hybrid culture
A DIGITALLY FABRICATED ENVIRONMENT

CUSTOMISED COMPONENT DESIGN


Part 3 of 3

Masters Thesis produced in collaboration with James McNicholas and Simba Matakwa

Masters Thesis Explanatory Document as discussed with: Tony van Raat, Mark Mismash & Regan Potangaroa

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I would like to thank my principle supervisor Tony van Raat for his feedback, advice and continued support through this research. A special thanks to the thesis team members Simba Mtakwa and James McNicholas, and to Louise Osborne, Tom Whelan, David Chaplin, Mike Austin, Mark Mismash and Regan Potangaroa for their support throughout the research and building phase. Lastly, a big thank you to my family and friends for their deep pockets all through this thesis.
Throughout history, western culture has had minimal influence on Indigenous Polynesian and Japanese Architecture.

Current advances in the technological age are playing a major part in traditional building techniques used by Polynesians and Japanese. It seems traditional building methods have been set aside, to accommodate newer, updated building processes which still result in an aesthetically similar form.

Modular Architecture is developing into a more influential and common style, allowing the architect to manipulate the built form by exploring new connection methods and developing new methods of construction. Modular Architecture limitations can be pushed further due to the advances in technology and digital fabrication. At present, the increase in prefabricated building components being used in Pacific Island Architecture is directed at minor building additions or building components. Recent predictions indicate that these regions will be hit harder in the future by natural disasters, so solutions to provide shelter and protection has become of high importance.

In this project the main objective is to create a series of prefabricated building models that are influenced by Polynesian and Japanese methods of construction, by examining, formulating and articulating connections that combine traditional Polynesian and Japanese joinery methods; Thus providing an opportunity to study the similarities between traditional Polynesian marine technology and building methods. This will showcase a series of connections that are adaptable to the multiple building designs and distinguishing indigenous architectural aspects. Major emphasis will be placed on traditional joining methods; how they can be simplified, combined and manipulated by digital fabrication, to create efficiency in the construction process. This will be followed by a report on results from strength testing the capabilities of the structure and the performance of the joints, which is very rarely done in architecture.
“The way in which we anticipate the future defines the meaning that the past can have for us, just as the way in which our ancestors projected the future determines our own range of possibilities. Thus for Gadamer, Vico’s formula entails that we understand history not simply because we make it but also because it has made us; we belong to it in the sense that we inherit its experience, project a future on the basis of the situation the past has created for us and act in light of our understanding of this past whether such understanding is explicit or not.” 1

“Material constraints aside, innovation is, in this sense, contingent upon a self-conscious reading, remarking, and re-collecting of tradition (Andenken), including the tradition of the new, just as tradition can only be revitalized through innovation.” 2

2. Ibid., 25.
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1.0 Introduction
1.1 Research Statement & Question

1.1.1 Team Research Statement

A digitally fabricated environment; an exploration into creating components that form customizable modules.

1.1.2 Individual Research Question

Connection
‘the action of linking one thing with another’

Cultural Connections; how can manual craft aid in detailed design and assembly of digitally fabricated elements?
1.2 Aims/Objectives

This research will aim to design prefabricated modules influenced by Polynesian and Japanese construction techniques. The project aims to explore tectonic detailing used in both Polynesian and Japanese culture. This research and physical modelling will be used to uncover the details and construction of traditional forms of design. This study will reveal the relationships between cultural design and contemporary form, and reflections in tectonic Japanese joinery detailing. There will also be an element of investigation into the Polynesian and Japanese influence on physical joints and how the two cultures align. Further research will consider the developments of handcrafted joints, the implementation of modern perspective and tools, while maintaining the high level of craftsmanship throughout all works.

“Where technology, as the maximization of industrial production and consumption, merely serves to exacerbate the magnitude of this proliferation, architecture as craft and as an act of place creation is excluded from the process.” 3

1.3 Project Outline

A brief explaining a possible solution to producing joints which maintain authentic historical elements of Polynesian and Japanese methods, yet create efficiency and ease with the assistance of digital fabrication.

The general points outlined in the brief, show sufficient grounds for research and development, a full report of the document, and a successful presentation of the design project.

The brief has been formulated to benefit an interest in cultural joinery as well as further research into the process behind designing and constructing modular architecture. This may have an end result of self-defined architectural typologies, in turn translated into a series of designs.

1.4 Focus and Challenges

- Investigation and modeling of Polynesian lashing methods.
- Investigation of traditional Polynesian canoe/boat technology.
- Investigation and modeling of Japanese joinery.
- Investigation of traditional Polynesian building forms.
- Investigation into fusion of Polynesian lashing and Japanese joinery.
- Invention of structural hybrid joints.
- Designing hidden or exposed junctions.
- Resolving issues of materiality.
- Resolving the technological implications of chosen material.
- Investigating methods of assembly.
- Understanding issues of habitation and interaction.
- Fabricating structures with high use of traditional methods.
- Integration of the team during individual investigation and design process.
- Team collaboration on design.
- Translation from computer aided design (CAD) to computer aided manufacture (CAM).
- Load testing of 1:1 scale model (lateral and vertical loads).
- Comparison and analysis of load testing data.

1.5 Methodology

Physical models, (existing or new) replicated with the use of current technological instruments and the aid of generative software for massing. This will be an integral part of this project. Hand drawings and digital models will be accompanied by physical models to aid in the exploration.

The physical models will allow mimicking of building techniques used by Polynesians and Japanese, and explore junctions and joining methods that they may have used. Working on a physical model allows a greater perspective and understanding of traditional building methodology to be gained. At this stage an exploration and application of modern building methods can be carried out, such as the use of different materials and perhaps the use different joining methods used by different Polynesian island groups, for example lashing, fixings. The overall outcome of this stage would provide the ability to develop and create a series of construction joints that have been designed personally. The chosen joint for the final build will be tested by modern day equipment, such as load cells, to gauge the strength qualities.

The challenge in this will be creating a digital model which is a carbon copy of the hand drawings or the physical model. The digital model will enable me to make changes to the mass, materials, connections, and the overall outlook of the model and an indication of its feasibility. The use of physical maquettes and digital modelling will enable the communication, investigation and justification of my decisions. The proposed research allows the exploration and experience of two worlds: the studio world and real world. A rare feat, in the Unitec Institute of Technology Masters Programme.

Further emphasis will be placed on exploring precedents of modular architecture, interactive environments, interior design, and Polynesian and Japanese methods of construction. Prefabricated buildings will be of great interest as a means of attaining knowledge of current techniques of how to piece together the built works.
2.0 existing knowledge
2.1 Literature Survey

To acquire the necessary understanding and knowledge needed to design this project, a variety of fields will be researched. These fields will include: traditional Polynesian Architecture, Polynesian marine technology, joinery in Japan, disaster relief, cultural architecture, traditional huts and shelters, modular systems, construction and detailing of structural and non-structural elements, and theories and methods of architecture relating to environment and human mentality.

For literature I intend to look at Polynesian architecture, marine technology used by various Pacific cultures, and Japanese joinery. There are a number of resources that are available; below is a brief summary of what is currently available from selected texts. These will further knowledge and provide guidance in these fields.

2.1.1 Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture

“Kenneth Frampton has delved into the hidden causes behind the always complicated process by which the discoveries of technology are brought into culture. New and original research has resulted in fresh textual matter and interesting visual material which, in combination, effectively rewrite the evolution of modern architecture. Because of the care and thoroughness that have gone into the uncovering of this hidden history, the book will be of equal interest to students of engineering, of architecture, and of cultural studies.”

Kenneth Frampton discusses, the history of contemporary form as an evolving poetic of construction and structure. Frampton utilizes readings of key French, German and English sources from the eighteenth century to present his analytical frame work. Structural engineering and tectonic imagination is clarified in the works done by architects such as Perret, Wright, Khan, Scarpa and Mies. Frampton illustrates how constructional form and material character were integral to an evolving architectural expression for these architects.

Frampton considers the conscious cultivation of the tectonic tradition in architecture as an essential element in the future development of architectural form, casting a critical new light on the entire issue of modernity and on the place of much work that has passed as “avant-garde.” Studies in Tectonic Culture outlines a number of factors that are relevant to this research. These factors have become the key generators from which ideas are developed from, whether it be form, function or connection. Various sections of the book reinforce the idea of the craftsmanship, the exposure of the joint with different levels of invention.

“Hand-finish is the most vivid testimony of sculpture. People touch things according to their shape. A single shape is made magnificent by perennial touching. For the hand explores, all unconsciously to reveal, to magnify an existent form. Perfect sculpture needs your hand to communicate some pulse and warmth, to reveal subtleties unnoticed by the eye, needs your hand to enhance them.”

Three words are used consistently throughout this book to describe and critique architecture: expression, experience and craft. These words, alongside others, will be applied and adapted to critique the designs in this research.


5. Frampton and Cava, Studies in Tectonic Culture, 3.
2.1.2 Canoes of Oceania

"In this book find the "space ships" at the end of an evolution of a thousand or two thousand years or more. The European explorers stumbled upon islands and found people whose canoes could sail closer to the wind than their own, without the aid of metal tools, metal fasteners, rope walks. Give the Pacific people some vegetable fibre, a log, a weaveable tree-leaf, a shell, and the gathered know-how of hard voyaging, desperation, lost-at-seas, and joyous landfalls, and they express the material thinking of the human combining the solution of technical problems with the ritual and aesthetic." 6

This is the most comprehensive survey of its kind as a result of years of research undertaken by Haddon and Hornell, on the Canoes of Oceania. The research undertaken is a comparative study of results by virtue of the extension of archaeological, ethological, linguistic and biological research. The overall aim was to describe the type of canoes still found in Oceania at the time of the research, tasking themselves with collecting, correlating and arranging all known and available details of canoe construction.

A significant highlight of the book is the vast amount of illustrations of canoe technology, which has never been seen before, backing up the facts that go alongside it. These illustrations are vital to this research as they can be compared and analysed against the construction technology used by the Polynesian people. Lashing and joining details are comprehensively covered in this book, including illustrating and instructing how the lashing with the joint are put together.

"The native people of the Pacific world were equal to the task as they adapted their cultures to the oceanic environment which surrounded them" 7

This book provides reinforcement and encouragement for innovation of lashing typologies which are comparatively similar amongst the oceanic island groups.

2.1.3 Samoan Material Culture

"Government and popular writers have referred to the Samoans as being the purest branch of the Polynesians." 8

This book documents and illustrates Samoan material culture, which is mainly based around architecture and complexities of Samoan society. Construction technique and cultural rituals used by Samoans are illustrated in a very detailed manner in this book.

"The technique may be useful to the Samoans in days to come when the broadening of their horizon will inevitably lead to the decay of their native arts and crafts." 9

The author looks to shed light on craftsmanship by recording it for future reference so that knowledge of this is preserved for generations to come.

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Construction and lashing details in this book are key for this research. The Samoan Fale is regarded as the most complex building to construct out of the Polynesian island group and this book comprehensively covers all the processes one must go through to build a Fale from scratch. Outlined in this book are construction details and building components used in a Fale. Changes to details over time have also been illustrated throughout the book, which is significant to this research as it outlines what and who may have influenced these changes.

2.1.4 The Samoan Fale

"UNESCO has long encouraged the study of the world’s traditional architecture as a means of promoting the cultural heritage." 10

This book provides information gathered from a builder’s perspective, straight from the real world experience. Key information sourced from this book to aid research consists of various tools, special techniques for thatching and lashing types, and various construction details used on the numerous forms of a Fale. The primary focus will be more specifically on looking at the lashing types and their development.

2.1.5 The Art of Japanese Joinery

"KIYOSI SEIKE, Professor of Architecture at the Tokyo Institute of Technology, is also an active architect both in Japan and abroad. He has published numerous books and articles on architecture in both Japanese and English." 12

In this book forty-eight commonly used joints in Japanese joinery are selected from several hundred known and used today. Seike provides in-depth historical and technical information about the selected joints and Japanese joinery, breaking down every aspect and variation of the joints. These joints are illustrated with detailed and clear isometric projections and photographs. Construction process, tools used, cultural protocols, material used and references to other cultures are all covered in this book.

9. Ibid., 7.
“Historically, the traditional Japanese carpenter has been architect and engineer as much as carpenter or joiner. Because his role has been so momentous, it is impossible to divorce discussion of Japanese joinery and carpentry from discussion of Japanese architecture itself.”  

The knowledge gained from this book about what joinery suits what type of construction, and the number of variations they can have, has greatly contributed to this research. Both negatives and positives on each joint have been listed in the book, those negatives are worked on in this research using components from Polynesian culture to try formulate a hybrid joint.

2.2 Precedent Survey

2.2.1 Sopolemalama Filipe Tohi

Sopolemalama Filipe Tohi, of Tongan descent now residing in New Zealand is renowned in Oceania for his paintings and sculptures which incorporate Pacific and Māori iconography. Tohi, although an artist by trade, is more recognised for his skill as a Tufunga Lalava (fig. 9), a master craftsman of the traditional art of Lalava - the Pan-Pacific technology used on houses, canoes, and tools before the introduction of western materials. Tohi has a vast understanding in Lalava patterns and language hidden inside the layers of sennit, obtained from his studies in construction.

“Samoa is the last of the Polynesian countries to make extensive use, even today, of its own traditional architecture in the construction of houses. Nowhere in the Pacific is a more felicitous traditional dwelling to be found.”

Tohi’s most noticeable lashing works are on the ‘Fale Maota at Nofo’ali’i’ in Apia, Samoa and most recently the University of Auckland Pasifika Fale (fig. 10), in Auckland, New Zealand. The Auckland University envisioned the Fale to be multicultural and not just showcase one culture, hence the name Pasifika Fale, which recognizes all the island groups in the Pacific islands. Pasifika Fale form is a direct influence of the FaleAfolau, but structurally it has a heavy western influence (fig. 11), with modern day technology being used to piece and reinforce the building. This is the case with most fales built in modern times, although a certain few found in Samoa are still built using traditional materials and techniques. This is mainly due to the building regulations of different countries, along with availability of experienced craftsmen.

“And in any case, the fale, being Samoan, would only be built by Samoans for Samoans.”

Tohi was one of many artists commissioned to showcase their culture in the Pasifika Fale. Tohi used Tongan lashing on the itu (middle section – structural core) to cover up the structural connections (fig. 12), the lashings used on this fale are purely decorative to showcase Tongan culture, it showcases his work in a structural environment, giving the illusion of being structural when it is not.

Regardless of a lot of Tohi’s work being non-structural, his knowledge, experience and skills are key to this research in enhancing skill levels and understanding of lashing. Great knowledge and craftsman skills were gained by attending workshops and working alongside Tohi at charity events. These skills allowed a greater understanding of the process of lashing and how to alter and manipulate it to be gained. Tohi workshops
only introduce the basic form and methods of lashing, encouraging the participants to formulate their own style to see what patterns they can achieve.

“All that appears to differentiate one lashing from another is the attention given to the potential ornamental elements of die finished lashing. If the lashings are easily visible from die floor of the fale, the master builder will ask that member of his team who has distinguished himself by his skill in this arcane craft to undertake the lashings. This specialist will be encouraged to use his talents to the fullest by weaving lozenges and other patterns into die lashing, often colouring every other strand with charcoal or chalk to heighten the decorative effect.”

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2.2.2 WikiHouse

Wiki House is an online open source construction set. The creators of the website aimed to allow anyone to design, download, and print Computer Numerated Control (CNC)-milled houses and components (fig. 14), which can be easily assembled with minimal formal building skill or training (fig. 15). Every element is labeled and instructions are given on how to put it all together, as larger designs have over 300 elements ranging in different sizes. All the designs are free to download, but the materials and cost of cutting has to be paid for by the person intending to assemble it. Design build projects are being uploaded from all over the world by architects, designers and builders. All designs are dictated by plywood sheet sizes and all designs are to be made with plywood. This website explores the interventions and limitations of plywood in a digital prefabrication realm, thus creating more knowledge and awareness of the product.

"Because of such new materials and the tools with which to mold them, it has become possible to move away from the traditional straight-line construction in wood and experiment with many new forms and shape. While the use of large sheets of plywood has resulted in an enormous saving of time and energy in putting down subflooring, for example, the wide range of electric woodworking tools now available has not only saved time and energy for carpenters but also altered woodworking techniques." 17

Knowledge and ideas obtained from this online source were beneficial to this research by way of structural connection types, material used, structural testing and techniques on how to transfer physical model ideas to computer. Numerous joinery connections are illustrated on the website, but have been tested on furniture. This catalogue of joints indicates the various ways of manipulation and intervention of secondary elements to the joints, it is also an indication of what can be cut by a CNC machine (fig. 246).

Only the oblique scarf joint has been tested (fig. 16), but only at construction level. Many of the online sources suggest that the structures with the joints have been structurally tested, but very rarely do you find data to back that up. This provides this research with the opportunity to structurally test the joints formulated in a built environment and back up the results with hard data to prove the joints’ performances. The data will indicate whether the joint has failed or not. Physical testing will highlight areas in which the joint has failed or held firm. Developments and improvement can be then made by remodeling on the computer, saving time from manually modeling the joints again. The final development can be cut on a CNC machine and structurally tested again.

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2.2.3 Folding Whare – Callum Dowie

The Folding Whare was the culmination of Callum Dowie’s thesis research at the Unitec Institute of Technology School of Architecture. He had not intended it to be a design built research project, but interest was shown in his research by people who were willing to fund the project to see the built outcome of the research proposal. The research undertaken by Dowie was targeted at huts in New Zealand, looking at various hut forms, function, technologies used, culture and history. The Folding Whare is the culmination of all these ideas, most significantly the idea taken from Kohika – pre-European Māori shelters excavated in an area of swamp land between Te Puke and Whakatane, New Zealand (fig. 18). The technologies used to compress and tension these shelters have been used in Dowie’s Folding Whare. The same process of application was used, but with the introduction of modern materials, in this case farm fencing components, rather than traditional materials used by the Māori people.

“I will cite nonetheless two examples that testify to the way in which the two basic modes of building, the compressive mass and the tensile frame, have been deployed throughout time in such a way as to create a life world that is cosmologically encoded.” 18

The methods by which Dowie translates and applies the compression and tension methods on the Folding Whare, is of importance to this research. Through model making, Dowie explored different avenues of placing a structure under compressive tension. Three variations of tensioning methods were tested; first was tension through rope (fig. 19), second was tension through ratchet straps (fig. 20), and third was galvanised steel wire, fence strainer (fig. 21). These ideas can be applied and developed in this research, and will be taken further by structurally load testing the structure. Folding Whare has not been structurally tested. Therefore, it is not clear if the structural system used is successful or not.
2.2.4 Auckland Museum – Pacific Lifeways and Pacific Masterpieces

Figure 21 - Assembly of the wall and roof junction. - plywood and polystyrene panels, steel compression ring, Galv. steel wire, fence strainer, piano hinge, screws.

Figure 22 - Auckland War Memorial Museum

Pacific Lifeways

Pacific Lifeways is a collection of over 1,200 artefacts, predominantly from Tonga, Fiji, Samoa, Kiribati, Niue, Cook Islands, Vanuatu, the Solomon Islands and Papua New Guinea. The artefacts reflect different communities of the Pacific islands groups residing in Auckland, by showcasing their tools and utensils for communal living, hunting, fishing, recreation and small scale replica of ocean voyaging canoes (fig. 23). The Fijian Island outrigger canoe, Camakau, is the largest exhibit (fig. 23.1), alongside smaller, more detailed canoe models.

Pacific Masterpieces

Pacific Masterpieces is a collection of over 600 Oceanic art pieces and artefacts ranging from delicate combs, feathered cloaks and shields. The items on display illustrate Pacific creativity using wood, shell, bone, fibre and craftsmanship in ceramic art, jewellery, weaving masks and tools (fig. 24). The Solomon Island outrigger canoe, Vaka Tapu, is the largest exhibit. These artefacts provide this research with a reference point, as real life examples of lashings and marine technology are on show to the public. The exhibition helps bridge the gap between research text and physical models, providing a greater understanding of how the lashing has been achieved.

Figure 23 - Kiribati exhibition – Baurua (left), ocean-going sailing canoe model. Wa (right), small dugout canoe for paddling on lagoons.

Figure 24 - Tools from Cook Islands, Tahiti, Papua New Guinea, Fiji and New Caledonia.
Figure 23.1 - Fijian exhibition - Camakau, Sailing Canoe.
3.0 design process
3.1 Process Architecture

3.1.1 Research by Design

This document is based on design, rather than being heavily dictated by theoretical knowledge attained through research. Design disciplines will be the setting for this research. As model making will be dictated by design, development and real world experience will be counted as research for this thesis. Design ideas that may be attained from theoretical knowledge, will be tested through physical model making, then assessed and developed using the same process.

3.1.2 Collaborative Practice

This research is one part of an overall collaborative thesis which consists of three team members (Simba Mtakwa, James McNicholas and Azmon Chetty)(fig. 338), who have each undertaken individual research. The intention was to run and base it off a real world environment of an Architectural Practice, where very rarely one person works on a project from start to finish alone. Initially the members of the team had individual research ideas which correlated to each other (fig. 230.1). Minor adjustments were made to the ideas so that they could be adjusted and placed into a design process format. The process begins with Simba, who does the initial “framework” of design, then it is handed over to James, who creates a “system” which takes the design and converts into components suitable for the CNC machine. The components are then handed over to Azmon, who figures out the “connection” between all the elements and how the structure will be pieced together. Through each individual research phase, collaboration is still taking place as research from any team member may influence another member’s research.

3.1.3 Work in Progress

The project does not stop upon hand in of this research, as it will be continued on and the designs developed further. What is presented through the collaboration is only a prototype of one conceptual idea. The prototype will be developed further, dictated through required briefs by possible clients who are interested in the project. Individual research and development will also be continued upon completion of this document.

3.1.4 Individual Research

A complete exploration through modelling is an important part of the process for this research project, as a practical application of information is being sought. A variation of typical Polynesian structural frames and Japanese timber joinery were tested. In order to grasp a greater understanding of how these methods were achieved in recognition to their differences, with the outcome of producing small scale models. Producing at a smaller scale provided a greater understanding of connections between structural members and the jointing systems used to fasten the members together. On completion of this model study it is hoped that a hybrid typology will be developed.

Each model is assessed on three factors obtained from the literature review. Each factor will be marked on a scale of low, medium or high. The three factors are:

- **Expression** – Whether the connections are indicative of heritage and tradition. Does the joint reveal the nature of the connection method used?
- **Craft** – Does it show different levels of intervention, gauged by how much craftsmanship is required to accomplish the joint?
- **Experience** – Will the joint heighten the experience of the building visually, as to the senses of touch and smell (singed rope)?
3.2 Individual Research

3.2.1 Exploration of Existing Building, Construction and Lashing Typology

3.2.1.1 Hybrid Typology: Model One

The Fijian Bure typology (fig. 26), was a starting point, as there was a personal connection to the history and culture. Throughout assembly of the model it was clear that the most common theme in the structural frame was the notion of layers. The notion of layers is evident in traditional structures from various island groups of the South Pacific, which were explored by visiting traditional Polynesian structures in Auckland ('Unitec' and 'Kelliher Estate Fale').

This model (fig. 25), illustrates how the structural members overlap each other. Each rafter sits on top of a boundary column, both are lashed together using a 'double V Lozenge Lashing' (fig. 29). The purpose of the double V Lozenge lashing is to stop any sideways movement or slippage. The rafters cross over at the top, creating a peak. These are then lashed together using a double V lashing method (fig. 30). The crossover of rafters allows for the positioning of the top ridge beam above and lower ridge beam to be lifted into place below. The lower ridge beam is the larger of the two and its weight assists in the tensioning of the roof structure. By looping a clinch knot (fig. 31) around the two beams a tension system is created to hold the ridge beams tighter. Tension and upward force is applied to the rafters, causing them to spread out and up when the ridge beams are being pulled together. The clinch knot is much used in traditional Oceanic canoes, but referred to as the 'collar lashing' (fig. 27). The purlins are then placed on top of the rafters and lashed into place using the Lozenge Lashing (fig. 32).

The role of the lashings and structural system were clear upon completion of the model. The ridge beam rafter beam crossover and purlin to rafter lashings were already understood due to easiness of replication. The lashing of the columns to rafters was unclear (fig. 29), as it can be seen that the double V Lozenge Lashing does not successfully connect both members together. The lashing only wraps itself around the rafter, and not the column, resulting in nothing pulling the rafter to the column. Further research highlighted that a tie beam (wall plate) was missing; the rafter sits on top of a tie beam, which sits on top of the boundary column (fig. 59). Traditionally this lashing was also used in outrigger canoes, but the bottom member had holes drilled through it to allow the rope to pass through (fig. 28). This connection was important to resolve in following models.

Expression: high
Craft: high
Experience: high
Figure 29 - Rafter and column connection, using a ‘double V Lozenge Lashing’.

Figure 30 - Rafter to rafter apex connection, using a ‘double V Lozenge Lashing’.
Figure 31 - Ridge beam connection, using a ‘Clinch Knot Lashing’.

Figure 14 - Purlin to rafter connection, using a ‘Lozenge Lashing’.
Model Two is an exploration of different lashing connections used by the Polynesians to lash the tie beam (wall plate) to the boundary column (cross T joint). This model shows a connection for the boundary column to tie to the beam. Illustrations were obtained from the book Samoan Material Culture, for 'Fly Flap Lashing' (fig. 34), which is widely used through Polynesia, as seen in the Māori culture (fig. 35), even though its origin is the Cook Islands. In the present day, its purpose is ornamental due to government building restrictions.

The process of making the fly flap lashing was difficult. The technique required multiple efforts to get the repetitions of directions correct. The tension of the connection can be varied by the number of revolutions made; hence, the more revolutions the tighter the join, which has shown less results in a weaker joint. One loose revolution could also let the tension out, and it is hard to achieve a tight revolution due to the complexity of this pattern, along with the rope slipping on the surface of the rope. Traditionally, a fibrous rope made from plant material (coconut sennit fibre or St. Thomas Bean Vine) would be used (fig. 36). “Sennit (called ‘afa, kafa, or ‘aha in most of Polynesia) is used for tying parts of traditional houses together, lashing canoes, and for making artefacts…” 19. This method involves soaking the rope in water before lashing; once the lash was complete, the rope would start to tighten as it dried.

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It was difficult to place the beam on the flat surface of the column, as it tended to slip and slide around when lashing. To mitigate this, a groove was notched in the centre surface of the column, helping to stabilise the beam by reducing the movement and stop it from falling off the edge (fig. 39).

The ‘fly flap lashing’ is decorative with a pattern created through the methods used. The person creating the lashing is in control of the amount of revolutions in the pattern. A minimal pattern would create a loose connection, whereas a more intricate pattern achieves a tighter connection. A hidden peg placed where the beam sits on top of the column can improve this (figs. 40, 41). The lashing is a vertical force, while a peg or a pin stops any horizontal movement. Doing this lashing it was found that even an intricate pattern leaves the connection loose.

Expression: high
Craft: high
Experience: high
Figure 37 - Fly Flap lashing repetitions.

Figure 38 - Fly Flap lashing pattern.

Figure 39 - Rafter and column connection: 1. V notch; 2. square notch; 3. circular notch; 4. rafter slipping on a flat surface.
Figure 40 - Axonometric showing how the beam sits on the peg.

Figure 41 - Rafter and column connection: 1. rafter sitting on a pegged flat surface; 2. circular notch; 3. section illustrating how rafter rotation is stopped.
This model was a further exploration of the idea developed from the previous two models. The purpose of this model is to make improvements on the stability of the tie beam, or rafter without tie beam, exploring how one join can be stabilised in three ways using the idea of restricting the lashing in design and function.

Traditionally in some parts of Polynesia a tapered top plate would be used to stabilise the rafters (fig. 43). This method stops movement on one vertical axis; lashing is introduced to stop movement on the horizontal axis. In contrast Japanese joinery deals with this issue by using internally hidden square stubs or pegs, which eliminate any sideways movements in the joint (fig. 44). The square pegs or stubs are ideal for situations where the column had to sit on a flat surface. ‘Bird’s mouth’ was also used quite often to stop any lateral movement by the rafter (fig. 45).

Contemporary methods used would be to skew nails in from either side (figs. 47, 48), then to lash over the joint, hiding the nails. Another method commonly used is drilling a hole through the beam and into the column. An M Bolt (figs. 47, 48) is then screwed through to tie the beam to the column (figs. 47, 48). The bolt head sits on top of the beam which can cause difficulties to lash over to hide the bolt whilst maintaining a smooth lashing. Countersinking the bolt head into the beam so that the head sits below the surface, is a way of hiding the bolt head (figs. 47, 48).
The Japanese concept of using internally hidden pegs is a process of stabilising the joint, started by placing a hidden, round peg where the beam sits on top of the column. In this instance, a square stub could not be utilised because it would be too difficult to achieve on a small rounded surface (fig. 49). The peg was best suited for this junction. A square peg works best as it stops any sideways movement, or the beam from swivelling (fig. 50). Square pegs are hard to make at a small scale due to having limited access to specialised machinery and the knowledge of using woodcarving chisels to do it manually. Because of this timber dowels were chosen as being the easiest way to peg on a small-scale model. This would not stop the beam from swivelling; however this was mitigated by notching the top surface of the column (fig. 51).

When using the peg system, the holes for the pegs have to be drilled dead centre in the column and beam, perfect alignment is needed for the holes. For example, if the hole was to be out by a millimetre, it could offset the alignments of both the notch and lashing. Once the peg hole is drilled, a Spindler Sander is used to create half round notches on the top surface of the vertical column. The notch prevents the tie beam from rolling off the edges, letting it house itself in the notch (fig. 39, 49), restricting any horizontal movement. The tie beam becomes a permanent fixture when housed in the notch, the positioning and sizing of the notch is dictated by the directional axis of the tie beam.

The lashing form used on this model is a slightly modified version of a clinch knot; the intention was to use an easy applicator lashing which performed a strong and simple lashing. The lashings are in two parts, vertical and horizontal, both separate pieces of rope. The vertical lashing is key in this joint because it is pulling the beam down, bracing it in the notch. For added strength, a hole was drilled centimetres below the notch on the column for the rope to pass through (fig. 52). The a hole achieves a tighter joint through greater tension. This was a strategic manoeuvre as it eliminated surface slip, as the vertical lash does not wrap around the column, instead simply passes through. Surface slip was found to be a major issue when doing other lashings because of the type of wood and rope being used. The hole also allows greater tensioning with every loop; the rope can be levered and pulled tight without unravelling the whole lashing. The sharp edge of the hole is likely to cut into the rope with any movement by the tie beam, or during tensioning, so the edges have to be tapered back for prevention (fig. 53, 54).

The horizontal lashing was extended further down from the junction point, so that it could hide the hole in the column. This also stopped the vertical lashing from having any surface movement. During application the horizontal lashing started to affect the vertical lash, mainly at the top junction, with the vertical lashing becoming tighter with every loop made by the horizontal lashing. This was positive, as more stability and strength was added to the joint, due to the downward force caused by the horizontal lashing, which is a modified version of the clinch knot. This lashing executes well because of its simplicity compared to lashing used in the previous model.
Overall, all three individual joining components work successfully to stabilise the beam to the column junction, making all three joints very strong. The three joints can support each other, albeit one joint has a loose lashing.

Expression: low
Craft: medium
Experience: medium

Figure 45 – 'Bird's Mouth' connection: 1. rafter and Square tie beam; 2. rafter and ridge beam; 3. bird's mouth cut out of a rafter.
Figure 46 - Column slots into a Square notch on the ridge beam to stop it from shifting on one axis.

Figure 47 - SquareTie beam and column connection: 1. skewed nails; 2. M Bolt; 3. M Bolt counter sunk.
Figure 48 - Square Tie beam and column connection: 1. skewed nails; 2. M Bolt; 3. M Bolt counter sunk.

Figure 49 - Round Tie beam and column connection: 1. tie beam sitting on a flat surface; 2. circular notch with a round peg; 3. section of how the tie beam sits in notch.
Figure 50 - Round Tie beam and column connection: 1. Square Peg; 2. Circular notch.
Figure 51 - Round Tie beam and column connection: 1. Dowel Peg; 2. Circular notch.
Figure 52 - Hole in the column allowing the lashing to pass through.

Figure 53 - Rope has been cut into by the sharp edge of the hole.

Figure 54 - The sharp edge has been tapered back.
Model four explores the connections used on a wall plate. The wall plate are the columns supporting and joining all associating beams. This wall plate connection was left out to deliver a more in depth study, acknowledging the larger scale and the complexity of the lashing methods used.

The two main reasons for the wall plates being used were firstly, the rafter beam would have a continuous surface area to sit on (fig. 59), rather than the small top surface of the column (fig. 60). Secondly, the inclusion of the wall plate was so that thatching or various materials could be hung on it to enclose the internal space.

The top plate is placed on the side of the boundary column, rather than placed on top, because of surface slip and small surface area. Placing the top plate on the top surface of the column creates issues with the lashing connections. The top plate needs a secondary fixing because the lashing has proven over time that it becomes loose from weathering and erosion of materials used.

“Their tops forked naturally or artificially shaped to receive the wall plates.” This allows the wall plate to slot in, creating more stability as it has little room to move in the given space. The depth and width of the fork is predetermined by the size of the wall plate timber. The depth is half the circumference or width of the wall plate and the length of the cut is the width or length of the wall plate.

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Buck, Samoan Material Culture, 13.
The two step Lozenge lashings, are applied once the top plate is held in position. This lashing is done in two stages. The first stage gives the lashing an ‘arrow like’ pattern, the second stage creates the diamond pattern. Stage one is easy to construct (fig. 56). Stage two is very complex and requires perfection and skill to achieve. Both stages have the same strength to hold the joint in place, the decision made is determined by one’s skill and knowledge. Another complication is the amount of rope available, as the diamond pattern requires a longer length of rope. Another factor is the sizing of the beams for the lashing, taking into consideration the width and length of the beams.

The rope slippage was a recurring issue when the model was complete, because the length of the forking on the wall beam was not long enough (fig. 61). The wall plate is sitting flush (fig. 62), with the top of the wall beam, the lashing sitting close to the edge. Any movement will make it slip off, causing the whole connection to loosen, causing the gap between the wall plate and beam to become larger (fig. 57). Fixing these issues requires the forkt to be deeper, allowing the wall plate to sit just below the top surface of column (fig. 63), which allows the lashing to be further away from the edge. For additional strength a clinch knot can be added at the point where the lashing transitions from the wall plate to the wall beam (fig. 58), the clinch knot adding further tension to the connection.

Expression: medium
Craft: medium
Experience: medium

Figure 56 – First step of the Lozenge lashing (arrow pattern).
Figure 57 – Diamond lashing, note how rope is close to the top edge.
Figure 58 – Diamond lashing with clinch knot, the clinch has pulled the rope away from the top edge.
Figure 59 - Rafter on wall plate: 1, Rafter; 2, Tie beam/Wall plate (tie beam, top plate); 3, column (boundary post); 4, ridge beam.

Figure 60 - Rafter on wall plate: 1, Rafter; 2, column (boundary post); 3, ridge beam.
Figure 61 - Forking length is too short.

Figure 62 - Forking length is flush with the wall plate.

Figure 63 - Forking length extends above the flush height.
Figure 64 - Multiple connections model. Form: ancient Maori pa site fence.
This model is a hybrid of Cook Islands and Māori culture, with the lashings originating from the Cook Islands and the structure from the Māori culture in New Zealand (fig. 65). The purpose of this model is to explore how multiple pieces of timber can be lashed continuously with a single piece of rope, rather than having to do each timber individually.

Research produced the ‘apatahi’ (continuous single Palisade), which the Māoris used to fortify their pā (village). The concept of the fence works well for this exploration due to the repetitive nature of the fence battens. The fence consists of three key elements – tumu - vertical fence post, kaho - horizontal rails (top, middle and bottom) and wawa - vertical pickets.

A Lozenge lashing is used to connect the top and bottom rail to the fence post. This is the only connection made between the two, with no other fixings holding the rails into place. In some cases the fence post was forked to allow the rail to sit in the slot, providing further stability. On the real scale, the fence would have a middle rail to make it stronger, enhancing stability, connection and strength.

Warp and weft technique is used to secure the pickets to the rails. This type of lashing is commonly used by Cook Islanders in their fish traps. This lashing is similar to ‘apatahi’ 21, or double-crossed lashing ‘kauwaerua’ 22 (fig. 66), used by Māori. The ‘apatahi’ (fig. 67), method is quick and efficient, as it eliminates the need to lash every element individually. The rotations are straightforward, with more rotations allowing for a stronger connection. As indicated in the model each batten has two loops around it, this could change as more passes would change the number of loops. A mistake was made on the model-the top and bottom loops are falling the same way. The loops need to fall in opposite directions to ensure that the picket is not falling to one side.

The form of the model is that of an ancient Māori pā site fence;

Expression: low
Craft: medium
Experience: medium

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22. Ibid.
This wall junction model was a detail developed in a studio project for a ‘NanoWhare’, a design build project with direct influences from Māori architecture (fig. 72). The main idea behind the junction was to use lashing as a means of connection between the wall panel and boundary column. The detail looks at utilising modern day materials, which are suited for climate conditions similar to New Zealand. The joining and lashing methods are similar to those used on Māori waka.

The boundary column has been rebated on both sides to allow the wall panels to house themselves into the column. The depth of the housing joint is determined by the size and width of the boundary column. If a rebate is too deep it could compromise the strength of the junction. On the other hand, the same situation arises with the width of the wall panels as they dictate how wide the rebate is. If a rebate is too wide or too deep, the wall movement under lashing tension could make the column split through either the centre or the side wings (fig. 73).

After the rebates are done, the column takes the form of an ‘H’ track junction, which is most commonly used in aluminium joinery. In this detail the interior cavity of the housing joint is lined with a ‘rubber O gasket’ which compresses and acts as a seal. The rubber is a sealed, once the walls are slotted in, creating an air lock and weather barrier (fig. 73). The seal is key for this junction as it stops any air or water passing through the join from the exterior. A drainage channel would be added and a possibility of a secondary rubber channel to maintain an air lock. More seals equates to more air locks in the joint. This allows the junction to be...
air tight with no moisture build up.

The wall plates have holes drilled through them to allow the lashing to pass through from one side to the other. The hole’s are lined with a circular rubber channel on the inside, stopping water damage to the wall cavity. Both sides of the holes edges are lined with a curved metal flashing (fig. 74). The flashing has to be curved so it does not cut into the rope as it passes through. Any serrations on the rope can comprise the tension on the join (fig. 53). To prevent any air movement through the holes, a modified rubber cap is inserted at either end. The rubber cap has to be modified in a way that allows the rope to pass through without hindering its course, also allowing the rope to be reused. Other possibilities would be to fill the hole up with a sealant, such as silicone. However, this would mean that the rope could not be reused if the structure were to be taken apart and put back together again.

The lashing method used in this detail is similar to what Māori use in ‘waka’ building (fig. 69) when they stitch the ‘rauawa’ (top board) to the ‘riu’ (hull) with the ‘paewai and taka’ (drift wood) in the middle to spread the lashing out.

Although characteristics of the model’s lashing are the same as used on the waka (fig. 69), the construction of the lashing has been altered to the overall complexity of the pattern. The lashing on the wall junction showcases Polynesian culture, with the person applying the lashing having the opportunity to apply their own variation in pattern. The three pegs on the interior side of the wall column allows the person applying the lashing to be creative and apply different variations. The pegs have been placed in a specific way to maintain the tension once the rope has looped around and levered itself off the peg.

Expression: low
Craft: high
Experience: high
Figure 72 - Sip panel junction detail by Azmon Chetty.
Figure 73 - Sip panel junction: 1. channel splitting due to wall thickness. 2. rubber air locks inside channels.

Figure 74 - Metal Flashing on the outer edge of the lashing channels.
Figure 75 - Conceptual bay model.
3.2.2 Collaborative Research – Conceptual Bay Form

3.2.2.1 Bay Concept, Model Seven

Once all three members of the team collaborated with their individual design concepts, an overall conceptual form for the prototype building is decided upon. The general idea behind the form is that the building can be adaptable by means of adding and subtracting bays, as illustrated (fig. 76). This model is a scaled concept of what form one bay may take. The form of each bay is dictated by the functions that eventuate from the programme, which is a student studio space with overnight facilities.

The model consists of modular components at irregular lengths from each other due to the variation of angles. Each component is joined together by a simple scarf joint, cut at different angles to form the bay. This joint is used both in Japanese (fig. 77), and Polynesian architecture. It is mainly used to fix together the eve battens, (fig. 78) and in canoe building it was used to fix together the boom (fig. 79). The scarf joint was the quickest and most efficient method of joining these irregular angles. On most occasions glue is used to bind and hold the scarf joint together. This is not an option for this project due to the requirement of being a temporary structure and the variations of angles. “If you glue the faces of the scarf joint, it becomes effective in resisting tension forces. Increasing the area of the scarfed faces increases the area of the adhesive contact, and hence increases the reliability of a glued scarf joint. However, increasing the area of the scarfed faces also reduces the effective length of the pieces being joined, greatly weakening the joint under some circumstances” 23. The glue would not be enough to secure the connection, as the joint faces are different sizes due to the angles. During application the joining surfaces tend to slip, throwing out the alignment of the joint. In most cases, to stop the surface slip, two dowels are slotted inside the joint. These are hidden once the joint is fully closed (fig. 80). This is one method of stopping the joint from slipping, however, it would not achieve much if there was no glue to hold both surfaces to each other. Without the binder both elements would twist and rotate, even more so if there were only one internal dowel in place (fig. 103).

Cotton thread has been used as the binding element for every scarf joint used in this model. Four holes are drilled at every connection point. The purpose of this is to manipulate the lashing so that it will cross paths after every loop, creating a stronger connection. The holes eliminate any surface slip because now the rope is passing through the timber, rather than trying to grip itself on the surface. The lashing crosses over, forming an ‘x’ pattern on both sides of the scarf joint, the inside face of the joint has a slight variation. As shown (figs. 81, 82), the lashing restricts horizontal movement in the joints as all four corners are tensioned diagonally causing joining surfaces to come together under friction (fig. 83).

“In major construction, lap joints are used not only at corners but also where joists or other cross members join or cross girders or other beams.” 24 Each bay is stitched together by nogs that slot into individual components using a cross lap joint. The cross lap joint gives the nog two advantages: it allows the nog to span long distances in which multiple bays are to be stitched together (fig. 84).

Figure 80 - Scarf joint can still be pulled apart without any binding: 1. Dowel peg.

84), and also eliminates the need for smaller elements spanning from frame to frame (fig. 87). Using a cross lap joint allows the nog to sit flush on both the interior and exterior surface. The nog is the same width as the floor joist. The cross lap needs to be precisely cut for it to work properly. If the cuts are too wide the joints will be loose (fig. 243-245), if the cuts are too tight the elements will not slot together and, as a result, can possibly split if forced together (fig. 73). Cross lap connection is constantly used in this bay model for floor, walls and roof frames so the cuts need to be perfect for all the surfaces to sit flush (fig. 86).

Plywood flooring is secured above the floor framing where it acts as a diaphragm. Once fixed it gives the floor added stability and strength. The scale of the joins on this model are too small to comprehend how they (join) work and whether they would perform at a larger scale.

Expression: medium
Craft: high
Experience: high
Figure 81 - 'X' pattern on the outer surface.

Figure 82 - 'X' pattern on the inside surface but slightly different variation.

Figure 83 - 'X' pattern lashings tensioning directions.
Figure 84 - Nog spanning over multiple bays: 1. nog; 2. bay frame.

Figure 85 - Axonometric of a cross lap joint.
Figure 86 - Flush cross lap joint.

Figure 87 - Nog spanning short distances: 1, nog; 2, bay frame.
This model is an exploration of the scarf joint on a larger scale so that it can be better understood once tested. The issue of slipping arose quite quickly in this joint – the use of two internal dowels pins was eliminated when the four holes for the rope needed to be drilled. There would be little space left for the two holes for the dowel as they could intersect the holes drilled for the rope, hindering the pathway for the rope. In the standing position only one internal dowel can be used to reinforce the joint. This will only prevent the join from slipping, but not from twisting. A solution for this would be to use two smaller dowels closer together, or to use a square peg. The difficulty in reinforcing with dowel is the precision required when drilling the hole using a vertical or horizontal drill press, as the edges of the join will not sit flush if the holes are slightly misaligned. This can be accomplished on a five axis CNC routing machine (fig. 89).

A square peg is more difficult to craft, but is more effective than a single dowel, as the square peg stops slipping and twisting due to its 90 degree angles (fig. 92, 93). To achieve a perfect square bore on a tapered surface is very hard to construct manually. A square mortise machine (fig. 90) is recommended to achieve the square bore. However, the bore heads are expensive and available only in certain sizes.

Glue is the most common binding element for timber connection as, once glue is used to bind the timber together, a permanent join is achieved. The requirements set out in the brief formulated by
the team, specify that the joints are not to be permanently fixed, so that the structure may be taken apart and reassembled. Solutions to these issues are illustrated in the model where rope is used as the binding element.

Using rope to bind the joints together raises the issue of tension and surface slip, as any surface slip will hinder and loosen any tension created by the rope, and, therefore, lead to a weak and unstable join.

To prevent surface slip the joint needs to be manipulated so that the rope is pulling both pieces of timber together under tension. Four holes are drilled, two on each piece of wood (fig. 91). The holes allow the rope to pass through the timber itself, giving the rope better leverage and a tighter grip on the timber with every loop.

The holes (fig. 95, 96), had to be tapered back so the sharp edges did not slice into the fibres of the rope, which would result in the rope snapping when under tension. The four holes are at even widths so that the load is spread, out with the rope looping through. The hole positions (fig. 95, 96), are dictated by the number of dowels or pegs used in the join. The model can only take two thin dowels, or a small square peg. The square peg would be more effective if placed centrally, as the two dowels have to be more spread out, depending on the width of the timber used. The holes (fig. 97) for the dowels need to be set at a certain depth as they could affect the channels of the pre-drilled holes for the rope.

In the application of the rope (fig. 95, 96) it was discovered that the patterns would not mimic each other on either side, as illustrated on the model. One side showed an X cross over pattern – the X pattern is crossing the load over by pulling the load side to side, causing friction and tension on the internal dowel (fig. 83). Yet the other side showed a square box pattern – the square pattern is pulling one member to the other (fig. 94), and with every loop the tension gets greater, minimising movement in the joint. This form of lashing is effective, yet aesthetically the pattern is irregular. The X pattern would not perform as effectively if it did not have the square pattern on the other side, due to each pattern having its own loading directions. For the lashing to perform better the X pattern would need to be mimicked on the other side, although this makes it more complex as it would then require another piece of rope.

Expression: medium
Craft: low
Experience: medium
Figure 92 - Axonometric of Scarf joint with square peg.

Figure 93 - Scarf joint with a square peg.

Figure 94 - 'Square' pattern lashings tensioning directions.
Figure 95 - 'X' pattern lashings.

Figure 96 - Square pattern lashing.

Figure 97 - Dowel (peg) hindering the lashing path.
3.2.3.2 Models Nine to Eleven

These models explore the scarf joint further, constructing alternative connections that are evocative to the naked eye and allowing the join to be more expressive of its structural qualities. The explorations for these models are based around the use of round dowels to stabilise the joint, and considering connections that can be exposed, but structurally stable. This process allows for adjustments to be made to the models, as issues with stabilising the joint did arise.

This connection maintains the hidden peg internally, but still does not prevent the two elements in the joint from twisting and being pulled apart. To address these issues external pegs were added to all four surfaces on both top and bottom elements. The pegs were aligned at opposite ends of each other so that they could tension off each other. The joint was placed under tension by the clinch knot lashing, the two pieces of rope being pulled tighter with every loop of the lashing, Here it is noticeable on the pegs how much tension is applied as the pegs have started to bend inwards (fig. 99). The lashing allows the joint to twist by 4mm max in either direction, but the lashing acts as a spring, with the spring motion pulling the two elements back into alignment (fig. 100). This method is very similar to the one used in ocean going vessels used by Polynesians, where the lashing would spring back the boom if it was not being physically handled (fig. 101). Exposed pegs create major issues when a flat surface is needed for lining, as the pegs would impede and disrupt the lining material. Eliminating the pegs on one surface to accommodate lining would disrupt the performance of the three other pegged surfaces. All four have to be present to work in unison.

Expression: high
Craft: medium
Experience: medium
Figure 99 - Strain placed on the peg from the clinch knot.

Figure 100 - Twisted scarf joint, lashing springs it back into place.

Figure 101 - Boom on Hekenukumai Busby’s Waka.
3.2.3.4 Pegged Scarf Joint. Model Ten

The internal dowel peg in this joint has been rotated from its horizontal position to the vertical. This exposes the peg in the joint – in the previous models the peg is hidden internally. The issue with one peg is that the joint can still twist and rotate, throwing the alignment out (fig. 103,104). Another dowel could not be added, as the distance apart would compromise the edges of the joint, causing them to split under tension or any movement. The angle of the cut on the jointing elements and size of the dowels would need to be changed to allow for a second dowel. Size of the dowel is important, as it needs to be cut to the exact height of the joint, or millimetres short. Any oversize would mean the surface edges would not be flush, hindering the lining which goes on that surface.

Expression: low
Craft: medium
Experience: low
Figure 104 - Scarf joint twisted with the peg in.
Figure 105 - Pegged and lashed butt joint.
3.2.3.5 Pegged and Lashed Butt Joint. Model Ten/A

“The most basic joint for splicing in the butt joint, which in Japan is classified as a scarf joint; and the simplest of all butt joints is the straight end butt. This joint is so plain and simple, however, that it is difficult to classify it as a true splicing joint. By far the majority of splicing joints employ tenons. Dowels, pins, or splines. “

The butt joint has many similarities to the scarf and mitre joint, as they all have flat faced surfaces at the joining point. Ideas that were difficult to achieve in the scarf joint are made easier by the simple butt joint due to its 90 degree cuts of the joining surfaces. This joint is used both in Japanese architecture (fig. 77, 78), and Polynesian architecture, mainly being used to fix together the eve battens (fig. 77, 78), while in canoe building it was used to fix together the hull and washstrake (fig. 106, 107).

Two internally hidden pegs connect the two pieces of timber together (fig. 108), the two pegs preventing the timber from twisting and collapsing. Two holes opposite to each other are drilled so that rope can pull the two pieces of the wood tighter under tension. Pegs are punched into the holes to force further tension on the join (fig. 109), ensuring the rope does not come loose. Trenches were dug out, spanning from hole to hole (fig. 110), giving a flat surface, the rope being slotted into the trench so it does not hinder any linings.

Two identical joins were made by using two different processes. One is completely hand crafted using hand saws, drills and chisels (fig. 111), and the other is completely made by modern day electrical tools, such as drop saw, hand held drill and horizontal drill press (fig. 112). The comparison of time, effort and craftsmanship is accounted to achieve the joint. Aesthetically there are no visual differences, even though the hand-crafted model took longer to complete.

Expression: medium
Craft: medium
Experience: medium

Figure 106 - Maori attachment of washstrakes: 1, primitive method; 2, batten on outer side only; 3, fully developed Maori method.

Figure 107 - Hull lashing of plank canoes: a, b, Tongareva; c, d, Sarna.
Figure 108 - Hidden pegs in the butt joint.

Figure 109 - Lashing tensioned by small pegs.
Figure 110 - Vice clamp was used to stabilise the join during lashing.

Figure 111 - Hand-chiseled trench for the lashing.

Figure 112 - Horizontal drill pressed used to bore out the trench for the lashing.
3.2.3.6 Pegged Oblique Scarf Joint. Model Eleven

Through discussion with the workshop technician, the oblique scarf joint was brought up as a way of resolving the issues with stability. Research showed the joint was more suited to construction. “The oblique scarf joint shown in Figure 21 is widely used in Japan as a splicing joint for roof-truss beams. This joint is a variation of the oblique butt joint, and its square-shouldered tenons not only increase the contact surface but make it more resistant to shifting and slippage” 26. The joint has multiple variations and can be manipulated to suit the construction it is being used for. Scarf joints can also be found on traditional Polynesian buildings (fig. 114), and canoes (fig. 115), and are commonly referred to as the lock joints.

An oblique scarf was opted for further exploration. Although the scarf joint appears simple, it is very hard to make as the right knowledge and tools are needed to construct it. In this instance, a band saw was used, however, the disadvantage of the band saw is that the cuts are inaccurate. The exposed vertical peg and the two pieces, (male and female – males being the bottom piece at all times) of timber do not align properly due to the crooked cuts made by the band saw (fig. 117). The joint would resist twisting if the cuts were perfect. To further strengthen the joint, stub tenons will be added to stabilise the member (fig. 116).

Expression: low
Craft: high
Experience: medium

26. Ibid.
32.3.7 Development of Oblique Scarf Joint.

It was proposed that the two pieces of 18mm plywood be separated to give the frame a larger footing leading to the structure having greater stability (figs. 120, 121). The separation allows the cavity created to be used as service channels. Lashing can now be done through the middle of the frame as, opposed to the outer edges of the frame.

Physically modelling the scarf joint proved difficult. In research computer modelling was adopted for the joint as it is easily replicated and manipulated using this three dimensional (3D) design software. "To make this joint even more secure and prevent shifting, in addition to the stub and tenons hardwood pegs are used inside the joint...." 27. The stub and tenon give this joint extra strength and stability. This is why the oblique scarf joint with stub and tenon is commonly used in traditional Japanese architecture, “The daimochi-tsugi, an oblique scarf joint with stub tenons, is usually used to join beams in the Japanese roof truss" 28.

The use of 18mm plywood to construct the final prototype design was opted for by the team due to availability and cost. 18mm plywood cancelled out the internal hardwood pegs due to its thickness. Machinery is needed to achieve this pegging in the 5 axis CNC or a horizontal mortise machine. Neither of these were available for this research project. The stub and tenons are easily cut on the available CNC machine, however, the issue of sliding horizontal elements is still of concern.

A method commonly used in Japanese joinery to stop sliding of horizontal pieces is the ‘external draw pin joint’ (figs. 118, 119), (the pin can also be referred to as a peg). Numerous numbers of draw pins can be applied to the joint to maximise stability. This concept became the driver in developing the scarf joint. A number of modifications were made to the draw pin – the straight square pin used by the Japanese does not lock or compress as it is simply there to stop movement. The pin was made wider and tapered on one edge; this locks the pin in under pressure. Struts were added to the joint to maintain the gap for the cavity (fig. 122), four pins passing through them to stop any slippage. Four individual elements have now turned into two; the struts and pins combine two elements, and those two are made into one (fig. 123-3). Pinned from either side, any slippage to the outside and inside has been stopped by the double pinning (fig. 123-1,2). The struts double as a component for lashing, as lashing would pull the two struts towards each other, placing the joint under compression. The Japanese have shown that the scarf joint can have multiple variations (figs. 124-129) although some of them are very complex and require a lot of skilled knowledge. With this research knowledge in mind, exploration began on the modification and strengthening of an oblique scarf joint by testing different strut patterns (figs. 130-137).

28. Ibid.
Figure 120 - Two frames made consisting of 4 pieces of plywood.

Figure 121 - Two frames is split into four frames.

Figure 122 - Frame locking system: 1. tapered peg; 2. joint strut.
Figure 123 - Oblique scarf joint: 1, side elevation n.f.s; 2, front elevation; 3, axonometric.
Figure 124 - Japanese 'Daimochi-tsugi', oblique scarf joint with stub tenons.

Figure 125 - Japanese 'Daimochi-tsugi', oblique scarf joint with stub tenons.

Figure 126 - Japanese 'Okkake-dassen-tsugi', rabbeted oblique scarf joint.

Figure 127 - Japanese 'Kanawa-tsugi', mortised rabbeted oblique scarf joint.

Figure 128 - Japanese 'Tsuka-tsugi', halved rabbeted oblique scarf joint.

Figure 129 - Japanese 'Miyajima-tsugi', halved oblique scarf joint.
Figure 130 - Variation one, oblique scarf joint with stub tenons with 2 struts and 8 tapered pegs.

Figure 131 - Variation two, oblique scarf joint with stub tenons with 2 struts and 8 tapered pegs.

Figure 132 - Variation three, oblique scarf joint with stub tenons with 2 struts and 8 tapered pegs.
Figure 133 - Variation four, oblique scarf joint with stub tenons with 4 struts and 16 tapered pegs.

Figure 134 - Variation five, oblique scarf joint with stub tenons with 4 struts and 16 tapered pegs.

Figure 135 - Variation six, oblique scarf joint with stub tenons with 4 struts and 16 tapered pegs.
Figure 136 - Variation seven, oblique scarf joint with stub tenons with 4 struts and 16 tapered pegs.

Figure 137 - Variation eight (chosen for development), oblique scarf joint with stub tenons with 2 struts and 8 tapered pegs.
Lashings between the two struts are explored to address and resolve the issue of slipage. Consideration of a simple concept with an elegant lashing design will show the concept and can be conveyed as an aspect of Polynesian culture. A ‘figure eight’ lashing is used in this model. Tension is easy to maintain with this lashing due to the rope rotations flowing in opposite directions and the use of only two struts (fig. 141). If more compression is needed on the joint a clinch knot can be added, as the body figure eight lashing is similar to the body clinch knot lashing, with the small difference of the clinch knot being a less complex loop pattern. The disadvantage to this form of lashing is the lack of vibrant and eccentric fashion, like those which have been commonly seen such as the ‘fly flap’ (fig. 38), or ‘diamond’ lashing (fig. 58).

Expression: low
Craft: low
Experience: low
Figure 139 - Strut holes drilled on the horizontal drill press.

Figure 140 - Zip ties used to hold the joint together before lashing.

Figure 141 - Start of figure 8 lashing.
The next phase of development from the previous model was the addition of two more struts. Evenly spaced struts allow for greater exposure of the lashing used. The lashing is more complex with the additional two extra loops which highlights the performance of the two struts being stronger than the one strut model. Tensioning the lashing further would be difficult with two loops to clinch rather than one. The difficulty is feeding the rope behind the first screen of rope in which the clinch know will develop (fig. 146).

The internal pattern of the lashing can be exposed by only using the middle half of the strut when looping. The strength and compression is lost by minimising the lashing footprint (fig picture of model 13-2), this would allow for a more exposed connection (fig. 143-145).

Multiple models were made to test other forms of lashing, with the intention of exploring a more exposed and expressive lashing, implemented in small, medium and large footprints. Three lashing types are used; clinch knot with small footprint. The strongest of the three (fig. 148), double X lashing with a medium foot print, the weakest and most complex of the three (fig. 149), and figure eight with double box lashing with a large footprint, the strength outcome being medium (fig. 150).

Expression: medium
Craft: high
Experience: medium
Figure 143 - Start of figure 8 lashing.

Figure 144 - Half way point of figure 8 lashing.

Figure 145 - Top view of the figure 8 lashing.
Figure 146 - Figure 8 lashing with clinch knot.
Expression: high
Craft: high
Experience: high

Figure 147 - Figure 8 lashing with small footprint on the strut.
Expression: medium
Craft: medium
Experience: medium

Figure 148 - Clinch knot with small footprint.
Expression: high
Craft: medium
Experience: high
Figure 149 – Double 'X' lashing with a medium footprint.

Expression: high
Craft: high
Experience: high

Figure 150 – Figure eight with double box lashing with a large footprint.

Expression: low
Craft: medium
Experience: low
Ideas taken from the previous model are developed further in this concept. The key aspect of this model was to develop the new lashing typology. Initialising the free range in application, the structural components in the joint dictate the lashing typology, as the struts have been extended out on either side to accommodate pegs. Pegging has only been done on the inside cavity of the joint as a deliberate ploy so that an alternative solution could be explored through lashing (fig. 152).

The rotation and pattern on the lashing is dictated by the person applying it, as long as the lashing is compressing the joint inwards. The pegs prevent slipping inwards, yet the peg slipping outwards is prevented by the lashing. The lashing binds together the struts to create two-compression points on the joint. The tension needs to be maintained as, if one rope is released, then the entire joint fails. If compression is lost, then the pieces of timber are free to slide. In general, the lashing in this model shows aspects of Polynesian links, since the pattern is similar to the first phase of the double V Lozenge Lashing (fig. 56), the outcome of the lashing strength is poor.

Expression: high  
Craft: high  
Experience: high
Figure 152 - First step of the Lozenge with struts internally pegged.

Figure 153 - Lashing over the strut overhang.
Moving forward many components were maintained but developed further in this model (fig. 151). The struts are positioned, as in model fourteen, in the company of additional pegs on the outer edges, preventing slippage in any direction (fig. 155). The pegs are also essential for the lashing, as their purpose is to pin and lock in the rope, eliminating any knots. The clinch knot lashing was used, as this knot has proven to be the strongest and most easily applied/applicable knot from previous models. Each strut has its own clinch knot lashing, providing four compression points, in contrast to the previous model where two struts were being compressed by one lashing. If one of the outer pegs were to break, the lashing would be still intact. The same would occur if one lashing were to fail, the other three would maintain compression.

Visually this lashing is not as elegant as the one on the previous model. It carries strong links to Polynesia and was commonly used in traditional building and canoes, but is referred to as a collar lashing (fig. 31). The clinch knot is not dictated by one form, however, as different variations or materials can be applied to it which may affect the overall strength and aesthetic value (fig. 156).

Expression: high
Craft: medium
Experience: high
Figure 155 - Clinch knot with struts internally and externally pegged.

Figure 156 - Clinch knot lashing inside the hull of Hekenukumai Busby’s Waka.
This model is an exploration, looking at different variations of a lashing to be used on the scarf and cross lap joint. The test development looks at the tensile and compression strength of each variation which is gauged by various factors, for example, bowing in the strut illustrates the tensile strength of the clinch knot (fig. 163).

Each lashing is assessed on:

- **Expression** - whether the connections are indicative of heritage and tradition. Does the joint reveal the nature of the connection method used?
- **Craft** - does it show different levels of intervention, gauged by how much craftsmanship is required to accomplish the joint?
- **Experience** - will the joint heighten the experience of the building visually, and then through touch and smell (singed rope)?
- **Strength** - tensile and compression strength of the lashing
- **Materials** - number of materials used
- **Cost** - cost of materials
- **Time** - application time

Figure 157 – Variation of clinch knot lashings (simple)
Judging is based upon personal experience, mixed with the knowledge attained from research and attending workshops in lashing and woodwork. A critical part of this analysis is gauging if a person with no experience of lashing could apply these methods. At the time of assembly, this will be reflected in the overall rating.

Each of the criteria will be marked on a scale of low, medium or high. Overall each lashing will be given a score from one to five – one being low and five being high.

Scarf joint struts

The footprint of the lashing has been minimised and kept in the middle deliberately, as this area is commonly where bending movement will occur when under pressure.

3.2.3.12.1 Lashing One. Model Sixteen

Lashing One: Clinch Knot (fig. 158, 159).

The clinch on this lashing has been extended from neck to neck, to allow more tensile strength.

Expression: medium
Craft: low
Experience: medium
Strength: medium
Materials: low
Cost: low
Time: low
Overall score from five: four
3.2.3.2 Lashing Two. Model Sixteen

Lashing Two: Figure Eight (fig. 160)

Simple figure eight lashing with no clinch, assessing how the lashing performs by itself.

Expression: low
Craft: low
Experience: low
Strength: low
Materials: low
Cost: low
Time: low
Overall score from five: two
3.2.3.12.3 Lashing Three, Model Sixteen

Lashing Three: Figure Eight Double Clinch (fig. 161)

Simple figure eight lash with a double clinch knots at both necks. Eliminates one large clinch knot in the centre and minimises the length of rope.

Expression: medium
Craft: low
Experience: medium
Strength: medium
Materials: low
Cost: low
Time: medium
Overall score from five: three

Figure 161 - Figure 8 double clinched.
Lashing Four: Twisted Loop (fig. 163)

A straightforward, simple loop with a peg through the middle. The peg is twisted to apply the compression, more twists allowing greater compression. In this case only one twist was used as the tension created kept snapping the strut. Lashing width was also minimised due to the same issue of the strut snapping, which indicates increasing the width or twists will increase tension, with a larger strut being needed. Two pegs are placed on either side to prevent the lashing from unravelling.

Expression:     low
Craft:           high
Experience:     medium
Strength:        high
Materials:       medium
Cost:            medium
Time:            medium
Overall score from five:  four
3.2.3.12.5 Lashing Five. Model Seventeen

Lashing Five: Clinch Knot with Pegs and Zip Ties (fig. 164)

The clinch knot is reverted back to in this development, this time with additions to gain more compression. Zip ties are pulling pegs towards each other by levering the struts, thus compressing the clinch knot in the middle. Strength is lost using this method as the neck, which is the widest part of the lashing, is not under compression since the collar is pulled to the narrowest part which causes the lashing to come loose.

Expression: medium
Craft: high
Experience: high
Strength: low
Materials: high
Cost: medium
Time: high
Overall score from five: three
Lashing Six: Clinch Knots with Pegs (fig. 165)

This model is similar to the previous lashing, showing the pegs are compressed towards each other using secondary clinch knots. The strength is lost in this lash as the clinch (fig. 166), is being pulled away from both necks. An option to fix this would be to use a double collar – placing two pegs through the middle and tension them back to the strut. This will pull the collar up and compress the widest part of the lashing.

Expression: high
Craft: high
Experience: high
Strength: medium
Materials: high
Cost: medium
Time: high
Overall score from five: three
Figure 165 - Clinch knot with pegs.

Figure 166 - Clinch squeezing inwards pulling away from the neck of the lashing.
The next phase of testing involved gauging the tensile strength differences of dry and wet rope (fig. 169). This is to determine whether the wet rope would create more compression once it had shrunk from drying. These tests are set up using the figure eight and clinch knot lashings most commonly used in this research. The length of rope and foot print is the same for both lashing types, as this allows for an equal playing field. The rope is soaked for a period of three days, followed by the water being drained and any excess liquid lightly squeezed out, leaving the rope damp.

After application the bows on the struts of all four models were checked and measured before leaving the lashings to dry. Three days later the lashings were assessed:

Figure 8

There was little change in the deflection on the bows – the wet lashing had pulled in 2mm maximum (fig. 171). Although upon touch the dry lashing feels a lot more firm (fig. 167); this could be noted as the middle half of the wet lashing dried quicker, causing the outer loops to slip and lose tension. This lashing is under more tension centrally, causing the strut to bend easily as it is unsupported at the centre point where it is at its weakest.
Clinch Knot

Significant changes can be seen with these lashings. On application the dry rope had surface spillage (fig 168). The wet rope gripped the surface and did not spill when the clinch was applied, due to the grip (fig. 170). The majority of the tension on the wet model is coming from the side loops, leaving the centre of the lashing loose and flimsy. The wet lashing has pulled in 5mm more after drying.

Figure 169 – Hemp rope soaked in a bowl of water for 4 days.

Figure 170 – Wet figure 8 lashing.

Figure 171 – Wet clinch knot lashing.
Figure 172 - Series of cross lap joint models.
3.2.4 Development of Cross Lap Joint

Four holes have been drilled on all four arms of the joint to assist and manipulate the lashing. This gives the lashing options of; sitting on the flat surface or being moved to the centre point where it is not hindering the surface if the flat surface is being used for lining. The first four models illustrate how lashing could be used, the surface is not used for lining.

3.2.4.1 ‘X’ Lashing on a Cross Lap Joint (fig. 173). Model Twenty Two/A

A hole is drilled through the centre of the joint, allowing the rope to pass through the middle, giving it the characteristics of a peg. Strength is maintained even with the small lashing footprint, due to the holes. The lashing compresses the joint from both ends, locking the elements in and does not allow them to slip away from each other. Overall one rope lashing tying together all four holes.

Expression: medium
Craft: high
Experience: medium
Strength: high
Materials: low
Cost: low
Time: medium
Overall score from five: four

Figure 173 – X lashing on a cross lap joint.
3.2.4.2 'Diamond' Lashing on a Cross Lap Joint (fig. 174). Model Twenty Two/B

There is no central hole for this lashing. Therefore, for extra strength, the footprint of the lashing was made bigger. The lashing provides resistance by having two holding points which are at opposite ends.

| Expression | high |
| Craft      | high |
| Experience | medium |
| Strength   | medium |
| Materials  | low |
| Cost       | low |
| Time       | high |
| Overall score from five: | four |
3.2.4.3 'Collar' Lashing 1 on a Cross Lap Joint (fig. 175). Model Twenty Two/C

This collar lashing only utilises one side of the joint, as its pulling force is only sideways. The lashing stops the joint from coming apart, however, it does not prevent twisting due to the lashing only tying together two sides, rather than four like ‘X’ and the diamond lashing.

Expression: low
Craft: low
Experience: low
Strength: low
Materials: low
Cost: low
Time: low
Overall score from five: two
3.2.4.4 ‘Collar’ Lashing Two on a Cross Lap Joint (fig. 176).
Model Twenty Two/D

Similar to the previous lashing, with a slight variation; three sides are tied together. Aesthetically, this lashing exposes the joint on both sides, giving a better perspective of the type of joint.

Expression: medium
Craft: low
Experience: medium
Strength: medium
Materials: low
Cost: low
Time: low
Overall score from five: three

Figure 176 – Collar lashing 2 on a cross lap joint.
3.2.4.5 Tensioned Loop on a Cross Lap Joint (fig. 177), Model Twenty Three

The tensioned loop is the simplest lashing in the series, with it also being the strongest. A tight loop is made by the rope passing through the predrilled holes once this is done the metal pin is threaded through. The loop is pulled over the pin putting strain on the rope, which allows the two elements of the join to be pulled together. A metal pin has been added through the centre of the join for added stability of the lashing.

Expression: low
Craft: medium
Experience: low
Strength: high
Materials: medium
Cost: high
Time: medium
Overall score from five: three
3.2.4.6 'X' Lashing on a Cross Lap Joint (fig. 178). Model Twenty Four

To achieve this lashing an extra four holes had to be drilled into the arms (fig. 179), giving a total of eight holes. The holes allow the lashing to pull tension in opposite directions. The leverage gained from the holes allows the lashing to be under tension during application. A metal pin has been added through the centre of the joint to stop any movement within the joint (fig. 179). Overall, this lashing was the one of hardest to achieve due to the two lengths of rope (fig. 180).

Expression: medium
Craft: medium
Experience: medium
Strength: high
Materials: low
Cost: low
Time: medium
Overall score from five: four

Figure 178 - X lashing on a cross lap joint.
Figure 179 - 8 holes for the lashing of the joint.

Figure 180 - Application phase of the X lashing.
3.2.4.7 First Phase Diamond Lash on a Cross Lap Joint (fig. 181). Model Twenty Five

Only the first phase of the Lozenge lashing could be applied to this joint, as two pieces of string would be needed and both need to be lashed at the same time, not one after the other. Without the four holes the pattern created by the lashing cannot be achieved.

Expression: high
Craft: high
Experience: high
Strength: low
Materials: low
Cost: low
Time: high
Overall score from five: three
3.2.4.8 Twist Tensioned Loop on a Cross Lap Joint (fig. 182).
Model Twenty Six

Keeping with the previous lashing (fig. 181) this one is slightly modified with the addition of a secondary loop. The pegs are twisted once they have been placed between the two loops, tension on the joint being dictated by the number of twists made by the peg. In order to stop the rope from unravelling two small holes have been drilled at opposite ends of the joint to house the pegs. Pegs can be added for further strength.

Expression: medium
Craft: medium
Experience: medium
Strength: high
Materials: medium
Cost: medium
Time: low
Overall score from five: three

Figure 182 – Twist tensioned loop on a cross lap joint.
3.2.4.9 Clinch Tensioned Loop Lash One on a Cross Lap Joint
(fig. 183), Model Twenty Seven

Double loop lashing, except the two loops have been pulled together by a clinch knot on two sides (fig. 159). Two more clinch knots can added for further strength.

Expression: low
Craft: low
Experience: medium
Strength: medium
Materials: low
Cost: low
Time: low
Overall score from five: three
3.2.4.10 Clinch Tensioned Loop Lash Two on a Cross Lap Joint (fig. 184). Model Twenty Eight

This is a double loop with four clinch knots. The clinch knots can be taken out if the joints need to be weakened, however, the clinch knot's tension is lost if one fails.

Expression: medium
Craft: medium
Experience: high
Strength: high
Materials: low
Cost: low
Time: medium
Overall score from five: four
3.2.5 Team Members Individual Concept Design

3.2.5.1 Team Work – Design Guidelines
- Non consent building (ten square metres)

“1. Building work in connection with any detached building that:
   (a) is not more than 1 storey (being a floor level of up to 1 metre above the supporting ground and a height of up to 3.5 metres above the floor level); and
   (b) does not exceed 10 square metres in floor area; and
   (c) does not contain sanitary facilities or facilities for the storage of potable water; and
   (d) does not include sleeping accommodation, unless the building is used in connection with a dwelling and does not contain any cooking facilities.

2. However, sub clause (1) does not include building work in connection with a building that is closer than the measure of its own height to any residential building or to any legal boundary.”

3. Uses the team’s bay layout which is dictated by the CNC machines cutting parameters. One bay 550mm width by 3600mm in length or 600mm by 3300 mm, maximum of 15 bays to keep within non-consent.

4. Weather-tight structure

5. Adaptable to change in relation to location and function

6. Design for student studio space with overnight stay capabilities

7. Showcases cultural elements through design

3.2.5.2 Team Members Individual Concept Design

3.2.5.2.1 Simba Mtakwa & James McNicholas – Concept Form Models

Figure 193 - Samoan Fale form concept model.
3.2.6 Exploration Models of Form, Structure, Cladding and Tension Systems

3.2.6.1 Samoan Fale Concept Form, Model Twenty Nine

Form

The form is derived from the Samoan Fale (fig. 194) without pou lalo, (wall post), which allows the roof members to run into the ground plain. This design is adaptable to change according to the conditions it may be used in. Certain elements can be added or subtracted to suit site and weather conditions. Note that this is only a model of one bay.

Structure

The structural system used in this design is made up of three key elements. The three elements are; the block walls, glue laminated trusses and the purlings. Form of the building is achieved by the curved glue laminated trusses; which are further reinforced by block walls (fig. 195). The block walls stop the truss from flexing outwards by providing a permanent barrier. The slots were left open in certain areas of the truss during lamination; this was done to assist the pegging of the purlings (fig. 196).

The gaps between trusses are maintained by the purlings which are pegged on both sides to prevent any sideways movement.

Cladding

The idea behind the cladding was to use one material to cover the whole structure eliminating the need for multiple components and fixing points (fig. 193). This concept introduces a cloth like membrane, possibly sailcloth or PVC, as they are highly durable and flexible, furthermore, they have the ability to mould to complex forms. The membrane in this model is fixed to cantilevered struts (fig. 197) that can be pulled in or out to manipulate the shape of the membrane and dictate the air flow. Fixing the membrane directly to the truss would eliminate the ventilation cavity being created by the strut, restricting the membrane’s ability to breathe. The strut is threaded through the truss and then is tensioned down by the tensioned wire rope (fig. 196).

Tensioning System

Wire rope is used as a tension to hold the structure down; turnbuckles (fig. 211, 212), will be used to control the tension on the building. This is not shown on this model as small-scale turnbuckles are rarely available in New Zealand. The wire rope pulls down on the struts (fig 196), which then pulls on the truss and the roofing membrane. Turnbuckles were chosen as they deal better with any adjustments made to the struts.

Expression: high
Craft: high
Experience: high
Figure 196 - Structural skeleton, without cladding.
Figure 197 - Model roof structure.
3.2.6.2 Maori Whare Concept Form, Model Thirty

Form

The form is derived from Māori wharenui (fig. 199), (meeting house) and Fijian Buri (fig. 26). It is simple as it eliminates any curved surfaces, making it easier to design and assemble. The form of the building allows it to have multiple configurations as shown in the model where two modules share an outdoor space.

Structure

The structure consists of four key elements: the bay frames, struts (long span nogs), wire ropes and the ply sheet cladding. This design explores the idea of cutting one solid frame out of a large piece of ply (fig. 200), then having a frame that is made up of multiple elements. Once the frames are tilted up the struts are slotted in, completely tying the structural skeleton together (fig. 201). Gaps between the frames are maintained by the cross-joints, allowing the struts to sit flush on the exterior surface. The structure is then placed under tension by wire ropes that span from one side of the building to the other (fig. 204). Trenches have been cut out of the struts to allow the wire rope to sit below the flush. Plywood sheets are used to line the exterior of the building, doubling as a diaphragm that braces the structure (fig. 203).

Cladding

Treated structural plywood sheets would be used to line the floor surface (fig. 202), exterior wall and roof (fig. 203). Sheets of ply can be removed and replaced with clear light panels if there is not enough natural light gained from open space at either end of the module (fig. 198).

Tension System

Two forms of tension systems are used in this model. One is the hand-tensioned rope and the other is the wire rope with turnbuckle (fig. 204). The hand-tensioned rope requires a lot more effort as it has to be manually tensioned, while the wire rope comes under tension by twisting the turnbuckle (fig. 205). The wire rope performs better over the rope due to strength and durability.

Expression: medium
Craft: high
Experience: medium
Figure 202 - Internal perspective - half of the floor panels fixed down.

Figure 203 - Structural skeleton with wall and roof cladding fixed down at the rear end of the building.
Figure 204 – Two forms of tensioning: left, rope and marine knots; right, wire rope and turnbuckle clasp.

Figure 205 – Wire rope tensioning system – semi open turnbuckle clasp. Twist to tension and compress the frame.
Figure 206 - Collaborative team bay model.
3.2.6.3 Collaborative Team Bay Model, Model Thirty One

Form

The form of this design is a hybrid of the Samoan Fale (fig. 193) and Māori wharenui (fig. 198). The form closely resembles some of the concepts that the team members have designed. The overall shape of the frame can change to suit its intended use as one side being lowered or raised as dictated by activity taking place in that space (fig. 191).

Structure

There are three key structural elements to this design: the frame, noggin and wire ropes. The frame is made up of multiple elements (fig. 207-209) connected by the scarf joint and figure eight lashing. In this design the nog only spans the distance between each frame. Where it is butt joined to the outer edges it does not span over multiple frames (fig. 213). The small distances between the frames are maintained by smaller round struts which are lashed together at every joint junction (fig. 210). Using turnbuckles attached to wire ropes, the frame is compressed inwards, locking the frame into place (fig. 212); these only stop upwards lift, the interior lining stopping any racking or twisting.

Cladding

This design uses the same cladding system as the design based on the Samoan Fale (fig. 193). The cladding struts are fixed on top of the frame and still maintain an air gap (fig. 212), this system is very similar to the ones that are used on camping tents. One large sheet of membrane will cover the entire structure.

Tension System

The structure is tensioned by turnbuckles attached to wire ropes spanning the width of the frame (fig. 211). The frames are tensioned individually as even rotations are needed on both turnbuckles. If one side is tensioned more than the other alignment issues could be created.

Expression: high
Craft: high
Experience: high
Figure 210 – Bay frame erected without tension system.

Figure 211 – Tension system, wire rope crimped onto hook turnbuckles.
Figure 212 - Bay frame tensioned with the turnbuckles hooked to the base of the model.

Figure 213 - Nog spanning between the outer edges of the bay frame.
Figure 214 - Cladding detail one.
Cladding the structure became a huge issue which started to dictate the design outcomes. Sailcloth, PVC sheets or any type of membrane was out of the question due to cost as they are made to order, along with the specifically designed brackets and fixings that would be needed. As a team the decision was made to explore flat sheet cladding options, such as corrugated iron, perspex, clear light and plywood. Through costing and research plywood was chosen as the best option for cladding. Therefore, the next phase was to use the knowledge gained from the research to create and develop cladding junctions.

### 3.2.7 Cladding Details Concepts

Cladding the structure became a huge issue which started to dictate the design outcomes. Sailcloth, PVC sheets or any type of membrane was out of the question due to cost as they are made to order, along with the specifically designed brackets and fixings that would be needed. As a team the decision was made to explore flat sheet cladding options, such as corrugated iron, perspex, clear light and plywood. Through costing and research plywood was chosen as the best option for cladding. Therefore, the next phase was to use the knowledge gained from the research to create and develop cladding junctions.

### 3.2.7.1 Cladding Detail One: Model Thirty Two

For this model (fig. 214-219) the round struts pegged on all sides of the framing boards are used. Building wrap is stapled on the outer surface of the framing board. Two cavity battens are then pinned into place using small round dowels. The battens are added to provide cavity space for the building to breathe. Next, the 9mm plywood cladding sheet is pinned onto the cavity batten using the timber dowels (fig. 216). The dowel pins had to be exposed as the cladding was not thick enough to hang on the dowel and have it hidden at the same time, (fig. 217). Once the cladding is attached four large holes are drilled right through the cladding, batten and building wrap. The holes are all aligned with the centre point of the strut on both horizontal and vertical axis. Four round lashing pegs, the same width as the hole, are pushed through. The pegs have been pre drilled on both ends and one end is fitted with a metal pin. The peg is pushed until the metal pin is hard up against the cladding, at this point the peg is lashed to the interior strut using the clinch knot lashing (fig. 218).

The cladding is very hard to remove once all four pegs are lashed back to the strut. Two major issues arose after assessment of the model. One was that there were too many penetrations in the cladding and building wrap (fig. 219). Water would seep through the cladding and into the building if these penetrations are not covered up by flashing or sealant (fig. 215). The other major issue is the exposed pin on the exterior cladding, which could be damaged by the environment or tampered with by public.

| Expression: | medium |
| Craft: | high |
| Experience: | medium |
| Strength: | high |
| Materials: | low |
| Cost: | low |
| Time: | medium |
| Overall score from five: | four |

Figure 216 - Front, round lashing peg with metal pin and cladding dowel pins; back, lashing strut and dowel pegs.

Figure 215 - Section of the wall detail one: 1, bay frame; 2, lashing strut; 3, strut peg; 4, cladding and lashing peg; 5, 9mm cladding; 6, cavity batten; 7, metal pin; 8, sealant around the round lashing peg.

Expression: medium
Craft: high
Experience: medium
Strength: high
Materials: low
Cost: low
Time: medium
Overall score from five: four
Figure 217 - Cladding system.

Figure 218 - Lashing system; clinch knot lashing.
Figure 219 - Section of the wall detail one: 1, bay frame; 2, lashing strut; 3, strut peg; 4, cladding and lashing peg; 5, 9mm cladding; 6, cavity batten; 7, metal pin; 8, dowel pins; 9, interior lining; 10, building wrap.
3.2.7.2 Cladding Detail Two. Model Thirty Three

This model addresses and improves on the issues that arose from the previous cladding detail. Cladding is now 18mm plywood, eliminating the exposed timber dowels used to fix the cladding into the framing (fig. 221, 223-225). Cavity battens were removed due to the structure being exposed on the inside, where the cladding is hard up against the frame (fig. 226). Two eye straps have now replaced the pinned peg that passed through the cladding (fig. 222). This eliminates any penetration and leaves a clean, uninterrupted exterior surface. The eye straps allow for multiple variations of the clinch knot lashing (fig. 227-230) as shown on the model, all possessing the same strength as each other.
Figure 223 - Drill with a depth rig for the metal pins.

Figure 224 - Metal pins on the edge surface of the bay frame.

Figure 225 - Cladding skeleton without the cladding panel.
Figure 226 - Section of the wall detail two: 1, bay frame; 2, lashing strut; 3, strut peg; 4, 18mm cladding; 5, metal pin.
### 3.2.7.2.1 Lashing One (fig. 227). Model Thirty Three

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Overall score from five: five

![Image of Lashing One on model 33, variation of clinch knot.](image-url)
3.2.7.2.2 Lashing Two (fig. 228), Model Thirty Three

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Figure 228 - Lashing two on model 33, variation of clinch knot.
3.2.7.3 Lashing Three (fig. 229), Model Thirty Three

Expression: high
Craft: high
Experience: high
Strength: high
Materials: medium
Cost: low
Time: high
Overall score from five: five

Figure 229 - Lashing three on model 33, variation of clinch knot.
### 3.2.7.2.4 Lashing Four (fig. 230), Model Thirty Three

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**Figure 230** - Lashing four on model 33, variation of clinch knot.
4.0 design outcome
4.1 Joint

Frame

The oblique scarf joint with the two pegged angled struts has been chosen to be applied in the team model (fig. 137). These joints will be used on the floor, walls and roof structure. The joint will be developed further during the design and application stage, with input from team members and supervisors.

Cladding

An uninterrupted clear surface was opted for, for further development as it complements the weather issues by eliminating any major penetrations on the cladding when fixing it on. The decision was also based on the use of 18mm plywood for the built design.

4.2 Lashing

Frame

The figure eight and clinch knot lashing have been chosen as, through discussion with the team members, it was clear that these lashings would complement the joint type being used. Both lashings perform well in compression and allow for variations in design during application. The lashing will be tested on the larger bay model, in which analysis of performance will be assessed. Both lashings will be compared against each other in terms of the overall output performance – stability, function, pressure and application – this could lead to further developments to enhance the lashing.

Cladding

Lashing used to tie the cladding back is an undefined area and, as illustrated in the cladding details (fig. 214, 220), a variation of alterations can be made to the clinch knot (fig. 218, 227-230). The decision making on lashing type used will be decided by the person applying the lashing.

Tension System

Turnbuckles with wire rope (fig. 211, 212) are chosen as the overall tensioning system due to performance, application, cost and availability of the turnbuckles. The context of the assembly site, such as the design, size, conditioning and context of the assembly may change the turnbuckles sizing and use of wire. It will be tested against other tensioning types, such as fence strainers (fig. 21) or ratchet straps (fig. 20).
5.0 team design process

Common Ground: the old & the new methods combined to create the teams design brief.

System
Dynamic Environments; the fabrication of customisable components and their ability to adapt to the programmed framework.

New Method (technologies & systems)

Framework
How can digitally fabricated structures define architectural typologies?

Connection
Cultural Connections; how can manual craft aid in detailed design and assembly of digitally fabricated elements?

Figure 230 - Team design process.
5.1 Individual Design Process

5.1.1 Simba Mtakwa – Framework
“principles of digital architecture that underlie a system, or concept”

Architecturally the program (use) of the space is informed by a particular dialogue / language. This dialogue will be used to identify the desired prototype. Through a process of research, an investigation of different spatial qualities through modeling, drawing, and testing will reveal the final outcome. This will be worked on individually and then collaboratively. The chosen form must: adapt, change and be flexible enough to be configured in different arrangements. Ways to do this will be through testing various methods in which an internal layout is fitted. The architecture will be formed by the spatial qualities of the structure; most importantly it will determine how the spaces can be used. Continuous feedback from team members and staff will ensure that this process is dealt with appropriately.

5.1.2 James McNicholas – System
“a set of connected parts forming a complex whole”

The production of a customisable prefabricated module, from components that can be both pieced together and taken apart. The work involves the mock-up of the intended concept, through a digital model prior to it being exploded into elements for nesting onto cutting sheets. Delivery of the concept is achieved through the collaborative nature of the process. We discuss and share work to understand the design for an adaptive system that is capable of being modified for aesthetic, performative and functional requirements.

The three-stage process is a continuous work in progress, assisting each other through its development. Changes are made regularly, though we limit the range of outcomes, depending on resources and scheduling.

5.1.3 Azmon Chetty – Connection
“the action of linking one element with another”

Works include the research and modeling of various joints, lashing methods and tension systems that are suited to this prototype. A physical catalog of models is produced for discussion. As team members we decide what joints, lashings and tension system will perform best. Further developments through more modeling or changes during application of the building process may be made.

The development of each component is not set, changes may be made upon completion of the built prototype. Load testing the structure will uncover the performance of each component (the joint, lashing and tensioning system), each component will unveil both weak and strong points of the structure. Further developments may be proposed for the prototype to increase its structural stability. The fabrication process utilising digital and manual techniques provides an opportunity to evaluate both component joints, and lashing and tensioning systems on the prototype. Following this the variations of each component will be recognised and compared to those being tested within the structure. The results will give indications as to which connections may need manipulation to strengthen their performance.
5.2 Context

Architecturally the project has a responsibility to address the contextual conditions: site, climate, culture, people, shelter, material, and projected fabrication costs. These and many more factors are considered in the process and adhered to through differing methods of design and assembly. As the work can be customised according to requirements, the proposed system is open to modification; a change in use or location.

The modularity and assembly of the structure allows for the system to be deployed in areas needing adaptive development: such as disaster struck regions, social aid zones, districts of residential growth, and commercial ventures. Globally it may be made accessible through a creative commons enabling others to contribute in further developments.

The proposal, like many, has its theoretical elements. This investigation considers the relationship between architecture and construction; through the craft in fabrication and assembly. Therefore, a built component must take its place in representing the intended scheme. The representation of structural components and methods of connection takes place through the digital fabrication of scaled elements. Additionally, manually made models will be produced, displaying methods of connection with influences deriving from Japan and the Pacific regions.

The setting for our work is Auckland, a city of a temperate climate. The selected construction material consists predominately of flat sheet plywood. The plywood succeeds in similar works for its structural performance, appearance, ease of workability, assembly and control in the fabrication process. The materials are locally sourced where applicable and are stored in a controlled environment (under sheltered conditions in the workshop). The workshop, where the CNC machine is located, is where the manufacturing and fabrication of the structure will take place.

The levels of fabrication taking place during the project are subject to: availability of facilities, support staff, our design intentions, work rate, skill level, material supply and the relative costs associated with funding this work.

5.3 Site

The scheme is intended to be non-site specific as the proposal considers the design, fabrication and assembly of an architectural system to be the primary focus. This is the driver for design, with ‘making’ at the heart of the project. The conditions of alternative sites and climatic conditions have become secondary in the design process. At times they are acknowledged where applicable as we endeavor to propose alternative adaptations; though this is not the main concern.

We set additional limitations to control the project’s scale by implementing the building under a non-consent classification, a temporary dwelling; positioned away from significant buildings, boundaries and other important structures. The footprint is to measure no more than ten square metres; this is the core five modules of the structure, with the additional six modules making up the ends, functioning as a detachable deck and pergola like components. The larger allocation of forty square metres is too large and unnecessary for representation of our intended proposal.

The location selected for positioning of the full eleven-module structure is a grass-covered plinth, a slightly elevated level outside and adjacent to the Masters of Architecture studios, on site at the Unitec Institute of Technology (fig. 231.1-235). This site is an ideal area to display the built works and functionally suitable for the intended occupants.
Figure 231.1 - Building site location, front yard of the Unitec Master of Architecture building.
5.4 Design Program

The design program for the proposed structure has been set as a single space for occupation by two to three students. A small studio where collaboration between peers and presentation of work can take place. The provision of desk space is of primary concern for achieving this purpose. The spatial environment is a condition of note, as its functional features are molded from the framework of the structure. The framework consists of elements seamlessly related to the structure, keeping the aesthetic and functional value. This will allow for a unique spatial experience, engaging the senses of the inhabitants. The space is intended to propose a notion of a greater awareness of our built environment through the display and connection of the structure itself. The aim is to fabricate a structure that people find both intriguing and useful; giving an opportunity for discussion around the proposed alternative methods of fabrication and assembly.

5.5 Brief

The brief for the scheme consists of requirements that would best suit the different focus areas of our research. The commonalities between our individual works form the background for the proposition.

The aim is to produce a design proposal for a modular system that allows for:
1. Ease of assembly and 2. Can be disassembled to allow for expansion and reduction.
It must express fabrication processes to showcase the craft and culture in the digital and manual construction techniques. Ultimately, it must propose a structure that is capable of permitting habitation. It cannot be simply a sculptural model, often seen in other projects that lack purpose.

Technically, the structure must be designed so that it adheres to the limitations of the available CNC machine’s capabilities. This being the parameters guiding the process of manufacturing from flat sheet materials; cutting plywood elements at variable scales and thicknesses. The depth of the modules ranges between 500-600mm and the width within the vicinity of 3600mm. The scope for these settings is derived from the WikiHouse precedent, (refer), along with the restrictions of both the digitally influenced CNC processes and our own manual skills in piecing together such a range of components.
Figure 236 - Half scale floor model.
The floor model was conceived as the end product of the computer file conversion. It was more a trial to see what the initial processes would be to get a computer file uploaded into the laser cutting software and then cut and pieced together. Not all file types are compatible with the software used by the laser-cutting machine. Issues with scale were the biggest factor. There was often rescaling of the design and checking measurements to see if they were correct.

The laser cutting machine was only capable of cutting certain materials. The model was specifically made at 1:2 scale to deal with the limitations of the laser bed and material restrictions as elements for a full scale model would not have fitted.

The majority of the time was spent on testing the file conversion across multiple programs to find a fully functional model that was compatible. It was clear that the computer modelled components had to be perfect, otherwise any incorrect or off-scale line increments would be cut by the machine resulting in pieces not fitting together properly.

Using the laser cutter the 9mm plywood could only be etched, because the plywood was so thick and dense. Even at a slow pace the heat from the laser would burn the timber. In terms of time and cost, the etching process was more efficient (fig. 237). Having the components etched onto the plywood meant cutting the pieces manually.

Hand cutting and chiselling proved to be time consuming and it was difficult to operate the bandsaw effectively.

The cutting had to be accurate so the components would join and slot in properly. Pieces had to be adjusted through sanding and air grinding. Care is needed when doing this, constantly checking the fit. Taking too much off would mean a loose fitting which is not ideal when no permanent fixings or glue is being used. Accuracy in cutting is key as any tolerance too big or small in the joint could result in too much flex when testing the structure. When tension is applied the joint could move too much through the alignment of the components, resulting in pieces such as the cladding stubs moving out of alignment with the bracing sheets.

Manual cutting is not as precise as cutting done via machine such as laser cutters or CNC machines (fig. 240). This could be due to a number of factors such as hand speed, control, state of mind (being cautious of workplace accidents), machine capabilities and calibration of accuracy. Manually cutting is simply not an option due to the number and size of the components. If the final structure is to be used in a disaster situation, e.g. cyclone relief, then it has to be cut quickly and efficiently so production can be quick and easy. Manually cutting and prepping the floor model took one week with two people, while utilising a CNC machine we expect to complete this process within one day.

Manually cutting the pieces means the final product is rough and tends to get uneven surfaces, with big splinters of wood (fig. 240).
Figure 237 - Simba cutting out the shapes on the etched sheet of plywood.

Figure 238 - Component pieces ready for assembly.

Figure 239 - Azmon using the air dime grinder to sand down the rough bits.
Figure 240 - Roughness of manually hand cutting the component pieces.
Figure 241 - Full scale wall detail.
5.6.2 Wall Detail 1:1

The idea for the wall detail was to test what tolerances would work; one or two millimetres out would make a significant difference in the tightness of the joint. There was no tolerance given to the scarf joint (which has been tweaked to be more square to allow more room for the pegs to pass through (fig. 123, 242)).

No tolerance was given to any of the vertical members as their joints need to be tight. Any loosening could mean offsetting the cladding slots once the joint is under tension.

Tolerances were given to the horizontal nogs, all three slots for the cross lap joints were given different tolerances ranging from 18mm (fig. 243), 19mm (fig. 244), to 20mm (fig. 245). The result being that the 18mm and 20mm tolerances were too loose, causing them to slip out easily without much friction holding them in place. The 18mm joint performed the best as there is some friction sliding the fin in and out. This friction allows the nogs to stay in place so, when the structure is completed, the joint will come under compression, further reinforcing the friction in the cross lap joint, which is aided by the cladding at the open end.

The same steps were required for the file conversion as the floor model. But the issue was that the dialogue process from the floor model had not been specifically noted so we found ourselves retracing previous steps. However we did have memory of the process and this stage did not take as long as anticipated (fig. 246). Once the CNC technician had uploaded the files onto the cutting software used by the computer that drives the machine there were no significant issues cutting the pieces. Post cutting, all pieces where measured and checked. All cutting by the CNC machine was perfect to the millimetre.

When putting the components of the model together it was discovered that the pegs (fig. 250) that lock the struts into place where not long enough and only had been placed on the outside of the joint. Not having pegs on the inside of the joint meant that it had freedom to move inwards (fig. 251), but not outwards, which could potentially collapse the joint, affect the lashing to tension the joint and finally offset all other components in the final building.

Two types of lashing are used to tension and compress the joints. The cross struts worked perfectly, allowing the joint to be placed under tension when pulled tighter by the lashing. The struts are deliberately placed at an angle for various reasons: strength, ease of application and, aesthetically, it exposed the lashing more by keeping it flat. The two types of lashing used are the figure eight (fig. 252), and the clinch knot lashing (fig. 256). The figure eight is not as strong as the clinch knot, but it compensates for this by being the more decorative of the two in this model. The figure eight pulls the two elements together in two phases (fig. 253-255), which means the tension has to be held on every loop. The clinch knot is the stronger of the two because it requires two phases, the loop (fig. 257), where tension is held on each rotation, and the clinch knot (fig. 258) is a secondary tensioning system. Essentially, the clinch knot makes up for any looseness in the ‘loop phase’, as it binds and pulls the rope and joint together.

The issues that came to light from the lashings were associated with the size of the rope and not having any notches on the struts. 0.5mm ‘hemp’ rope was used to lash the joints together (fig. 252, 256), too much strain from tensioning or surface friction (rubbing of the rope) would lead the rope to snap; this joint was not under maximum tension. The size of the rope dictates how much tension is placed on the joint. Thicker rope means more surface coverage by less loops (fig. 293), more allowance for strain which equals a tighter joint. In this case smaller rope, 0.5mm, means more loops to cover the same surface distance as the larger rope (fig. 256), leading to less strain and a weak joint.

Having no notches on the struts created some issues because the person applying lashing had no control over how many loops to apply, plus the notch would give the lashing centricity. The notch would also allow the rope to sit below the surface and not flush on the surface. By sitting flush it allows the rope to have side to side movement, causing the edge of the strut to cut into the rope and eventually weaken the lash, or even snap if there is too much lateral movement in the connection.
Figure - 242 Squared oblique scarf joint.
Figure 243 - 18mm, zero tolerance given in the cross lap joint.

Figure 244 - 19mm, 1mm tolerance given in the cross lap joint.

Figure 245 - 20mm, 1mm tolerance given in the cross lap joint.
Figure 246 - Unitec CNC machine in the process of cutting the component pieces of the wall model.

Figure 247 - 18mm Plywood loaded onto CNC machine.

Figure 248 - Second phase cut.

Figure 249 - Racking the sheet so all the pieces fall out.
Figure 250 - Tapered pegs are too short so does not lock the joint sufficiently.

Figure 251 - No internal pegging allows the joint to slide inwards on the strut.
Figure 252 - Figure 8 lashing.

Figure 253 - How to do a figure 8 lash: step 1, peg the rope and loop it under bottom strut.

Figure 254 - How to do a figure 8 lash: step 2, loop it over and around the top strut.

Figure 255 - How to do a figure 8 lash: step 3, pull the rope back and under the bottom strut, keep repeating process.
Figure 256 - Clinch knot lashing.

Figure 257 - How to do a clinch knot lash: step 1, peg the rope and loop around both struts.

Figure 258 - How to do a clinch knot lash: step 2, on completion loop a secondary loop (clinch) around the first loop, apply tension with every rotation.

Figure 259 - How to do a clinch knot lash: step 3, pull the clinch tight, either peg or knot the end.
Figure 260 - Prototype module at full scale.
Conversion process for this model was more strenuous and time consuming due to the number of pieces that needed to be cut. All the line-work had to be selected to check the parameters: cutting depth, inside and outside cutting paths to see that all the elements where still correct and configured properly for the CNC process. During this process, a mock cutting set out was made on the computer to see how many pieces could fit on a 2400mm x 1200mm sheet of 18mm plywood. This gave us an idea of how many sheets of plywood we needed to purchase. In total thirteen sheets of 18mm, untreated, non-structural, BB grade plywood was purchased, but, like with any other plywood, the thickness varied amongst the sheets, with a variation of thickness either millimetres above or below the specified thickness. This is also dependent on the grade of the plywood. The sheets purchased varied between 17mm and 17.9mm. On one sheet alone, the thickness varied in places by 1mm.

It was during the CNC process that issues arose about cutting layout. The cutting layout presented to the technician was not gaining the maximum usage out of a plywood sheet. The technician reconfigured the cutting sheets and brought the components closer together in order to get maximum use out of each sheet.

The next step was to set up cutting passes for each individual sheet. The passes dictate the quality of the finished cuts and the time it takes to make those cuts. The machine could either cut the components in one pass, meaning 19mm deep cut on an 18mm plywood sheet or it can do multiple passes, cutting 6mm at each pass. Less passes means poorer quality and less time, more passes means higher quality and more time. Therefore we had to weigh what was to be compromised.

After the cutting had commenced the cut components were measured, revealing that the machine had added up to an extra 2mm on one axis, mostly on the larger elements. The machine had somehow calibrated itself incorrectly, leading to the boundary line moving up to 2mm ‘out’ on one axis. This was simply an error in the CNC process. The technician had no knowledge of how to recalibrate the machine to fix the problem so we had to persist. The affected pieces were shaved back using a band saw and then either hand sanded with a sanding block or an air die grinder. This issue would be minor as the edges were to be shaved back manually, the resulting finish quality is not as sharp or strait edged as would be got from an initial CNC tooled cut.

5.6.3 Prototype Module at 1:1

Conversion process for this model was more strenuous and time consuming due to the number of pieces that needed to be cut. All the line-work had to be selected to check the parameters: cutting depth, inside and outside cutting paths to see that all the elements where still correct and configured properly for the CNC process. During this process, a mock cutting set out was made on the computer to see how many pieces could fit on a 2400mm x 1200mm sheet of 18mm plywood. This gave us an idea of how many sheets of plywood we needed to purchase. In total thirteen sheets of 18mm, untreated, non-structural, BB grade plywood was purchased, but, like with any other plywood, the thickness varied amongst the sheets, with a variation of thickness either millimetres above or below the specified thickness. This is also dependent on the grade of the plywood. The sheets purchased varied between 17mm and 17.9mm. On one sheet alone, the thickness varied in places by 1mm.

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A significant issue occurred when cutting the pegs and struts. As these were such small pieces it was thought they could be cut quicker by lowering the number of passes. The bigger pieces were being cut at four passes (4mm, 9mm, 13mm, 18mm), this was taken back to two passes (9mm, 10mm) for the smaller pieces. Not factored in was the amount and size of the accumulating saw dust. More passes created small amounts of fine saw dust (fig. 263), which is easily sucked up by the dust extractor attachment, less passes meant large, thicker clumps of dust which is harder to extrac (fig. 264). Usually an air gun is required to blow out the cutting channels of any excess clumps that were not sucked up by the extractor.

The smaller pieces had been laid out quite closely to each other on the cutting sheet so when cutting the tool jammed, which made the whole sheet shift resulting in it losing its datum point. The reduced number of passes and the faster cutting rates of the spindle had combined to jam on the sheet. The debris heavily blocked up the cutting channels (fig. 264). This led to the tool bit pushing the dust along as it was cutting to a point where the dust got so compressed that either the tool or the sheet had to give.

Figure 263 - CNC cutting passes: 1, 4mm; 2, 9mm; 3, 13mm; 4, 18mm.
Fortunately the smaller pieces were the last components to be cut on that sheet. Once all the cutting was finished we had enough free space left on the previously cut sheets to cut the smaller pieces on. This time the cutting passes were increased and wider margins were configured between the pieces. Small tabs (fig. 265) were also left on the final cut so that the piece would not shift when cutting its way around. These were easily sanded back.

When testing struts to see if the pegs would slot into the holes in the struts we noticed that the peg holes were varying in size. The holes had been programmed to cut after the strut had been cut, so the stubs holding the strut were not effective in stabilising it when the peg holes where being cut, allowing the strut to move around. This did not affect the final model structurally because the pegs where tapered. The effect was only seen when tapping in pegs with varying heights (fig. 266).

The quality of the plywood did create some problems because we had opted for the cheapest in the market. Choosing BB grade - 18mm sheets for $50 each, manufactured in China, we compromised quality for cost. The quality was poor and this was first displayed when the pegs would burst while the CNC machine was cutting them due to cheap glue being used to make the plywood. In the end extra pegs had to be cut as back up if any more were to burst when the assembly phase began. When hammering the pieces together the edges would start splitting under pressure (fig. 267), which did not compromise the structure, but left an uneven and rough edge.
Keeping an eye on the number of components was crucial for us, there would be no access to the CNC machine once the cutting was done due to the time schedule for presentation. The large pieces were easy to track, but the smaller pieces took the most time to count (all 202 pegs). Pegs can be manually cut on the band saw, but the struts are too complex to be cut manually.

Half a day was spent gathering up the fixings (turnbuckles, ring screw hooks, crimps, eye straps, hemp rope, jute twine and wire rope) (fig. 268). Just under $120 was spent on getting most of these fixings as we had managed to source turnbuckles and wire rope from Unitec Institute of Technology, Architecture workshop. If the model were to sit outside and be exposed to the elements the cost of fixing would double because stainless steel fixings and wire would be needed to stop rust from occurring. In this instance we opted for the galvanized steel option as the structure was going to be built in a fully enclosed, indoor studio space.

The entire range of component pieces were moved to the studio space once they were prepped and sanded (fig. 269). The individual elements were then matched and stacked (four identical elements) so it was easy to locate the elements when piecing together the structural building frame. The stacks were then moved around to form the frame layout on the floor. This gave an appreciation of how much space the structure required in the allocated area.
A further discussion took place about what would be the easiest method to assemble and erect the structural frame.

- Option 1: Build the frame bottom to top whilst it is free standing. The advantage of this method is that the frame does not need to be picked up and tilted into place. The disadvantage is that the frame could tip over (fig. 270, 271) or buckle without any support from either side making it hazardous for people around it or building it. The joints will be flimsy on their own, allowing the joint to have too much movement while the structure is being erected. The movement would cause the frame to break up if it were to tip over because it is not one solid frame but a number of elements joined together to make one whole module. This would cause arms of the scarf joint to rupture and snap.

- Option 2: Build the whole frame in four portions (fig. 272). The advantage of this is that a majority of the lashing and joining can be done on the ground. This option would also minimise ladder use as it would require the person lashing or hammering to be on a ladder for long periods of time when banging the nogs into the cross-lap slots.

The disadvantage of this option is that the weight of each portion, when erecting, requires a lot of manpower to lift and hold the components in place. Once the portion is in place it needs to be held up while the other portion is slotted into place. Additionally, any pre wrapped lashing would become loose because it would not have been processed while the frame was under compression. This option may have been the easiest and safest way to erect and piece the portions together. In any other situation, a crane or pulley system would be beneficial.
- Option 3: Completely build the frame on the ground and tilt it up. The advantage being the whole structural frame is built on the ground and the majority of the joinery is done on the ground, thus minimising the use of a ladder. Once the frames are tilted up and placed side by side the nogs can be slotted in to join them together, thus making a bay. Once the second frame is up the structure can support its own weight and be free standing without additional assistance. The biggest advantage of this option is that once the frame is tilted up the frame compresses the joints which aids in the lashing process as the joint is already under a certain amount of compression.

The disadvantage of this option is that the frame is free standing without support. Unless it is tied back to something that can hold the frame's weight, or there are people holding it, there is nothing to stop it from tilting and falling over. The nogs must be removed, then slotted back in each time another framed module is erected, as the nog spans multiple bays; the length and quantity of these elements are dependent on the completed scale.

It was decided that the third option was most appropriate due to the location of the build and what assembly options would best suit alternative locations.
The first frame was pieced together on the floor using a rubber mallet (fig. 273). The struts were slotted into the larger pieces first. Once the strut was in place the component pieces where then elevated allowing the arms of the scarf join to line up and slot into each other (fig. 274, 275). The large pieces had to be manually held in place to allow for the pegs to be hammered in. The pegs locked the joint completely, thus keeping separation, allowing us to move on to the next joint. This process was repeated all the way around in the making of an enclosed frame.

Once the frame was completed it needed to be stood upright and moved away to make space for the assembly of the second. We quickly found that three of us would not be enough to lift the structure into position. There was a possibility the frame would buckle under its own weight due to the flex occurring on parts of the frame that were not supported; (fig. 276), when tilting it up the unsupported distances between the three team members were too great. The frame would bend inwards where there was no support. The pressure while lifting it upwards in three positions would place immense strain on the unsupported parts, commonly referred to as the ‘bending moment’. The frame consists of multiple elements and if the bending moment occurs near where these pieces are joined (fig. 277) the pressures could buckle the components without notice, causing significant damage to the scarf joint.
Figure 273 - Frame assembly layout and assembly on the floor.

Figure 274 - Oblique scarf joint separated.

Figure 275 - Oblique scarf joint connected.
Figure 277 - Scarf joint bending inwards.

Figure 276 - Frame bending inwards.
Additionally, the movement could occur at the support points if there are any joints on them, or anywhere near. This would occur if there are no joints on the unsupported span where the pressure will be looking for a release point and if that point is where the frame is being supported then it will cause it to buckle outwards. A buckle at a supported point would be dangerous if it is being held up by a person.

The only way to safely tilt the frame up without it buckling was to get more people. This added more support in key positions, cutting down the distance between support points, which minimised the flex in the frame. It was decided that best way to mitigate any bending movement was to slot the nogs into the housing joints (fig. 278). Once the nogs were slotted in they maintained the gaps between the frame and also spread the load along the unsupported spans, creating a more rigid diaphragm.

When the first frame was tilted upright (fig. 270) the nogs were to be slotted in to stabilise the base of the frame. At this point it was noticed that some of the slots for the nogs were not lining up because of an error in the orientation of a floor component. The fault was corrected once the frame was manually stabilised by the team members. Knocking out some pegs and rotating the floor joist elements achieved this. The frame was left freestanding once corrections had been made and work began piecing the second frame together. We felt that the frame was stable enough to be left on its own which proved wrong half way through the build of the second frame.
During the assembly of the second frame a creaking noise was heard. The frame that was previously upright was on its way down. It ended up landing on top of the frame that was being built on the ground (fig. 279, 280). Luckily no one was injured. It was again evident that the grade of plywood was poor. The frame had incurred major damage as one of the larger elements had split (fig. 280), but not to the point where it had broken away completely. The upside to this incident was that the frame had maintained its shape when it had fallen over, giving us an indication that the connections were doing their job.

The fallen frame was tilted upright after it had been checked over for any other damage. As four people braced the frame to stop it from falling over, discussion and survey took place on what the frame could be tied back to. The frame was situated in a tight space where it could not be moved to another part of the room. Once the upright frame was braced securely work recommenced on the secondary frame on the floor. The base of the finished frame on the floor was dragged closer to the frame that was already upright. By moving it closer it would allow us to quickly tie the two frames together using the nogs, meaning the two frames could support and brace each other without having to be manually supported. The secondary frame was tilted up (fig. 282) whilst the first frame was braced. Once the frames sat side by side the nogs were hammered into their housing joints, combining both frames to make one bay.

Once combined the structure had doubled in width creating a bigger footprint. The larger footprint allows for better weight distribution throughout the structure, thus allowing the structure to be more stable under its own weight. During the design phase we knew weight distribution was key for structural performance as the connections are free of glues or any permanent metal fixings. An even weight distribution allows for even compression of the structure. The module may fail if one connection is under significantly more pressure (fig. 283) than another (fig. 284) in the same frame as the joint that has less, or no, compression can cause a loose joint that can affect the whole bay by having too much movement. Take the scarf joint: if the element was to slip out it would make the frame lean slightly to one side, throwing the alignments out for the cladding, interior components or any other key element.
Through research we managed to apply two other forms of compression to the joints and the structure if the weight alone could not compress the structure evenly. The first step was to place the structure under controlled compression through tensioning by using wire cables fitted with industrial strength turnbuckles (fig. 285). These would force the structure to compress, hopefully putting the structure back into alignment if it was out. Second, was to put struts on both arms of the scarf joint then lashing in between to pull the joint together, this time placing compression and tension on each individual connection (fig. 252, 256). Using these methods meant the structure has three lines of defence, so if one were to fail, there are two other systems backing it up while fixing the one that had failed.

In the meantime, the rope for the lashing was measured and prepared for the next day. After the preparation we decided to have a trial run, which would determine the length of rope used on one connection. This helped to gage how effective the thicker hemp rope would be before tensioning down the structure with the wire cables. It was good practice to have the trial before the final phase of the build commenced as it provided a extra day in advance to resolve any issues that arose from it.

Originally the plan was to crimp the rope around the strut. However, it was found that the metal crimps would cut into the rope, possibly severing it and forcing it to snap under tension. The other issue with crimping the rope was that the crimps were too small to slot the rope into. When trying to thread the rope through the crimp the rope fibres split apart (fig. 286), making the rope lose its shape and thereby loosing strength. Bigger crimps were available, but around the channels that the rope is fed through they could not close enough to stop the rope from slipping inside the crimp. This would cause the lashing to lose tension over time.

A solution that would eliminate crimps and hold the rope in tighter position was hammering the inside peg out to allow the rope to pass through the hole. Once the rope was through, with 20mm over hanging, the peg was hammered back in, locking the rope in place (fig. 287). Once the rope was locked in, three people pulling on the rope applied tension. This resulted in the whole bay moving, but the rope did not slip or snap at any point. The joint was then completely lashed to gauge how much tension could be applied to the connection. The issue was that tension was being lost when looping the rope around the strut. This was due to the rope trenches locking themselves into the channelled edges (fig. 288) of the struts where there was no allowance for any further movement.
Figure 285 - Wire rope, turnbuckle and ring screw hook.

Figure 286 - Rope unraveling when passed through the metal crimp.

Figure 287 - Lashing rope is locked into place by the strut pegs.

Figure 288 - Lashing rope channel locking on the edge of the strut.
The best way of gaining more tension was to elevate and pull the rope towards the builder, not letting it touch the strut (fig. 289) that it was going to be looped around. Once tension was gained the rope would be lowered flat on the strut (fig. 290), still maintaining the tension the rope was wrapped around the strut (fig 291), allowing the channels to hook into the corner. This technique allows the rope to be kept under tension while applying the loop.

Traditionally, wet coconut sennit would be used for lashings. Wetting the sennit gives two advantages: firstly, better grip with no rope burn and, secondly, the sennit compresses as it dries, as the plant fibres shrink. Coconut sennit is rarely available in New Zealand, but there are other forms of sennit ropes available, though the choice was made not to use them. Sennit needs to be wet on application for it to be effective. The downside of this is that the moisture from the wet sennit could seep into the plywood, causing it to swell and rot if the wood is untreated.

The rope used in this instance is untreated hemp/sisal (fig. 268) which is cheaper whilst maintaining strength. The rope is made of plant-based materials, consisting of hemp and flax fibres, which makes the rope denser. Though it can seem dry, it has a tendency to hold moisture on the inside, eventually causing the rope to rot. The rope was to be treated with tarring, but this process is very labour intensive. Eventually the hemp rope was replaced by ‘Manila’ hemp (no relation to the hemp plant) which is more durable, flexible and water resistant. The option to use hemp rope was based on the site of the assembly (indoors). In a waterproof area the rope can be used effectively. If the site were to be located outdoors Manila hemp would be used only as precaution as the lashings would be protected from external conditions by a weather skin.

During the trial run, two different types of lashing methods were applied. One being the ‘figure of eight’ (fig. 292), and the other a ‘clinch knot’ (fig. 293). Both lashing selections performed as expected, the clinch knot being the stronger of the two as it held stronger under tension and held its shape once the ends of the rope were pinned into place. With both lashing types in place the frame was jolted numerous times around the position of the scarf joints that had been under tension from the lashing. This was undertaken to see if gaps would appear where one face of the join met the other. We were more than satisfied the lashing had compressed the joint to the point where it did not open up.
The next day, the housing slots on the nogs were shaved back 2mm on the band saw and extra pegs were cut in case any pegs burst in the final phase of the build. The remaining nogs were slotted into place on the structural frame. Once the nogs were in place the structure was deemed safe to move to its final resting place for the event (fig. 294). During the move the frame held firm as one solid piece. After the move the frame was checked to see if the joints and pegs had deflected. The top half of connections near the roof had moved by 1-2mm. This was easily fixed as they only needed to be tapped back into alignment with the bottom half of the joint. At the same time all the pegs were checked. The pegs that moved during the test were hammered in, with only one peg failing the test.

After positioning the structure, prep work commenced on the wire cables so that the structure could be tensioned to the ground before starting the lashing. One end of clothesline wire was then fitted with a galvanized hook and turnbuckle. Once the wire is passed through the turnbuckle ring-head it has to be folded back where it is then threaded back through the eye of the metal crimp. A large hand operated crimper is used to the crimp the wire into place. An alternative method of crimping the wire would be to use wire rope rings. They are more efficient as you loosen them to adjust the lengths of the wire without having to cut them. We opted to stick with the metal crimps to see how they would perform and they were a lower cost option.

Centre points were marked out in the floor cavity space of each frame. The mark was set back from the building edge so that tensioning mechanisms did not hinder the cladding / brace performance. After drilling holes, stainless-steel ring screw hooks
were secured down. The turnbuckle hook and eye piece (fig. 285) lengths were adjusted before hooking them into the ringed hook on the floor. The wire was then thrown on top of the structure where it was aligned and slipped into the tracks cut for it on the edges of the nogs. The wire on the other side was then hand pulled and placed under tension. At this point, another person measures and bends the wire to where it needs to be cut. The turnbuckle is fixed once the wire has been cut and crimped. Hooked onto the ring screw the turnbuckle is left un-tensioned as the same processes are repeated on the frame next to it. The turnbuckles are tightened on all four sides (fig. 285); all four turnbuckles having the same number of turns to apply equal tension over the whole structure.

Lashing the connections commenced once the structure was under tension from the turnbuckles. The frames featured two types of lashing. One frame had the ‘figure of eight’ and the other had the ‘clinch knot’. During application, the lashings completed on the top half were noticeably harder to apply because the person had to stand higher on a ladder to undertake the lashing. Stability was difficult to maintain when doing the lashing in such a position. The rope needed to be pulled and tightened to gain the maximum amount of tension. Employing a scaffold system would have been ideal as it allows for a stable footing on a wider and longer platform.

The last phase of the build was connecting the cladding panels (12mm ply brace sheets) (fig. 295). In terms of their alignment, the holes on the cladding panels did not align with the connecting stubs on the structure (fig. 296). The fault was again due to the CNC calibration. Some edges had more than two millimetres taken off them. Manually the slot sizes were increased with the use of chisels to remove excess material. Additionally, it was under tension that we found the structure had shifted a few millimetres, further off-setting the cladding in some places. The frame had to be pushed and pulled to align the cladding boards with their fixing points. As the boards where being fixed it was noticed that the structure had started to re-align itself, the boards shifting the alignment to where it should have been. Lashing the boards to their allocated struts was abandoned due to time constraints prior to exhibiting the work. Yet the boards proved to sit securely on their own without anything holding them back to the frame (fig. 297). Similar issues with alignment were faced when putting the floor panel down. The same process was taken to mediate the problem and eventually it slotted into the housing stubs without any problems.
Figure 295 - Module with cladding panels attached.

Figure 296 - Cladding alignment.

Figure 297 - Cladding struts between the lashings.
5.7 Structural Load Testing

5.7.1 Load Testing Equipment

After the assembly, discussions took place with Dr Regan Potangaroa (structural engineer at Unitec) on what methods and equipment were required to test the structural loading on the single module prototype (fig. 260). He indicated that a tension / compression load cell (fig. 298), and tension kit with convertor brackets (fig. 299), electronic weighing indicator (fig. 300), spring cylinder jack with hand pump (fig. 301), steal tie downs (fig. 302), jack push frame (fig. 306), and a concrete pad (fig. 307), would all be needed for testing to go ahead.

5.7.1.1 Tension / Compression Load Cell (fig. 298)

From the outset a tension / compression load cell was desired by the engineer. This would be the best option in testing deflection. It allows testing of tension and compression whilst other load cells only work in compression. As the frame to be tested is a lightweight structure only a small load cell was selected; it has a loading capacity of ten tons.

5.7.1.2 Tension Kit Converter Brackets (fig. 299)

The load cell currently works in compression only. Like most load cells to make it work in compression, specially machined steel brackets need to be screwed on which allow the cell to be used for testing tension. The kit brackets are fitted with round eye rings, which are lined with ball bearings to allow the load cell to be used in a flexible environment where it can be twisted or placed at odd angles. These brackets did not come with the load cell as they are made to order items as load cells are commonly used for compression only in weight testing.
An electronic weighing meter is required for any testing as it plugs into the load cells and gives the operator the readings and any analytical data coming from the testing process. The indicators settings have to be calibrated to the specific load cell that is being used. Each load cell has different weighing capacities that have to be programed on the indicator’s. A high spec indicator had to be purchased for this load cell as it needed to be capable of reading tensioning data.

What jack to purchase was dictated by the loading capacity of the load cell, as it was deemed pointless to not have a jack that could not apply the maximum loading capacity of the load cell. A heavy-duty - fifty-ton, low profile, spring cylinder, hydraulic jack was chosen. The jack is detached from the hand pump as only a heavy-duty pipe connects the two, a safer option due to the loading capacity and the overall weight.

The floor of the bay model needs to be securely fixed to the ground, not allowing for movement in the floor when the frame is being pushed by the jack. Steel tie down frames were selected as they prove to be stiffer then timber (fig. 303) when put under strain from load testing; invalidating and complicating any deflection results.

The steel components for the tie downs needed to be sized and fabricated. The tie down frame is made up of a 100 x 50mm C-channel beam, 16mm threaded rod, DynaSet drop-in anchor, high tensile screw nuts and circular split washers (fig. 304).
A strong and sturdy frame is needed for the jack to push off (fig. 305). The frame is to be fabricated from steel as it will have immense force placed on it during the testing. Due to the force placed by the jack, the frame will need to be braced and fixed to the ground so that it does not flex or fall back; releasing any pressure during the test. Failure of the frame could result in invalidated and complicated deflection results. It could also lead to damaged gear, if the frame were to fall over.

Ground surface condition is key for the testing process, as it must provide a stable and strong surface that can take the impacts of the loading during the test. A reinforced concrete pad is needed for the test as the steel tie downs and jack push frame need to be fixed to a solid surface. The concrete pad needs to be large enough to take the footprint of the prototype. It must be 100mm thick so that the 'Dyna' bolts sit deep enough to hold securely. If the pad is not thick enough the pressure from the loading could rip the tie down and move the frames from the grounding, causing the whole structure to shift and collapse, hindering any deflection results.
When testing the gear it was noticed that the wires from the indicator to the load cell had not been connected and the indicator had not been calibrated. The supplier subsequently collected the gear where an additional two weeks were required to fix it in preparation for testing.

During this time, the workshop technician brought up an issue with the weight of the gear. As the jack and load cell had to be elevated at such a height it would pose a safety risk to the people who were undertaking any tests. The issue was not only around the weight, but also considered the fabrication of the jack push frame (fig. 305). Due to the considerable weight because of the large steel sizes specified by the engineer it would need small a crane to manoeuvre it. These issues were resolved by to tilting the frame on its side to test it while it was lying down (fig. 307). This would eliminate the need to elevate any of the testing gear and cut down on the size and weight of the push frame structure.

The workshop was chosen as the location for the test as it is an enclosed building with the floor space being covered. The workshop floor is also structurally reinforced, so it provides a lot more depth for the tie down frames to be securely fixed to the floor. The biggest advantage gained from placing the test in the workshop was that the jack push frame could be eliminated as a concrete wall column can be used to push the jack off.

5.7.2 Assumptions Prior to Testing

Frame

It is predicted that the resulting impact from the load cell will cause significant damage to the frame of the prototype. The forces inflicting the structure may cause the components to burst from their connections. Damage, such as splitting and snapping of individual elements is expected, at the point of impact and on those parts that have larger spans; they are more prone to bending. The junctions between components will most definitely be the areas of concern. The type of joint at these points; braced by struts, pegged and lashed will be under considerable stress. Although the frame is very flexible, a large force impacting the side is likely to break it on contact. The loads may spread across the frame causing other junctions to disassemble. It is believed that on a larger prototype, with more modules connected to each other, the framing will perform considerably better as the scale of the latticed diaphragm is increased; with more stability across parts.

Material

The initial prototype’s frame is fabricated from unapproved non-structural grade plywood, with low quality adhesives joining the layers of timber. It is not expected that the elements will maintain their original form post impact. It is predicted that at certain points throughout the frame they will move, bend, split, snap and even combust under such intense loads. As the timber will be damaged, we will be looking at where it occurs, so any issues in future models can be resolved.

Tensioning System

The cables providing additional tension to secure components are expected to hold them in their relative positions, whilst allowing for movement as loads spread across the module. The specific gauge of the wire will be monitored; if it fails to maintain its figure it will need to be modified. If the loading is so great that the components bust from their housings, the cable is at risk of stretching, fraying or snapping. The wire in use does not feature the high tensile properties that may prevent it from snapping under significant stress. The turnbuckles connecting the cables to the eye ring hooks in the bearers may become loose or snap at their connection.

Rope

The rope is expected to flex during the testing. If the lashing is too tight it is more likely to snap at the pegging point, because the rope is compressed, racking from the test will cause the friction between rope and peg, which may cause the rope fibres to tear. If both lashing types (figure 8 and clinch knot) fail in compression, the rope may lose tension causing allowing the components to move. If both lashing types come under tension it may cause the rope, or the struts, to snap. It is unclear what the tensile rating for the hemp rope is, especially when used in construction.
5.7.3 Test Setup and Procedures

5.7.3.1 Testing Setup

The process required finding a suitable area to test the frame. The workshop was the most suitable location; with the appropriate facilities and protection from external elements. After selecting the position we set up the structure. Once the frame was laid out on the workshop floor, the angles of the frame had to be adjusted to allow people to pass through the adjacent space.

The following steps were taken prior to the event:

- We would no longer push off the concrete block wall of the workshop, as the wall may not take the impact of such a loading capacity.
- The components of the module were pieced back together to form the original frame of the presented prototype. Polyethylene sheets (fig. 307) were slid under the frame to mitigate friction upon impact.
- Holes were drilled into the concrete floor in specific locations for the positioning of the DynaSets (fig. 308). The steel rods would slot securely into these.
- The C-channel profiled steel lengths were cut with holes drilled into them for alignment with the M16 threaded steel rods. This frame locked together with the Dynasets would clamp the structure together. The base was bolted down using nuts and washers.

(fig. 309).

- Tension cables were pulled around the frame and fitted to the eye-ring hooks; fixed to the 100mmx100mm bearers of the base (fig 285). The turnbuckles were tightened until the entire structure remained rigid.
- The inaccuracies of errors in the CNC process led to the nub holes on the brace panels having to be further chiselled out for the slots to align with the frame. These sheets were lashed back into the 'specifically positioned nogs'; to provide bracing for the structure.
- The roof sheet was coated with epoxy resin, mixed before it was set to the frame. Screws were then added to secure the piece further. This was undertaken as it would be the point of impact in the process of being hit by the load cell; a reinforcement application.
- A timber beam (4x4) was then bolted and screw fixed onto the roof sheet (fig. 310).
- Reference points were allocated at different points of the structure to measure the deflection.
- Timber off-cuts were (Dyna) bolted to the floor. Nails extruding through them and the structure, acted as such reference points (fig. 311).
- Our workshop technician, Tom Whelan, constructed rigging for the load cell. Elevated to 385mm (midpoint

Figure 308 - Simba drilling the holes for the steel tie downs.

Figure 309 - Steel tie downs.
of the module) off the floor, the rig allows for the load cell to move along the channel (fig. 312).

- The jack only extrudes up to 60mm. The rigging would allow the transitioning and packing within the rig to be easier while the structure was clamped to avoid it from moving back to its original position (fig. 313).
When testing commenced, the results of each push had to be recorded at every 10mm interval (fig. 315). As mentioned earlier the jack only extruded up to 60mm at load 7, a transition had to be made to allow for the reset. One side of the structure had to be clamped while this transition was carried through. While the loading carried on at load 7, the structure was starting to show the impact of this. The floor joists started coming apart (fig. 317) whilst the lashed joints tightened (fig. 318) and held the bracing sheets together. When the structure was in compression there was a lot of twisting and bending which resulted in the structure getting affected at parts not predicted to be points of failure (fig. 317).

As the pushing carried on, there was a lot of deflection due to the looseness in the junctions of the joints. Although there was an impact on the structure, it had to go through the ‘slack’ of which the system had made. This had an impact on the readings as it became apparent the structure was very flexible. At load 11, another transition had to be made. By load 13 there was a lot of creaking and noise as the structure was showing signs of giving in (fig. 319, 320). As the lashing held the bracing sheets on and the components together, the floor area was starting to show signs of impact. At load 15 another transition was made. Another two readings were made until there was enough to plot a diagram of the results; of how the structure performed (fig. 315, 316).

After the loading tests were complete the data from the findings was calculated. More tests had to be made to make an understanding of where the structure was going to fail. This was important because it would allow us to know the exact points of failure and how these connections could be improved. The entire structure managed to get 61kN of force (fig. 322,323), a small figure when compared to the amount of force (500kN) that is allowed for a standard NZS3604 wall system with steel tie bracing.
Figure 315 - Analysis data sheet: showing increments and weighing force.

<table>
<thead>
<tr>
<th>Load (tonnes)</th>
<th>Load (kN)</th>
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</thead>
<tbody>
<tr>
<td>0.03</td>
<td>1  2</td>
</tr>
<tr>
<td>0.07</td>
<td>3  4</td>
</tr>
<tr>
<td>0.17</td>
<td>5  6</td>
</tr>
<tr>
<td>0.29</td>
<td>7  8</td>
</tr>
<tr>
<td>0.37</td>
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<td>11 12</td>
</tr>
<tr>
<td>0.49</td>
<td>13 14</td>
</tr>
<tr>
<td>0.53</td>
<td>15 16</td>
</tr>
<tr>
<td>0.55</td>
<td>17 18</td>
</tr>
<tr>
<td>0.57</td>
<td>19 20</td>
</tr>
</tbody>
</table>

Revised Load

<table>
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<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.45</td>
<td>0.48</td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

Figure 316 - Graph showing the performance of the structure. No flat line in the graph meant the structure could not hold the load; bending meant it failed the test.
Figure 317 - (g) Floor joints coming apart at the 7th push (this was not predicted as a fail point).

Figure 318 - (b) Wall joints coming apart at the 7th push.

Figure 319 - (g) Floor joints coming apart at the 13th push (this was not predicted as a fail point).
Figure 320 - (b) Wall joints coming apart at the 13th push.

Figure 321 - The floor started to bow from the pressure at the 15th push.

Figure 322 - (g) Floor joints coming apart at the 19th push (this was not predicted as a fail point).
5.7.4 Test Results

The positives found from undertaking the test were that the entire frame did not break apart under the impacts of the loading. All components were found to be in one piece as they did not burst, split or snap. As the individual elements in each component are isolated they could be easily replaced if damaged. The flexibility of the frame was seen when impacted, as was predicted, as the errors in previous processes would allow this to occur. It may be seen as a failure for it to move around. As it is only one lightweight, unsupported module, movement was predicted. More modules and additional bracing may mitigate this in the future. Negatives were found to be associated with the following: The connection between elements needed to be more accurate as there was too much ‘play’ in the component junctions. The resulting movement across the frame was shown through results that displayed there were higher levels of deflection, and lower levels in the ability to receive a high loading capacity. When the module was under stress it lacked ductility, this was seen mostly through the connections in the floor that moved under pressure, bending to the point where they would be in need of replacement. The point in the floor (lower right corner) that received the most noticeable damage was affected by not having its ply covering attached, to aid in bracing; the element was not made for the prototype. This damage was expected. Results showed that this initial prototype, as predicted, would not be acceptable in meeting structural requirements; revisions would be required.

Figure 323 - (b) Wall joints coming apart at the 19th push.

Figure 324 - The joint g had to be cut apart as it would not separate after testing.
The plywood did not suffer significant damage to the point of failing as a suitable material for construction. Although, there were areas of flaking at the points of compression. The tension cables did not fray, stretch or snap to the point of needing replacement, though a higher gauge wire may be proposed for additional security in future. The turnbuckles and hooks performed well, keeping the tension across the frame. Under compression the amount of stress affecting the cable resulted in the hook being pulled out of position. The bearer, a soft wood, gave in to the pressure and allowed the hook to shift. Finally, there was no sign of damage to the lashing, as all components were held stable in loading.

5.7.5 Improvements to a Future System

As stated earlier, the application of an appropriate structural material would drastically improve the overall performative quality of the framing. A better graded timber, approved for quality adhesives and strength, would be desired. Although the test showed, as predicted what was successful and what went wrong. Ignoring the damage at the point of impact, which was expected from the outset, the areas of the structure to be improved were those located around the floor, where the pegging alone did not prove sufficient in cases of undue stress. The resulting issues may be fixed in future prototypes through redesign of such elements as the floor components; with a lashed connection being implemented to increase flexibility under both tension and compression. The nogs may also be made deeper for additional stability. Further suggestions for improving the overall frame’s performance would be an upgrade to the fixtures and systems used for maintaining tension. A higher gauged cable (synthetic) would provide additional strength across each module, with a similar selection in ‘rope’ for the process of lashing. Additionally, longer threaded hooks may be used for connecting to bearers. What we learnt from this process, we intend to take into the development of the next prototype, and share with those interested.

To conclude, the initial design was processed as a non-consent project; as such, it did not have to follow the specifications relating to building regulations. It regarded the process of design, fabrication and assembly as the predominant focus. Excluding the additions of internal and external components, the frame (a prototype for an exhibition) was tested under NZS 3604 EM6 (previously P21) Section 5 (Bracing Design). The testing was undertaken to provide a platform for future work. It explored how the module would perform in a simulation of lateral loading. We found the process to be very beneficial, as a stage of ‘real world learning’; where we gained knowledge of the procedures involved with testing such structures. The work can be seen to provide a platform for further developments and similar design / build projects.
6.0 conclusion
"Technique may be drudgery to the student but it has a romance of its own. It indicates how different groups of people have sought to supply their material needs by adapting an old method to local material, by evolving improvements, or by inventing a new technique. Throughout each technical process difficulties occurred that had to be surmounted and human thought is expressed by the manner in which skilful fingers sought to achieve the desired end. The end product may or may not be a masterly result but the details of technique reveal the stages of evolution through which the craft has passed. Technique reveals stasis or advance. When available, it must form one of the most valuable methods of judging what culture elements have been shared in common before the separation of various groups, what elements have been improved, and what developed as new inventions to meet local requirements or express the peculiar genius of a people." 30

Knowledge and practice of traditional building techniques has been set aside to accommodate contemporary building methods, it seems that built form still remains the same.

Investigating and modelling joineries and lashings influenced by Polynesians and Japanese architectural structures, and considering the Fabricating structures without traditional connections such as; nailed, bolted and so forth.

The physical models allowed the mimicking of building techniques used by Polynesians and Japanese, and to explore junctions and joining methods that they may have used. As a result, it was possible to choose on a physical model to gain a better perspective and understanding of traditional building methodology, then explore and apply modern building methods. Emphasis was placed on exploring precedents of modular architecture, interactive environments, interior design, Polynesian and Japanese methods of construction. Model making will dictate design, development and real world experience will be counted as research for this research. Even through the individual research phase collaboration was still taking place as research from one group member may influence the research of all/other members.

6.1 Individual Research

A variation of typical Polynesian structural frames and Japanese timber joinery was tested.

Research and modelling were carried out of various different joints, lashings and tension systems, suited to this prototype. Development of the joint, lashing and tensioning systems does not stop upon completion of the prototype build, as the load testing of the structure will reveal whether any of the chosen components have failed or not. CNC provides this thesis with the advantage of load testing numerous joints, lashings and tensioning systems on one structure, as every component's piece can be pieced together using a different system of joining; guiding the process of manufacturing from flat sheet materials; cutting plywood elements at variable scales and thicknesses.

Some of the issues faced when hand cutting the pieces were that the cutting was tedious and repetitive. Another issue that arose was the scale because most component pieces where so small that hand cutting them was hard and time consuming. Hand cutting brought to light, and further reinforced, that manual cutting is not as precise as cutting done by machine, such as laser cutter or CNC machine.

No tolerance was given to any of the vertical members as the joint has to be tight; any tolerance in the joint could mean offsetting the cladding slots once the joint is under tension. The CNC had no issues cutting the pieces once the CNC technician had uploaded the files onto the cutting software used by the computer that drives the CNC machine. By not having pegs on the inside of the joint as well, meant that the joint had freedom to move inwards but not outwards which could potentially collapse the joint, hinder with the lashing to tension the joint and finally offset all other components in the final built building. Two types of lashing are used to tension and compress the joints. The cross struts work perfectly to allow the joint to be placed under tension when pulled tighter by the lashing. The two types of lashing used are the figure eight loop lashing and the clinch knot 0.5 millimetre hemp rope. Too much strain from tensioning or surface friction would lead the rope to snap, as the joint was under maximum tension. The size of the rope dictates how much tension is placed on the joint, thicker rope means more surface coverage by less loops and more allowance for strain, which all equals to a tighter joint.

6.2 Construction of the Bay Model

Conversion process for this model was more strenuous and time consuming due to the number of pieces that needed to be cut. The machine could cut the components in one pass meaning eighteen millimetre deep cut on eighteen millimetre plywood. The major issue that occurred was when cutting the pegs and struts. As these were small pieces the technician thought he could cut them quicker by lowering the number of passes. Once all the cutting was finished we had enough free space left over on the previously cut sheets to cut the smaller pieces out of. This time the technician had upped the cutting passes and had wider gaps between the pieces. When testing struts to see if the pegs would slot into the holes in the struts, we had noticed that the peg holes where varying in size. Pegs can be manually cut on the band saw but the struts are too complex to be cut manually. The individual pieces were then matched and grouped in four identical pieces; this made it easy to locate the pieces during assembly. A long debate took place between the group about which would be the easiest method to build and erect the structural frame. The joints will be flimsy on their own and will have too much movement while the structure is being erected. The first frame was pieced together on the floor using a rubber mallet, and the struts where slotted in to the larger pieces first. The large pieces had to be manually held into place to allow for the pegs to be hammered in. The pegs locked the joint completely, also keeping separation, allowing us to move on to the next joint. The frame is made up of multiple pieces, therefore, if the bending movement occurs anywhere near where these pieces are joined, it could buckle without any give, causing damage to the scarf joint.
The frame was left freestanding once the fault was fixed and work
began piecing the second frame together. Building the frame
together the second time did not take as long as the first frame,
as right methods sorted due to the recalled knowledge and
techniques were picked up from building the first frame. Once the
Frame s sat side by side, some of the fins where hammered into
their housing joints which combined both frames to make one bay.

Throughout my research I managed to apply two other forms of
compression to the joints and the structure (lashing and wire rope
fitted with turnbuckles), if the weight of the structure alone could
not compress evenly. Second was to put struts on both arms of
the scarf joint, then lashing in-between to pull the joint together,
this time placing compression and tension on each individual
join. In the meantime, the rope for the lashing was measured
and prepped for the next day. Another issue with crimping the
rope was that the crimps were too small to slot the rope into. This
resulted in making the rope lose its shape, which led the rope to
lose strength. By using bigger crimps, the channels that the ropes
are fed through could not close up enough to stop the rope from
slipping inside the crimp, causing the lashing to lose tension over
a period of time.

This process required the inside peg to be hammered out to allow
the rope to pass through the hole, once the rope was through with
two centimetres over hand the peg was hammered back in locking
the rope in place. Once the rope was locked in, tension was
applied by three people pulling on the rope; this resulted in the
whole bay moving but the rope did not slip or snap at any point.
From this I started to test how much tension I could apply on the
joint by completely lashing it; in process; I discovered that I was
losing tension through grip when in the process of looping the rope
around the strut. Both lashing s performed as expected, as they
held strong under tension and held their shape once the ends of
the rope where pinned into place. With both lashings in place the
frame was jolted numerous times, particular where the scarf joint
that had been under tension from the lashing. During the move,
the frame help firm as one solid piece. After the move, the frame
was checked over to see if the joints and pegs had deflected.
Having positioned the structure, the lashing the joins commenced
once the structure was under tension by the turnbuckles.

The last phase of the build was putting on the cladding panels,
this brought up a major issue in terms of alignment, as the holes
on the cladding panels themselves did not align with the panels
nubs on the structure. As the cladding boards where being fixed
we noticed that the structure had started to re-align itself; this was
seen as the cladding shifting the structure back into alignment.
Lashing of the cladding boards where abandoned due to time
constraints. In end the boards have proved to be securely locked
in without anything pegging it back to the cladding struts.
6.3 Theory and Practical Outcome

Can you take classical materials and technologies and use them in modern technologies such as; lashing and CNC?

Yes…but there is perhaps a new language to learn.

Polynesian and Japanese traditionally used materials that had everyday purpose. These materials have drastically change through the decades, the availability of the ‘everyday’ materials are rarely found or used due to implications of rules and regulations around structural strengthening. Alternative materials have to be opted for, to mimic traditional materials uses, however the performance in the alternative materials exceeds well, meaning they can be used structurally, once manipulated and tested to the governing building standards. The technologies traditionally used have high influences both in the past and in modern day. Throughout this research, the identification and concepts of traditional methods and technology have been developed and modified to assist highly with the use of modern day technology and practises. The brief was conducted to ensure the cultural and historical reference is clearly mentioned throughout the research, giving the formality for methods of application. Assembling of joineries and lashing would guarantee the craftsmanship will flourish through the person doing the assembling, as they will gain experience and knowledge using modern materials through the eyes of traditional Polynesian and Japanese practices. The physical modelling completed by the one doing the application, is given freedom of decision to dictate the outcome of the lashing. The form, style, rotations, pattern and perforce of the connection are all considered to the liking of the one applying the lashing.

Through trials of different variations of the lashings, the person gains knowledge and understanding of the methods.

The attribution of the knowledge gained from the trial of different variations of lashing and joinery made, has derived from in depth research, theoretical and thorough documentation of all processes taken place throughout the project. Thus, gave a clear obligation on changes needed to further develop the project.

Real world experiences were gained during the fabrication and assembling of the model. This gave a true insight of what will function or not, giving a detailed knowledge in reference to the practicality of fabrication and assembling which is vaguely expressed in the work of an architect.

Working as a team gave extensive perspective on collaboration processes, dynamics of team working and dealing with each dynamics.

6.4 Team Dynamics

There were points of confusions in what was the responsibility of each member towards their participation in the team. Having the nature of sharing work spaces, discussions took place daily around the concepts, developments of the design and fabrication processes.

Lack of communication and confusion did occur through parts of the collaborated study, with members having other commitments outside the research study. This resulted in a breakdown between members, leaving each member on their own tangent and unsure of the status of the other members contribution.

The testing itself, failed the New Zealand Building Standards, however, as we had not intended to build a model to meet these standards, the group itself did not fail.

Personal preconceptions about the collaboration showed the importance of how things should be designed, fabricated and assembled. As the collaboration was an initial time of working as a team, it showed the precision of real life dynamics in the workplace, such as a person’s work ethics, time management between work and play, and the intervening of a fourth party.

Overall, the research project gave allowance to further develop passion in culture, craft, technology and construction. Giving the bases to manually fabricate models to be developed and tested in built form, having gained priceless knowledge and experience on the tactic of working in a collaborated research project team.
6.5 Future Directions

The final research document alongside the design material will be presented in the format of a thesis document. The thesis will be made available in tertiary institutes, public libraries, to governing bodies within the Pacific and as an online resource or downloadable reference to aid similar research in the near future. The information obtained may be used as support material for conference presentations, research papers, information pamphlets, reference for designs and general film or media articles. The research may also be used by design professionals, fellow students, community members, tourists and government officials that wish to further their knowledge or educate the people around them with this specific research or elements of it. I envisage that the predominant outcome that the research will be through the construction of a particular or a series of modular systems.

I see the project initiating a process of discussion and collaboration, taking place amongst community members and design professionals, leading to outcomes influenced by all parties. The final outcome of the architecture should exploit aspects of Polynesian and Japanese architecture, encourage interaction, promote design efficiency and be adapted to both different functions and locations. Architecture that displays future possibilities of how present process and design work can further contribute in architectures ability to be more accessible to the community, this can be further emphasized by incorporating elements of local architecture, giving the community at large a sense of belonging.
7.0 bibliography


8.0 appendix

8.1 Sketches

Figure 325 - Concept sketches.
Figure 326 - Concept sketch.
Figure 327 - Pin joint concept sketch.
Figure 328 - Miter joint concept sketch.
Figure 329 - Cross lap joint concept sketch.
Figure 330 - Ridge beam concept sketch.
Figure 331 - Building form and joint concept sketch.

Figure 332 - Building floor plan concept sketch.

Figure 333 - CNC twist joint and peg concept sketch.

Figure 334 - Scarf joint concept sketch.

Figure 335 - Scarf joint concept sketch.
8.2 Final Presentation Drawings

Figure 338 – Simba Mkhwa: presentation layout.

Figure 339 – James McNicholas: presentation layout.

Figure 340 – Azmon Chetty: presentation layout.
Spatial Definition

The design program for the proposed structure has been set as a single space for operation by two to three students. A small studio where collaboration between peers and presentation of work can take place. The provision of desk space is of primary concern for achieving this purpose. The spatial environment is a condition of note, as its functional features are molded from the framework of the structure.

The framework consists of elements that are seamlessly related to the structure keeping the aesthetic and functional value. This will allow for a unique spatial experience, engaging the senses of the inhabitant.

The depth of the modules is to range between 500-600mm and the width to be within the vicinity of 3600mm.

Figure 341 – Simba Mikhwa: Panel One
Interior Quality

Much of the space is dynamically formed due to the nature of the building; this allows the user to be more aware of their surroundings, while the poetics of the space is realised through the articulation of spatial arrangements.

The space is intended to propose a notion of a greater awareness of our built environment through the display and connection of the structure itself. The aim is to fabricate a structure that people find both intriguing and useful, giving an opportunity for discussion around the proposed alternative methods of fabrication and assembly.
Furniture Variations

A natural flow between the furniture and the structure allows for an effortless transition between seating and desk. This particular furniture variation is articulated and variegated to allow the user to engage with the spatial qualities of the space.

The furniture flows from exterior seating to internal workspace: a space for students to work collaboratively on projects, in a stimulating environment.
Digital Anatomy

The elements of the building are exposed. The structure’s joining system together with the furniture are reveal how the building is put together. Architecturally this allows the user to be aware of how the the entire structure is pieced together. The furniture variations can change and alter to suit the requirements intended for the building.

Architecturally the project has a responsibility to address the contextual conditions: site, climate, culture, people, shelter, material, and projected fabrication costs. These and many more factors are considered in the process and adhered through differing methods of design and assembly. As the work can be customised according to requirements, the proposed system is open to modification: a change in use or location.

Section Perspective BB

Figure 344 - Simba Mtakwa: Pannel Four
Design for Evolution

An Adaptive System

Architecture is about designing spaces for habitation to facilitate experience through occupation. Function is first, though efficiency in production and fulfillment in living can’t be achieved without the implementation of ‘spatial dynamics’. The ability for spaces to adapt to requirements over time. Designing for evolutionary structures that implement a system of continuous development.

A. Linear frame: symmetric form. Regular modulation.
C. Linear Dynamic: flexible frame adaptable to desired framework.

A1 Timber Board & Batten
B. Membrane Skin
C. Metal Sheet

Figure 345 - James McNicholas: Panel One
Additive Modulation

Designing a dynamic system facilitates evolutionary development: the system speeds up the construction process; makes the creation of an 'idea' an achievable exercise. There is an increase in the variety of forms. It enables these rather explorative concepts to become real and habitable. Environmentally, it uses less man-made material; reduces waste and lowers costs in the manufacturing process. It allows for people with less skill and experience to build and be a part of strengthening their community.

Dynamic Environments

1. 1 Ton Component Ring
2. x4 Rings form One Module
3. Struts & Pegs create secure Component Junction
4. Nogging Fins create diaphragm; maintain dimensional strength
5. Bracing Sheets added as underlay to building envelope
6. Connectors enable additional modules to be attached

The building is a hybrid system: a modular arrangement of panels and stick elements. An open system that allows for a combination of parts to be incorporated into future work. For support of the functional program, mechanical servicing, or finished aesthetic.

Figure 346 – James McNicholas, Pannel Two
Customised Components

Building Information Model

The system involves the process of taking a digital file from conception through development and into fabrication. The digital model holds all the elements that will be manufactured for construction. The built form is an exact representation of the virtual realm; all modeled data is fabricated to become real material. As the model is adapted and developed over time it allows for future growth of an architecturally fabricated environment.

Figure 347 - James McNicholas: Panel Three
Manufacturing Parts

WikiHouses generative script allows for components to be exported to flat cutting sheets, with the click of a button. We implemented this as part of the process, with the aim of fabricated building elements. There are restrictions to the process of designing elements for export. As the parts are configured to fit a sheet with dimensions measuring 2400mm x 1200mm, anything made oversized would not be produced.

1. The "Plugin" allows individual elements to be exported to cutting sheets. These parts can be tagged and nested for efficient use of material and ease in assembly processes.
2. The parts can be "printed" from sheet material such as plywood. A CNC machine can mill each part, resulting in a mass collection of puzzle pieces.
3. These cut parts can be set out on the ground in their intended arrangement, joining together to form larger components and a complete module. The system is open to all skill levels.

Fabrication Process

1. Layout
2. Cut
3. Assemble

Figure 348 - James McNicholas: Pannel Four
Variation of the Oblique Scarf Joint (square version)

- **Variations:**
  - a. 2 stuts, 8 pegs, 1 lashing
  - b. 2 stuts, 8 pegs, 1 lashing
  - c. 2 stuts, 8 pegs, 1 lashing
  - d. 4 stuts, 16 pegs, 2 lashing
  - e. 4 stuts, 16 pegs, 2 lashing
  - f. 4 stuts, 16 pegs, 2 lashing
  - g. 4 stuts, 16 pegs, 2 lashing
  - h. 4 stuts, 16 pegs, 2 lashing

**Wall Detail**

**Exploded Oblique Scarf Joint (square version):**

1. Female half of the oblique scarf joint, 18mm plywood (x2)
2. Male half of the oblique scarf joint, 18mm plywood (x2)
3. Tapered interlocking pegs, 18mm plywood (x 8)
4. Cross struts, 18mm plywood (x2)
5. Figure 8 lashing, 4mm hemp rope cut at 1.5m lengths (x1)

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Figure 349 - Azmon Cheffy: Panel One
Floor Detail

Variation of the Dovetail Joint

- **a.** 2 stuts, 8 pegs, 1 lashing
- **b.** 2 stuts, 8 pegs, 1 lashing
- **c.** 2 stuts, 8 pegs, 1 lashing
- **d.** 3 stuts, 12 pegs, 2 lashing
- **e.** 3 stuts, 12 pegs, 2 lashing
- **f.** 4 stuts, 16 pegs, 2 lashing
- **g.** 6 stuts, 24 pegs, 3 lashing
- **h.** 2 stuts, 8 pegs, 1 lashing
- **i.** 2 stuts, 8 pegs, 1 lashing
- **j.** 2 stuts, 8 pegs, 1 lashing

Exploded Dovetail Joint

1. Male half of the dovetail joint, 18mm plywood (x2)
2. Female half of the dovetail joint, 18mm plywood (x2)
3. Tapered interlocking pegs, 18mm plywood (x8)
4. Cross struts, 18mm plywood (x2)
5. Figure 8 lashing, 4mm hemp rope cut at 1.5m lengths (x1)

Figure 350 – Azmon Chetty: Panel Two
Lashing/ Cladding Detail

Lashing Type
a. Figure 8 lashing, Hemp rope, 1.5m
b. Clinch knot lashing, Hemp rope, 1.5m

c. Cladding Junction Detail
a. 18mm plywood
b. Prefabricated aluminium "H" channel with 40mm housing
c. "O" compression rubber gasket. When compressed it create air locks in the joint
Tension System & Load Testing

Tension System
a. Turnbuckle hooked and tensioned to the 100 x 100 bearer
b. Fixings: from top to bottom hook turnbuckle, ring screw hook, crimp, eye strap, hemp rope, jute twine and wire rope
c. Each bay is tensioned twice

d. Illustration of the tension system at 50kn of strain during load testing

Lashing Type
a. Wikihouse oblique scarf join, 7th push, 23kn of pressure
b. Oblique scarf join, 7th push, 23kn of pressure
c. Wikihouse oblique scarf join, 13th push, 43kn of pressure
d. Oblique scarf join, 13th push, 43kn of pressure
e. Wikihouse oblique scarf join, 16th push, 50kn of pressure
f. Oblique scarf join, 16th push, 50kn of pressure

Figure 352 - Azmon Chetty: Panel Four
8.3 Group Model

Figure 353 - Group bay model at half scale: Tension system

Figure 354 - Group bay model at half scale: Interior furniture

Figure 355 - Group bay model at half scale: Interior furniture
Figure 356 – Figure 353 – Group bay model at half scale
8.4 Individual Models (by Azmon Chetty)

Figure 357 - Variation of oblique Scarf joint: 2 struts; 8 pegs

Figure 358 - Variation of oblique Scarf joint: 4 struts; 16 pegs

Figure 359 - Variation of oblique Scarf joint: 2 struts; 8 pegs
Figure 360 - Variation of oblique Scarf joint: 3 struts; 12 pegs

Figure 361 - Variation of oblique Scarf joint: 2 struts; 8 pegs

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Unless otherwise stated all drawings, photographs, and digital collage by Azmon Chetty, 2014.

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Figure 22 - Pegged scarf joint.

Figure 21 - Pegged scarf joint.

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Figure 19 - Pegged scarf joint.

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Figure 10 - Pegged scarf joint.

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Drawing by Simba Mtakwa, 2014

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Drawing by Simba Mtakwa, 2014

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Drawing by Regan Potangaroa, 2014

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