Centre for
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Research

Developing Remote Residential Construction Methods.

A systematic study of existing configurations and design methods for developing remote residential construction systems.

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Research and publication by the
Centre for Building Performance Research,
Victoria University of Wellington.

In partnership with:

Studio of Pacific Architecture.

February 2019

Edition information

ISBN 978-0-475-12430-2

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The Document Register is provided at the rear.

Preface

This report presents the findings of a 'Summer Research'. A 400-hour undertaking in response to a project presented by a client, and the potential of it being a pilot study for other huts and accommodation in New Zealand's remote areas. The current study aims to 1) research case studies and collate what has been successful due to the variables of each project 2) complete solutions for services of, clean water, wastewater and energy 3) suggest solutions for other scenarios based on case study findings. The ultimate aim of this project was therefore to find solutions for constructing residential dwellings in remote locations in New Zealand, based upon precedent studies, and other variables such as site and time restrictions; using the client's project as a vehicle of study.

Acknowledgments

This work was funded by the joint investment of Studio of Pacific Architecture and the Victoria University of Wellington through the Victoria Summer Research Scholarship Programme.

This work is made possible by the valued efforts of the partnering researchers from the research group at Studio of Pacific Architecture.

This blend of partnering connects the academia and practical realms, essential for such advanced and pragmatic research and implications.

Notes

The intent of this project is to assist two parties: architects (expert) in finding solutions for remote construction, and potential clients (knowledgeable) wishing to gauge potentials ways of building and the feasibility of the project. Due to the two targeted audiences of varying knowledge, some of the outputs have been refined in user friendly formats for reaching the wider audience. Contrastingly, this report is for experts and researchers, wishing to see the full set of findings and the process of the investigation

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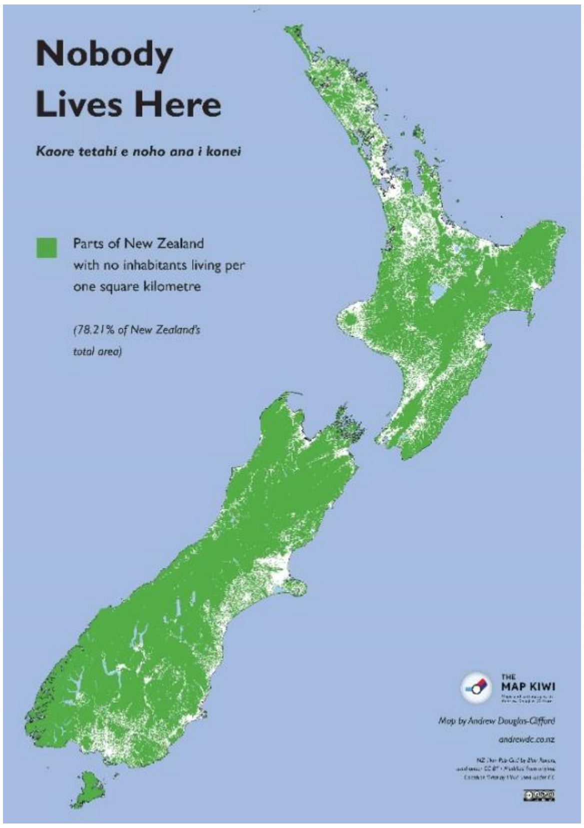
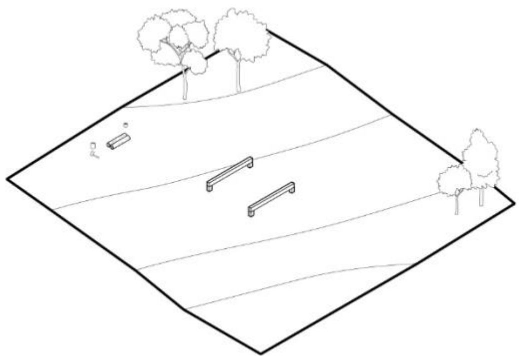
Introduction

This research investigates design and construction methods for remote residential dwellings in New Zealand. The vehicle of this study is a cabin in Matahiwi, in the Wairarapa region of New Zealand's North Island. Currently, there are limited ways of designing and building quality and permanent edifices in inaccessible sites on New Zealand. Conversely, most of New Zealand's land is undeveloped and not lived on. In addition, areas of preserving the landscape, native flora and fauna, with a series of Department of Conservation Huts (DOC huts) dotted few and far between (refer to appendix).



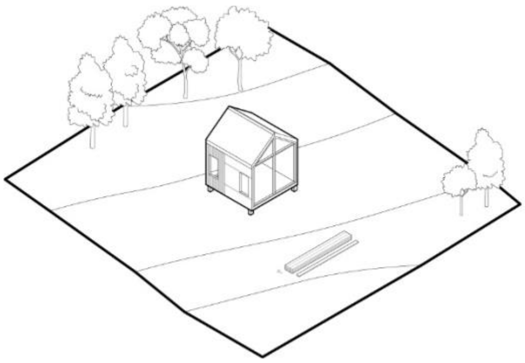
1 Map showing uninhabited parts of New Zealand ((Douglas-Clifford, 2017)

Construction methods used past and present in New Zealand have been determined as:



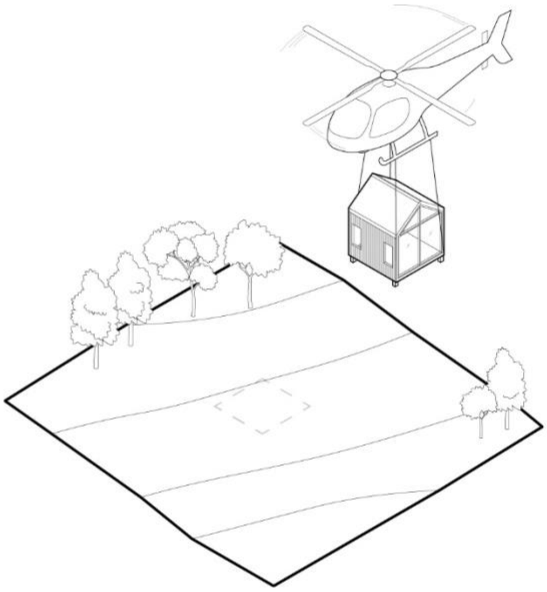
2 From the site construction (Author's own)

- From the site: an early technique involving building structures using materials gathered or harvested on or around the site. Examples within New Zealand include: Maori Raupo huts of the early 1880s, and their earth construction dwellings such as cob and rammed earth (McCartney, 2002).



3 Materials brought to site (author's own)

- Materials brought to site: perhaps a technique people associate with most low technology construction of residential dwellings. Bringing raw or pre-primed materials to site and constructing the building with systems such as timber framing from milled timber.



4 Prefabrication (author's own)

- Prefabrication: an emerging technique involving constructing the dwelling in pieces, or whole, in a factory off-site. Transporting the pieces or whole building to site via land, water of air transport followed by either minimal or no assembly on site. If assembly is required, it can often be completed by unskilled labourers with basic tools.

A fourth means of constructing could be the combination of any of the above methods. For example, materials for a concrete slab brought to site, slab is cast and a whole prefabricated dwelling is positioned using a helicopter and bolted appropriately to the foundations.

This report focuses on prefabrication, to create a viable proposition for constructing the 'Matahiwi Cabin' and advice for the construction of other remote dwellings. Furthermore, solutions for services will be proposed. The services examined are:

- Electricity
- Clean water
- Waste disposal

In the case of remote sites, it maybe easiest to produce or take care of these onsite, but offsite options are considered briefly. For the purposes of this project, more weight is directed to the construction methods, as the services are potentially more site specific due to rainfall in the area, sunshine hours, on grid connections etc. As how every project should be, in both services and construction design, the environment is considered, and aimed to be put first, to create sustainable, green buildings.

Due to a high client interest, and the drive being the actual project Matahiwi cabin, the findings of this report are directed to the client and their desires. Overall, this project aims to suggest ways of constructing small buildings in short time frames, on remote sites where some traditional construction methods may not work, with Matahiwi Cabin as the pilot study.

Research Questions

The focus of this study can be summarised by the following research questions:

How can one single storied module, of 50m2 floor area with limited complexity, be able to be constructed in a remote site in New Zealand, with an on-site time frame of less than a week, without wet trades?

What are suggestions for other potential sites and building scenarios for remote residential construction within New Zealand sites, based upon precedent works?

Background

Finding Case Studies

For the sourcing of case studies, technical and construction information, a variety of techniques and search engines were employed. These include some formal database searches (which will be outlined later) for general research into construction of remote dwellings. To match the practical application of this research for the Matahiwi Cabin, which is planned to be built in the next year, research via Google and given examples from clients and project architects have been incorporated.

Literature Review: databases

To create a credible base of information, several highly regarded databases were searched and mined for sources. These are below with reasoning as to why searched:

JSTOR

JSTOR is a 'cross-disciplinary digital library providing access to academic journal articles, books, and primary sources' (Victoria University of Wellington, 2019). This seems to hold good basis of information, with articles written about small prefabricated remote dwellings, which crosses disciplines of construction, history, and environmental and planning.

Australian Building Construction and Engineering Database: BUILD

Comprising of 'published and unpublished material on construction, engineering and aspects of economics, administration and management related to building and construction' (Victoria University of Wellington, 2019). BUILD was trialled as it has articles in the subject area and relevant geographical location.

ProQuest Central

As a multidisciplinary source of scholarly, general and reference materials (Victoria University of Wellington, 2019), ProQuest Central appears to cover a wide range or sources across multiple subjects.

Wiley Online Library

Peer-reviewed journals are more highly regarded in the field of research as more academics have formally edited by more qualified persons than those that are not peer-reviewed. As Wiley Online Library contains 'Full text peer-reviewed ejournals from the Wiley group of publishers' (Victoria University of Wellington, 2019), it is added to the list of useful databases.

Taylor & Francis Online

As 'a collection of electronic journal articles and encyclopaedias covering a wide range of subjects' (Victoria University of Wellington, 2019). Taylor & Francis Online is a beneficial database. It contains key information and journal articles about topics such as remote residential construction.

Scopus

Scopus is 'A multidisciplinary abstract and citation base of academic literature including peer reviewed journals, books and conference proceedings across all fields of science, technology, social sciences, and arts and humanities' (Victoria University of Wellington, 2019). As discussed, peer reviewed journals are highly reliable in that more than one set of eyes have looked over them. Scopus also claims to cover a wide subject range.

Literature review: key terms

With these databases, a small number of keywords selected find relevant sources. These derived from the project title, and then more or less added to narrow or widen the search.

Essentially, two angles of search were trialled. The first towards the construction methods themselves, and the second to the off-grid and sustainable energy, waste, and water strategies.

The way of deciding whether a source is 'relevant' is from manually reading the titles. Words such as 'house' word searched for manually which depict a dwelling for a small family or unit of people.

Literature review: excluding texts

After the first manual exclusion of works, some texts were deemed irrelevant yet again, each for unique reasons and after reading the articles' abstracts. The reasonings are outlined below and ultimately help curate a specific, useful selection of texts but also to find other systems and reflect on why they are not being researched.

Articles were found about 'Earthships' which use earth from the site to build rammed earth dwellings (Rachel, 2011). Whilst this is a solution to remote residential, it comes from the category 'from the site'. This can be a more time-consuming construction method and therefore is not suitable for this specific brief which relates to dwellings less than 50m2, with an on-site construction time of less than a week ideally (excluding foundations).

Furthermore, articles relating to 'robotics' appear to be more related to automated construction, and are thus deemed irrelevant, however, this developing technology may be used for rapid, remote residential construction in the near future.

Some articles came up related to 'suburbia' which is ultimately not 'remote' by definition of having little connection to other buildings, networks, or people. Thus, these articles were removed.

A number of articles were found to be about 'post-disaster' architecture and structures. Whilst these scenarios yield fast construction of homes, the abstracts tended to include the term 'temporary' which is not the goal of a cabin which is aimed to be returned to for many decades to come by potentially many different users. In saying this, 'relocatable' was not excluded as it may indicate the prefabrication style or be suited to a particular brief.

Other results discuss perception which is irrelevant in this discussion of construction and transportation methods. Therefore, these articles were removed from the literature list.

Literature review: results

Please refer to the appendix for a comprehensive table of all the searches and found literature. The table is designed to be straight forward, and the searches replicable.

There are 5 columns in the table and 'Database' refers to the search engine used (refer to 'Literature Review: databases'). Following this, 'Search Term(s)' is the exact term entered into the search bar, note the use of different notations such as the speech marks ("") to enclose terms and ensure the search engine searches the terms together. 'Results' is the number of articles the database returns. It was aimed to get this number below 100 to reduce the articles to what the engine deems as relevant and therefore less titles to read through. Next, 'Relevant Articles' is a list of articles that the abstracts were read through and articles were excluded manually (see 'Literature Review: excluding texts'). In the table, the halftoned grey titles are ones excluded as in the above section. The final column 'Notes' is other notes or exclusions of the search. Each horizontal bar refers to one search. Down the left side, the vertical lines indicate the searches aimed at finding articles regarding the services and operation of the dwelling opposed to the construction. Whilst this area is touched on in the report, a comprehensive description of the services solution is outside the scope of this report. transportation methods. Therefore, these articles were removed from the literature list.

Literature review: summary of key literature

Kiwi prefab: Cottage to cutting edge

This source was not found systematically, but narratively, through the prefabNZ website.

A 2012 book, by Pamella Bell and Mark Southcombe 'Kiwi prefab: Cottage to cutting edge' describes a switch in New Zealand's prefabrication sector; from 'cheap, small, relocatable, standard homes' to the recent prefab home which is 'design rich, high-quality, and readily customised to individual sites and needs' (Bell, 2012). The book describes what prefabrication is, key terms, and contextualises a history of Kiwi prefabrication.

Completing the book, is a series of essays, by international authors and a documentation of prefabrication challenges, accomplishment and emerging potentials (Bell, 2012). The book is written in an accessible style, with several images to make it an easy, yet informative read.

U.S. Department of Energy Solar Decathlon

This source was not found systematically, but narratively, from recommendations in meetings.

The U.S. Department of Energy Solar Decathlon is a tertiary education, international competition, comprising 10 contests, that challenges student teams to design and build highly efficient and innovative buildings powered by renewable energy. The winners will be those teams that best blend design architectural and engineering excellence with innovation, market potential, building efficiency, and smart energy production.

The combined competition features two tracks, the **Design Challenge** and the **Build Challenge**. The Solar Decathlon provides a hands-on experience and unique training that prepares the competing students to enter the clean energy workforce. This international competition has been a driving force in raising awareness about clean energy since its inception in 2002. Technologies and solutions used in Solar Decathlon homes have advanced the residential building industry both in the United States and abroad.

Solar Decathlon is more than a competition. It is an intensive learning experience for consumers and homeowners as they experience the latest technologies and materials in energy-efficient design, clean energy technologies, smart home solutions, water conservation measures, electric vehicles, and high-performance buildings.

The first Solar Decathlon was held in 2002; the competition occurred biennially in 2005, 2007, 2009, 2011, 2013, 2015, and 2017. The next Solar Decathlon is planned for 2019-2020.

Words adapted from (U.S. Department of Energy, 2019).

The DOE Solar Decathlon website contains a comprehensive list of all the entries from past years, with documentation and images. Particularly with the Victoria University team's entry of 'Meridian First Light House' in 2010, this competition provided a sound starting point for finding case studies of constructions within a short time frame, that utilise sustainable services and systems.

Remote Area Building and Sustainable Development

A journal article by Simon Scally, published by The Royal Institute of Australian Architects in *Environment Design Guide*, December 2011, the article discusses concepts of building and designing sustainable dwellings in remote regional areas of Australia.

> 'Compared with urban settings, remote locations involve substantial environmental and financial penalties in establishing, maintaining and operating buildings, infrastructure and connected services.'
>
> (Scally, 2011)

The article includes design and construction process considerations and adds weight to the notion of creating sustainable buildings, from cradle to grave. It also suggests that remote dwellings are required to be sustainable, for the benefit of multiple parties.

HOUSE 2011

An article published in The Architectural Review, highlighting winning houses. The key criterium is seeing 'how the design [...] is affecting and testing responses to urban issues and global challenges'(Slessor et al., 2011). Which translates to 'how to build efficiently and cut construction times, how to reduce energy use, and how to live in balance with nature' (Slessor et al., 2011). Within the article there are some prefabricated examples: 236 – Just K, Zero Energy House, and 239 – Prefab House by MYCC which is also sited remotely.

This article confirms the relevance of this study; that there is an interest in designing beautiful, architectural homes which are prefabricated.

Buildings and ecological science: the autonomous house

This paper describes the project of building a unique autonomous house in Japan. After treating the general concept of an autonomous house, the self-sufficient-sustainable systems for "Izu-Atagawa Autonomous House" to be built at Izu-Peninsula, 80 km south-west of Tokyo are explained in detail with visual presentations. (Tanaka, 1992)

It covers the idea of 'in symbiosis with the environment' and breaks down the concept of being self-sufficient. Tanaka classifies autonomous houses into: a) dwellings self-sufficient for energy, b) dwellings self-sufficient for energy and resources, c) completely self-sufficient dwellings. Classification c) refers to units which are not only self-reliant for all energy, water, and food, but for clothing too. They take in a 'minimum of industrial goods through contact with the outside world'. (Tanaka, 1992)

Izu-Atagawa Autonomous House itself, has provisions described for: heating, cooling, hot water, heat for cooking, sources of electrical power, water, drain water treatment, food, and the materials for the building itself and maintenance (Tanaka, 1992). These are portrayed in a series of hand drawn sections, and a list of other self-sufficient dwellings is provided.

Literature review: summary

Overall, the existing literature is limited and neither of the two searches uncover data specific to the project. There was largely and technology or engineering approach taken, or preliminary design advice. There were limited reports of how people solved their different brief and situation. The issues with finding relevant literature, likely stem from the fact that each project is different, with a unique set of requirements, challenges and issues. However, as this research addresses construction of essentially any remote residential dwelling in New Zealand, the information from the systematic literature review can be considered for any project.

From readings, it is also inferred that prefabrication is the most viable construction method for remote locations, due to the lower on-site times and costs. The other benefits of prefabrication, such as increased quality (Prefab NZ, 2019) will also be valid.

Remote residential dwellings should strongly consider being self-sufficient and environmentally friendly. Search terms such as ‘remote residential construction’ came up with articles on self-sufficiency and energy systems. Even more so when ‘off-grid’ (which some cases can be interchanged with ‘remote’). From the selected readings, there is a high push on passive design, energy and water saving tools incorporated in other remote dwellings. Thus, the literature review confirms that services are key in the construction and planning of remote dwellings.

Methodology

Establishing a method

A simple method was created, with the goal of using analysed case studies to create suggestions for other remote residential projects. This became a 6-step process as outlined:

1. Finding case studies and sorting them into a table

   Case studies were found from Google, Arch Daily, and literature largely in a separate and informal search, and precedents from the clients themselves (refer to **Data Gathering**). ‘Applicable’ case studies were pursued (refer to **Defining ‘applicable’ case studies**).

2. Finding additional information

   In aim to complete the table as much as possible, the case studies were revisited using the references and mined for all possible information to fit into the table. Terms were also used to classify the buildings according to research (refer to **Types of prefabrication**).

3. Editing data set down and creating graphs

   In order to create a useable set of data, some case studies were removed due to lack of key information (refer to **Editing the data set**). From here, a series of graphics, including graphs, dendrograms and tables were made in order to find trends and patterns.

4. Analysing and making conclusions from the data set

The graphs were then examined and key trends were identified and reported on. From here, some case studies become of interest, outliers and areas of potential were identified.

5. Making the data accessible

   A 'toolkit' was recreated for early scoping of remote residential projects done by clients and architects and providing a relevant case study.

6. Filling in gaps and completing other tasks

   A series of other tasks specific to the Matahiwi Cabin were completed, including Solar buy back rates, insulating a CLT wall and how any remote residential dwelling can deal with waste management.

Data gathering

For the sourcing of case studies, technical and construction information, a variety of techniques and search engines were employed. These include some formal database searches (which will be outlined later) for general research into construction of remote dwellings. To match the practical application of this research, research via Google and information given from clients and project architects has been incorporated.

Defining 'applicable' case studies

When finding case studies, some ultimately had to be rejected due one or both of two things:

- Their irrelevance to the Matahiwi Cabin
- Their lack of pertinent information

This occurred before entering data into a large spreadsheet with a series of case studies running horizontally and different variables running vertically. These were under the categories of: fabricated, built, site, project overview, prefabrication system, construction materials and systems, construction time, cost, weight, transportation, and lastly, references. In total, there were 31 columns and only projects with information filling at least 10 columns have been included. In terms of irrelevance, if the project was larger than 200m2 or not prefabricated, information was no longer looked for as the project would be outside the scope of the brief.

The table was laid out as follows, sectioned for this report format:

5 Diagram of spreadsheet showing ordering (author's own)

The above image shows the ordering of the different below sections.

				FABRICATED		BUILT		SITE	
No.	Name	Completion year	Status	Region	Country	Region	Country	Topography	Soil type

6 Section 1 of spreadsheet (author's own)

PROJECT OVERVIEW			
Size (m^2)	Number of buildings	Storeys	Prefabrication system

7 Section 2 of spreadsheet (author's own)

CONSTRUCTION		Wall		Roof	
Foundations	Floor	Structure (primary)	Cladding	Structure	Cladding

8 Section 3 of spreadsheet (author's own)

CONSTRUCTION TIME			COST			
Off-site (days)	On-Site (days)	Total time (days)	Currency	Rate	Price in local currency	Net cost (NZD)

9 Section 4 of spreadsheet (author's own)

WEIGHT			TRANSPORTATION		
Per unit (metric tonnes)	No. units	Gross (metric tonnes)	Method	Carboon footprint	References

10 Section 5 of spreadsheet (author's own)

Thus, each section of the spreadsheet was filled out with available information and some reasonable judgement. It was aimed to be as complete as possible.

Editing the data set

With the spreadsheet in hand, some case studies without the key information were ejected for the graphing set. The key information was set as: project name, status (built of unbuilt), built location (country), project size (m^2), prefabrication system (component, panel, volume, whole building), on-site construction time (days), transportation (truck, helicopter, helicopter capable). The 'helicopter capable' examples were all transported via truck, but have been deemed to be capable of being transported using helicopter based on a personal assumption made according to size, weight (due to materiality and size) information. It essentially means that it is plausible and they could be transported via helicopter if hooks were added, or if the elements were wrapped in a tarpaulin and perhaps more trips were taken than if transported via truck and crane. Thus, case studies with all this information have been included in data analysis which shortens the list from 46 to 32.

Principles behind existing construction methods

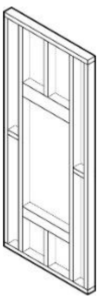
Construction vs Remote construction

The traditional construction site and the remote construction site have various differences, which can result in limitations for remote construction. Key ones are that there may be difficult access to the site, large vehicles and machinery such as concrete mixers, and diggers may be unable to reach the building site. In remote locations the costs associated with transporting materials and labour are high (Scally, 2011) thus the capital costs can be very high, to house and keep builders on a site for a long time, even up to a year, which many traditional builds can take. Another factor which makes remote residential builds challenging is the consideration of weather. Sites in high altitude may have stormy weather which means that a shorter build time is favourable, to reduce the chance of damage occurring to the build in its unfinished state. Poor design decisions will result in a high dependence on the continued importation of materials and fuel, and/or regular visits by specialists (Scally, 2011) to ensure the building is managed and maintained. The distances involved will compound the costs associated with this ongoing requirement (Scally, 2011). Thus, the build should support the owner's ability to maintain the dwelling, or employ local trades when necessary.

Types of prefabrication

Definitions for the classifications of prefabrication types are derived from PrefabNZ. These are used to sort the projects, and definitions are as below.

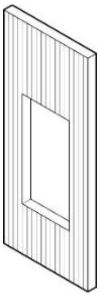
Component



11 Component prefabrication (author's own)

'The lowest level of prefabrication' (Burgess, 2013), this method usually results in the physically smallest, but largest number of items leaving the factory for site. It is essentially stick and subassembly prefabrication. 'Stick' refers to material members, which are precut, presized, preshaped, and designed to lock into together. 'Subassemblies' include building elements such as fixtures, fittings, windows and doors, as well as prenailed trusses (Bell, 2012).

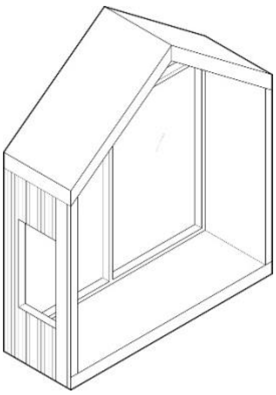
Panel



12 Panel prefabrication (author's own)

Nonvolumetric, two-dimensional prefabricated units are manufactured and transported as a flat-pack. There are two classifications of panels: closed and open. 'Closed' being wall framing complete with windows, doors, services, claddings and lining (Bell, 2012). 'Open' being the framing and cladding on one side (Burgess, 2013), but missing the elements to be a 'closed' panel.

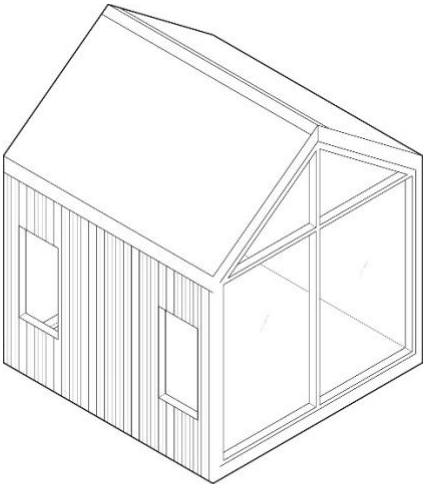
Volume



13 Volume prefabrication (author's own)

Also known as modular, sectional, or volumetric, this refers to structural units brought to site and combined with other modules to create the whole dwelling. These units 'are manufactured in controlled conditions with a high degree of services, internal finishes and fit out installed in factory prior to transportation to site. Additionally, pods and cores are non-structural units and are often used within conventional buildings. This approach is well suited to highly services areas like bathrooms and kitchens which are high value and can cause disruptions and delays to site due to the collaborations of different subcontractors. (Bell, 2012)

Complete building



14 Whole building prefabrication (author's own)

These are commonly known as portable, relocatable or transportable dwellings. Within the factory, they may use traditional or other prefabricated technologies to manufacture the complete dwelling. From the factory they are transported and attached to permanent foundations. (Bell, 2012)

Hybrid

This term refers to a combination of the above systems. Such as transporting a module and adding panels to complete the dwelling. Bell claims that 'hybrid prefab systems combine the benefits of two prefab construction systems, balancing construction efficiency with flexibility and consumer choice' (Bell, 2012).

For placing case studies under their appropriate prefabrication type, available text was read. In cases where it was unclear, images were examined to deduce the system used for that particular build.

Applicable Case Studies

Provided is a table of all the case studies identified, and some base information. Values rounded to whole numbers, some inferred.

To code the table, the following abbreviations and colours have been used:

SIPS – Structural insulated panels

STEPS – Steel thermal efficient panels

CLT – Cross-laminated timber

LVL – Laminated veneer lumber

unknown – value unavailable of unknown

Blue text – inferred data

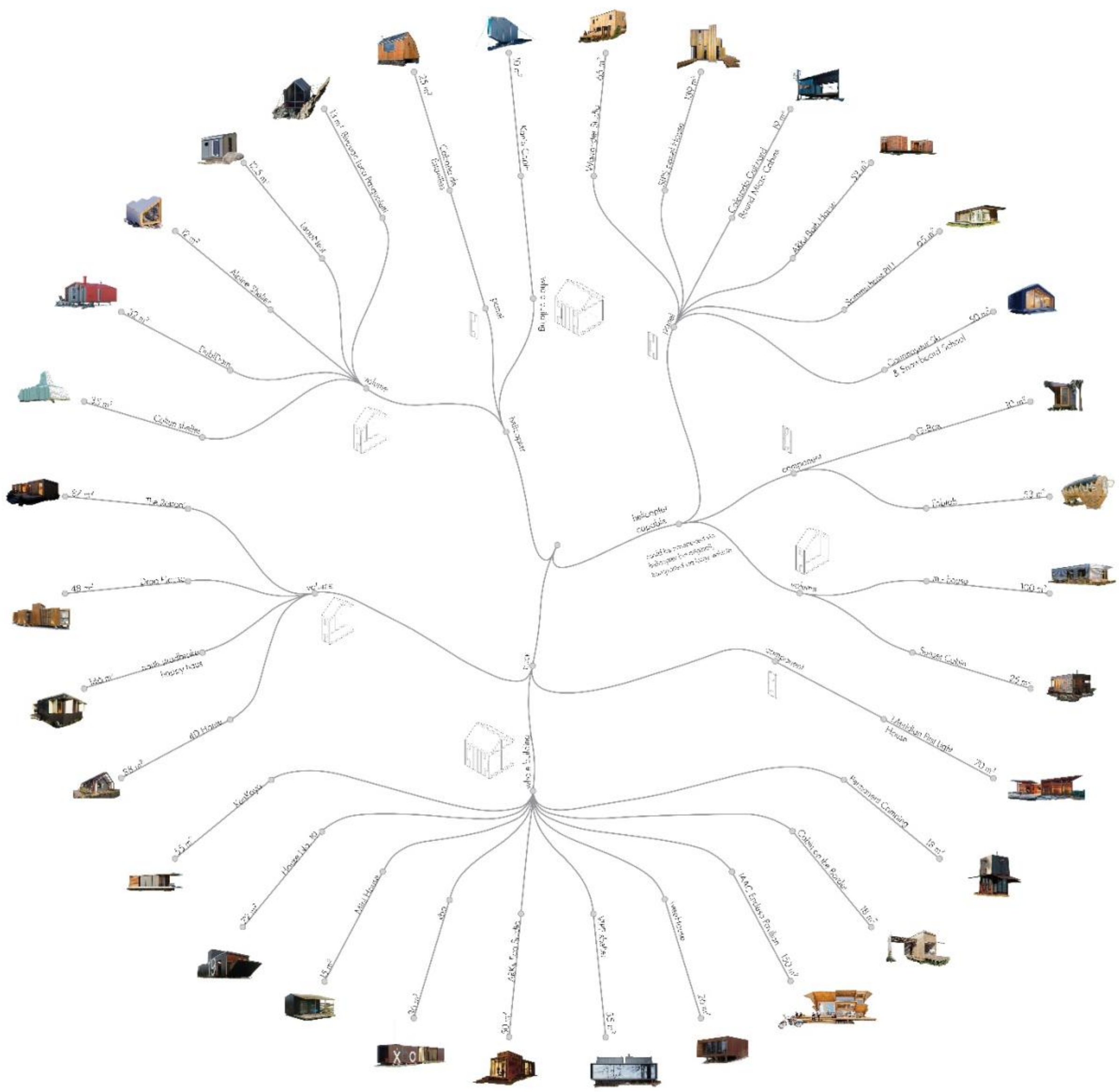
#	Name	Built location	Prefabrication system	Size (m²)	On-site build time excluding foundations (days)	Main material/system
1	Trailer Equivalent #2	UK	component	40	uknown	Timber frames
2	Warrander studio	New Zealand	panel	65	4	CLT frame
3	Meridian First Light House	New Zealand	component	70	7	LVL frame
4	Cabin on the border	Turkey	whole building	18	1	LVL frame
5	Bush House	Australia	component	168	uknown	Steel frame
6	PurePod	New Zealand	unknown	20	uknown	Steel frame
7	Min Cat	Brazil	volume	70	uknown	CLT panels
8	Călțun shelter	Romania	volume	35	2	Steel and CLT
9	Cabaña de Estanilles	Spain	panel	25	2	Timber frame
10	DublDom	Russia	volume	32	1	Steel frame
11	Turn Point	New Zealand	volume	114	uknown	Steel frame
12	Kanin Cabin	Slovenia	whole building	10	1	CLT panels
13	SIPS panel House	Chile	panel	139	10	SIPS
14	SIPS residence	Australia	panel	80	uknown	SIPS
15	Alpine Shelter	Slovenia	volume	12	1	Steel frame
16	IAAC Endesa Pavilion	Spain	whole building	150	1	Timber frame
17	Rock Reach House	USA	panel	93	uknown	Steel frame and STEPS
18	4D Home	USA	volume	88	7	Timber frame
19	Taliesen Mod.Fab	USA	panel	50	uknown	Steel frame and SIPS
20	The Rolling Huts	USA	unknown	19	uknown	Steel frame and timber
21	weeHouse	USA	whole building	26	1	Steel frame
22	G-Box	UK	component	10	1	Timber
23	VIPP shelter	Denmark	whole building	55	2	Steel frame
24	Colorado Outward Bound Micro Cabins	USA	panel	19	15	Steel and timber
25	Courmayeur Ski & Snowboard School	Italy	panel	50	5	Composite sandwich panel
26*	LeapNest	unknown	volume	12	2	Steel frame and SIPS
27*	Modular Mountain Shelter	Bulgaria	volume	8	uknown	Aluminium and timber frame
28	Bivouac Vigolana	Italy	panel	14	uknown	LVL
29	Bivouac Luca Pasqualetti	Italy	volume	13	1	Steel frame and CLT
30	Fablab	Spain	component	53	7	CLT frame
31	ARKit Bath House	Australia	panel	53	20	Timber frame
32	ARKit EcoStudio	Australia	whole building	50	1	Timber frame
33	xbo	Norway	whole building	36	2	Shipping container
34	north stradbroke happy haus	Australia	volume	146	1	Timber frame
35	Straw House	Switzerland	component	-	uknown	Compressed strawboard
36	Amalia	Austria	unknown	68	1	Timber frame
37	Mini House	Sweden	whole building	15	2	Sandwich panels
38	m - house	England	volume	100	2	Timber frame
39	House No. 19	The Netherlands	whole building	72	1	Steel frame and CLT

40	Permanent Camping	Australia	whole building	18	1	Steel and timber frame
41	Drop House	France	volume	48	1	Timber and steel
42	Vermont Cabin	USA	volume	152	uknown	Timber frame
43	Sommerhaus PIU	Germany	panel	65	1	Timber frame
44	The Retreat	UK	volume	87	1	Timber frame
45	KenKaya	South Africa	whole building	55	1	Steel frame and SIPS
46	Sunset Cabin	Canada	volume	25	10	Steel frame

*Unbuilt.

Selection of System

Analysing the case studies and the whole data set



15 Dendrograph of case studies (author's own)

The first diagram (image 15) is a dendrograph, which splits the data off into a series of sub categories, with the ends of each 'branch' being each case study with an image and the name. The grouping of the branches indicates data distribution and if each branch is followed, several pieces of information can be gathered about each case study.

From analysing the graph, the following trends and patterns have been noticed:

- **There are a limited number of case studies achieved using helicopter**

  With just 7 out of 32 (22%). This may be perhaps due to the uniqueness of the build, and in most scenarios, truck being a cheaper, easier method of transport.

- **All the case studies achieved using helicopter are small dwellings**

  The largest of these is Călțun Shelter at 35m^2. Călțun Shelter is a hiker's retreat with 3 'rooms' and shelter for 22 people. The fact that only dwellings smaller than the brief of this dwelling (40 – 50m^2) have been transported is of concern because it has never been done before. These precedents can however be used to decide and strategize the construction.

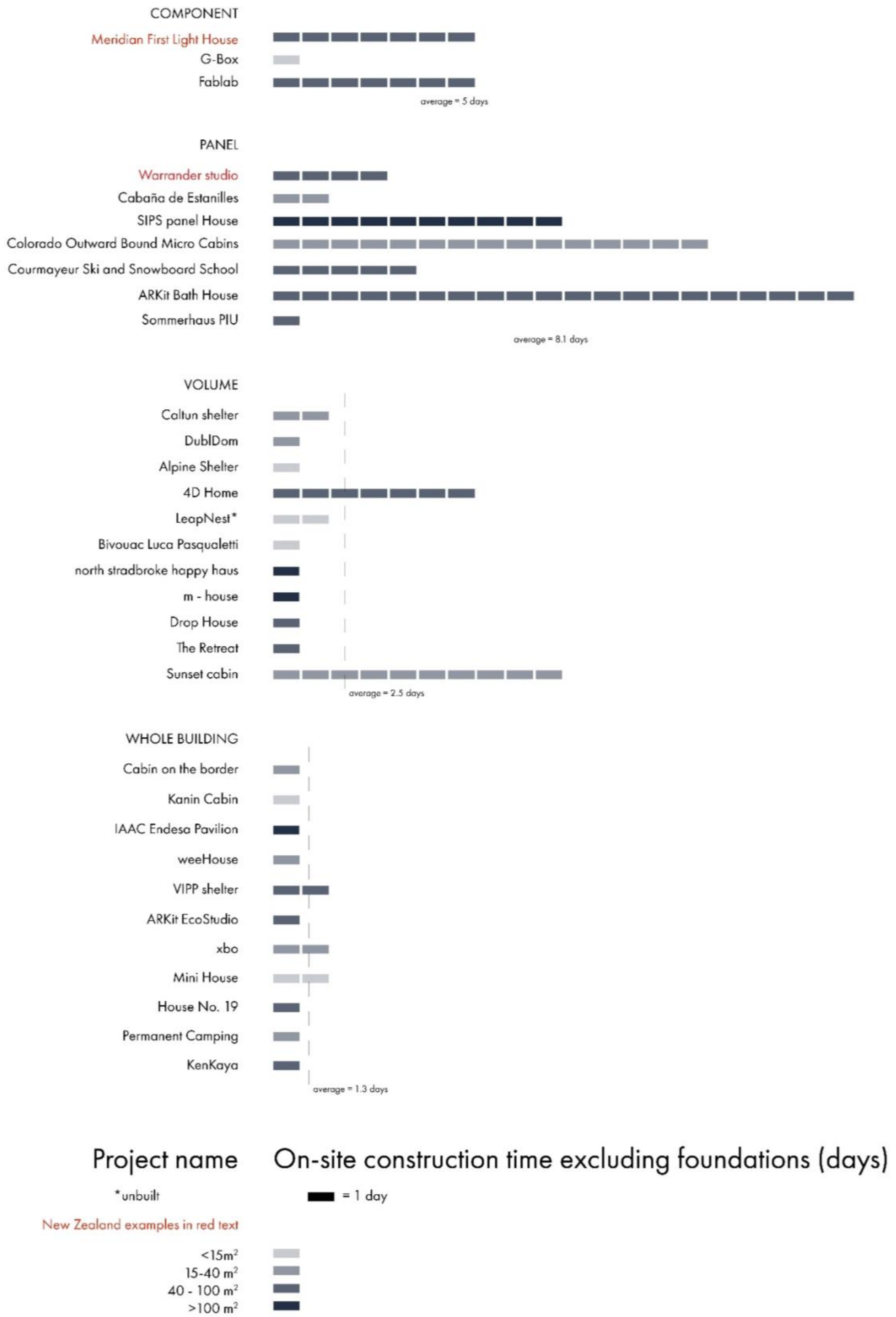
- **Most helicoptered projects use 'volume' prefabrication**

  This is probably for not exceeding the helicopter's lifting capacities, whilst still being able to create spaces big enough to achieve the brief by adding multiple volumes together. Călțun shelter used 3 volumes, DublDom used 2, Alpine Shelter used 3, LeapNest uses 2+ (model variant), and Bivouac Luca Pasqualetti used 4 volumes.

- **Panel, component, or small volumes are the most helicopter capable**

  This is solely based on the lifting capacity of helicopters, and the perceived weight of each unit based on the materiality and size. Which reserves the 'whole building' prefabrications for trucks as they are heavy weight but depending on truck size, there is a building size limit.

To summarise the findings from this graph, 22% of precedents were transported via helicopter, and all are less than 35m^2 which may provide a problem as the brief for this project is made up of 3 building 50m^2 or more. Also, volume was used most to achieve helicoptered buildings with 4 – 2 volumes as in the case studies, to match this, component, panel and small volumes are the most helicopter capable prefabrication techniques due to lifting capacities of the helicopter and perceived weight due to materiality and size.



16 Graph of case studies, on-site construction time, prefabrication style and size (author's own)

The second graph (image 16) is a bar graph, mapping three variables: on-site construction time, the prefabrication style, and the size of the dwellings. In this same graph, the number of examples of each prefabrication style can also be seen, and the names of each project, should they wish to be searched. One box is equal to one day, and the boxes are coloured shades of grey based on the size of the dwelling, within 4 groups (see the key). The average on-site construction times are shown with the dashed lines.

The following have been found:

- **Panel construction results in the longest average on-site construction time**

  The trend shows that according to the case studies, panel construction tends to take the longest, with the average on-site construction time being 8.1 days. In saying this, there are examples of panel construction taking less than 1 week, all under 100 m^2. These include Cabaña de Estanilles, Warrander Studio, and Sommerhaus PIU. Additionally, this data has the greatest spread with no correlation to the size of the dwelling. This suggests that people can achieve their product in shorter and longer time frames, using panel construction.

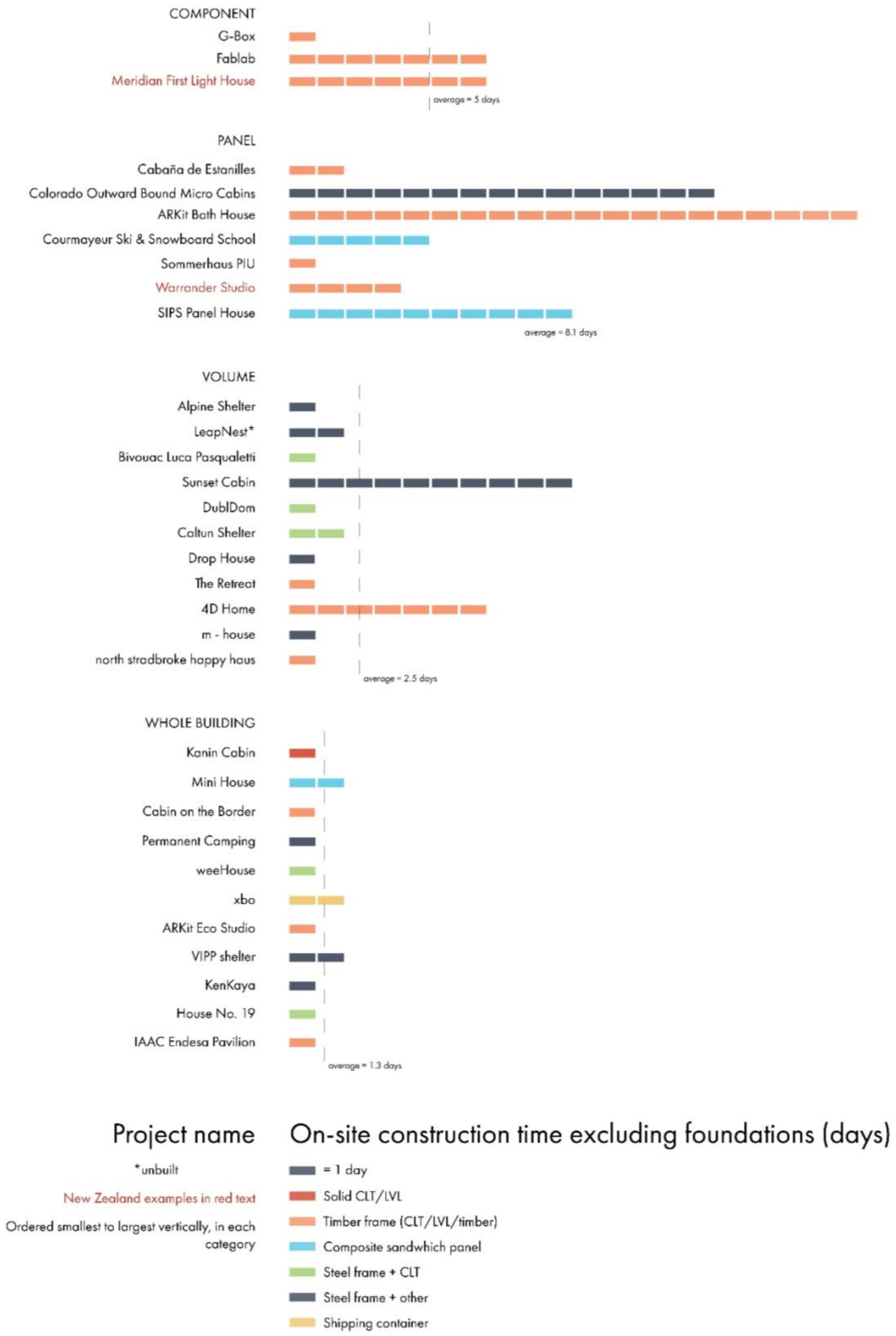
- **Whole building prefabrication takes the least time**

  With the average of 1.3 days it is proving to be the fastest construction method. Additionally, the data has the smallest spread – indicating highly precise data.

- **The higher the degree of prefabrication, the shorter the on-site construction time** (other than panel)

  The prefabrication types are ordered from least degree of prefabrication to highest degree of prefabrication, top of the page to bottom of page. From here, it is easy to see this trend with the exception of panel construction, which contradicts what is assumed to occur and the rest of the graph.

As above, from the data and graph, panel construction takes the longest on average. Over than this, the higher the degree of prefabrication, the shorter on the on-site construction time, which matches presumptions.



17 Graph of case studies, on-site construction time, prefabrication style and size and main material (author's own)

The next graph (17) is essentially, the second graph, with two key changes which assist in seeing the data differently. Firstly, the buildings are ordered from smallest to largest, vertically in each prefabrication category (component, panel, volume, whole building). The second change is the addition of material or key building systems. To display this, the projects have been colour coded according to the key below the graph. Whilst classifying the different constructions can result in a loss of information, it is useful for seeing data set patterns as a whole.

The following have been found:

- **All the component constructions used timber framing**

  This suggests that component prefabrication lends itself to replicating traditional construction methods (timber framing) with a few alterations to lead to a shorter on-site construction time. This use of the known construction may make it more likely for builders to agree to projects of a component prefabrication nature, and shorter build time due to the familiarity with the system.

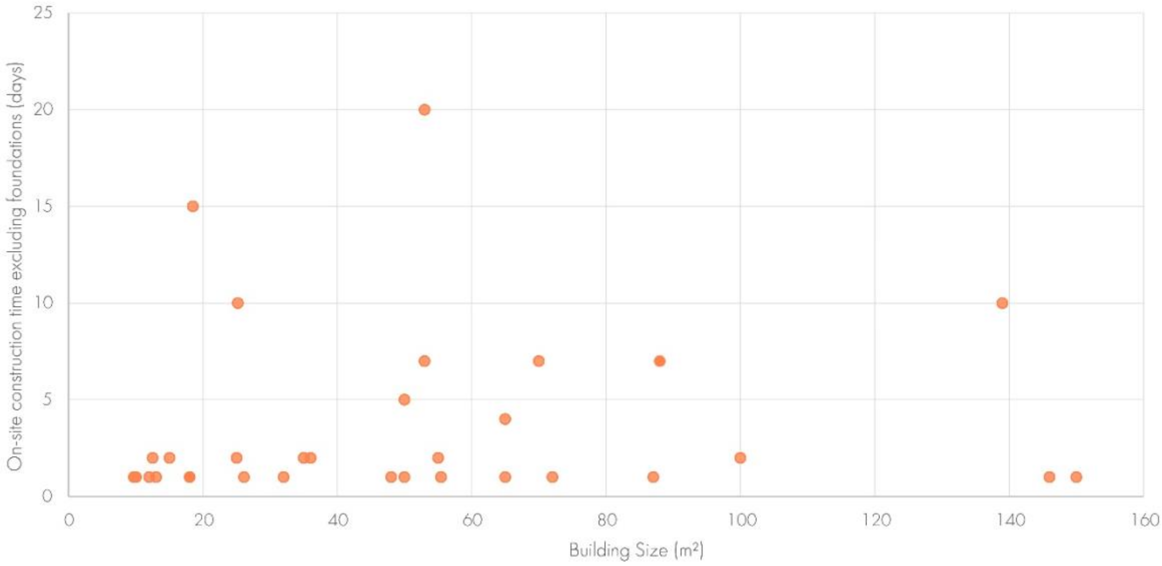
- **Whole building prefabrication has the widest variety of construction materials and systems**

  Whole building is the only category to feature all 6 classifications of construction. This may be due to the high level of control guaranteed within a factory setting. With such high control, there may be more room for experimentation and use of non-traditional techniques.

- **'Steel + other' is the most widely used construction system**

  This may be due to the high strength and rigidity of steel frames, meaning it is easy and safe to transport with limited damage to the system. Also, steel has higher strength to weight ratio that standard timber, so the loads for transportation would be less.

From this third graph, component prefabrication has used traditional timber framing techniques, yet whole building prefabrications have used a wider variety, for this data set. 'Steel + other' is the most common building system, perhaps due to its high strength to weight ratio for transporting elements to remote locations.



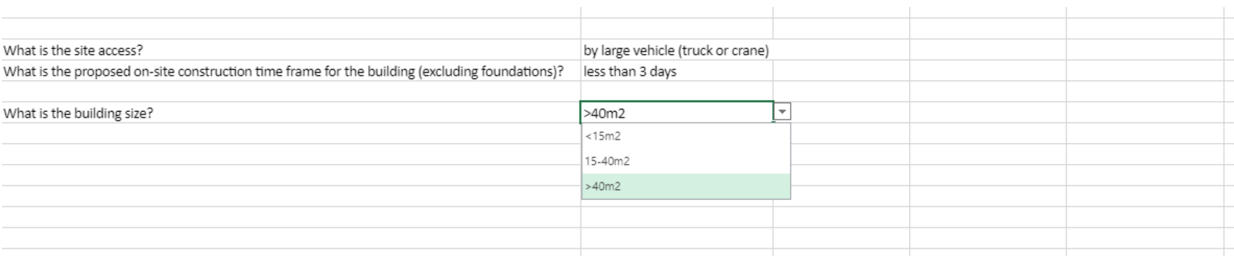
18 Building size vs on-site construction time graph (author's own)

The final graph is a scatter plot, plotting the building size against the on-site construction time excluding foundations. It is difficult to see a pattern in the graph and the plots simply show disarray or 'no trend'. The fact that there is no relationship, is useful in its own right. This is because it contradicts a logical expectation that the larger the build, the longer the on-site construction time, simply because there is more to build. However, this data of remote prefabricated dwellings suggests that the time on-site, is not related to the building size. Perhaps the act of prefabricating can greatly shorten the build time from traditional methods, regardless of the size.

Creating a 'toolkit'

The 'toolkit' aims to firstly, give an indication based upon case study research as to whether the project is possible. And secondly, to suggest feasible prefabrication systems for the project, and a suitable case study. The prefabrication systems are: 'whole building', 'volume', 'panel' or 'component'. For the purposes of simplicity, 'hybrid' has been omitted as the other terms can help decide what the main system is, and it can be hybrid, (e.g. panels and component) as required.

The 'toolkit' requires just 3 questions to be answered in an Excel spreadsheet, each with a small number of drop-down options. The drop-down options come almost directly from the initially curated spreadsheet of case studies.



19 Screen capture of toolkit 1 (author's own)

After answering the questions, the best options are indicated with an 'X', and a case study name is suggested, and in some cases, some additional notes (as in 20).

	whole building	volume	panel	component
best options	X	X		
case study	m - house			
notes				

20 Screen capture of toolkit 2 (author's own)

The suggested case study that had similar answers to the above questions. As there are limited case studies which used ‘helicopter’ as the transport, some of the recommended case studies are deemed ‘helicopter capable’ (refer to **Editing the data set**). Additionally, ‘best options’ refer to methods used in multiple case studies to achieve the building based on size, time frame and site access. The other options without an ‘X’ are still viable.

Concurrently, the user can edit their answers to see other prefabrication styles used for similar projects. Doing this can help create a wider range of case studies to work with and the systems could be adapted.

Client requirements and values

Whilst the toolkit can assist in determining whether a remote residential project is possible, by using analysed precedents, the decision of prefabrication method and construction can be completely overridden by the user. Some factors which may cause clients to differ from the toolkit’s suggestion include:

- Material preference: aesthetics, sustainability, availability, economics
- Degree of permanence: portability, longevity, design flexibility
- Cost: low or high capital cost, low or high maintenance
- Complying with local building regulations: Certain construction techniques may require a lengthy and difficult process in being consented by local authorities, so these may not be favoured

These factors can also be considered during the developed design stage of the project.

Matahiwi cabin

For the purposes of this research, Matahiwi cabin is the pilot case study for other potential dwellings constructed for remote locations. Whilst Matahiwi cabin itself, is accessible via truck from the neighbour's drive, constructions which can be helicoptered will be discussed and researched.

Matahiwi Cabin: trialling the ‘toolkit’

Using key elements from the brief for the Matahiwi Cabin, the following answers were added to test the toolkit:

What is the site access? ‘by large vehicle (truck or crane)’

What is the proposed on-site construction time frame for the building (excluding foundations)? ‘less than 1 week’

What is the building size? ‘>40m2’

The results are that volume and panel are the best prefabrication options, and that a key precedent to look at is ‘Courmayeur Ski & Snowboard School’.

If an answer is changed, for example if **What is the building size?** Answer is changed from ‘>40m2’ to ‘15-40m2’ then the suggested case study is ‘Cabaña de Estanilles’. So now two case studies are suggested and can be examined.

Matahiwi Cabin: prefabrication choices and brief

From the toolkit trial, volume and panel are the suggested methods. The clients then assessed their requirements and values and have ultimately decided on the following:

- A panel system using CLT panels and wood fibre insulation
- A design which can be disassembled and then put back together

These choices are put forward in the next phases of design.

Design implications relevant to the selected system

CLT

Cross laminated timer (CLT) is usually made by laminating more timber layers such that grain directions in alternate layers are at right angles to each other. Glue is applied between the layers on timber faces (Nairn, 2017). CLT in New Zealand is generally available made out of Radiata Pine and from factories based in Nelson.

For this part of the report, as following client requests, solid platform CLT construction will be analysed.

Weight

A factor in the design of any prefabricated building is the transportation and lifting (PrefabNZ, 2019) which directly relates directly to the weight of the units. Any vehicle has limits as to the weight it can carry. Moreover, the size and weight of the units, will need to be altered in the design phase to suit the mode of transport. If the transportation involves a short trip, multiple trips may be able to be executed. For the application of DOC huts, helicopters may often be required to transport elements, for these remote, inaccessible by car sites.

For the case of CLT, XLAM CLT has an average density of 480 kg/m^3 (XLAM NZ, 2017). Most helicopter lifting services in New Zealand are able to lift 1000 kg (1 metric tonne) (refer to table below), meaning that a helicopter would comfortably carry three 2.4 m x 3 m x 0.08 m thick panels, as they reach roughly 840 kg.

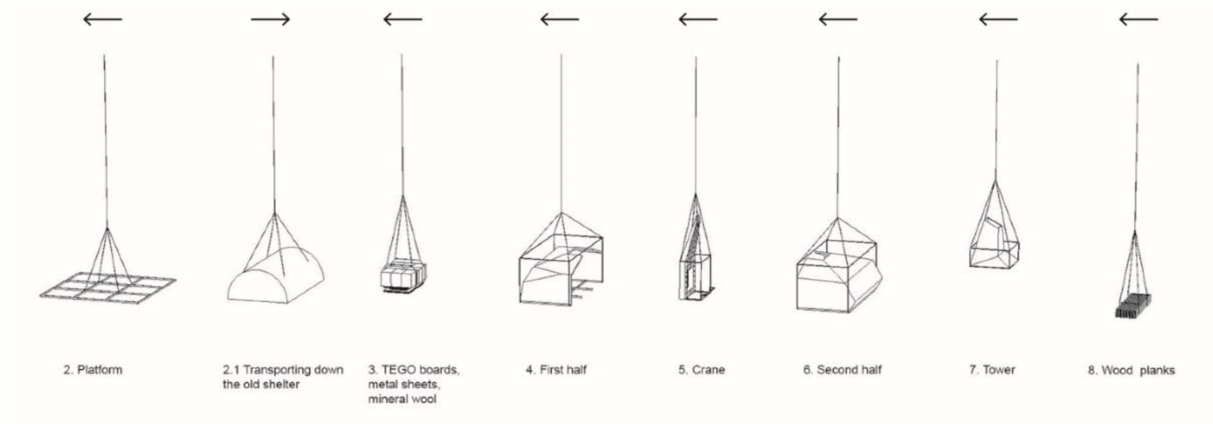
An initial list of New Zealand helicopter lifting companies, and their lifting capacity, has been provided. These came from the first two pages or so of a Google Search ‘helicopter lifting NZ’. For the extended table, please refer to the spreadsheet entitled **Helicopter lifting services NZ**. Whilst there may be more helicopters, they may not be available for commercial lifting jobs, and reserved for firefighting or emergency rescue helicopters.

Company	Location	Fleet (lifting)	Lifting capacity (metric tonnes)	Link
Beck Helicopters	Eltham, Taranaki	Bell UH1 Iroquois (Huey)	1.81	http://www.heli.co.nz/
INFLITE commercial	Auckland	AS350 SQUIRREL	0.95	https://www.inflitecommercial.co.nz/
Amalgamated Helicopters LTD	Caterton, Wairarapa	MD600N	2.04	https://www.amalgamatedheli.co.nz/
Skywork Helicopters	Auckland	Eurocopter AS 350B3	1.2	http://www.skyworkhelicopters.com/index.cfm
Hanmer Springs Helicopters	Hanmer Springs, Canterbury	AS350FX2 ZK - HJM	1.0	https://www.hanmerhelicopters.co.nz/
Helicopter Services	Taupo	ZK-HKC AS-350 B3	1.4	https://helicopterservices.nz/
Heletranz Helicopters	Auckland	Eurocopter AS355 Squirrel	0.94	https://www.heletranz.co.nz/
Heli Glenorchy	Glenorchy	AS350-B3	1.4	https://www.heliglenorchy.co.nz/heli-glenorchy/
Precision Helicopters	New Plymouth	Eurocopter AS350 B2	0.9	http://www.precisionhelicopters.com/
Anderson Helicopters	Hokitika	Airbus AS350B2 Squirrel	1	https://aheli.net/
HELIWORKS	Queenstown	AS350 B3	1	https://www.queenstownhelicopters.nz/
Frontier Helicopters	Whakatane	SIKORSKY UH60 BLACKHAWK*	3.6	http://www.frontierhelicopters.co.nz/
Rotor Work	Waikato	Eurocopter AS350 B2 Squirrel	1	https://www.rotorwork.co.nz/

*Coming to New Zealand soon (Kahu, 2019) and soon to change company name to 'Kahu'.

The row highlighted, is the best choice for Matahiwi Cabin as it is a local company and a high lifting capacity of 2.04 metric tonnes. Ex-military helicopters generally have the capacity to lift larger loads (2 – 4 metric tonnes).

In cases where a new prefabricated building is being erected in place of an existing building, the return trips can be utilised in to transport existing materials or structure. An example of this is the Călțun Shelter (refer to 21), which replaced an old existing shelter in the mountains of Romania (Archdaily, 2015). Arrows have been added to help in the comprehension of the diagram. In step 2, the helicopter transports the existing shelter back. In step 6, 'crane' refers to a segment of the building opposed to an actual crane.



21 Transportation plan for Călțun shelter (Archdaily, 2015)

⟵ = To the site

⟶ = From the site

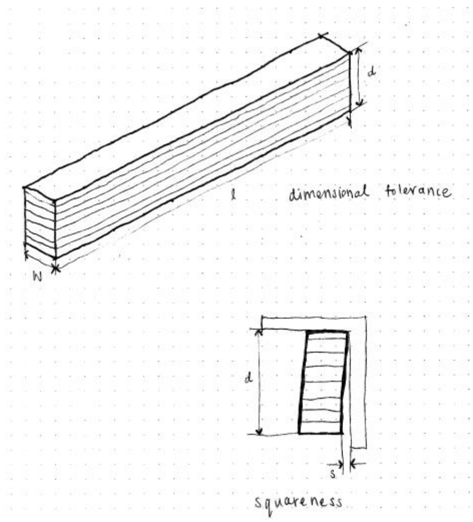
As above, a simple transportation plan can be created and people can work on the build whilst the other parts are being transported. These weight and size limits need to be considered in the design development phase.

Tolerance

As timber is a natural material, shrinkage and expansion can occur in fluctuations of temperature, or due to age. Even more so, with pieces that interlock, line up, or fit into each other, require an amount of construction tolerance to be designed in.

According to the Handbook of Construction Tolerances, there is a flow on effect from the manufacturing, to the constructing. First is the dimensional tolerance in the fabrication of the members themselves, as supplied by the manufacturer, this - along with movement - is then accommodated by construction tolerance. (Ballast, 2007)

Generally, each manufacturer works to their own tolerances (Ballast, 2007) and will include them in calculations prior to fabricating the units (XLAM NZ, 2017). The Handbook of Construction tolerances suggests allowing 3 – 5 mm for prefabricated timber elements (Ballast, 2007). For SIPS panels, allow ± 3 – 6 mm (Ballast, 2007).



22 Fabrication tolerances for CLT adapted from (Ballast, 2007).

As from the guidebook, yet converted to the metric system, the following dimensional tolerances and squareness are below (image 22).

For dimensional tolerance:

- *d*: + 3mm per 300mm of depth, - 5mm or 2mm per 300mm of depth (whichever is largest)
- *l*: ± 2mm per 6100mm of length (if less than 6100mm then ± 2mm)
- *w*: ± 2mm

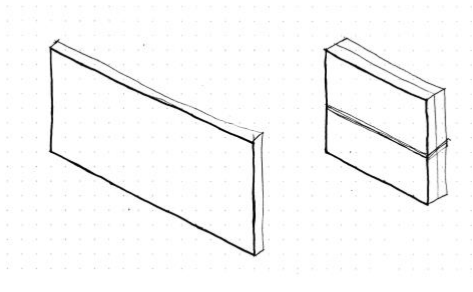
For squareness, when set to a carpenter's square, expect ± 3mm per 300mm of depth.

As explicated, refer to the specific manufacturer for tolerance guidelines, yet expect ± 2 – 5 mm for prefabricated CLT elements.

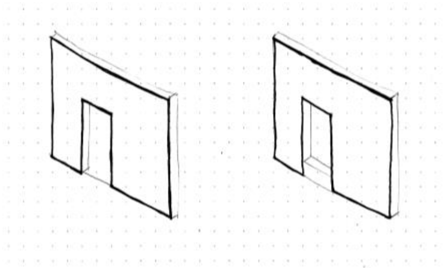
Shape factor

For transporting via helicopter, the panel has to be rigid and structurally sound, to avoid damage to the elements. As said by the Infrastructure Health & Safety Association of Ontario, load shapes can affect in-flight handling (n.d.). Longer or flimsy loads may be more prone to breaking if appropriate care is not taken. An experienced helicopter pilot should be able to assess whether a load can be taken and they can be marked with their required orientation by using north or other marks to match mark to laydown locations (IHSA, n.d.).

Some key guidelines associated with wall panel transportation have been diagrammed:



23 Helicopter lifting guidelines 1 (author's own)



24 Helicopter lifting guidelines 2 (author's own)

The first axonometric diagram (23) shows that if a large panel can be transported, consider designing two panels of less length and strapping them together appropriately for helicopter transportation. By doing this, the load has less extremities and the weight is more evenly distributed. Thus, the load is safer to carry and there is less risk or damage.

The second axonometric (24) shows a suggestion for transporting a wall with a large notch. This notch, would compromise the structural integrity of the panel. Consider transporting the panel with a member to support the bottom of the notch, which can be removed after transportation. This will help keep the panel rigid, and avoid breakage or damage above the notch.

With any load, remove loose sheeting, tarps, or other wrappings. Loose material can blow around, injure workers, and damage the aircraft if drawn into engine intakes. Additionally, the load's centre of gravity is below the rigging attachment points. (IHSA, n.d.).

Thus, considerations of rigidity and centre of gravity in the developed design phase is essential. Additionally, some discussions with the selected helicopter company to make the design possible are necessary.

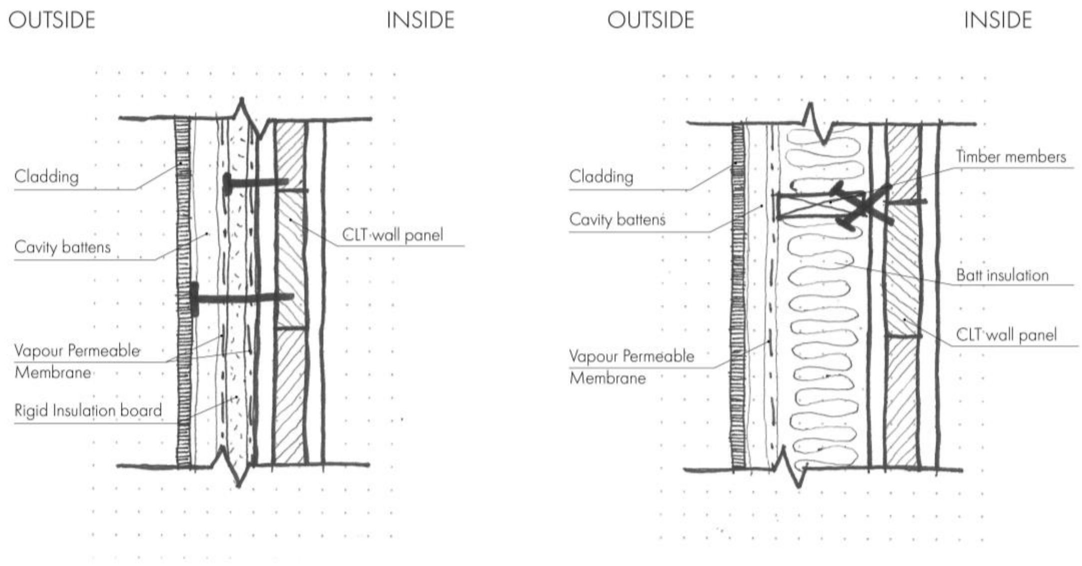
Insulating a CLT wall

Essential to any dwelling, is appropriate insulation. In the non-traditional construction method of erecting solid panels, there is a different method of insulating, opposed to placing batts in between wall framing elements. According to XLAM:

"Thermal insulation should be installed against the outer face of panels to keep the timber warm. CLT panels themselves offer good thermal resistance, however additional insulation will usually be necessary to achieve code compliance. If rigid insulation is used (EPS, XPS or PIR), the cladding system can be attached to cavity battens screwed to the CLT through the insulation."

(XLAM NZ, 2019)

From this text, these detail diagrams (25) are inferred. Using batt insulation would require the addition of timber or other members to fix, and keep the insulation in place.



25 Inferred details of insulating a solid CLT wall (author's own)

Type	Sub - type	Composition	Conductivity (W/mK)	Thickness (mm)	R-Value	Fixing of insulation	Fixing of ventilated cavity and cladding	Notes and conculsions
Batt insulation	-	Polyester fibre, sometimes with wool blend or recycled PET	0.045	45 - 210	1.0 - 3.6	Timber members fixed to the structural timber panels	To timber members for insulation fixing	Potentially most sustainable due to the recycled PET or wool content
Rigid insulation	EPS	Expanded polystyrene, sometimes with recycled content	0.032	60 - 120	1.88 - 3.75	Can be fixed directly to the CLT	Can be attached to cavity battens screwed to the CLT through the insulation	
	XPS	Extruded polystyrene	0.028	10 - 120	0.36 - 4.28	Can be fixed directly to the CLT	Can be attached to cavity battens screwed to the CLT through the insulation	
	PIR	Polyisocyanurate	0.022	50 - 100	2.25 - 4.5	Can be fixed directly to the CLT	Can be attached to cavity battens screwed to the CLT through the insulation	Thinnest product for highest R-Value
	ICB	Insulated cork board	0.04	90 - 200	2.25 - 5	Can be fixed directly to the CLT	Can be attached to cavity battens screwed to the CLT through the insulation	Not locally sourced
	Wood fibreboard	Reclyclable wood fibre	0.04	40 - 200	1 - 5	Can be fixed directly to the CLT	Can be attached to cavity battens screwed to the CLT through the insulation	Not locally sourced

Therefore, there are currently two ways to insulate a CLT or solid panel construction wall: batt insulation and rigid insulation. A table has been created, showing the various options.

Whilst batt insulation is perhaps to most sustainable option due to its recycled content, the introduction of timber members to fix the insulation, will create thermal bridging. The timber members will also create a thicker wall, and batt insulation itself needs to be thicker than rigid insulation to achieve the same R value (as in table, batt insulation has the highest conductivity value of 0.45 W/mK, closely followed by ICB and Wood fibreboard at 0.04 W/mK). With rigid insulation, the thermal bridging can be avoided by directly fixing the insulation to the CLT. An issue with rigid insulation is that options in New Zealand all contain large amounts of plastic, which is not the most environmental choice. However, the options that use natural products, will need to be imported from overseas, increasing the carbon emissions.

To conclude, there are two options for insulating a CLT wall: batt and rigid insulation. Batt insulation is the most sustainable, yet thermal bridging is created with the addition of members to fix it. Rigid insulation in New Zealand is made of plastic and perhaps less sustainable, amplified by the fact that all natural based options need to be imported.

Wastewater

Please refer to **On-Site Wastewater Options** diagram.

In order to be self-sustained, or in situations where it is too expensive or not possible to connect to the main sewage system, on-site treatment of wastewater can be considered. In this section, the types of wastewater and the ways to deal with them are outlined, with recommendations. Much of the information is from Level, a development by BRANZ.

Water and solids from the toilet, kitchen sink and dishwasher are considered 'black water'. Whereas waste from the bathroom sink, and shower are termed 'grey water'. Water from the clothes washing machine can be classified as either. There are different systems that deal with the different types of water, in either split or combined systems, and there are ways of reducing the load on the selected systems. (Level, 2018)

In New Zealand, the options in which to deal with wastewater on site are governed by local authorities. The recommendation is to use an aerated wastewater treatment system (AWTS) or advanced sewage treatment system (ASTS) as they provide a higher treatment of the by-products (Level 2018), making them a safer and more hygienic solution than septic tanks for example. Another benefit, is that they are accepted by all local authorities in New Zealand (Level, 2018). When the waste flows into the septic tank, the solids and liquids separate, and effluent is directed land-application disposal (Level, 2018). AWTS and ASTS treat the waste in 'anaerobic and aerobic treatments' and the created water can be used for land-application disposal, or irrigation (not of vegetables and fruits) (Level, 2018). Thus, a clear benefit of AWTS AND ASTS become apparent; the ability to use the treated water for irrigating ornamental and landscaping plants.

Once a system is selected, whether the system is combined or split is next to be decided. Combined systems channel both grey and black water into the same system, and deal with them together in either a septic tank, or the advanced wastewater treatment systems described above. Split systems allow for the grey-water and black water to be treated separately and can be used in conjunction with either septic tank or an AWTS or ASTS. Grey water goes straight to a simple filter system, generally comprising of a filter bag (Level, 2018), which can then be used for land-application disposal, irrigation, or toilet flushing (not recommended by BRANZ). The black water will go to the main treatment system. BRANZ recommends the option to divert the grey-water from the sink and shower directly to the main treatment system (Level, 2018). Reasons for diverting the water stem from the knowledge that faecal, or other undesirable matter are going down the drain of the grey water systems. This could include washing small children, or cleaning hands after farm work with livestock. Motives for selecting a split system, include reducing the load and power required for the running of it.

To lower the load on the selected system, there are several options. A composting toilet can be employed, which either uses 'batch-type' or 'continuous' composting. Batch-type is a vented system that collects waste in bins, which are then moved when full, to a place generally on the land to complete the composting (Level, 2018). They generally do not need much under floor space (Level, 2018), making them a cheaper option and suitable for retro fit. Continuous composting toilets have 'one [large] chamber where all waste is received and stored until composting is completed' (Level, 2018). The finished compost is then removed and buried, and these systems require great under floor space (Level, 2018). Both batch-type and continuous systems tend to have urine separation, which can be directed to on-site treatment, soak away, or storage for citrus fertiliser (Level, 2018). Another very simple way, is to install water saving fixtures for all the different sources of waste water. This could include water saving shower heads, toilets, taps, and large appliances such as dishwashers and washing machines.

Overall, from this research into onsite waste-water options, a split system, with the option to divert grey water to the main treatment system is recommended. This main treatment system should be an AWTS or ASTS and all the treated water can be used for irrigating non–edible plants.

Solar buy back rates

Solar power is an obvious choice for dwellings aiming to be self-sufficient, or dwellings in remote locations without any connection to the mains system. When photovoltaic panels are used in residential applications in New Zealand, if the dwelling is connected to the 'grid', owners have the option to sell the surplus power they make after servicing their own home. Within New Zealand, 6 power companies currently offer solar services: Genesis, Meridian Energy, Trustpower, Nova Energy, Contact, and Mercury. The table below compiles the current (Dec 2018 – Jan 2019) deals and rates on each of the providers' websites.

Company	Buy back rate (cents/kWh)	Import/ export meter price (NZD)	Conditions/notes
Genesis	8	100	-
Meridian Energy	8	150	'If solar is right for you, we'll waive the import/export meter installation fee (valued at $150) if you choose to get a system installed by Harrisons'. (Genesis, 2018)
Trustpower	7	155	'Solar buddies' allows you do sell your power to your friends at a rate you both agree to. (Trustpower, 2018)
Nova Energy	7.4	unknown but required	-
Contact	8	125	-
Mercury	12	0	'When you buy a Mercury Solar package and fix your energy rates for 3 years you'll get a great buy back rate* of 12c per kwh. You'll also get GEM for Solar, our handy online tool that delivers insights from your solar system.' (Mercury, 2018)

From analysing the table, there is minimal difference in the prices per kWh. Mercury offers the best deal (as indicated with the orange line), at 12 cents per kWh, yet users must sign up to a 3-year contract. The options of power company, that the house owners can choose from is limited to the selection of companies that service the area.

Discussion

Methodology

The decided methodology - of finding case studies, and analyzing to create suggestions for other remote residential projects – excelled in some points, but fell short in others. These will be reviewed.

The process of narratively searching to see what other people with similar briefs have done was beneficial, especially when sorted into a table, albeit incomplete. With the sample size at just 46, it was limited, but a wide variety of project sizes, sites and styles were examined. With this plethora of information, it became easy to see what can be done, and how it was done. Time frames, construction methods, prefabrication methods, and materiality become known and collated. The collation in the table, with all the variables, meant they could quickly be compared and graphs were created.

Unfortunately, the methodology raised a number of assumptions and limitations whilst searching through the case studies and recording data. The inclusion and consideration of variables can help find relationships, yet the excluded variables become the limitations of conclusions and even can some inconsistencies or strange and unexpected findings. Whilst some of these variables were found to be excluded in retrospect, others had no data available about them, such as the number of people on-site building, or the time to prefabricate inside a factory. Besides, seeing as published works were examined, the sample is innately biased and the information, inferred or stated, was assumed to be true. Refer to the **Limitations** section for a detailed outline of the key limitations of this report.

Overall the methodology was useful, to see find what tricky remote constructions have worked, yet comparing them gave light to a number of limitations and assumptions stemming from unconsidered or unavailable data. This method also relies of the accuracy and honesty of the published information.

Panel construction

This report investigates a tension between the built, and the unbuilt. It essentially showed that in many cases, people have made their projects work, thus the clients of Matahiwi Cabin can do the same. Said clients, have loosely decided that they wish to use a CLT panel construction, based on many considerations such as how it feels, how it looks, the sustainability of material and local sourcing. However, this research of a select number of case studies shows that on average, panel style prefabrication takes the longest, out of component, volume, and whole building prefabrication. The average time is 8 days, which is longer than the brief and research question stating 5 days. There are a number of reasons why this is the case, with a number of limitations as previously discussed. However, the research does not rule out panel prefabrication as an option as considered in this section of the Discussion, and the following.

As the degree of prefabrication increases, and thus work done in a factory increases, a logical expectation is that with these increases, the on-site construction time should decrease. The trends in this report show that this is the order of average on-site build time from shortest, the fastest:

1. Whole building – 1.3 days
2. Volume – 2.5 days
3. Component – 5.0 days
4. Panel – 8.1 days

Whilst volume being the second fastest behind whole building matches this assumption, ‘component’ and ‘panel’, seem to be in an unexpected order. Then, a key question is raised – does the size of the build affect the on-site construction time? Which logically, it should. However, when the building size (m^2) is plotted against the on-site construction time excluding foundations (days), the points are in no logical pattern (see 18), indicating there is no direct relationship. Thus according to the results found from the selected case studies, the building size does not directly determine the time to build onsite, excluding foundations.

A probable reason why panel construction is proving the slowest, may be the knowledge of the builders and familiarity with the prefabrication system. Forms of component prefabrications are common worldwide, with prenailed timber trusses, wall framing, or kitchen cabinetry, staircases brought completed to sites. Volume prefabrication would require a significant amount of planning and designing prior to construction in a factory. It is assumed that this increased time and effort would shorten the on-site construction time, by a longer design and prefabrication time period. Whole Building prefabrication is essentially creating the whole build, using whichever techniques are known or desired, in a factory and shipping it to site. The key variables of consideration for whole building prefabrication are size and weight. Panel prefabrication is different to these described methods in that is prefabricated for a time somewhere between component and volume, yet perhaps has less familiarity than component, and less planning than volume prefabrication, rendering it the slowest.

There are a number of examples that have completed a build, using panel construction in under 5 days and have been outlined in the appendix. Another CLT build is included also.

Matahiwi cabin

A finding from this report is that Matahiwi is a feasible project, as the case studies show dwellings on more difficult sites with faster required construction times, have been successfully completed. There are however, some key further research and planning that would need to be considered, including: the number of people building, the construction timeline, a transportation plan, and the degree of completion of the wall.

Conclusion

This research project, based upon collecting and sorting case studies, has rendered some results, which could be most interesting to apply to the practical world of architecture. Fortunately, Matahiwi cabin is the real-life project which will apply some of these findings. Matahiwi cabin becomes pilot study for other potential DOC huts in remote locations, sometimes only accessible by foot or helicopter.

In answer to the research questions:

> How can one single storied module, of 50m2 floor area with limited complexity, be able to be constructed in a remote site in New Zealand, with an on-site time frame of less than a week, without wet trades?

The answer is not definitive. Essentially, various people in the case studies have picked a method and made it work, and the same can happen with any project. For each remote residential brief, there may be a most logical choice, however, that is not necessarily by the best choice. The client values are what is most important, be it material preference, sustainability, economics, time, or design. Within the selected case studies, panel prefabrication has on average the longest on-site construction time, excluding foundations, of 8.1 days (when analysed against component, volume and whole building prefabrication). A number of limitations have been identified and discussed, which weaken this statement. However, this finding does not mean that all panel projects will take this long and it is ultimately up to the architects in their developed design phase to make whichever system work for them.

The second research question:

What are suggestions for other potential sites and building scenarios for remote residential construction within New Zealand sites, based upon precedent works?

This question is partly answered in the above question: that many methods can and have worked overseas, and could be applied to the New Zealand context. For brief and site-specific suggestions, based on what has been achieved overseas, the toolkit and the comprehensive spreadsheet provide recommendations based on site access, build time and build size, and the latter is all the data collated, organised into a table form.

Overall, this is simply the start of this branch of remote residential research. Whilst answers which are not definitive may be frustrating or confusing, to some they are good news. Remote residential construction of small dwellings can and has worked. Therefore, it will work for Matahiwi cabin and other New Zealand remote sites with the appropriate planning of the prefabrication system and how these affect the construction and transportation timeline.

Limitations

As with any research, there are a number of limitations of the report. These can restrict the applications of the report and lessen the validity of the conclusions made.

Fore mostly, this research relates to one flat site and one set of clients and a simple design, which is the Matahiwi Cabin. As the concept of creating future DOC huts in New Zealand is in its preliminary stages, it proves difficult to research. Some of the information is replicable and can be used for base scoping of other remote residential projects.

The actual weight and size a helicopter, large vehicle (truck or crane), and small vehicle (car or utility vehicle) can carry was undetermined. 'Helicopter capable' is also a loose definition and all 'helicopter capable' buildings were transported via truck in the original case study. 'Helicopter capable' generally means that each unit appears to be in the weight boundary of 1 to 2 tonnes and the elements appears structurally sturdy enough to withstand the potential forces in transporting. In the case of volumes, hooks could be added, for components, they could be tied into a bundle and covered in tarpaulin. More trips may need to be taken which would affect the on-site construction time but this has not been calculated.

Due to time restrictions, only a small number of case studies were identified and researched. Additionally, the researched cases were biased in that they were all published, and the large majority have internet pages. This combination of a limited number of biasedly found case studies, results in conclusions which are biased and potentially to generalised. Similarly, the accuracy of the data relies on the honesty of the published works, and some information may have been omitted. Or, projects that failed may have not been published, thus the data does not give a correct representation of all remote residential, prefabricated projects.

Limitations into the accuracy of the data. Often, the data was inferred upon analysing images or diagram provided by the architects. This was for categories such as materials, prefabrication system, and on-site construction time.

Moreover, some variables or factors were completely disregarded in the case study stages, including the table and the graphing. These include the number of people working on the building site and their level of skill or knowledge. This could greatly affect the construction time and even the construction design of the build. Also, the services for each case study are not considered. Installing utility rooms such as a bathroom, kitchen or even a simple sink would greatly add to the construction time and feasibility of some projects, dependant on location. The addition of wiring and plumbing may also influence the prefabrication design, such as open or closed panel construction, further altering the on-site construction time. Buildings such as G-Box, and Călțun shelter have no known plumbing for example. In addition, there is limited inclusion and research into how the local knowledge affects the case studies. For example, much of Scandinavia is more familiar with timer construction, largely LVL and CLT. Whilst New Zealand construction of single residential dwellings is also in timber, timber frame construction is more common and is where the experience is in. For example, a CLT build may be much faster in Scandinavia than what it is in New Zealand due to the local experience and developments in the Scandinavian construction industry. Likewise, the quality of finish is not considered. The difference between a shelter in the woods, designed for a place to roll out your sleeping and shelter from the rain, opposed to an executive getaway, with all the comforts of home and more, greatly modifies almost every aspect of each case study.

As expressed, there are a number of assumptions which result in limitations of the report. Whilst these do not make the report redundant, they do need to be considered.

Further research

So as to further strengthen this research, some details and information into the micro scale of prefabrication would be required.

Specifically, research into how the different prefabrication styles affect the design process and the design itself. This could be accomplished through an example building, with construction solutions for it to be created in each prefabrication style: component, panel, volume, whole building and even hybrid. From here, reflections could be made as to how the design changes, or the design process and things that need to be considered. For example, with whole building, there is little to no room for changes to the internal structure once on-site which becomes an extra factor to consider in the design process. Thus, completing the developed design phase with a single building, in each prefabrication style would be beneficial.

So as to complete this research and create project specific research, an in-depth construction timeline plan could be created. This could include research specific to the construction methods and material innovations. Additionally, research and calculation into the number of people required to build within the given time frame could be executed. The construction timeline could be formed with the elements ordered as to which arrives first and which specific construction steps are taken, in order. Suitable contingencies, as found in this report, would be added to render the timeline comprehensive and researched. Additionally, cost calculations could be prepared in the construction timeline planning to achieve a secure gauge of expected costs.

As this report has largely excluded the ‘hybrid’ method of prefabrication (transporting volumes and walls for example to finish the build), this method and benefits of it need to be explored. As few case studies were found to utilise a combination of methods, it was omitted from this research but there may be untapped potential.

Overall, there is more than enough scope to justify a second phase of research, perhaps in the Summer 2019 /2020. If this research was after the construction of Matahiwi Cabin, then as built evaluations could be completed and reflections and research into how to improve the construction method for the next remote residential construction, be it a DOC hut or a different private client.

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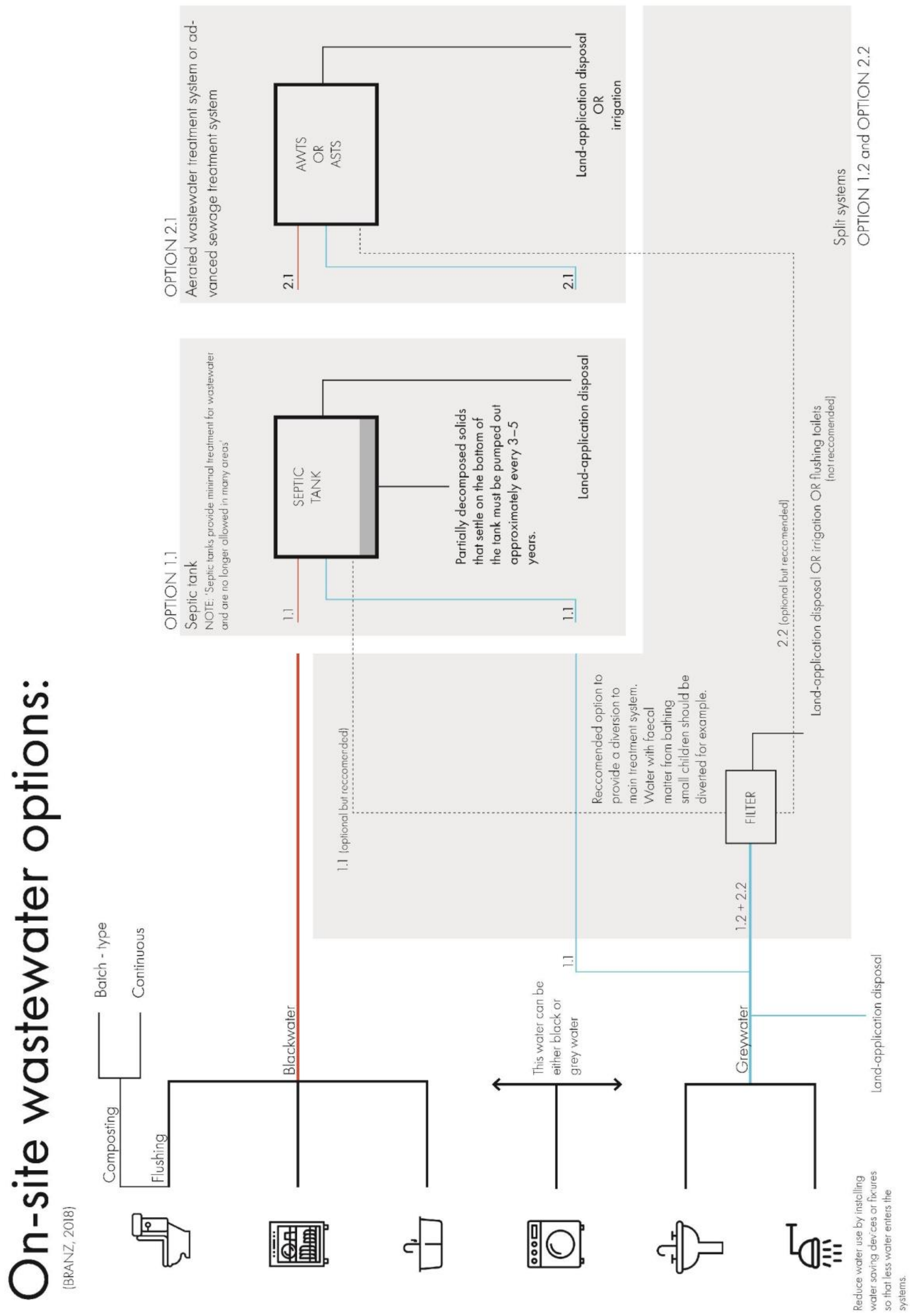
APPENDIX 1 – IMAGES

DOC huts in the local area (Wairarapa) (Department of Conservation, 2011)

Database	Search term(s)	Results	Relevant articles	Notes
JSTOR	remote construction	134103		
		5137	*Remote Area Building and Sustainable Development* *Building with flying robots*	INCLUDE: Architecture & Architectural History AND Engineering AND Population Studies AND Transportation Studies
	remote construction AND prefabrication	197		
	remote construction AND prefabrication AND residential	72	*Prefabricated construction: Developments abroad* *The effect of the quality-oriented production approach on the delivery of prefabricated homes in Japan*	
	constructing dwellings remotely	203		
		12		INCLUDE: Architecture & Architectural History
	"self-sufficient" "off-grid" dwelling	10	*Independent lifestyle* *Superbia. A suburban future?* *Earthships: The Homes That Trash Built*	'temporary' excluded
Proquest	remote construction	486440		
	remote construction AND prefabrication	638		
	constructing dwellings remotely	1328		
		19		INCLUDE: Architecture
	remote construction AND prefabrication AND residential	280	*Moving modular construction forward across the country*	
		21	*HOUSE 2011*	INCLUDE: Architecture
	"off-grid" architecture	2903		
	"self-sufficient" "off-grid" dwelling	149	*Go off-grid in ecocapsules that run on solar power* *Living Off-Grid*	
	"self-sufficient" "off-grid" dwelling waste	113	*Analyzing Sustainable Energy Opportunities for a Small Scale Off-Grid Facility: A Case Study at Experimental Lakes Area (ELA), Ontario* *Gimme (sustainable) shelter: The earthships of Taos County*	
	"off-grid" dwelling waste	423	*Waterless, off-grid and able to charge your phone: Inside the toilet of the future* *10 fascinatingly sustainable housing solutions*	
Wiley	remote construction	139232		
	remote construction AND prefabrication	806		
	remote construction AND prefabrication AND residential	227		
		47		INCLUDE: Architecture and planning
	"off-grid" dwelling	9842		
	"off-grid" dwelling architecture	2309		
	"off-grid" dwelling	132	*Introduction to Green Building Materials & Systems* *Smart Living Architecture: Solar Prototypes* *IAAC Endesa Pavilion Barcelona*	INCLUDE: Building Design
	"off-grid" dwelling water	82	*Energy, water, refurbishment, and sustainable building design* *Foundation Systems*	INCLUDE: Building Design
	"off-grid" dwelling power	5765		INCLUDE: Building Design
Taylor & Francis Online	remote construction	107686		
	remote construction AND prefabrication	892		
	remote construction AND prefabrication AND residential	375		
	"off-grid" dwelling	8262		
	"off-grid" dwelling water NOT supply	2101		
	"self sufficient" house	12610	*A Scale Model House for Demonstrating Energy Efficient Alternatives* *BUILDINGS AND ECOLOGICAL SCIENCE: THE AUTONOMOUS HOUSE* *A Self-Sufficient Solar House, Freiburg, Germany* *Journeys with the Autonomous House*	
	"self sufficient" house NOT social	1575		
	"self sufficient" house waste system	2355	*A systems view of temporary housing projects in post-disaster reconstruction* Design and practical application of an innovative net-zero energy house with integrated photovoltaics: a case study from Solar Decathlon China 2013	

Database	Search term(s)	Results	Relevant articles	Notes
Scopus	remote construction	11834		
	remote construction AND prefabrication	18	*Towards force-aware robot collectives for on-site construction* *Performance and Perception in Prefab Housing: An Exploratory Industry Survey on Sustainability and Affordability* *Development of a light weight flat pack timber wall and floor panel for housing and small scale structures in remote locations where there is no conventional construction industry*	
	remote construction AND prefabrication AND residential	1	*Success and failure in industrialized prefabricated housing*	Duplicate
	Remote residential construction	190	*Sustainable vacuum waste collection systems in areas of difficult access*	
	"off-grid" dwelling	13	*Energy sovereignty in Italian inner areas: Off-grid renewable solutions for isolated systems and rural buildings*	
	(prefabricated AND residential AND construction) AND (services)	26	*A comparative study of environmental performance between prefabricated and traditional residential buildings in China*	
	("off-grid" dwelling AND water)	7		
BUILD	remote construction	33		
	remote construction AND prefabrication	0		
	remote construction residential	3	*Solar '95 : renewable energy : the future is now : proceedings of the 33rd annual conference of the Australian and New Zealand Solar Energy Society, November 29 to December 1, 1995, Hobart, Tasmania*	
	"off-grid" dwelling	0		
	"off-grid"	1		


On-site wastewater options:
(BRANZ, 2018)
Composting
Flushing
Batch - type
Continuous
Blackwater
This water can be either black or grey water
Greywater
Land-application disposal
Reduce water use by installing water saving devices or fixtures so that less water enters the systems.
1.1
1.2 + 2.2
1.1 (optional but recomended)
FILTER
Reccomended option to provide a diversion to main treatment system. Water with faecal matter from bathing small children should be diverted for example.
2.2 (optional but reccomended)
Land-application disposal OR irrigation OR flushing toilets (not reccomended)
OPTION 1.1
Septic tank
NOTE: 'Septic tanks provide minimal treatment for wastewater and are no longer allowed in many areas'
SEPTIC TANK
Partially decomposed solids that settle on the bottom of the tank must be pumped out approximately every 3–5 years.
Land-application disposal
OPTION 2.1
Aerated wastewater treatment system or advanced sewage treatment system
AWTS OR ASTS
2.1
Land-application disposal OR irrigation
Split systems
OPTION 1.2 and OPTION 2.2

Min Cat (case study 7)

Location: Sa0 Paulo, Brazil
Year built: 2015
Architect: Mapa
Size: 70 m^2
Prefabrication style: volume
Walls, floor, roof: CLT
Cladding: timber
Foundations: steel frame
Transport: truck
On-site construction time: unknown

Images showing the construction and design of Min Cat (MAPA, 2018).

Whilst there is no clear data as to how long this build took, as it is a volume prefabrication method, the assumption can be drawn that it took less time on-site than the average panel construction would take. This study is of note because whilst it is a simple volume constructed from CLT panels and works in a modular format.

Cabaña de Estanilles (case study 9)

Location: The Pyrenees, Spain
Year built: 2015
Architect: Noem
Size: 25 m^2
Prefabrication style: panel
Walls, floor, roof: Timber frame
Cladding: timber
Foundations: gabion baskets and timber
Transport: helicopter
On-site construction time: 2 days

Images showing the construction and design of Cabaña de Estanilles (NOEM, 2014).

This project has fast construction period, and uses panels that are open on the interior side, to install insulation and services. DOC huts in NZ may employ a similar transportation and construction technique to achieve the dwellings.

Călțun shelter (case study 8)

Location: Călțun, Romania
Year built: unknown but circa 2015
Architect: Archaeus
Size: 35 m^2
Prefabrication style: volume
Materials: Timber frame
Cladding: timber
Number of units: 3
Weight (metric tonnes): 6.4
Transport: helicopter
On-site construction time: 2 days




Images showing the construction and design of Călțun shelter (ArchDaily,2015).

Călțun shelter is intended for hikers and mountaineers to take refuge. It has room for 19 guests, and 3 mountain rescue team members (ArchDaily, 2015). A well executed project in a very remote and extreme location which is not dissimilar to the locations of some of the DOC huts. Fast and efficient construction with steel frames and CLT panel construction.