
  - **Base Plaster Layer**: Render for an aesthetic finish. Lime plaster is best for the exterior as it is the most robust and flexible and allows vapour permeability.
  - **Timber Box Beam**: Is filled with straw to provide a continuous thermal envelope.
  - **Small Timber Plate**: To aid in the fixing of the posts to the box beam.
  - **Straw Bales Stack**: Bonded with timber posts notched internally into straw bales.
  - **Small Timber Posts**: Placed centrally at intervals to provide partial load-bearing support. Posts can be placed on interior or exterior of wall; however, centrally placed posts mean there are no thermal breaks.
  - **Interior Clay or Lime Plaster Layers**: To protect the straw bales from moisture and also allow water vapour to pass through the wall.
  - **Timber Bottom Plate**: Creates an uplift for the straw bales to sit on to separate the bales from contact with any moisture.
TIMBER FRAMED INFILL METHOD

The timber framed infill method is a wall system method that also uses timber as the load-bearing component and straw as the infilled, insulative component. A more standardised timber frame is used, but is built wider than normal to accommodate the width of the bale. Instead of having to notch the straw bales to accommodate the timber structure as with the previous system, the bales are ‘persuaded’ into place. Bales are then compressed using tension straps around the bond beam and bottom plate, with the beam then fixed down into the timber frame. This method of construction is more commonly used in contemporary straw bale buildings as it utilises an already established method of construction and there is no reliance on the bales for the structure.

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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<tbody>
<tr>
<td>- Timber as the load-bearing member in the system allows greater flexibility in design</td>
<td></td>
</tr>
<tr>
<td>- Greater flexibility in cladding choice because of the ability to fix into the timber studs</td>
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<tr>
<td>- Timber frame is a more standardised method of construction, meaning a greater understanding for construction methods involved</td>
<td></td>
</tr>
<tr>
<td>- Roof can be erected prior to wall erection so the bales are protected from rain</td>
<td></td>
</tr>
<tr>
<td>- Enables multi-storey construction</td>
<td></td>
</tr>
<tr>
<td>- Timber on exterior of wall system means there is more potential for thermal breaks</td>
<td></td>
</tr>
<tr>
<td>- Authorisation by local planning authority is difficult although easier than load-bearing method</td>
<td></td>
</tr>
<tr>
<td>- External location of frame can cause difficult waterproofing junctions</td>
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Figure 3-16, Top Right: 1:10 scale model of the Timber Framed Infill method
Figure 3-17,18, Bottom Right: Examples of straw bale construction using this method.
Figure 3-19, These small pictograms indicate the main points taken from the precedent analysis and modelling.
3.8 STRAW PANEL PREFABRICATION

Prefabrication describes any manufacturing process that takes place within a controlled environment away from the building site. It can be either modularised, panelised or complete buildings. Prefabrication offers an effective and efficient way of producing buildings, and at the same time, reducing the embodied energy associated in the production. A faster construction time, less wastage, and greater precision in a factory built situation all mean that the amount of energy affiliated with building on-site is reduced.

Prefabrication has long been a part of standard construction in New Zealand. In residential buildings 91% of all wall frames and 95% of all roof trusses are prefabricated. Yet the ideal way to implement straw as an urban material is through prefabrication, due to the familiarity of this method. It reduces the stereotypical rural connotations associated with straw, while also reducing the carbon footprint and embodied energy of the final building. The controlled off-site building environment means that there is less waste and greater material efficiency, while also reducing the risk of the straw getting wet during construction. The greatest benefits to be gained from prefabrication come when multiple units are being constructed. Thus a multi-unit panelised design is an appropriate typology for straw use in Christchurch, if the surrounding urban environment allows. Refer to the Site Analysis, section 5, of this document.

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The current direction of straw building internationally is moving away from the standard Nebraskan or lightweight systems, towards a prefabricated way of design. Standard on-site methods of construction are slow and there is always risk of the bales getting wet. Prefabricated straw bale wall panels combine the performance and low environmental impact of traditional straw bale with reduced labour and more consistent results.\textsuperscript{44} They also make the use of straw construction available to a wider range of people. In Europe there are two panel manufacturers who are doing exactly that: Modcell in England and Ecococon in Lithuania. The Modcell panel uses laminated veneer lumber and straw bales in it’s design. Unique to the Modcell product is the idea of the ‘Flying Factory’.\textsuperscript{45} A Flying Factory is a pop-up assembly space for the panels, local to the site. An empty factory space is used for the duration of the project and following completion it shuts down. Part of this includes the use of local workers that are trained to build the panels. The emphasis on local in the manufacture of this panel means that the embodied energy is greatly reduced, because of the benefits of prefabrication, and the reduced transport costs. Ecococon make a similar type of panel to the Modcell one but using compressed straw instead of straw bales.

The particular panel proposed for Christchurch uses similar principles of design and manufacture to the Modcell and Ecococon Panels. Everything required to manufacture the panels can be sourced locally: workforce, materials and factory space.

\textsuperscript{45} Craig White, "Modcell Straw Technology", International Straw Bale Conference, Methven, NZ, 2016, 4 March 2016
**MODCELL PREFABRICATED STRAW PANEL**

Modcell is a sustainable prefabricated straw bale panel made of a timber frame with straw infilled. A ‘flying factory’ is set up close to the building site, where a local team is trained to assemble the panels. Weathertight, rendered panels are then delivered to site. This off-site but local manufacturing means there is less waste, a lower embodied energy and a faster erection on-site. The presence of laminated veneer lumber (LVL) timber in the panel means a greater load-bearing capacity and means that there is greater flexibility in cladding choice. The examples shown highlight the flexibility of the panel in the different typologies it can be applied to.

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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</table>
| - Doesn’t have to be clad with plaster meaning a range of aesthetics can be achieved.  
- Is prefabricated offsite in factories so there is less time spent on site where there is potential for the straw to get wet.  
- High load-bearing capacity due to use of timber in system, allowing multi-storey construction.  
- Super insulated, high performance and low energy product  
- Manoeuvrable and compact | - Manufacturer of panels is labour intensive  
- Panel module sizes can restrict/dictate the design dimensions.  
- Timber in panel has potential to cause thermal breaks |

Figure 3-25, Top Right: 1:10 scale model of the Modcell panel  
Figure 3-26,27 Bottom Right: Examples of straw bale construction using this method.
Figure 3-28, These small pictograms indicate what is learnt from this precedent. They indicate the main points of what has been learnt and taken from analysis and modelling of the system.
ECOCOCON PREFABRICATED STRAW PANEL

The Ecococon prefabricated straw panel uses pressed straw, instead of straw bales, in a timber frame. By using pressed straw there is less reliance on the quality and size of the straw bale, but potentially there is a longer manufacture time. This system is made up of separate component panels; sills, lintels, columns, braced wall panels. Allowing the panels to be easily manoeuvred on-site. A team of four people can install 100m² of wall in two days.  

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<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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</thead>
<tbody>
<tr>
<td>- Able to be assembled quickly with few workers involved</td>
<td>- Manufacture and compression of panels is labour intensive</td>
</tr>
<tr>
<td>- Offsite manufacturing increases quality of panel and ensures fast erection of dwelling.</td>
<td>- Panel module sizes can restrict/ dictate the design dimensions.</td>
</tr>
<tr>
<td>- Uses compacted loose straw, removing the need for consistent bale sizes</td>
<td>- Many different panels require lots of fixings across the building</td>
</tr>
<tr>
<td>- When panels are joined together there is a continuous straw envelope, removing any thermal breaks in system</td>
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</tr>
<tr>
<td>- Individual panel components (lintel, sill, wall, raking wall) allow fast assembly onsite</td>
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</tbody>
</table>

Figure 3-30, Top: 1:10 scale model of the Ecococon panel
Figure 3-31,32, Bottom: Examples of straw bale construction using this method.
Figure 3-33, These small pictograms indicate what is learnt from this precedent. They indicate the main points of what has been learnt and taken from analysis and modelling of the system.

Figure 3-34, Sectional Perspective of the Wall System
3.9 TIMBER

Timber has a long history of use in New Zealand. It is a well used and well established building material, with the majority of homes in New Zealand built using it. It is the 3rd largest contributor to GDP after meat and dairy,\textsuperscript{47} which shows the important role that it plays in New Zealand’s economy. As a bio-material, timber has many of the benefits that straw does, in terms of sustainability and carbon footprint, and as with straw it absorbs carbon and stores it.

1kg of timber, through its growth, will store 1.47kg of CO\textsubscript{2} and return 1.07kg of oxygen to the atmosphere.\textsuperscript{48} In 2014 the forestry sector was responsible for removing 26.8Mt of carbon dioxide from the atmosphere.\textsuperscript{49} This equates to about 30% of the country’s total emissions.

\textsuperscript{47} Forest Owners Association, "2014 Facts and Figures", (Wellington, NZ: Ministry for Primary Industries 2014), 4
\textsuperscript{48} Andrea Leys, "How Carbon is stored in trees and wood products", Forest and Wood Products, 4-5
\textsuperscript{49} Forest Owners Association, "2014 Facts and Figures", (Wellington, NZ: Ministry for Primary Industries 2014), 43
being offset by our exotic forests. If this wood is burned the CO2 is put directly back into the atmosphere. By storing timber in buildings, the carbon that was sequestered is stored and not released back into the atmosphere.

Figure 3-35 shows the total plantation area of 1.746 million hectares. 6% of this total area is located in the Canterbury region (108,371ha). The accessibility to the supply of timber to Christchurch, ensures resilience in the material use. The map of major timber processing plants also shows three in close proximity to Christchurch (located in Rangiora, Christchurch and Rolleston) which reinforces the resilience also around the local processing of timber. Both timber and straw are local materials to Christchurch and are abundant as a resource. This should be evident in the future direction of the city’s built environment.

Both straw and timber are low carbon, local materials that need to be utilised in a way where their best qualities can be used to create low carbon architecture. Timber works well in a system with straw because the best qualities of each material are made the most of. The load-bearing qualities of timber and the insulative properties of straw work well together to form an efficient wall system. This is explained further in the prefabricated panel design in chapter 6.

Figure 3-36, Map showing locations of major wood processing plants. Note the 3 major plants grouped around Christchurch.
4.0 PRECEDENTS
4.1 PRECEDENTS

The precedents described in this section all influence different parts of the final design of this project as explained briefly below and in more depth in the individual precedent analysis.

The first precedent, the LILAC Ecological Co-housing was chosen for the way it addresses community living, and its use of the Modcell prefabricated straw panels.

Next, Sarah Wigglesworth’s office and home uses straw and other low carbon materials on a difficult and restrictive site. Her approach to material use and passive design methods influence the approach to the chosen site and the design.

The third precedent is the straw bale townhouses in Fano which exemplifies the use of straw in a medium density environment and the use of other bio-based materials in conjunction.

The final studied precedent is Peter Beaven’s Tonbridge Mews in Christchurch. This precedent informs the design aesthetic of the proposed housing development. It was selected because of it’s Christchurch based design principles that will help to integrate the proposed housing scheme into the urban framework of the city.
PRECEDENT 1: LILAC ECOLOGICAL CO-HOUSING

Location: Bramley, Leeds, UK
Architect: White Design Associates
Built: 2012
Straw Wall System Used: Modcell prefabricated straw panels

LILAC (low-impact living, affordability and community) is a 20 home community that demonstrates a successful combination of density, sustainability and community in a design that exemplifies the use of natural materials.\textsuperscript{52} The dwellings in this community are made using Modcell prefabricated straw panels which create a super-insulated interior environment and mean the carbon footprint of the community is small. The way that the residents live and use energy, is also an important part of this design in order to reduce the overall ecological footprint.

The community aspect to LILAC demonstrates a way of building communities that are resident-led. The design combines both private and public facilities such as a common house, dining area, laundry and workshop. The site design is based on limiting the on-site presence of cars and maximising communal gardens and green spaces, where residents can interact and enjoy similar activities.

Figure 4-04. These small pictograms indicate the main points taken from the precedent analysis. This precedent was chosen for its design around community and this is evident in the points learnt. Figure 4-05, Right: Simple analysis of complex plan for greater understanding of planning.
PRECEDENT 2: STOCK ORCHARD STREET

Location: Stock Orchard Street, London, UK
Architect: Sarah Wigglesworth Architects
Built: 1999
Straw Wall System Used: Partly load-bearing, partly timber frame with straw infill

Stock Orchard Street is an office and adjoining house with the aim being to demonstrate sustainable living in an urban environment. The architect responds to difficult site conditions, being located next to a railway line, through the use of appropriate materials such as straw, recycled concrete and cement bags which provide an acoustic barrier. The design combines recycled and low carbon materials in a tectonic and contemporary response to the site. Sustainable principles have also been included such as passive heating and cooling, rainwater storage, solar heating, and a green roof. A low carbon footprint has clearly been at the centre of this design. Also exemplified is an integration between home and business. Each function has different architectural expressions, with the exterior of the home being a collage of textured elements and the office being more subtle in its expression. The design exemplifies how natural materials and sustainable principles can be used in even the most urban of sites.

Figure 4-09, Above. This precedent was chosen for its use of natural materials in an urban environment on a difficult site. Figure 4-10, Right. Exploded perspective of building with features labelled.
PRECEDENT 3: STRAW BALE TOWNHOUSES IN FANO

Location: Fano, Italy
Architect: Studio Archetica
Built: 2014
Straw Wall System Used: Greb timber framed, straw infill

This project in Fano was for three terraced townhouses, the first of its kind in Europe that used both straw and hemp. Design objectives were focused around using innovative building materials in a contemporary, comfortable and sustainable way. This project uses a construction technique called Greb where prefabricated timber frames are infilled with straw bales and then cement plaster is used on the exterior. Straw bales are used for the external and common walls and internal walls are made of hemp bricks. Timber is used as the load-bearing component for its flexibility, because Fano is located in a high seismic area.

The design of these dwellings includes different areas of private space; rooftop gardens, and balconies. This means that although living in a higher density development, privacy is still retained.


Figure 4-11,12,13. Pictures show material choice and the design potential when using a combination of timber and straw.
Figure 4-14, Left: This precedent was chosen for its multi-storey design that uses many natural materials in an urban environment. The seismic difficulties around the site also are relevant to Christchurch.

Figure 4-15, Right: Simple analysis of building floor plans and section
PRECEDENT 4: TONBRIDGE MEWS

Location: Shrewsbury Street, Christchurch
Architect: Peter Beaven
Built: 1974
Wall System Used: Concrete block, timber frame
Number of Units: 18

Tonbridge Mews is located close to the Avon River, adjacent to Hagley Park. The development is arranged as a series of townhouses situated around both private and communal spaces, as well as semi-public thoroughfares through the site. The design of each individual dwelling is varied in both the interior and exterior. This avoids the uniformity often associated with high density development and helps to integrate the units into their long established residential neighbourhood. Varying heights of the dwellings and the relationships between each dwelling creates an interesting streetscape, one where Beaven’s traditionalist approach focusing on place, is evident. The arrangement of the townhouses around compact courtyards form the shared communal space. The multi-layering of the spaces and the manipulation of form stems from an understanding of the local tradition. Beaven’s ideas about a specifically Christchurch architecture will be discussed further in section 5.1.

Figure 4-16,17,18. Pictures show steep pitched roofs and a changing form creating a changing but also a somewhat regular elevation.
Figure 4-19, Left: This precedent is to gain a greater understanding of the best way to incorporate the proposed design into the Christchurch urban framework.

Figure 4-20, Above: Analysis of the site layout.
5.0 SITE ANALYSIS
5.1 CHRISTCHURCH CONTEXT
HISTORY & HERITAGE

Christchurch City is situated on the eastern edge of the Canterbury Plains, just north of the Port Hills and spreads as far as the Pacific coast. The city is built on a combination of shingle and the swampland associated with the Avon and Heathcote Rivers.²⁵

In Pre-European times Māori frequented the area, having Pā near what is now Barbadoes Street and at Riccarton but also on Banks Peninsula and north at Kaiapoi.²⁶

In 1843 the Dean's family from Scotland were the first to settle in Christchurch in the area of Riccarton. This area was chosen for European settlement with the standard, rectangular colonial grid layout chosen as the urban plan, made possible by the level land. However, this posed problems that were only evident after settlement. Constant flooding by the Waimakariri, Avon and Heathcote rivers caused problems for the town, meaning that flood protection and widespread draining of the swampland ensued and has continued until recent times.²⁷ The early buildings were constructed using mainly timber as it was the most accessible and this remained the common building material for most of the 19th century for all types of building; public, commercial and residential. The abundance of timber was relatively short-lived and soon a brickworks was established at the foot of the Port Hills, which held deposits of clay and stone. Brick and stone became the predominant building material, making the building stock a mix of older timber buildings and newer masonry. The architectural style of the area was established as Gothic Revival and then progressed into Edwardian which was popular at the time.²⁸

In recent times high-rise buildings have been the dominant central city building typology, dwarfing the historic buildings such as the Christchurch Cathedral. Many of these buildings have also since been demolished as a result of the 2010 and 2011 earthquakes.

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²⁵ John Wilson, "Contextual Historic Overview - Christchurch City", Christchurch City Council, 2005), 9
²⁶ Ibid, 10
²⁷ Ibid, 10
²⁸ Ibid, 81

Figure 5-01, Christchurch Settlement in 1852
THE CHRISTCHURCH STYLE & PETER BEAVEN

The Christchurch Style is used to describe the architectural movement of the 1950s and 60s, and includes the work of well-known architects Sir Miles Warren and Peter Beaven. The style originates from the architectural tradition and character of Christchurch, one that been largely lost with the destruction caused by the earthquakes and subsequent demolition of much of the city. Much of the 19th Century Victorian Gothic Revival architectural character of Christchurch was lost; steep pitched roofs, local and traditional building materials, ornament and detail, much of which is absent from the modern buildings of the rebuild. Figure 5-02 of Cranmer Court and 5-03 of the Provincial Chambers, where Peter Beaven had his office, highlight a sense of proportion and scale, factors which are important in integration into the Christchurch streetscape.

In the booklet, ‘Housing in the City’, David Turner says that each city has a unique characteristic or feature that creates its identity. This identity for Christchurch is based on the tradition and past aesthetic of Gothic Revival buildings throughout Christchurch. The use of both formal and informal elements and the direct expression of materials that is evident throughout

The Christchurch environment influenced many of New Zealand’s best architects, one of whom was Peter Beaven. Defining characteristics, all present in Christchurch’s colonial architecture later emerged in Beaven’s mature work. His belief in multi-layered architecture that responds to place, is responsive to the nature of materials and local building traditions stemmed from his formative environment of Christchurch. Peter Beaven's values are very much

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60 David Turner, Unitec, Housing in the City, 2015, pg 4

61 Peter Beaven, Peter Beaven Architect, (Blenheim, NZ: Peter Beaven Architecture Ltd, 2016), 266
traditionalist. In his book he writes, “It is generally accepted that this capitalist system is on the way to destroying the planet”. He goes on to say that possibly it is the small scale, local, sustainable and traditional architecture that is the new pathway. Beaven’s analysis of the Gothic Revival buildings of Christchurch and the local tradition is exemplified through his modern adaption and style. Tonbridge Mews, analysed in section 4.1, is one of Beaven’s best. His response to the site smoothly integrates the design into the urban framework of the city and uses design principles that emulate Christchurch’s style. Other buildings of note include Carlton Mill Road, a 5 storey residential building beside the Avon River, which is an interesting design on a difficult site. Of most note with this precedent is the design detail of the steep pitched roof with deep eaves as shown in figure 5-04. Beaven’s competition entry for the Christchurch Town Hall on Kilmore Street (Figure 5-05) is most interesting due to the buildings response to the site. The steep form of the roof is designed to remind of the strong shapes of the Port Hills. The asymmetry of the building allows full engagement with the site and the river through a continuous foyer.

It is important for any new building to enhance the identity of the city, as Peter Beaven did. We must use the values that we have learned from “the tradition of architecture through its small-is-beautiful, local and sustainable process.”

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62 Peter Beaven, Peter Beaven Architect, (Blenheim, NZ: Peter Beaven Architecture Ltd, 2016), 10
63 Ibid., 167
64 Peter Beaven, Peter Beaven Architect, (Blenheim, NZ: Peter Beaven Architecture Ltd, 2016), 195
Christchurch’s climate is largely influenced by its location beside the ocean, the Port Hills and being in close proximity to the Southern Alps. The predominant wind direction is from the north-east which brings cool sea temperatures, and also the south-west which brings air cooled by the Alps, often with rain. A north-westerly wind is also frequent, usually during summer, bringing warmer temperatures from across the Canterbury Plains. These winds are often gusty and have influenced development patterns across the city with protection provided by building layout, planting and fencing. The strong north-easterly wind is a key reason why Christchurch City is not orientated toward the beach as are most major cities in New Zealand.

The average temperature ranges from 22 degrees during the summer at its hottest to 0 degrees Celsius, at it’s coldest. The location of Christchurch means that it encounters extremes in temperatures, sometimes reaching 30 degrees during summer and getting below zero during winter. Annual rainfall ranges from 600-700mm with the monthly rainfall ranging between 40 and 60mm all year round. Snow is also not uncommon, with the city experiencing on average 3 days of snow a year. Christchurch is located on latitude 43.5 degrees south. It has a minimum sun angle of 23 degrees in winter and increases to 70 degrees at its maximum in summer.

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On Tuesday 22 February 2011 Christchurch was hit with a magnitude 6.3 earthquake that badly damaged the city and killed 185 people. The epicenter of the earthquake was shallow and located close to the CBD of Christchurch, meaning that the destruction was great. This earthquake is considered to be an aftershock of the earlier 4 September 2010 earthquake in which there was much less devastation.68

The earthquake occurred during lunchtime when many people were on the streets during their breaks, meaning that there were potentially a lot less casualties. The Canterbury Television and Pyne Gould Corporation buildings had the most casualties with 115 and 18 respectively. As a result of the earthquakes and the damage sustained, over a quarter of all the buildings in the CBD were demolished.

Because Christchurch City was built on swampland, liquefaction was an issue as a consequence of the seismic activity. Streets and homes were covered in thick silt and water, ruining whole suburbs, of which some may never be re-inhabited.

These earthquakes, as devastating as they were, provided a catalyst for change and a re-development of the city.

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EARTHQUAKE RECOVERY

Following the earthquake, the Government formed the Canterbury Earthquake Response Authority (CERA) which was in-charge of directing the road to recovery. CERA’s main purpose was the re-development of the central city in order to form a vibrant city centre with social and economic benefits. CERA and the Christchurch City Council (CCC) formed the Christchurch Central Development Unit (CCDU) which, following consultation with the public, developed the Christchurch Central Recovery Plan.

As part of the planning of the rebuild a community consultation process, called ‘Share an Idea’ was introduced that allowed the public to voice what they wanted to see in the central city. Central to the ideas put forward were features that would activate the central city and bring people back as the diagram illustrates. The five main initiatives to develop the city stem from this consultation process.

1. Green City
2. Stronger Built Identity
3. Compact CBD
4. Live, Work, Play, Learn and Visit
5. Accessible City

This plan aims to create a more livable central city, with core anchor projects aimed at bringing the public back into the city center. These projects are arranged in precincts and include attractions that help to create a complete central city.

Of great interest in the proposed plan is the location of the residential housing areas. Housing in the central city is restricted to the North and East Frames, which border the central area. For the purposes of this project it was decided to work within the proposed Central Plan. The impact of the plan on the chosen site is described and analysed further in the Chosen Site Analysis, section 5.4 of this document.

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70 CERA, Christchurch Central Recovery Plan, 2014, Page 21,
THE HOUSING CRISIS IN CHRISTCHURCH

The recent earthquakes in the Christchurch area and the subsequent red zoning and demolition of a huge number of dwellings has resulted in a high demand for housing in the region. The current demand can be attributed to earthquake related factors however long-term demand is more likely to be driven by population increase.

Earthquake damages houses:

It is estimated by the Christchurch City Council that 91% of all dwellings in greater Christchurch were damaged in the earthquake, and due to irreparable damage, over 15,000 of these were demolished. Influx of rebuild workers:

In 2011 the Canterbury Employment and Skills Board stated that 30,000 workers would be needed on top of the existing working population in the next ten years. This influx of workers puts pressure on the housing supply as much of this demand is temporary.

Population Growth:

In 2014 the population of Christchurch was 366,000. By 2041 the population is projected to grow by 25% to 453,000 with the housing demand likely to increase proportionally. The current demand for housing also has repercussions for housing prices, employment and education. A lack of housing and accommodation creates a reluctance for migrant workers to move to Christchurch because of the high associated costs. This is especially true if workers are moving with families.

74 CCC, Christchurch City Fact Pack, 2010, page 5

Figure 5-10, Housing shortage causes diagram
Christchurch needs 10,000 more homes to meet the current demand, and as discussed previously, a high demand is set to continue.\footnote{Stuff, Tim Fulton, "Housing on Track to Meet Demand", Last Modified 15 October 2015, Accessed August 4, 2016. http://www.stuff.co.nz/the-press/business/the-rebuild/73065531/}

An effective way of supplying the required housing for the city is needed, especially over the next 30 years. The location of this new housing will also be hugely important, with the focus needing to be towards infilling and densifying the city rather than greenfield development. City density is directly related to carbon emissions, with sprawling cities being much less sustainable than cities that are compact. By both densifying and using low-carbon building materials, a sustainable method of providing housing is possible.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure5-11.png}
\caption{Christchurch estimated and projected households. Exact projections will depend on factors such as birth rate and mortality, which is why a low, medium and high projection are given.}
\end{figure}
5.2 CHRISTCHURCH URBAN ANALYSIS
RURAL VS URBAN

The rebuild of Christchurch offers an opportunity to change the traditional sprawling patterns of the city. As more homes are constructed, and the city rebuilt, more people will find themselves drawn to the central city for work and enjoyment. Instead of continuing to create housing on the outskirts where people have to travel long distances, building in the inner city encourages walking or cycling.

The diagram shows the comparative relationships between different city areas and their proximity to transport, the CBD, amenities and work, along with land vacancy and price.
Christchurch Circulation:

This map shows the main roads and train lines in Christchurch alongside the Earthquake Red Zones. The more central the location, the more accessible it is to all parts of the city. The map also shows the correlation between the Avon River and the red zones.
Christchurch Land Zones:
This map shows the different land zoning across the city. The outward progression of the zones is evident, with business zones centrally placed amongst all other zones. Rural zoning surrounds the urban areas. Centrally placed residential areas around business zones are the most appropriate location for any inner-city housing development due to the accessibility to all daily needs.
Figure 5-15, Sprawl vs Intensification:

This map shows the different approaches to development of the city. Since the earthquake the proportion of infill development against greenfields development in the city has dropped due to the large proportion of land that has been re-zoned. The Land Use Recovery Plan sets a target of increased infill development for the coming years with an aim of 55% of development being infill by 2028.  

One of the key aims of this project is to promote low carbon architecture as an urban building material, thus a central city environment is the most appropriate location for any exemplar development. Research and analysis also proves that a centrally based site is the most fitting for this project. Analysis now moves towards the Central City.

76 CERA, Land Use Recovery Plan, Christchurch, 2013, page 18
Christchurch Central City  
Demolished Buildings & Red Zone:  
This map shows all demolished or partially demolished buildings within the central city as a result of earthquake damage. This means there are large areas of vacant land available for redevelopment. Much of this is residentially zoned (see Figure 5-14) or zoned within residential frames (Figure 5-18) that allow for inner city living at higher densities. Abundance of vacant land means that no buildings are required to be demolished.

Figure 5-16, Christchurch Central City demolished buildings and red zone
Christchurch Central City

Ammenities:

Ammenities across the whole city are generally clustered towards the city centre. This map highlights the location of some ammenities; libraries, schools, supermarkets, public facilities, emergency services and transport centres, in the Central City. This provides an understanding of the best location for the site to be in proximity to important parts of everyday life.

Figure 5-17, Central City Ammenities
Christchurch Central City Recovery Plan Zones:

This map shows key projects and precincts outlined as anchor projects in the rebuild. Living in walkable proximity to these attractions is of huge benefit to any residents, with the facilities meaning it is possible to work, play and shop without having to travel huge distances. As this project is based around fitting into the proposed central city plan the blue areas outlined as residential frames are of note as they are already zoned to accommodate densified living. Specific site selection within the central city is analyzed in the coming pages.

Figure 5-18, Central City Recovery Plan Zones and Precincts
5.3 SITE SELECTION

CHOICE OF SITE

This diagram highlights the sites of interest after analysis through the previous mapping. The decision to refine to these three sites comes from the availability of land due to demolished buildings, the proximity of the sites to amenities and the way that these sites fit into the rebuild plan. Being able to fit in with the proposed precincts and structure of the central city allows the development to contribute to the experience of the city. All three of the sites selected to analyse have different site conditions and will change the way the design is approached. In this section each site is analysed to select the most appropriate one for the project.
**SITE 1: ADDINGTON**

This selected site is located off the main circulation routes and is relatively undeveloped. Development in Addington has been centred around the road frontage of the main roads meaning that sites such as this one have remained untouched. New business in Addington is associated with innovation and it is becoming known as the professional business centre of Christchurch. This indicates that a development which utilises straw and low carbon materials would potentially fit into the community well. The location of the site sits at the threshold between different typologies, and main roads meaning that it would need to offer a means of connection between these, as well as permeable interaction with the community. The railway line also needs to be addressed in design.

Figure 5-20, Site 1, Addington Site Analysis showing surrounding circulation, building typologies and environmental factors
SITE 2: AVON LOOP

This site is separate from the main forms of circulation and surrounding housing, as it is an area isolated by the looping of the Avon River. Prior to the earthquakes, the Avon Loop was a strong community. Flooding and liquefaction meant that this area was red zoned and the houses subsequently demolished. A development here could bring the community back into the Avon Loop.

The building typologies that surround the Avon Loop are typical of a central city community; a mix of industry and low to medium density housing. Any development here would need to complement the river as it is a dominant and interactive feature of the site.

Figure 5-21, Site 2, Avon Loop Site Analysis showing surrounding circulation, building typologies and environmental factors
SITE 3: CAMBRIDGE TERRACE

Cambridge Terrace is a much more central site, situated on the banks of the Avon River, in close proximity to Cathedral Square. This site has a close connection to bus routes, and under the new Accessible City initiative, cycle lanes which are also proposed alongside the main roads and the Avon River. This site sits at a threshold between the building typologies of the inner central city and the slightly outer, residential area of the central city, meaning that the site needs to act as a means of connection between these. The changing building typologies around each side of the site are typical of any central city where there is often a combination of housing, workshops, retail and business. This means there are differing site parameters and levels of noise and interaction.

Figure 5-22, Site 3, Cambridge Terrace Site Analysis showing surrounding circulation, building typologies and environmental factors
<table>
<thead>
<tr>
<th>Location</th>
<th>Main Building Typology</th>
<th>Site Size &amp; Density</th>
<th>Site Strength’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADDINGTON</td>
<td>Factory/Industrial</td>
<td>30,000m²</td>
<td>- Close proximity to train station and public transport routes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Located in a thriving business district, meaning work is close to home.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Culture and business type of suburb is orientated towards innovation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 dph</td>
<td>- Surrounding factories provide spaces for the ‘flying factory’ concept of off-site fabrication.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Proposed site housing typology may not fit into the commercial typology of the surrounding area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Heavy traffic area due to surrounding industry.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Potential noise issues with train line and industry.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Separate to CBD and proposed anchor projects.</td>
</tr>
<tr>
<td>AVON LOOP</td>
<td>Single Detached Houses</td>
<td>70,000m²</td>
<td>- Site is largely cleared due to damage so there is no need for demolition.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 dph</td>
<td>- Located in an already established housing environment that is known for its focus towards sustainability.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Close connection to Avon River and Avon Precinct.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Large site area has potential for a large sized development.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Site has geotechnical and liquification issues along with flooding restrictions meaning development could be difficult.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Site is planned to become a public park as part of the Avon Precinct.</td>
</tr>
<tr>
<td>CAMBRIDGE TERRACE</td>
<td>Low Rise Terraces/Townhouses</td>
<td>15,000m²</td>
<td>- Site is cleared of damaged buildings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 dph</td>
<td>- In close proximity to anchor projects throughout the central city</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- On fringe of CBD makes for easy access to work opportunities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Has good road frontage.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Difficulties in design with need for response towards the PGC Memorial and other proposed projects on site.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Located at a junction of different building typologies and functions so consideration is needed to find appropriate typology for site.</td>
</tr>
</tbody>
</table>
SUMMARY OF FINDINGS

Based on the analysis of each of the sites strengths and weaknesses, the Cambridge Terrace site was chosen as being most likely to allow the aims and objectives of this project to be achieved. This site has great potential for a sustainable development, and is close to important facilities. While the Addington site is potentially closer to a 'flying factory' location for prefabrication, a 'flying factory' located in an industrial area like Addington is only 2.5 kilometres from the site.

Greater analysis of the site will allow design criteria to be formulated and a brief to be produced for the successful development of the site.
5.4 CHOSEN SITE ANALYSIS
SITE LOCALITY & HISTORY

The chosen site is approximately 15,000 square meters in area and is located to the north of the City Centre on the northern bank of the Avon River. The site is bound by four roads; Colombo Street, Kilmore Street, Manchester Street and Cambridge Terrace.

As the block is orientated east-west there is potential for wind corridors caused by the predominant, cold easterly and the north-westerly. The height and orientation of the buildings need to be regulated to ensure that no cold draughts are caused and that the development interior is protected from the harsh elements.

Under the Proposed Recovery Plans, Kilmore Street is proposed to become two-way (currently one-way) and become a major public transport route, as is Manchester Street. The Avon River Park and Precinct also borders the site, with public walk and cycleways proposed. This means that the site will have a high number of passing pedestrians and traffic. The proximity to many alternative methods of transport means that the reliance on private vehicles can be reduced to further add to the sustainable nature of this development.

Across Cambridge Terrace, on the banks of the Avon River, sits a Band Rotonda built in the 1930s. This was also damaged during the earthquake but is to be reconstructed.

The majority of the buildings that existed on the site before the earthquake were either residential or small business premises. Following the earthquake, all of the buildings were demolished, but a few new buildings having been built recently (see Figure 5-25, Chosen Site Locality).
In pre-European times this land was covered in dense kahikatea, totara and houhere forests, mixed with wetlands and waterways. The chosen site is situated at an interesting threshold where the type of forest changed, from kahikatea to totara to the less dense houhere forest. Figure 5-26 shows the extents of the different types of forests. Along with forest cover this site was also wetland, as was much of the area adjacent to the Avon River. It also contained many spring-fed streams that drained into the Avon.


Figure 5-26, Historical site forest cover
Figure 5-27 is of the 1850 design for the city and shows all of the smaller tributary waterways of the Avon. As the city was developed these streams were controlled with underground pipes.

However during the 2010 and 2011 earthquakes, where much of the infrastructure was damaged, these streams ruptured the ground, and briefly returned to their original state. By overlaying this waterway map with a map of post-earthquake destruction, correlations between the worst affected parts of the city and these streams and old riverbeds can be made. Di Lucas of Lucas Associates is responsible for making this connection and believes that any development needs to be carefully designed to minimise the effect of these underground rivers.78

Figure 5-28 overlays a post-earthquake map with the map of the waterways. Of the seven most significant building collapses, six were located on areas of historic waterways.

These historic waterways need to be addressed in the design. Di Lucas recommends, "respecting the natural systems better by avoiding high rise building and where possible 'daylight' the waterways by creating natural corridors".79 This is further addressed in section 6 of this document.

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FUTURE PLAN

The chosen site is zoned mixed use in the Central City Plan. It is also located in the Northern Frame which is a zone outlined for intensified central city living. It is currently partially occupied by three office buildings and an ‘international rental car precinct’ is proposed, which is due to be completed in May 2017. The commercial function of the site however does not fulfill the purpose of a designated housing frame, or mixed use development on a centrally located site.

A densified housing development would fit in well with the natural progression towards the CBD. Figure 5-29 highlights this and the gradual increase of heights and densities.

For purposes of this project it is chosen to focus on housing for this site, rather than a mixed use function, as is consistent with the aims and objectives. It is also assumed that the rental car precinct is not proposed for the site, allowing the housing development, as proposed in this research project, to take its place as an alternative.
Figure 5-30, Proposed projects in proximity to site

**OTAKARO ORCHARD**
Central City community garden and orchard aimed at demonstrating and promoting post-earthquake resilience and permaculture. For locals and visitors to gain inspiration and knowledge for sustainable food practices.

**CHRISTCHURCH TOWN HALL**
Restoration and re-development of the Town Hall after damage as a result of the earthquakes. It is to provide performance space to complement the adjacent Performing Arts Precinct.

**AVON RIVER PRECINCT**
New riverside promenade aimed at creating a city waterfront that is safe and vibrant and where cultural values are shared. Attractions alongside the river such as the Terraces and Watermark create points of interest for precinct users.

**VICTORIA SQUARE UPGRADE**
Victoria Square is to be revamped to increase the users of this public space. New features of the area, such as a punt stop, alongside restored heritage monuments will activate this space.

**AVON FOOTBRIDGE**
New pedestrian footbridge over the Avon is proposed adjacent to Cambridge Terrace. It aims to increase pedestrian and cycling activity along the Avon and will become an added focal point of the Avon River Precinct that follows the river.

**PETERBOROUGH VILLAGE**
An organisation of local residents who have interests in the area of Peterborough Street. Core values of this group are aimed towards sustainability, community and a more enjoyable local environment for all residents.

**ST MARK’S YOUTH CENTRE**
Transitional Housing hub for youth is planned on the site of what was St Luke’s Church. The purpose of the centre is to rehabilitate youth who are seeking medical help and counselling. This centre will also provide living options for around 40 of these people.

**PGC MEMORIAL**
Planned memorial for the 18 people who lost their lives in the PGC building collapse. Early ideas are towards a planted and landscaped memorial chosen by the families of the victims.

**MARGARET MAHY PLAYGROUND**
Central City playground aimed at encouraging families to spend time and relax in the central city. Becomes a unique focal point and attraction in the development of the central city area.

**EAST FRAME DEVELOPMENT**
Residential housing neighbourhood in the central city aimed at providing a greater choice of housing to people wanting to live centrally. Combines housing with restaurants and outdoor entertainment activities to create an attractive central living environment.
SURROUNDING DENSITIES

Urban containment has a multitude of benefits which mean that the city can develop local character through greater connectivity, density and social interaction. The surrounding densities of the site are important to ascertain if, in the future, a high quality public realm is possible and to ensure the development will not compromise the character of the area. The typologies and functions of the surrounding area are a mix of commercial, retail, residential and industry suggesting that there is an element of flexibility in the function and typology for the proposed building. The earthquakes changed the urban structure so greatly that much of the community, or the buildings that facilitate the community, are non-existent and are yet to be re-built. The densities of the area reflect this, with adjoining site housing densities of 1dph or 12dph, which is lower than is standard, especially in the central location. The proposed zoning of the area indicates the density is to increase with inner city medium and high density housing projects both proposed and being built. The site is located on the edge of the North Frame, a residential zoned area, which, along with the East Frame, is to house the majority of the central city population. Being in the North Frame means that the proposed sustainable, medium density development fits into the plans for the city centre, and can act as a sustainable precedent for future development.

Figure 5-31, The site has a mixture of surrounding typologies
<table>
<thead>
<tr>
<th></th>
<th>NORTH</th>
<th>EAST</th>
<th>SOUTH</th>
<th>WEST</th>
<th>FURTHER NORTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENSITY (Dph)</td>
<td>1 dph</td>
<td>15 dph</td>
<td>49 dph</td>
<td>12 dph</td>
<td>38 dph</td>
</tr>
<tr>
<td>NUMBER OF DWELLINGS</td>
<td>1</td>
<td>15</td>
<td>49</td>
<td>12</td>
<td>38</td>
</tr>
<tr>
<td>BUILDING TYPOLOGY</td>
<td>Single Detached</td>
<td>Multi-Unit Attached</td>
<td>Low-Rise</td>
<td>Low-Rise</td>
<td>Multi-Unit Attached</td>
</tr>
<tr>
<td>PARKING ALLOWANCE</td>
<td>None</td>
<td>Attached Garages</td>
<td>None</td>
<td>Attached Garages</td>
<td>Attached Garages</td>
</tr>
<tr>
<td>FUTURE PLAN</td>
<td>Mixed-Use</td>
<td>North Frame Housing</td>
<td>Cultural Precinct</td>
<td>Mixed-Use</td>
<td>Residential Housing</td>
</tr>
<tr>
<td>APPROXIMATE HEIGHT</td>
<td>4m</td>
<td>6m</td>
<td>10m</td>
<td>10m</td>
<td>6m</td>
</tr>
</tbody>
</table>

Figure 5-32, Analysis of city blocks surrounding site
EXISTING BUILDINGS

The site has historically had both retail and residential buildings but as a result of the earthquakes all of the buildings that once existed on site have been demolished. The buildings that exist on the site today have been built post-earthquake. As of February 2017 four office buildings occupy the site. These buildings are proposed to remain untouched but the 'international rental car precinct', currently under construction on the eastern side of the site, is disregarded as part of this project. Instead, the eastern side of the site (5300m²) is the intended location of the proposed housing development. A connection however, is needed between the buildings that exist now, and the proposed buildings.

Figure 5-33 below shows how the site has changed over the past seven years in terms of the buildings that exist on it. Note that much of the site is still vacant in 2016 (the building in the south-eastern corner has since been demolished), but of recent times the eastern area of the site is occupied.
Figure 5-34, Pictures of site and existing buildings
Figure 5-35. Plan analysis of existing buildings on site
Figure 5-36, Analysis of CORE Education Office Building to inform the design decisions that are made for my development so that there is continuity across the buildings.
Figure 5-37, Analysis of Office Buildings to create consistent design across site
Figure 5-38, Site layout and refinement of selected site area for design.
6.0 DESIGN
6.1 DESIGN BRIEF

Site:
Block between Cambridge Terrace and Kilmore Street, Christchurch Central, North Frame
- Site area for application = 5300m²
- Aim to achieve a density of between 40 and 50 dph

Design Aims:
- Promote sustainable living through effective design that integrates into the design style of Christchurch.
- Exemplify the use of low carbon materials through the use of prefabricated panels in design.

Design Objectives:
- Create a design solution for a medium density housing development that connects the residents to the city through interaction and social experience in environments that are melded into the site and surrounding areas.
- To explore and demonstrate the benefits of the housing typologies ability to encourage a healthy and diverse community that is environmentally aware.
- Demonstrate liveability and accessibility in created public and private space.
- Design with an understanding of place, giving sensitivity to the 'locale' including past natural and cultural events.

Details:
- Maximum height is 17m, or 4 storeys, but based on existing buildings and adjacent city blocks a more appropriate height is 2-3 storeys
- Design towards the proposed parks and public amenities on the surrounding sites.
- Design using passive solar design methods, incorporating resilient and sustainable methods of design.
- Facilitation of sustainable transport choices such as cycling, electric cars and public transport
- Develop a link or connection to the historic waterways on the site
- Create a permeable link between Kilmore Street and the Public Spaces on Cambridge Terrace, e.g the Otakaro Orchard, PGC memorial and Avon Precinct.
While the design of the medium density housing project is centred around providing a low carbon prototype, other key points of focus are needed when designing.

The nodes in figure 6-01 show the underlying design focuses in order to achieve the project aims.
6.2 PREFABRICATED STRAW PANEL DESIGN

"The panel is a combination of elements that together provide the complete structural, air, moisture and water protection requirements demanded of a wall."  

The prefabricated straw panel design is based on a collection of information, beginning with analysis of existing methods (refer to section 3.7). By identifying the projects needs, a panel can be designed which best meets these.

Advice on the structure and design of the panel was sought from Paul Jaquin, an engineer specialising in straw panel design, who helped to develop the Modcell panel in England. Many of the details shown are based on details sourced from 'The Essential Prefab Straw Bale Construction Guide' by Chris Magwood.

Figure 6-02 shows early conceptual design iterations of the prefabricated panel. Each design looks at different methods of constructing the panel. The initial thoughts towards the panel design have taken into consideration the conditions in Christchurch, however, it is not until the design is developed and refined that an accurate housing design can be considered.

The roof and midfloor of the dwellings are of standard timber construction. The midfloor uses timber joists with straw filled between. The roof uses timber rafters, again, with straw infilled between rafters for insulation.

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Figure 6-03 outlines the important structural components that make up the prefabricated straw panel. Each of these components are refined in detail in the following pages.
STRAW INFILL

The straw panel has been designed with straw as the infill component. The timber members in the system will carry all of the vertical load capacity and transfer this to the foundations. While straw does have load-bearing capacity, timber has a much greater capacity. The main benefit of the use of straw is its thermal performance, which depends on the orientation of the bale. This panel uses straw bales on edge as it increases the insulative value of the straw, and means that the panel is thinner. The R-value of this straw panel is around 5.6M²°C/W. 81

A standard bale is 450mm wide, 350mm high and (roughly) 900mm long. The panel contains five bales that are stacked vertically and compressed between the top and bottom members (to give a total straw height of 2.25m). A panel width of 1.8m, two bales, has been chosen based on the suitability of standard bale sizes and the flexibility that a panel width of this size offers. The straw bales are compressed into the timber structure once it has been fixed together to ensure there are no thermal breaks.

81 Accepted values based on laboratory testing at Oak Ridge National Laboratory, USA 1998. Bruce King et al. Page 193

Figure 6-04, Straw as an infill component in the panel. Not to Scale
The bottom plate of the panel is structurally responsible for transferring the loading on the panel to the foundations. The bottom plate is the point which the panel is fixed to the foundations so adequate fixing is required to prevent the uplift of the panel and resist lateral forces acting against the panel.  

The Modcell panel uses a bottom plate depth that matches the top plate, (between 250 and 300mm for a panel width of 3.6m). For this project a bottom plate of 360x63mm laminated veneer lumber (LVL) is to be used on two 90x45mm timber upstands. A depth of 63mm is enough to support the loading from above and transfer these to the foundations. The upstands provide separation from any moisture that may permeate through the concrete slab foundation and any potential flooding. Damp proof membrane is also used under the panel.  

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83 Modcell Straw Technologies, Modcell Technical Guide, Bristol, UK, 15  
84 Confirmed by discussions with Paul Jaquin, 18 October 2016  

Figure 6-05, Bottom plate design. Not to Scale
SIDE PLATE / POSTS

The posts are responsible for transferring loads to the foundations. The posts are 90x45mm timber studs\(^85\) connected with 25mm structural plywood. The plywood helps to brace the panel and form a load-bearing system, to carry the loads. The plywood overlaps the top and bottom plates and is fixed together using structural screws. This will place the structural loads directly onto the posts.\(^86\) The top plate and the plywood sheeting is screwed together and fixed using standard L brackets, which add extra fixing strength.

The posts sit flush with the end of the straw bales, meaning that a cavity is formed between the straw and the ply (see figure 6-11). This is filled with compacted loose straw to ensure no thermal breaks.

A 140x45mm bracing post is also used, placed centrally either side of the panel. This is fixed in line with the straw, which will require some notching of bales. The intention of this brace is to prevent distortion in the frames and help in carrying the vertical and lateral loads. Having a centrally placed timber member reduces the fixing centres to 900mm, allowing for more flexibility in cladding choice (see plaster render/cladding section).

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\(^{85}\) Sized using NZS3604:2011 stud sizes chart, and confirmed with Paul Jaquin, 18 October 2016
TOP PLATE

The top plate is responsible for transferring loading to the posts and providing structural spanning over the length of the panel. It also provides compression onto the bales to create a strong thermal barrier.

The panel uses a 200mm deep LVL top plate. The exact size and loading requirement of this member depends on the exact placement in the building and would need specific engineering. However, generally this is an appropriate depth for this member, when compared with systems such as Modcell, used in the LILAC project. Such a thick member means that although this part of the panel has no insulation, it is unlikely to cause a thermal break due to the thermal properties of the timber. As with the past components, the width is 360mm.

The top plate is fixed using structural screws and brackets to the plywood to transfer loads.

This figure is based on the Modcell panel as a precedent and advice from Paul Jaquin.

Modcell Straw Technologies, Modcell Technical Guide, Bristol, UK, 9

Figure 6-07, Top Plate Design. Not to Scale
PLASTER RENDER / CLADDING

Typically a straw bale wall will use a plaster render to seal and fill the surface of the straw bale while also providing moisture control and structural bracing. A plaster skin is "reinforced and butressed against buckling by the straw bale core, resulting in composite structural performance".89 One of the most important factors of using straw is to use materials that are vapour permeable to allow moisture to pass through the straw and not condense on any internal panel surfaces.

Because of the benefits that the plaster provides the panel is to be rendered in a lime plaster. Lime is more resilient than other plasters especially in the harsh climate of Christchurch. The plaster is designed to cover the timber edges to the panel, therefore will need mesh reinforcing to create a substrate for the plaster. The reinforcing also helps to brace the panel. A plaster layer can be anywhere between 25mm and 75mm thick.90 For Christchurch conditions, an exterior thickness of around 50mm is preferred. 50mm interior plaster is also applied.

It is also possible to clad the panel in more conventional building materials through the use of timber battens fixed to the timber structure. This provides a cavity that can then be plastered to seal the straw and protect from any moisture that may get into the cavity. The interior of the panel can also use timber cavity battens to create a cavity for services such as wiring and plumbing. This can be achieved without the use of the battens, however, the straw bales would need to be notched to accommodate. Standard plasterboard can then be used as the interior lining.

89 Bruce King, et. al, Design of Straw Bale Buildings: The State of the Art, (San Rafael, CA: Green Building Press, 2006), 21
90 Ibid., 19
Overall panel size to be 2500mm high, 1800mm long and 450mm deep.

Figure 6-09, Final Panel Design
To create an aesthetic where the straw is visible is difficult as any clear material is impermeable and has the potential for condensation to form, and thus the straw begins to decompose. Sarah Wigglesworth’s home and office (see section 4.1) uses a clear corrugate cladding but it is unknown as to the performance of this straw bale wall. To achieve it in this project, a corner join panel has been designed. This panel is 400mm by 400mm (less the interior plaster) and joins the wall panels in both the interior and exterior corners. By keeping this panel totally separate from the other panels, there is the ability to form a second watertightness barrier with the use of a water resistant membrane. Thus the watertightness of the corner panel may at times be less reliable, but the important wall panels will remain waterproof.

The panel is much the same as the larger panel in terms of structural make up, except that timber battens are used with a perspex cladding to reveal the straw. At the internal corners the same principles can be applied and a ‘truth window’ can be formed.
Figure 6-11, Panel to concrete foundation detail. Not to Scale
Figure 6-12, Panel to panel connection detail, cut horizontally through panel. Not to Scale

- Straw bales and timber members to finish in line
- 140mm x 45mm timber trim joiner, screw fixed to panel posts
- 90 x 45mm timber posts
- 25mm structural plywood
- 140mm x 45mm timber trim joiner, screw fixed to panel posts. Plaster render is to cover the trim
- Straw bales
- Detail does not show lime plaster. Plaster is to cover the whole panel including timber frames.
Lime plaster render is to cover the straw and trim joiner using mesh. Interior plaster shown as 50mm thick.

90 x 45mm timber posts. Screw fix through trim joiner into posts

25mm structural plywood to screw fix into adjoining wall panel wall panel where possible

90 x 45mm timber posts

Straw bales and timber members to finish in line

50mm thick lime plaster render applied to exterior of straw and timber

Figure 6-13, Panel to panel connection detail Not to Scale
Based on detail by Modcell Straw Technologies, Modcell Technical Guide, (Bristol, UK), 12
Figure 6-14, Panel to timber midfloor detail. Not to Scale

The climate of Christchurch affects many of the decisions made around the use of the prefabricated panel. High rainfall and strong winds mean that the wall should be protected thoroughly to avoid any moisture coming in contact with the straw. This can be achieved through large overhangs and an effective rainscreen.

The panel dimension of 2.5m high by 1.8m long restricts the design. By keeping the size of the dwellings to iterations of 1.8m panel lengths, it makes for simple assembly and means that only one panel width is needed.

Another design restriction is the placement of the panels vertically. By keeping the panels inline, the vertical loading paths have a direct, straight route to the foundations. This reduces the loading on each of the panels.

The best way to design with these restrictions is to overlay a grid onto the site that represents the width of the panels. Not all dwelling typologies are appropriate for this, so the most fitting is assessed in section 6.3.

The regularity created through the use of the panels fits in well with the traditional style of Christchurch. It also is in keeping with the aesthetic of the existing buildings onsite as assessed in section 5.4.

To create a simplicity in the design of these panels, window glazing is effectively the absence of a straw panel, meaning glazed panels are full height. Doors can be approached in the same way. The design around the use of the glazing needs to be carefully considered to protect the privacy of the residents, and to avoid overheating.

Figure 6-15, Final panel model. Scale 1:10
6.3 SITE LAYOUT

The site is located at a central point of many major attractions in the central city and is in the perfect position to create a link between these. This encourages public movement through the housing development and subsequently activates the interior of the site. It creates interaction with the public and helps to promote the use of low carbon materials in the city. The idea of permeability is crucial to the design and clear access routes to the site are needed to inform the public that they can move through the housing community. Adjacent to the site is the PGC Memorial. The site acts as a gateway to the memorial, so a clear public path through to create this connection is important. Figures 8-06 and 8-07 in the appendix show the movement through the site at both the micro and the macro levels and show how the site plays an important role as a destination in citywide movement. The proposed Avon Precinct that adjoins the Avon River, and a new bridge across the Avon will both increase the public use of this area and help with activation.

Figure 6-16, Site locality map with surrounding projects
The site is bordered by two busy main roads, which affect the site layout. Dwellings are orientated towards the street to provide a strong frontage which is typical of Christchurch as analysed in section 5 of this document. The acoustic properties of straw mean that even with the close frontage, noise will not be an issue in the dwellings. Another important reason for the orientation of the dwellings towards the street, is to provide wind protection from the unpleasant, prevailing easterly wind in the centrally located public space. The strong northerly aspect of the site means that the public space will have sunlight for most of the day, as will the dwellings. As explained previously, movement through the site is important to establish interaction. The main movement paths through the site are shown and the dwelling arrangement should integrate with these. The dwelling arrangement is also based on the underground waterways that run through the centre of the site (refer to figure 5-27 & 5-28). The public space is aligned with these waterways and ensures that the area occupied by these remains natural.

The site parameters plan (figure 6-17) shows an indicative block dwelling arrangement on the site. This is not the best typology or layout, and this is analysed in figure 6-18.
This model shows an apartment block housing typology with a clear link between Kilmore Street and the Avon and PGC areas. This typology is less appropriate due to the minimal public and private space and the difficulty of creating this using the prefabricated panels.

A courtyard apartment typology provides separated public and semi-public spaces while having enhanced permeability. The scale and density that this typology creates is too high and will not necessarily integrate into the surrounding urban framework as intended and analysed in section 5.4.

The stacked dwelling typology is a collection of housing modules arranged in a high density cluster. It creates a good separation of public and private spaces, but often private spaces between dwellings are located very close together. This typology becomes difficult when integrating the straw panels due to the waterproofing around the dwelling connections. Ensuring that each of the dwellings has sunlight is also difficult.

A terraced townhouse typology is more in-keeping with traditional Christchurch buildings, so integrates better into the surrounding area. It also enables a smooth transition between public and private spaces. This typology works well with the panel design and is the best typology moving forward.
This is not seen as a co-housing scheme but a cluster of houses. No communal facilities are provided. Often the perception of co-housing facilities is of alternative people living in a commune. An aim of this project is to introduce low-carbon materials as an urban building product to encourage it’s use in the city. By associating these materials with the common, mostly negative, stereotype of co-housing, it reduces the attraction of living in a medium density development and of using low carbon products. A sense of community is needed to make the scheme successful, however, it is anticipated that these dwellings will be individually owned and not part of any co-housing, group ownership scheme.

It is anticipated that the residents of these dwellings will be a mix of young families and working couples so both the site and the dwellings on the site have been designed for flexibility depending on who may use the dwellings.

As mentioned in section 5.4, the site is well connected to public transport routes and cycle lanes. Because of this, vehicle parking is less of a priority, although it is decided that there should be an allowance of one vehicle per dwelling. Carparks are to be located to the north-west, and the south-east corners of the site to create a separation from the rest of the site, allowing a greater density to be achieved. The carparks are located at either ends of the site to allow close access to the different housing blocks in the development.

As referred to in section 6.2 one of the limitations of using panels is the need to design in regular grids. Two housing typologies have been designed, a 3 storey option and a 2 storey option, that act as housing modules.
As mentioned previously, two different housing types have been designed. The decision to limit the dwelling designs to two typologies for this project is based on keeping the dwelling simple in terms of limitations with the panel, however a greater range of dwelling options could be developed using the panel.

As the complex is at medium density, the separation between private and public space is key. Figure 6-05 shows the development in a possible arrangement for one of the blocks. It shows an articulation in the dwellings to create a semi-private space that acts as a threshold between public and private. This transition space may often be shared amongst residents, but methods of separation such as planting and screening will help to separate between private areas.

A dwelling arrangement as shown in the final iteration of figure 6-05 shows a regularity but at the same time definition between dwellings. This is consistent with the Christchurch design style and the existing buildings on site (analysed in section 5.4) where there is clear separation between different levels and different units.

Figure 6-20, Diagram showing the development of the arrangement of the dwellings
Figure 6-21 shows a grid overlaid onto the site with dwellings orientated along these. The grid is the connection between the site design and the panel design, with grid lines shown on the plan at panel dimensions of 1.8m long and 0.45m deep. All dwellings are designed using panel lengths as a basis. Size is a restriction of the panel, so by keeping to standard panel dimensions a simple and iterative way of using the panels is achieved.

By keeping the design simple and standard, the overall carbon footprint of the complex is kept small because there are less components involved in the design. Simplicity ensures that the use of the panel is successful as people would be put off using straw if the dwellings leaked or had to be repaired due to problems created by complexity.
The height of the buildings affects the feeling of both comfort and enclosure in the central public space. It is also crucial in defining the placement of the buildings to ensure that each dwelling receives adequate sunlight. Figure 6-22 is cut north to south through the site at the closest point between clusters of dwellings. It shows that the height of the 3 storey dwelling type allows sunlight into the outdoor areas of the rear dwelling. A range of dwelling heights allows light to reach the central public space as the three storey building shades this space as figure 6-22 shows.

Figure 6-23 is a sun study of the site and shows that most of the site receives sun all day round, the exception being the dwellings on the western side of the site that are shaded by the CORE Education building at sunset. Due to their outlook and the abundance of northerly aspect sunlight this is not an issue. The northerly aspect also provides perfect orientation for solar photovoltaic panels on the roofs of the dwellings.
One of the intentions of the design brief was to achieve a density of between 40 and 50 dwellings per hectare (dph). The site plan shown has 24 dwellings at a density of 45 dph. This density is high enough that, "in time, social and environmental benefits will materialise and a vibrant [community] will be the result".91

The central pathway weaves around the dwelling clusters and represents the underground waterways on the site. Swales and planting around the paths will also help to create a connection.

The site plan shows shared party walls between each dwelling in a darkened colour on the dwellings. Utilising shared, party walls is a sustainable option for design as it means less materials are used. The insulative and acoustic qualities of straw mean that these are not issues.

91 David Turner, Unitec, Housing in the City, 2015, page 1
6.4 DWELLING DESIGN

As the site is based on a modular type design, only one block in the complex is designed in depth (as explained in Scope and Limitations, section 1.4). This is the northern most block that borders Kilmore Street.

The two housing units have been designed in accordance with principles of sustainability and passive solar design. These include:
- Solar photovoltaic panel on roofs
- Controlled north openings
- Large eave overhangs
- Water storage tanks
- Adequate cross ventilation

They have also been designed in regards to the limitations of the straw prefabricated panel, as explained in section 6.2.

Dwelling one is a two bedroom, two storey dwelling type. Dwelling two is a three storey dwelling with a second level mezzanine floor. Access for both of these dwelling types is located on the north, off Kilmore Street. The dwellings are all set back from the street to create separation from the road.

Material choice for these dwellings is based around low carbon materials and creating a design aesthetic that fits in with Christchurch and the surrounding buildings. The prefabricated panel has been designed to be flexible with cladding choice, so there are many options to achieve the required design aesthetic.
DWELLING TYPE ONE

Dwelling type one is a two bedroom dwelling based around a courtyard.

The dwelling has an internal measurement of 3.6m wide, 9m along its longest side and 3.6m along its shortest.

The courtyard offers enclosed private space for the occupants to dwell with relative privacy. The open plan living, kitchen and dining spaces open up onto the outdoor living area that receives ample sunlight from the north due to the thin plan depth.

The dwelling is 2 storey but the upper storey doesn’t fully cover the footprint of the lower storey. This is to create an articulation in the elevation design.
Figure 6-27, Dwelling type one sectional perspective

- Solar photovoltaic panels
- Lime plaster finish
- Straw insulates roof
- Timber louvres on north facade to control sunlight
- Timber deck
- Cross ventilation through dwelling
- Water storage tanks
The second dwelling type is a 3 storey townhouse with an internal measurement of 5.4m wide by 9m long. The grid lines indicate individual panels.

The footprint of the dwelling is minimized to maximize the public space on the site while also keeping the density within what was intended.

The living spaces are located on the south side of the dwelling, so the void is based around getting sunlight into these spaces. A deck off the second level living space separates the living area of this dwelling type from the ground level to create a private outdoor living area. Keeping the deck separate from the dwelling ensures there are no risks with waterproofing and the panel.

Figure 6-28, Dwelling type two floor plans
Figure 6-29, Dwelling type one sectional perspective

- Solar photovoltaic panels
- Straw insulates roof
- Straw insulates midfloor structure
- Timber deck
- Void allows cross ventilation through dwelling
- Timber louvres on north facade to control direct sunlight
- Water storage tanks
Figure 6-30, Block site plan with dwelling floor plans
ELEVATION DESIGN

As mentioned previously, material choice for these dwellings is based around low carbon materials and the limitations of designing with the prefabricated panel. Each of the straw panels is rendered using a lime plaster to allow vapour permeability. The large glazed openings on the northern facade are controlled using timber louvres. The corner straw panels are also exposed in places across the elevation (refer figure 6-09). The straw aesthetic is used sparingly in selected corners of dwellings as to not overpower the overall design aesthetic. The combination of these elements creates a verticality that is balanced through the horizontality in the exposed floor structure, visible through the glazed openings.

The overall block is symmetrical, which refers to the colonial style of many of Christchurch’s buildings. Exaggerated eaves and steep roof pitches also help to create an aesthetic that subtly represents the traditional Christchurch style. An abundance of trees and greenery helps to create privacy but also helps to partially return the site to its original extensive forest cover (see section 5.4)
THE KILMORE - MANCHESTER STREET CORNER

The corner of the site where Kilmore Street and Manchester Street meet is an important corner as it becomes the main entry to the site from the retail stores on Kilmore Street. This corner becomes a place of congregation for both the public and at times the residents. It becomes the face of the housing complex which is an opportunity to show that these dwellings are made of straw. One way of doing this is by using a truth window of exposed straw, which nearly every straw bale home has. This will inform the public that the dwellings are made of straw and create an attraction into the site. Peter Beaven writes that every corner should have a "memory of substance", and by creating a feature of the straw this will imprint in the memory of those who see it. There are issues regarding the moisture protection of straw panels that use a clear cladding, so using the method shown in figure 6-10 will reduce a lot of the risk. Planting and seating will also be used to aid in creating an attractive corner.

Figure 6-32, Sketch showing design possibilities for addressing the corner of the site

92 Peter Beaven, *Peter Beaven Architect*, (Blenheim, NZ: Peter Beaven Architecture Ltd, 2016), 173
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7.0 CONCLUSION
7.1 CONCLUSION

This project explored how low carbon materials can be used to provide a sustainable medium density housing model, reducing the contribution that the urban environment makes to climate change. The project began first with research, which included attending the International Straw Building Conference. Generally finding information about straw bale building is difficult, especially in New Zealand, which made this conference incredibly valuable for gathering relevant information. Analysis was then directed towards existing methods of straw building and other precedents. Investigation into the needs of post-earthquake Christchurch and the best approach to the chosen site meant that there was a strong understanding of all the requirements so that the correct design decisions could be made.

Analysis has concluded that it is possible to integrate low carbon building materials into an urban environment, with the outcome being through the use of straw panel prefabrication. The proposed housing scheme exemplifies that the integration of low carbon materials is possible. By focusing on the use of local, low carbon materials, cities can reduce their carbon footprint and ensure that the city is resilient. This project focused on Christchurch, however, the principles can be applied to any city. Many cities across New Zealand are facing housing shortages, and if these cities used a similar design approach of low carbon prefabrication, housing can be built that doesn't excessively contribute to climate change.

I view the project as an opportunity to increase awareness towards the need for low carbon architecture and the availability that we have to this in New Zealand. Most people are unaware of straw as a building product, and would never consider using it to build their own homes. I believe that the research and findings discussed in this project can aid in changing this view and that the outcome is evidence that straw building does not need to be restricted to the rural environment.

The project also addresses the need to densify cities. In regards to sustainability, densification is a much more sustainable option. As cities sprawl, the more the rural countryside is affected, and thus, in Christchurch for example, less straw is produced. I believe that the design response and process as explained in this document does create a viable method of low carbon architecture design in the city. However, much of this relies on the technical decisions made around the design of the prefabricated panel being incredibly accurate, and while an extensive effort has been made to achieve this, further consultation with an engineer would confirm the decisions made. Indepth collaboration with a specialist engineer would confirm choices made in the detailing of the panel and how it would best work in application. This would allow the panel to become a realistic option in todays building market, where there is a lack of low-carbon alternatives.

There is potential for future research to be focused around improving the sustainability of the final outcome. The overall housing design could be assessed with a more rigorous criteria of sustainability, such as the Living Building Challenge. Future improvement would be focused around refining the aesthetic of the housing development further towards the Christchurch aesthetic style. Features such as the site entry corner and the public space would be developed in more depth and more dwelling types would also be designed to provide more options towards housing. A greater analysis and thought of the possible aesthetic when using the panel would allow these new typologies to create differences in the aesthetic.
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<tr>
<td>STRAW</td>
<td>Straw Bales used as load-bearing structure or as infill in dwellings. Also can be used as insulating material.</td>
<td>Is a by-product of grain production, so is readily available wherever grain is grown.</td>
<td>All over NZ but especially Canterbury, Southland, East Coast, North Island.</td>
<td>Uncommon throughout New Zealand</td>
</tr>
<tr>
<td>TIMBER</td>
<td>Large amount of uses in Construction including; structure, cladding, flooring, roofing.</td>
<td>Most available building product in NZ</td>
<td>All over NZ but main timber growing regions are Central North Island and Northern South Island.</td>
<td>Most popular method of standard building construction.</td>
</tr>
<tr>
<td>CONCRETE</td>
<td>Concrete is a mixture of aggregate and cement. Used often as a precast or in-situ infill element.</td>
<td>Readily available throughout NZ</td>
<td>Cement and aggregate is sourced throughout New Zealand.</td>
<td>Hugely popular in building construction for many different uses.</td>
</tr>
<tr>
<td>STEEL</td>
<td>Used as a reinforcing or load-bearing component in buildings. Many other uses including roofing, framing.</td>
<td>Readily available throughout NZ.</td>
<td>NZ’s steel is produced at Glenbrook Steel Mill, just south of Auckland, due to the accessibility to iron sands</td>
<td>Used, in some form, as a component in almost all building projects</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Application</th>
<th>Availability in NZ</th>
<th>Production Areas</th>
<th>Popularity of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAMBOO</td>
<td>Multitude of uses in construction including; flooring, scaffolding, structure</td>
<td>Most bamboo products are imported from Asia</td>
<td>Not commercially grown in New Zealand for building.</td>
<td>Not often used in construction in NZ.</td>
</tr>
<tr>
<td>HEMP</td>
<td>Combined with lime or cement as an infill into timber framed walls, or as a brick</td>
<td>Any large quantity needs to be imported. Small growers in the Waikato and Nelson areas</td>
<td>Sparingly grown on farms across NZ. Is a fledging industry.</td>
<td>Not often used in construction in NZ.</td>
</tr>
<tr>
<td>HARAKEKE</td>
<td>Historically bundled and used as wall panels with clay often applied to the outside. Fibres also used as rope or linen</td>
<td>Is abundant around NZ but not commercially grown for building</td>
<td>Not commercially grown in New Zealand for building.</td>
<td>Used historically but very little in recent times.</td>
</tr>
<tr>
<td>RAUPO</td>
<td>Historically bundled and used as wall infill panels. Clay often applied to outside</td>
<td>Past draining of wetlands has reduced Raupo abundance, meaning mostly unavailable for construction.</td>
<td>Not commercially grown in New Zealand for building.</td>
<td>Used historically but very little in recent times.</td>
</tr>
</tbody>
</table>

Figure 8-01. Comparison chart of bio-based materials
Figure 8-02,03, Maps of grain growing regions in NZ
Figure 8-04, Map of grain growing regions in NZ.
Christchurch Property Value:

This map shows the average property prices per suburb across the city in order to gain an idea of where affordable land is located. Reflected in this map are the suburbs most affected by the earthquake. The eastern side of the city has by far, lower average prices than other areas, because of the effect the earthquake had. Typically, the prices of property in any city center are high, whereas here they are averagely priced against the rest of the city. The map also highlights a contradiction in the assumption made that city-fringe, rural property is cheaper, as we can see that generally the further out the more expensive the suburbs are.
Figure 8-06, Site movement at the micro scale

Figure 8-07, Site movement at the macro scale
9.0 APPENDIX B
9.1 FINAL DESIGN SOLUTION (NTS)
This scheme design is about meeting people's needs while maximizing density, while still retaining a sense of community. It creates a mixed-use environment that will be an example of what is possible with the use of sustainable materials, in Christchurch and also New Zealand. Over time, the site will be a range of home sizes from 2-bedroom to 4-bedroom units. The houses are designed to be compact while still providing the sense that they are separate from one another. The units are accessed through a service yard providing space with a smooth flow to a private outdoor courtyard. The courtyards are based on a grid plan to ensure efficient use of space. The plan is designed by the architects, however, the design offers flexibility for expansion.