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Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study into the Fijian Construction Industry

A dissertation submitted by

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Abstract

Modular construction is an innovative construction method which involves the prefabrication of modules within an off-site controlled factory environment, prior to transportation and onsite assembly. This construction method has gained traction globally due to being efficient, cost-effective, and sustainable. The implementation of modular construction as a residential housing solution within the Fijian construction industry is explored within this dissertation, with the aim to address housing shortage and improve disaster resilience. The dissertation proposes how modular housing can provide Fiji with a resilient, sustainable and culturally appropriate construction solution, designed to withstand the unique climate and socio-economic circumstances of the region.

The introductory chapter details the projects background, aim and objectives. The potential for implementing modular housing to assist in developing Fiji's construction industry is outlined, with a goal of providing readily available shelter following disaster events and supporting long-term development. The key objectives of the dissertation are to engage with industry stakeholders, conduct a comparative and case study analysis, and propose a modular design solution utilising CAD software.

The literature review investigates modular construction, Fijian culture and construction industry. Additionally, subsequent materials and environmental considerations associated with construction are examined, with the aim to ensure the proposed construction method can occur inline with Fiji's sustainability goals. Identification of the advantages of modular construction, including reduced environmental impact and increased time efficiency, and limitations within remote areas are determined. Additionally, case studies from various countries are reviewed in order to determine methods of implementing and adapting modular construction into Fiji's residential construction industry.

The comparative analysis evaluates traditional and modular construction method based upon comparative criteria which includes sustainability, social and cultural acceptability, cost-effectiveness, and time efficiency. A case study analysis of traditional and modular construction methods from various countries was conducted, identifying the implementation of the construction methods within varying contexts. From the comparative and case study analysis, it was determined that modular construction has the ability to provide Fiji with sustainable and resilient residential housing. However, transportation logistics and cultural acceptance remain as key challenges.

A modular design solution developed utilising CAD software has been proposed. This includes a proposed floor plan, elevations, 3D representation's and alternative configurations. The design places emphasis on cultural compatibility, environmental safeguards and the ability for future expansion. The material choices and construction techniques determined have a focus upon cost efficiency, durability and sustainability. Design feedback was obtained from study tour participants, detailing areas for further consideration and analysis.

The concluding chapter provides a summary of the dissertations outcome and the potential impact of modular construction upon the Fijian construction industry. Through conducting the analysis, confirmation was provided that utilisation of modular construction can assist in enhancing Fiji's resilience to natural disasters, fulfil housing needs and reduce environmental impact. Recommendations for future research are details which include analysis upon transport methods, sustainable materials and residential services. It also proposes that further industry engagement occurred in order to ensure the proposed modular housing solution fulfil the stakeholders' requirements and enables collaboration with the end users.

Therefore, this dissertation provides a deeper understanding of how modular construction can be implemented into the Fijian residential construction industry to address the current construction and development challenges. Through offering a sustainable and resilient alternative, this dissertation aims to support the development of Fiji’s housing infrastructure, promoting a proactive and reduce dependence on reactive, post disaster rebuilding.

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Abbreviations

The following abbreviations have been used throughout the dissertation:

ADRA	National Disaster Recovery Agency
AI	Artificial Intelligence
ASTM	American Society for Testing and Materials
BCF	Building Code of Fiji
BIM	Building Information Modelling
CLT	Cross Laminated Timber
CNC	Computer Numerical Control
FSC	Forest Stewardship Council
GBCF	Green Building Council of Fiji
ICC	International Code Council
IoT	Internet of Things
IRC	International Residential Code
JIT	Just-in-time production
LCA	Life Cycle Assessment
MBI	Modular Building Institute
NBCF	National Building Code Fiji
NCC	National Construction Code
NCP	New Columbo Plan
NEC	National Electrical Code
NGO	Non-Government Organisation
OSM	On-site Manufacturing
PPE	Personal Protective Equipment
SPC	Sustainability Performance Criteria
SPI	Sustainability Performance Indicators
TP	Think Pacific
UK	United Kingdom
UPS	University of South Pacific
UniSQ	University of Southern Queensland
WAE	Works as Executed

Chapter 1

Introduction

1.1 Introduction and Background

Modular construction has proven to offer an effective and sustainable solution to housing shortages globally. This resolution is through decreasing construction duration, labour costs and requirement for skilled labourers, and an increase in productivity. Therefore, modular construction poses as a functional solution to post-disaster relief shelter and the ability to provide safe, dependable, and sanitary housing within developing nations. Given these advantages, this research project aims to explore the application of modular construction within the context of Fiji.

Think Pacific facilitated a Fijian engineering study and cultural emersion experience in June 2023, during which participants, including myself, were subjected to the challenges faced in the region due to various constraining factors. These factors include resource cost and availability, lack of skilled workers and engineers, and in-efficient project and waste management. Additionally, Fiji is highly susceptible to high intensity and frequency of natural disaster which has led to the development of a reactive mindset, preventing the nation from forward planning, and developing. This dissertation will aim to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian village communities. The focus will be on providing safe and readily available shelter which can not only withstand natural disasters but be reprepared quickly and easily post-event.

This will occur through an analysis of design innovation and the current design trends within modular construction, including the materials utilised, and sustainability of the design. The advancement of manufacturing systems and current market products will also be analysed, assisting in the determination of ensuring efficiency and reduction of construction timelines for the construction and maintenance of residential housing. The challenges which are currently faced within the Fijian construction industry will be addressed and solutions proposed in relation to modular housing. This will pave the future direction for potential innovation and aim to fast-track construction in Fiji which is not only up to standard but also provides a method of reducing the impact natural disasters place upon the community.

Therefore, the benefits and outcomes regarding modular construction determined through this dissertation will have significant impact upon the nation. This dissertation aims to assist with the development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development.

1.2 Project Aims and Objectives

The aim of the dissertation is to propose a suitable solution in the form of modular construction which can be implemented within developing countries as a method of improving living conditions and response to natural disasters. Modular housing is becoming an increasingly common construction technique within countries such as Australia due to its flexibility, fast construction time, high quality, and cost-effective nature. This dissertation will be a case study of Fiji, an island located within the South Pacific region, with the aim to determine the impact and opportunities as a result of implementing modular construction.

By doing so, the benefits to the community and how the construction process will improve the counties forecasted development will be identified. This dissertation will aim to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities. This is proposed to occur through providing safe and readily available shelter which can not only withstand natural disasters but be reconstructed and repaired quickly and efficiently post-event.

Therefore, the objectives of the research project are as follows:

- Research: Conduct diverse research into modular housing and the opportunities, innovations, sustainability, design, manufacturing, and existing case studies. This will enable challenges to be identified and solutions to be proposed.
- Industry engagement and consultation: conduct surveys and interviews with industry professionals within Fiji to gain further insight into the challenges faced and opportunities present for modular housing.
- Comparative analysis: Compare the efficiency, sustainability, and cost-effectiveness of modular houses and materials used within Fiji in comparison to traditional construction methods.
- Case study analysis: an in-depth analysis into modular housing projects which have a focus on design, manufacturing, and implementation aspects. The fundings are to reflect the feasibility, benefits, and outcome of the application such elements in Fiji.
- Proposal of a modular housing solution using CAD software to be implemented in Fiji: develop a proposed modular building housing solution design which encompasses the findings of the research and analysis.
- Design feedback: Obtain design feedback from focus group of engineering study tour participants who have an experience and understanding of the cultural beliefs, limitations and opportunities of the Fijian construction industry via a questionnaire.

1.3 Expected Project Outcomes

The expected outcome of this dissertation is to develop a modular housing design which is suitable to be manufactured and implemented within Fiji. This design will assist with providing resilience to the community and development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development. A comparative and case study analysis will assist in providing reasoning and data as to why the proposed outcome will be beneficial. Furthermore, the expected outcomes determined through this investigation will include the following:

- Development of a design using CAD modelling software which could be manufactured and implemented within Fiji to reap the benefits determined through this dissertation.
- Evaluation of the materials, cost and construction process associated with modular construction and benefits obtained through implementation within Fiji.
- Determination of the environmental and sustainability benefits of modular construction in regard to materials, lifecycle and construction.
- Understanding of modular construction application and benefits that if implemented, could be bestowed upon Fijian communities.
- Determination of the benefit’s modular construction post natural disaster regarding repair turnaround, availability of materials for maintenance and completion efficiency/ease.

Therefore, the above listed dissertation outcomes will enable a proposed solution to the issues currently faced within Fiji surrounding residential housing through the introduction of modular construction. This solution will not only enhance Fijian communities’ resilience, but also provide a sustainable and readily accessible method of construction, ultimately contributing to the nation's long-term growth and stability.

1.4 Dissertation Outline

The dissertation consists of six chapters and three appendixes, following the generic template provided within the ENP4111 resources and study book. An abstract for the project is provided at the start of the report, providing a concise summary of the dissertation. This enables the readers to obtain a quick understanding of the key points and findings, assisting in determining the dissertations relevance for future research application. The first chapter of the dissertation is the introduction which outlines the background to the project, introduces the topics to be discussed and provides a list of the projects aims, objectives and expected outcomes. This chapters serves as a basis for the remainder and is evaluated against within the conclusion chapter to determine if the research was successful in meeting the proposed objectives.

The second chapter contains the dissertation literature review which investigates the Fijian culture regarding housing requirements, opportunities and practices, details modular housing and investigates case studies. This review will serve as a basis for the analysis occurring as a part of the dissertation's methodology and enables a suitable, fit for purpose, design to be proposed. Additionally, the requirement for research to occur is also investigated, which displays the need and the potential benefits of conducting the proposed research.

The third chapter contains an outline of the methodology which will be pursued as a part of the dissertation to ensure the required project outcomes are achieved. This includes a detailed literature review, contained in chapter two, industry expert consultation, a comparative and case study analysis and the proposal of a modular housing design solution. Additionally, key areas of project planning are discussed including safety and key consideration to ensure that the aims of the project are able to be achieved within the allocated timeframe. The following chapters contain the outcomes of the methodology, with chapter four containing the comparative and case study analysis and chapter five containing the proposed modular housing design solution and design feedback.

Chapter six contains the dissertations conclusions which consist of a summary and discussion of the project’s outcome, an analysis of the project’s ability to fulfil the objectives and aims outlined in chapter one and a reflection. Further research and recommendations are also listed which details areas in which further study is recommended to occur to further expand upon the ideas and topics discussed within the dissertation.

All relevant references are then listed, followed by the project’s appendixes. These appendixes consist of the projects plan, questionnaire data and ethical clearance supporting documentation. These appendices offer support to the information contained within the dissertation and enable researchers to make their own assumptions of the information and discussions had surrounding the project’s topic and outcome.

1.5 Conclusion

In conclusion, the aim of this dissertation is to undertake a comprehensive analysis into the Fijian construction industry and modular construction. By doing so, a design solution will be proposed as a residential housing solution, which aims to provide an efficient, sustainable and resilient solution to the current housing and disaster response challenges within Fiji. By focusing on the manufacturing system of modular residential housing and undertaking stakeholder engagement, the proposed solution is aimed to become a practical blueprint for the implementation of modular constriction within Fiji, assisting in both immediate living condition improvements and long-term, nation development.

Chapter 2

Literature Review

To develop and propose a modular housing solution applicable to Fiji, it is important to first identify what modular housing is and its benefits. Housing availability, longevity and affordability are key characteristics of modular construction which not only will ensure the communities can reap the benefits of the construction alternative, but also reduce ongoing maintenance costs and repair turn around. The following literature review investigates the Fijian culture regarding housing requirements and practices, details modular housing and investigate case studies and opportunities for the construction method. This review will serve as a basis for analysis occurring as a part of the dissertation's methodology, enabling a suitable, fit for purpose, design to be proposed.

2.1 Definitions

The definitions detailed are those which surround modular housing design and construction. These terms are from the modular construction industry and are defined using a combination of my own personal experience within the industry and intellectual property as referenced.

2.1.1 Modular Building

Modular construction is a modern method of construction which can be defined as the production of prefabricated or standardized volumetric or three-dimensional components or units of a structure in an off-site factory. These components are then transported and installed on site to construct all or an aspect of a building or structure (Lim, Ling, Tan, Chong & Thurairajah 2022). Through typically utilizing a cell-like componentry, the construction time is reduced significantly with minimal site disturbance, being a cost-effective construction technique. The size of the modules is limited by transportation regulations; however, module size varies dependent upon the design. Dependent on the size of the structure, a single module can be the eternity of the house, or multiple smaller modules can be pieces together to produce the required design.

Figure 2.1: Modular Construction of an Apartment Block (Ausco 2018)

Modular construction can impose significant benefits including increasing on-site efficiency and reducing the risk of impacts from lack of contractors or inclement weather. The modules consist of a standardized design which enables flexible and easy construction. There are different levels of finish which can be produced prior to the components being located on site and fixed in place. The most common includes all finishes, fixtures and fittings being installed prior to arriving at site, which reduces the extent of required onsite labor.

The potential benefits of modular housing in comparison to traditional construction methods are extensive if the design and construction processes are completed and implemented correctly. The efficient and easy installation which increases productivity and reduces the room for error, poses significant benefits in regard to time, cost, safety and the products design life.

2.1.2 Residential and Commercial Modular

Residential modular construction is classified as a class 1 – 3 building within the Fiji National Building code, and includes prefabricated, kit, shipping container residential houses. Class 4 – 9 buildings are defined as all commercial and industrial buildings, including schools, resorts, heath spaces, transport, multipurpose and public works infrastructure.

2.1.3 Modular Building Alia's

Within the construction industry, there are multiple terms used to describe modular housing. These terms consist of manufactured homes, prefabricated homes, system-built homes, and pre-built homes. All the terms refer to the building principle of constructing aspects, or the entity of a home off site in a factory or manufacturing plant and transporting the components to site for assembly.

2.1.4 Off-site Constriction

Off-site construction refers to the construction methodology modular manufacturing is classified as. This being, when the majority of the buildings prefabricated and constructed is off site, and transported to its permanent location for placement and installation. Construction methods such as modular componentry, workshop assembly, and prefabrication are all classified as an off-site construction method. Once elements are transported and craned into position, they are placed onto the necessary footings which are constructed prior to the component's arrival. This enables a smooth and efficient construction process.

2.1.5 On-site Construction

On-site construction refers to the 'traditional' construction methods encompassing the construction of all building elements occurring on site, often being referred to as stick-built construction. This includes materials being cut and installed which is completed on a needs basis to construct the building. During this process, various trades will attend the site during different sequences of construction when required.

2.1.6 Infrastructure

Infrastructure refers to physical facilities and structures society requires to operate. In the instance of modular housing, the structure itself, roads and services are all classified as infrastructure. The requirements for infrastructure within modular construction include roads and other auxiliary access in which the components are delivered, as well as the transport plant, crane and equipment used to assemble the housing. When the components are installed onsite, trades are utilised to make 'infrastructure connections' into sewerage, electricity mains, stormwater and telecommunications, enabling the home to be connected to such facilities.

2.1.7 Lean Construction

Lean construction is the principle of producing minimal waste and increasing efficiency by being open to change throughout the construction process. This method prioritizes the end customer, focusing on continual improvement and corporative relations (Rajab, 2022) throughout all aspects of construction. This includes the design, construction, maintenance, and recycling of a structure which can in turn, improve social, environmental, and economic factors. The goal of lean construction is eliminating waste from operational and technical perspectives in which modular construction can assist in doing so. This is through use of optimized, purpose-built factors utilised within off-site construction methods, which aim to maximalize productivity, reduce wastage, and lower risk through simplification of the construction process. Through the production method of modular construction, higher levels of sustainability are evident in comparison to site-built homes due to less wastage, reduced onsite construction time, and reduction of environmental impact and footprint.

2.1.8 Standard

A standard is defined by Standards Australia (2022) as “a published document which sets out specification and procedures to ensure that a material, product, method or service is fit for purpose and consistency performs the way it was intended.” The Fijian Ministry of Trade, co-operatives, SMES and communications have various standards which relate to all aspects of design, construction, and operation, to ensure the services, product, or material archives and/or conforms to the require standard. Standards are critical, contributing to the economy, innovation, ensuring safety, social and environmental issues are addressed. A vast majority of standards within Fiji have been adopted from Australian and New Zealand Standards, with the ‘Fiji Standards’ being an example of voluntary standards as they are not governed by law. In this instance, if the service or product is demonstrated to conform well or exceed the standard then it is acceptable, however, it is best practice to abide by these standards. This is in comparison to regulatory standards which are established by the government and require mandatory compliance. These standards are facilitated by government agencies and departments which aim to protect the safety and health of the environment and people.

2.1.9 Building Code

The building code is a national framework for the minimum building requirements, addressing aspects related to health, safety, accessibility, amenity and sustainability. Within Fiji, the Fiji National Building Code is managed by the Fijian Ministry of Public Works, Meteorological Services and Transport. The code aims to increase environmental protection and climate resilience, build a safer place for the community while respecting cultural and geographical differences, ensuring a thriving community can be achieved for everyone. Modular construction at both a residential and commercial level requires mandatory compliance with the building code.

2.2 Fijian Culture

Within Fiji, tradition and culture has been passed down through generations, within various eras, including the pre-colonial era, post-colonial era, and the present (Goundar, 2015). Fiji consists of over three hundred islands located within the South Pacific Ocean. Fiji's culture is therefore characterized by a relaxed pace of life, and tropical environment. Due to British colonialism, western influence has left a cultural imprint on the indigenous people and introduced migrant populations into society. However, Fijians core values and native traditions remain evident throughout the social, political and technological advancements which have occurred.

2.2.1 Indigenous Fijians

The indigenous Fijians, known simply as Fijians, continue to make up the majority of the population within the Fijian islands, with their origin on the land being deeply respected. Fijians are well known for their identity and status within society. They present a strong and secure belonging to their land, through their community and culture, with their inner confidence making them intensely forthcoming people. Through centuries of tradition, adaptation and resilience, the Fijian culture maintains deep connection to the land and sea. The people honor their ancestral ties through ceremonies, storytelling, and art, being one and working with the land. The indigenous culture possesses a strong sense of community and hospitality, known as "vei lomani." This is when individuals come together to support one another in times of celebration and hardship, with this spirit of connectedness being the underlying denominator of Fijians cultures resilience and vibrancy.

The Fijians tie to the land is evidently sacred and is rooted in centuries of tradition and spiritual connection. For the Fijian people, the land is not just a physical space, but also a living entity imbedded with ancestral spirts and divine significance. The land is a central place within the Fijian culture, known as "Vanua." Vanua shapes the physical surroundings, representing a connection between the physical environmental and the cultural, social, and spiritual aspects of life, shaping the Fijian's social structures, customs and beliefs.

Traditionally within Fijian society, land ownership is communal, with clans and tribes collectively stewarding the resources of their ancestral territories. Due to this belief, a deep sense of responsibility and respect for the land is embedded, with the land being seen as a gift from the gods which must be cherished and protected for the future generations. Ceremonies and rituals such as the "Sevu Sevu" ceremony further reinforce the spiritual bond between the people and their land, displaying gratitude and reverence. Therefore, the Fijians tie to the land transcends mere ownership, with it being a sacred bond that sustains their cultural identity, nourishes their livelihoods and bestows a sense of belonging.

2.2.2 Colonization

From 1874 to 1970, Fiji was a colony of the British crown until they gained independence as the Dominion of Fiji. When British rule was established, a period of strife followed, which was partnered with European settlers and traders' activities which occured within the islands. The government wished to further expand their empire within the remote pacific as a strategic advantage. During this time, European settlement of the island occurred in a manner which recognized the indigenous social hierarchy, language, and culture. This is due to the Fijian chieftain system of land and governance being similar to the lord system within the United Kingdom, causing the British to incorporate their social structure more considerately as they colonized. This led to the Fijians respecting and honoring the British monarchy as they offered the country improvements and advancements.

Indians migrated to Fiji in the 19^{th} and early 20^{th} century, constituting for the majority of the population from 1956 to the late 1980's. Migration occurred due to Indians gaining employment on European trading ships or as laborers which the British migrated to Fiji during their colonial rule. Currently, Indians are the second largest ethnic group within Fiji, with 60% of the Fijians living in Australia being Indo-Fijians.

2.2.3 Geography

Fiji is an archipelago located within the South Pacific Ocean, contributing to Fiji's diverse and unique geography. The islands are located approximately 2,000 kilometers from New Zealand and consist of over 330 islands, as seen within the below figure. Due to the island's volcanic origins, lush and mountainous terrain is present throughout. This includes rugged peaks of the interior regions, with the surrounding waters of the islands containing vibrant coral reefs. The islands have a tropical climate which is of warm temperatures and high humidity, assisting with supporting the lush rainforests and vegetation across the islands. Due to Fiji's location within the pacific, great influence of its cultural and economic dynamics is present, with a significant reliance agriculture and tourism.

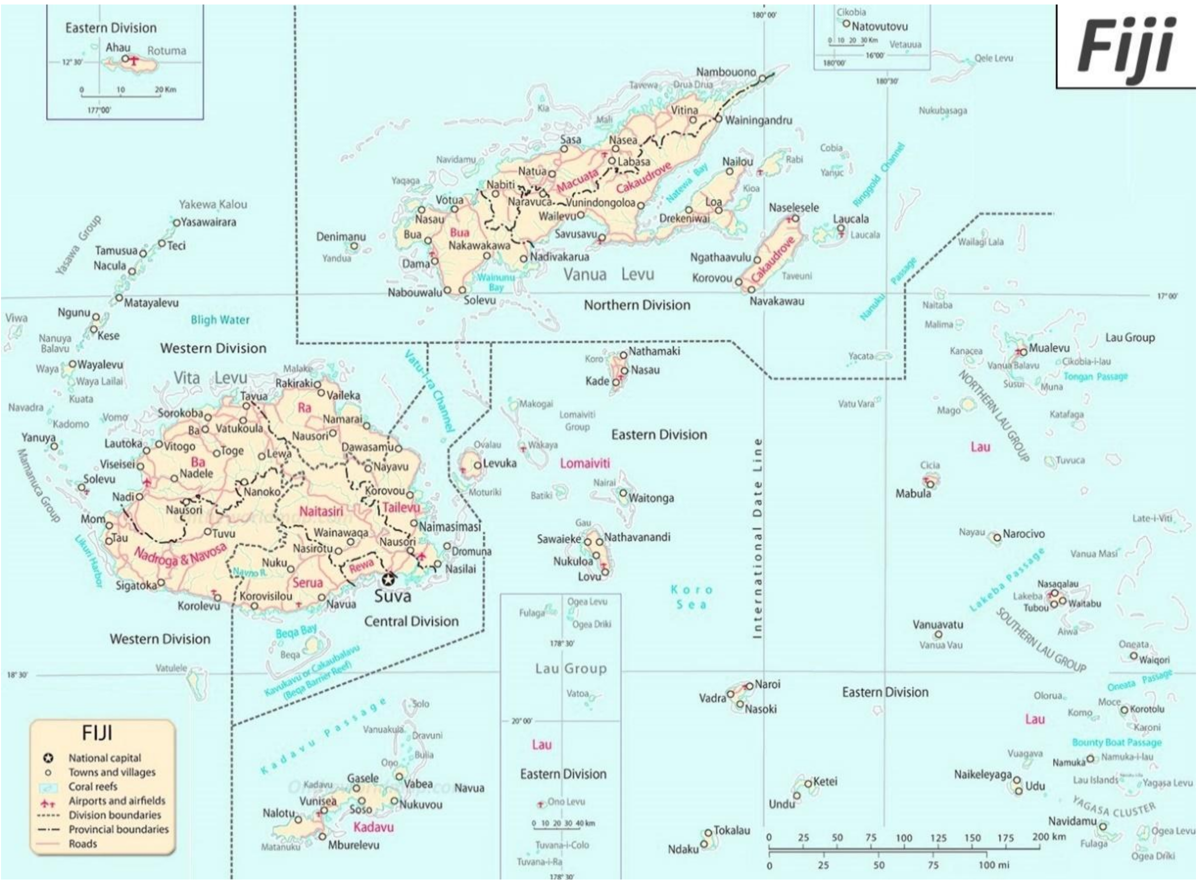

Figure 2.2: Detailed Map of the Fijian Islands (Fiji, 2021)

Currently 87% of the Fijian Islands are tribally owned native land, in which native culture and communities continue to exist. Within these villages, there is minimal infrastructure, including running water, sewage, and telecommunications. Government presence is restricted to the education and health care facilities, with the justice system left largely to the community.

Within society today, the most notable difference is between the two main islands of Fiji, Viti Levu and Vanua Lavu, and the remainder of the country. As Viti and Vanua are the two largest islands, they have been subjected to the largest amount of urbanization and westernization. This is present within their architecture and means of living, with traditional Fijian social structure being sparse due to the rise in commercially driven economy.

2.2.4 Social Structure

Many Fijians continue to live in tribal villages which are headed by chiefs that are in charge of ensuring harmony and discipline. The villages consist of large networks which have close or distant kinship ties, with everyone in the village usually being related in some way, such as through marriage or patrilineal heritage. When an outsider is accepted into the tribe, they receive the benefits and rights of the family, becoming honorary brothers and sisters of a village. There is extreme emphasis within villages of the communal understanding of a home and family as they encompass more than just a nuclear family and their house. Rather, it includes the entire tribe and village.

Within the village, resources and economic property are shared, with the social organization being very communal. This includes, for example, the children being raised as a collective effort of a community and joint meals being available for all interested. 'Kerekere' is the custom of any relative or neighbour being able to request a favour or ask for something which they need, with it being willingly provided without expectation of repayment. This is where the generous and inclusive nature of Fijian people comes from, with all being taught from a young age to offer and share everything they are given. This means that no person will go unloved or uncared for with a sense of personal belonging and economic security provided for all.

The stability of food and resource supply is essential for those within villages that continue to live a subsistence-farming lifestyle. The collectivist culture can place many indigenous Fijians at a disadvantage within an urban setting due to adjusting to a competitive spirt of the capitalist economy. Regardless, the orientation towards inclusion influences all to be general and conscious of their unneighborly relationships.

2.2.5 Religion

Fiji's religious landscape is as diverse and is a reflection of centuries of cultural exchange and spiritual evolution. Prior to European colonization, indigenous Fijians practiced a complex system of animistic beliefs centered around the worship of ancestral spirits and deities. Central to this traditional religion was the concept of "Kalou-Vu," the supreme god believed to be the creator of the universe and all living things. Ancestral spirits, known as "Kalou," were also honored, with each clan or tribe having its own set of deities associated with specific natural phenomena or ancestral lineages.

Following the arrival of European missionaries, Christianity spread rapidly throughout Fiji. Methodists, Catholics, and other denominations established churches and missions across the islands, converting a significant portion of the indigenous population to Christianity. This period of religious conversion was marked by both peaceful assimilation and violent resistance, as traditional Fijian beliefs clashed with the teachings of Christianity.

Despite the widespread adoption of Christianity, elements of traditional Fijian religion remain deeply ingrained in the cultural fabric of the islands. Many Fijians continue to incorporate traditional rituals and ceremonies into their Christian practices, blending old and new beliefs in a syncretic expression of faith. Additionally, Hinduism and Islam have also become prominent religions in Fiji, introduced by Indian’s immigrants brought to the islands by British colonial authorities in the late 19th and early 20th centuries. Today, Fiji's religious landscape is characterized by a rich tapestry of beliefs and practices, reflecting the country's diverse cultural heritage and history of colonization. While Christianity remains the dominant religion, traditional Fijian customs and beliefs continue to play a significant role in shaping the spiritual identity of the islands' inhabitants.

2.3 Fijian Residential Housing and Construction

2.3.1 Fijian Residential Housing

Typical housing within Fijian villages reflects the traditional values, lifestyle and community spirt of the indigenous Fijian culture. Traditionally, bures were the typical form of residential construction within villages. However, more common nowadays are homes made from blocks, corrugated iron and any other building material readily available, as shown in the below figure. Within a village, each family have their own house which are all centred around the chief's house, the church or churches and a meeting house known as the "vale ni Bose." This central gathering place serves as the heart of the village, where villages come together for ceremonies, social events and defines the bond of kinship and solidarity within the village.

The design and layout of homes reflect a blend of traditional and modern influences due to urbanization, globalization and economic development. Within urban areas and modern developments, residential houses often feature western-style architecture that includes concrete or brick construction, tiled roofs, and internal amenities. The houses typically have multiple rooms such as bedrooms, kitchen, living and bathrooms arranged in a functional, efficient layout. Within traditional and rural villages, the cultural layout which includes two rooms, a common space and sleeping space, is still present. Extended family often live together or in close proximity sharing communal spaces and resources. Amenities and kitchen facilities are minimal, with little furniture used or located within the homes.

Figure 2.3: Typical Fijian Housing in Lavana Village (Fiji, 2022)

2.3.2 Bure

The traditional Fijian house, known as the bure, is an embodiment of indigenous architectural ingenuity and cultural heritage. A bure is constructed from locally sourced materials such as bamboo, woven pandanus leaves, coral, seaweed and thatched coconut palm fronds, which is dependent upon the location. Its design reflects a deep understanding of the climate and environment, with a steeply pitched roof to shed heavy rainfall and provide shade from the intense tropical sun. Inside, the space is open and airy, with minimal walls allowing for natural ventilation and airflow to mitigate the humidity of the islands. The raised floor, often made of hardwood or woven mats, enables the living space to be elevated, reducing the risk for potential flooding, along with creating a sense of connection with the earth below.

Traditionally, the bure is divided into separate areas for sleeping, cooking, and socializing, with woven mats or grass mats providing comfortable seating and sleeping surfaces. Decorations may include intricately woven wall hangings, carved wooden implements, and woven baskets, reflecting the craftsmanship of the Fijian people. Beyond its practical function as a shelter, the bure holds deep cultural significance as a symbol of communal living and kinship ties, serving as a gathering place for villages to come together, share stories and bind kinship.

Figure 2.4: Bure (Fiji, 2012)

2.3.3 Cultural Housing Requirements

Fijian houses are not just structures, rather are embodiments of cultural values, traditions, and benefits of the communities. The fundamental cultural respect for the land is evident within Fijian housing, with houses design to co-exist with the natural environment. This includes considerations for elevation to mitigate flooding, maximisation of airflow, and connectedness to the land to signify environmental stewardship and sustainability. Furthermore, Fijian houses serve as hubs for communal living, reflecting the importance of kinship ties and extended families. Within both traditional and modern settings, the houses are built to accommodate multiple generations along with fostering a sense of unity, cooperation, mutual respect and support within the community.

The tradition of having two doors within a house, particularly within a bure, holds significant cultural significance The dual-door design symbolizes a respect for the elders and the acknowledgment of their esteemed status within the household. One door is typically designated for the younger members of the family, while the other door, often larger and more ornately decorated, is reserved for the elders. This architectural feature reflects the cultural value placed on hierarchy and intergenerational respect within Fijian society. Elders hold a revered status, and the provision of a separate entrance for them signifies their importance and authority within the family unit. It also serves practical purposes, allowing elders to enter and exit the house with ease and dignity, without having to navigate through the hustle and bustle of daily household activities.

In Fijian culture, the chief, or "Turaga ni Koro," traditionally holds a position of high esteem and authority within the community. Apart of this includes the chief having the highest house within the village, both literally and symbolically. This acts as a visual representation of their leadership, importance, and requirement for respect. Historically, the chief's house, known as the "bure ni sa," would often be situated on the highest point of the village, both for practical reasons such as defence and visibility, as well as to symbolize the chief's elevated status within the community. Today, it also serves as a gathering place for important meetings, ceremonies, and discussions, where decisions affecting the community are made in consultation with the chief and village elders.

While the practice of the chief having the highest house has evolved over time, with many villages now adopting modern housing styles and layouts, the symbolic significance of the chief's elevated status remains deeply ingrained in Fijian culture. Even in contemporary Fiji, the chief continues to hold a position of respect and authority within the community, and their house often serves as a focal point for cultural and social activities, preserving the traditions and customs that have shaped Fijian society for generations.

There is a deep-rooted aspect of Fijian culture and tradition known as “tabu ni vanua” or “tabu meke,” being the tradition of burying people beneath the posts of houses. In indigenous Fijian society, this practice was believed to instil the house with spiritual protection and strength, as well as to honour the ancestors and establish a connection between the living and the dead. According to Fijian belief, by placing the remains of ancestors beneath the posts, their spirits become guardians of the household, watching over and guiding their descendants. This practice also serves to reinforce the bond between the living and the deceased, ensuring that the wisdom and teachings of past generations continue to shape and influence the present.

Additionally, burying the dead beneath the posts of houses is seen as a way to return the ancestors to the land from which they came, completing the cycle of life and death in accordance with Fijian cosmology. While the practice has become less common in modern times, it remains a powerful symbol of cultural identity and spiritual connection for many indigenous Fijians, highlighting the enduring significance of tradition in shaping the cultural landscape of Fiji.

2.3.4 Fijian Construction Industry

The Fijian construction industry plays a pivotal role in shaping the counties physical infrastructure and economic development. Fiji has a growing population and rapidly increasing levels of urbanization which is demanding a rise in residential, commercial, and public infrastructure. The construction industry within Fiji includes various sectors such as design, manufacturing, construction, engineering, and project management. Although the rise in construction is extensive, there are various constraints faced within the country surrounding maintenance, materials, remote construction and work, health and safety (WHS) issues.

The traditional construction methods of Fiji are rooted in indigenous knowledge and craftsmanship, existing alongside modern building materials and techniques. Within rural areas and traditional villages, the Bure is still a common structure consisting of locally sourced materials including thatch, bamboo, and wood. This displays a sustainable approach to building, harvesting only what is required and enabling regeneration of the material. These traditional building techniques demonstrate culture, assisting in providing resilience to communities during times of natural disasters due to the bures design.

Within city centres consisting of urban development, the construction industry is characterized by modern building materials such as concrete, steel and glass. Within Nadi and Suva, high rise commercial complexes have begun to shape the skyline due to tourism, real estate, and infrastructure development. Recent initiatives that promote sustainable construction, green building standards and energy efficiency have been implemented into the industry. These initiatives are gaining momentum and reflect growing awareness of environmental and social responsibility within the industry.

Fiji continues to face challenges regarding the ability to obtain skilled labour, finances, regulations and vulnerability to external factors such as natural disasters and global economics. Various initiatives have been implemented by the government, private sector, and international partners to address these challenges, with the aim to foster a resilient construction industry that is prepared to contribute to the economic growth and sustainable development of Fiji. One example includes educational initiatives to provide fee free training to Fijians within the construction industry, However, they face the challenge of losing their educated to higher paying and opportunistic counties such as Australia and New Zealand. This has created significant issues within the country as their workforce comprised of young traded and educated individuals is reduced, while the industry is continually increasing.

Remote construction within Fiji present unique challenges due to the geographical dispersion of the islands, terrain and limited access to materials, resources, and infrastructure. Within remote villages, traditional construction methods are impractical or insufficient to meet growing demands for infrastructure and housing. In order to address this need, modular housing can be implemented as a solution, which is what will be explored within this dissertation. Furthermore, the materials used need to be analysed to ensure that they are sustainable and fit for purpose. One solution is using bamboo as an alternative building material that is locally sourced and environmentally sustainable. By utilizing bamboo, remote villages are able to reduce reliance upon imported material, reduce their environmental impact and support the local economy.

Furthermore, remote construction poses challenges in Fiji in relation to transportation logistics. Accessing construction sites throughout the islands can be difficult due to limited infrastructure and transportation options. Methods of transportation such as boats and aircraft can be deemed impractical and unreliable within instances of adverse weather conditions and increased demand. The road infrastructure within the mountains can be limited and unreliable which can impact and prevent the delivery of materials and equipment. In order to combat these issues, innovative transportation solutions are being developed and explored to improve transportation logistics within remote parts of Fiji. One solution being utilized is the use of hovercrafts and amphibious vehicles which are able to navigate land and water. These vehicles have been successful in providing access to remote islands and coastal areas that traditional vehicles are unable to access. Seaplanes and helicopters are another means of transportation being implemented which offer efficient transportation of personal and cargo to remote construction sites. Through the implementation of these transportation methods, reduced travel time and increased project efficiency can be seen, reducing costs, and increasing outcomes.

The Fijian construction industry relies on a combination of modern and traditional tools and equipment that reflects on blending indigenous craftmanship and contemporary technology. Within the traditional Fijian construction industry, tools commonly utilized include chisels and axes, used to shape natural materials. The tools and skills were often passed down through generations and remain essential for traditional building techniques and construction. Modern construction equipment is being increasingly utilized within Fiji and consists of power tools for cutting, drilling, and fastening which is in turn, increasing efficiency and productivity. Earthmoving plant and equipment are also being utilised which assist with civil works, site preparation and clearing within residential, commercial and infrastructure projects. Limitations surrounding transportation of plant due to the road network and availability, along with affordability of power tools is evident.

Maintenance issues within the Fijian construction industry arise from a range of challenges which pose impact upon sustainability, safety and the longevity of buildings and infrastructure. One of the major issues faced is the requirement for regular maintenance on existing structures which does not occur, resulting in deterioration, structural weakness, and safety hazards. This occurs due to competing priorities and limiting resources and maintenance programs. This demonstrates that maintenance is often overlooked and not considered as a top priority, resulting in significant repairs being required. The harsh environmental conditions within Fiji also place strain upon the construction industry. This includes storms, humidity and saltwater exposure which increase the wear and tear on buildings. Inadequate training and capacity of the construction workforce also contributes to the maintenance challenges being faced. Due to skilled labour shortages and lack of technical experts, correct repair and diagnosis is impacted and therefore reduces the effectiveness of maintenance works. Material availability and transportation logistics also impact and impede on maintenance, especially within remote and rural areas of Fiji. This can result in delays and inefficiencies when addressing maintenance issues which in turn, increases the risk of further damage and deterioration.

While the construction industry within Fiji has significantly developed and progressed, there are still extensive challenges which need to be addressed to ensure efficient and quality construction occurs. Restrains surrounding construction materials, tools, labour, and transportation need to be evaluated to develop proactive and efficient plans. Issues surrounding building and infrastructure maintenance need to be addressed to ensure the longevity and improve the sustainability of the structures. Overall, various constraints and opportunities have been identified in which modular construction can work within the industry to begin to address the issues and improve the end product.

2.3.5 Fijian Construction Industry Trends

The current trends within the Fijian construction industry are reflective of the global shift occurring towards more sustainable development, moderation of infrastructure and increased urbanisation. An increased emphasis upon sustainable construction practices is one of the most notable. This is due to the global focus of reducing carbon footprint and utilisation of renewable energy and resources (Sims and Dwyer, 2022). Fiji has begun to adopt green building and energy efficient design practices and utilise renewable materials within construction which align closely with international sustainability standard within urban areas. Additionally, traditional Fijian architectural elements and materials are increasingly being incorporated into designs, producing a blended design style consisting of contemporary and cultural heritage aspects.

Within the recent years, the Fijian Government has begun to procure and develop infrastructure to assist with supporting economic growth. This infrastructure includes large scale projects including development and upgrades of ports, airports and the road network (Raj, 2021). Through doing so, the government aim to improve the connectivity within the archipelago and increases Fijians position with the trade and tourism sector of the South Pacific region.

With an increase in urbanisation, the demand for residential buildings has also increased, evident within Suva, Fiji's capital city. Due to an influx of Fijians relocating from rural villages to urban areas in search of opportunities, education and employment, the need for affordable residential housing solutions has also increased. As a result, construction of mix use and apartment complex developments has increased to match the demand for affordable residential housing (Kumar, 2023).

Therefore, the above demonstrates that the construction industry trends within Fiji are focused on economic development, affordable and readily available residential housing, and sustainability. When developing a proposed design for this dissertation, it should be insured that the design is in line with these current trends to ensure it is deemed relevant to the country's needs.

2.3.6 Fijian Construction Industry Processes

Similarly to Australia, the Fijian construction industry follows and typical standard sequence containing the following phases: planning, design, approval, construction, and post construction. Each phase and their subsequent requirements are further detailed below. This process should be considered within developing a proposed design for this dissertation to ensure all required components are considered and regulatory conditions are met.

The first phase is planning which involves confirming the projects scope, requirements and objectives with the client, relevant stakeholders and/or industry partners. Within this phase, the location of the project site/s is confirmed, feasibility of the project and requirements evaluated, and budget determined (Lal, 2020). In order to ensure the project meets environmental standards and regulatory requirements, project stakeholders, including the developers, engineers and architects, collaborate.

The design phase is then commenced, with engineers and architects are engaged to develop detailed plans, including architectural, structural and civil plans for example, and specifications for the project. Approvals are then required to be obtained from government agencies prior to construction commencing. Required approvals include land-use approvals, environmental impact assessments and building permits. Dependent upon the project's complexity, this process can be complex and length, often requiring coordination and approval from various agencies (Bola, 2022).

The construction phase includes preparation of the site, construction of the foundation and structural members, and installation of finishes and fixtures. Within Fiji, the construction industry primarily utilises manual labour. However, within recent years, the availability and utilisation of plant and modern machinery, assisting in improving construction efficiency and reducing costs has increased (Singh, 2022). Following construction, a final inspection and testing occurs to ensure the building complies with all regulation's, standards and approval conditions. Defects are required to be remediated prior to occupation. The post construction phase also includes a formal handover of all work as executed (WAE), warranty and operational manuals, and in some instances, maintenance planning (Chandra, 2021).

2.3.7 Natural Disaster Impact

Due to Fiji's location, the nation is highly susceptible to a range of natural disasters, including cyclones, tsunamis, floods, landslides, and earthquakes. As a result, significant impacts and destruction can be caused to the buildings, roads, and other critical infrastructure within the islands. Within the Fijian construction industry, natural disasters have had a profound impact, posing significant challenges to development of structure, resilience and economic stability. Following a disaster event, a mass surge in demand for repairs, reconstruction and rehabilitation is experienced. As a result, construction companies are required to mobilize quickly and efficiently to assess and repair damage, procure materials and tools, and secure skilled labour to the affects areas. This often occurs within areas that have challenging conditions such as limits recourse access and transportation.

Along with this, disasters impose impacts and delays on existing construction projects which results in additional costs and contractual disputes. Infrastructure projects will suffer various setbacks as a result of the damage which is imposed on the site, material and equipment, along with disruptions to transportation networks and labour availability.

The financial impact of disasters and the requirement to rebuild following can strain the government, construction industry and the communities. Budgets dedicated to improving infrastructure may be redirected to the rebuilding of facilities, housing, and amenities which as a result, delays grown within the county.

The maintenance of residential, commercial and infrastructure within Fiji is impacted by the country's vulnerability to natural disasters. One of the maintenance restrictions due to disaster events is the requirement for regular inspections of building components such as the roof, walls, and foundations to ensure they have the capacity to withstand the events. This can include ensuring roofing materials are secure, walls are reinforced, and correct drainage systems are implemented to prevent water intrusion and damage. Following an event, the maintenance restrictions can also include prompt repairs and restoration efforts to prevent further damage and ensure homes are habitable. This can include addressing structural damage, repairing roofs, and restoring essential services such as electricity and water supply.

In response to natural disasters, the Fijian construction industry is required to prioritize resilience and risk mitigation measure within the design, construction and planning of buildings and infrastructure. This can include adopting building codes and standards which incorporate cyclone-resistant materials, structural reinforcement, and hazard mitigation measures to reduce the potential impacts and increase the likelihood of structures having resilience within disaster events. This can include installation of impact-resistant windows and doors, reinforced roofing materials and sturdy anchoring systems. By building more resilient infrastructure and increasing the strength of disaster management capabilities, Fiji is able to manage the effects of natural disasters, promoting sustainable development while withstanding the environmental challenges faced.

2.4 Modular Housing

Modular buildings are defined as three-dimensional structures or volumetric units constructed within a factory production setting and transported to site for assembly (Generalov, V, Generalova, E & Kuznetsova, A 2016). Although this construction technique is not a new concept, with ready-cut building components being adopted since the 17th Century (Musa et al, 2016), it is evident that the scale and benefits seen within modular construction today have developed immensely. There has been significant investigation within the construction industry to determine how modular construction can assist with offsetting rising labour costs and addressing housing shortages.

During World War II, modular construction was utilized to construct soldier’s accommodation and became increasingly popular for residential and commercial construction due to the high demand for housing (Quale, J 2017). Today, the modular housing construction technique is being used throughout the world due to its key characteristics, posing significant advantages in comparison to traditional methods. Such applications and the extent of use include those identified within table 2.1 below.

Table 2.1: Examples of levels of off-site manufacturing (Goodier, C, Lawson, M & Ogden, R 2014)

Parameters	*Levels of off-site manufacture* *1. Manufactured components*	*2. Elemental or planar systems*	*3. Modular and mixed-construction systems*	*4. Complete building systems*
Examples of construction technologies	• Timber roof trusses • Precast concrete slabs • Composite cladding panels	• Structural steel frames • Timber framing • Light steel framing • Structurally insulated panels	• Prefabricated plant rooms • Modular lifts and stairs • Modules placed on podium level • Bathroom pods in framed buildings	• Fully modular buildings
Proportion of off-site manufacture (in value terms)	10–15%	15–25%	30–50%	60–70%
Reduction in construction time relative to level 0	10–15%	20–30%	30–40%	50–60%

Note: Levels of OSM based on work by Loughborough University (Gibb, 1999; Gibb and Isack, 2003). Level 0 represents site-intensive construction using traditional materials with little off-site manufacture, except for windows and doors, etc.

2.4.1 Modular Construction Benefits

In comparison to traditional construction methods, modular construction poses benefits regarding cost, time and quality. Within modern construction, there are various considering factors that require planning, such as legal requirements, sustainability, economic, environmental, and social impact which all contribute to decision making outcomes (Goodier, C, Lawson, M & Ogden, R 2014). Modular buildings are built to the same building codes and standards as traditional construction, however typically, they are over designed. For example, in Japan they have specific building codes for modular buildings which exceed the traditionally built home requires in order to assist with the extra stress of transportation and placement upon the structure. The key advantages of modular construction in comparison to traditional building techniques include the following:

- Construction duration is reduced, and method is simplified, resulting in reduced site management and labor costs, and earlier investment returns.
- Factory quality assurance processes and pre-delivery check produce a higher quality product with a reduced number of defects.

- Building materials quality and methods are increased as it is kept indoors and no weathering can occur which could pose impact to the buildings structural strength, and construction methods can be improved due to the factory environment.
- Construction time is reduced by limiting laborers travel time and elimination of unworkable days due to the majority of the fabrication and construction occurring in a controlled environment. The time benefits can be seen in the following figure.

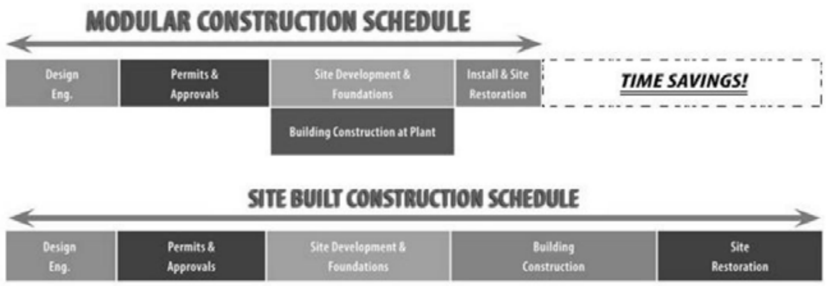

Figure 2.5: Time benefits of modular construction (Modular Building Institute, 2012)

- Large scale economic production is improved with examples of 15 story structures being complete within 8 days (Thompson, T 2019).
- Materials consist of a double-skin nature posing excellent properties surrounding acoustic and thermal insulation, and fire safety. Additionally, the materials are lightweight and use less resources to construct, resulting in less wastage and opportunities for recycling and reuse.
- The majority of the design work is conducted by the supplier resulting in reduced costs for the client and providing a more streamlined and readily available approach.
- On-site labor requirements are reduced, and factory production productivity isincreased meaning installation is streamlined resulting in safer construction due to reduced site activities being performed.
- Cost is reduced for on-site labor, materials, travel and machinery.
- Surrounding residents and noise sensitive facilities (e.g. school or hospitals) disturbance during construction is reduced.

- Buildings have the ability to be dismantled and reconstructed or replaced, enabling reuse and ease of maintenance.
- Environmental benefit through waste minimization and increased engineering standards. Less disturbance occurs to the site as there is less time spent on it, reducing the need for extensive rehabilitation.
- Lower the work, health, and safety (WHS) risks and improves the quality of working conditions. As the majority of the construction work is completed within a controlled environment, safety practices and equipment can be improved when working in dangerous situations in comparison to being on site.

Therefore, it is evident that modular construction poses significant benefits and flexibility in comparison to traditional construction methods. With reduced duration, cost, and wastage, it can be determined that modular construction design and manufacturing systems will continue to be developed and become a well-favored construction method.

A survey was conducted within the United States which questioned the engineer, architecture and construction firms on the importance of sustainable criteria within prefabricated building (Chen, Okudan, & Riley 2010). The sustainable performance criteria investigated are as follows:

	Economic criteria	Social criteria	Environmental criteria
Focus of clients/engineers	E1: construction time E2: initial construction costs E3: maintenance costs E4: disposal costs E5: life cycle costs E6: defects and damages E7: durability E8: the speed of return on investment E9: flexibility (adaptability)	S1: health of occupants (indoor air quality) S2: influence on job market S3: physical space S4: aesthetic options	P1: site disruption P2: recyclable/renewable contents P3: energy efficiency in building use (thermal mass) P4: reusable/recyclable elements P5: material consumption P6: energy consumption in design and construction
Focus of contractors/ precasters	E10: loading capacity E11: integration of building services E12: lead-times E13: material costs E14: labor costs E15: constructability (buildability) E16: integration of supply chains (logistics)	S5: workers' health and safety S6: labor availability S7: community disturbance S8: traffic congestion	P7: waste P8: pollution generation P9: water consumption

Figure 2.6: Sustainable Performance Criteria (Chen, Okudan, & Riley 2010)

The Modular Building Institute (MBI) identifies that when using modular construction techniques in comparison to traditional building methods, a decrease in site disturbance and material wastage is present. Modular buildings themselves can be recycled and reused as they have the capacity to be removed from site, refurnished and reinstalled at another location in an efficient and sustainable manner. Therefore, the application of modular construction is only just beginning, with new technologies continuing to advance the construction methods scope, resolve evident housing problems and posing significant benefits within the industry.

2.4.2 Modular Construction Types

Modular construction can occur in the same format that traditional residents are constructed, with different methods and processes of fabrication and assembly. This is transferable within residential and commercial modular construction with the scope altering based upon client brief requirements and limitations surrounding transportation, budget, and design. The following are different systems and materials which can be implemented within modular construction.

Framing systems traditionally comprise of single or double skin masonry walls, timber studs, joists and bearers or cladding over a stick framed timber frame. Modular construction on the other hand, due to the desire to minimize on-site labor requirements, utilize methods that reduce wastage and environmental impact, and increase efficiency. Some framing system types commonly utilized within modular house construction are as follows:

- Steel and timber frames, which utilize similar construction methods to traditional housing. This includes the use of steel or timber floor framing, studded framed walls and roof trusses for load transfer. The main considerations with this method are transportation weight, termite, and wind loading requirements.

- Concrete in the form of panelized structures is used within modular construction. In this case, precast walls are flat packed onto a truck which enabled installation on site. This is in comparison to installing whole concrete modules with the main considerations being transportation and weight restrictions.
- Sandwich wall is a method which utilizes metal for roof and floor framing, and sandwich panels for the external walls of the building. The panels are similar to those of freezer walls, coming in various systems that are fixed to floor and roof framing. This method provides good energy efficiency properties yet looks generic and bland. Often this method is used as part of construction for certain elements rather than the entirety of a building.

Under the guidance of engineers, footing systems are required to be designed for the modular structure and any imposing wind load requirements. During modular housing construction, there is always a point in which in-situ components such as the footing system and modular components are merged together (Murray-Parkes 2017, pg.103). At this point, coordination and accuracy is required to ensure ease of installation following delivery. The footing system of a structure acts to transfer the buildings load into the earth, situated typically below the ground (ABCB, 2022). This is consistent with traditional building methods in relation to the buildings structural integrity, site investigation and site-specific footing system based upon the site conditions. The footing system is required to comply with structural and geotechnical requirements and can be a variety or combination of systems. These systems can include the following:

- Driven and Screw piles are, as the name suggests, piles that are either driven or screwed into the ground until they achieve the required bearing capacity. Usually, they are steel unless a larger load is required, then they will be concrete.
- In situ slabs consist of a slab which is cast with footing beams underneath it, with the modular building being placed directly on top. This method is not commonly utilized as modular construction typically consists of built-in floors.

- Stumps consist of excavated holes to a specified depth depending on soil classification, which are then filled with reinforced concrete. A steel column is then directly placed vertically upon the concrete which is where the modular building will be situated upon. Steel stirrups can be utilized to replace the need for columns where members are able to be bolded to the stirrups. This form of footing possesses bearing capacities, therefore requiring additional subfloor bracing.

Construction types for modular housing will be further explored throughout this dissertation to identify opportunities for innovation and additional sustainable measures within the context of the Fijian construction industry. The methods and materials noted within this portion of the literature review will serve as a basis for further research to be conducted and base level assumptions and analysis to be made.

2.4.3 Current Modular Construction Trends

Modular construction is required to be designed and engineered to the design standards of its country. However, there is currently no design standard or code within Fiji for modular construction. To combat this, traditional construction standards and codes are utilized and modified to suit the construction technique. This occurs through overdesigning in order to death with the stresses imposed upon the structure during transportation and cranage.

Within Australia, an example of modular construction can occur through the following off-site process:

- The chassis is constructed and flooring placed on top.
- Wall and roof framing is constructed and erected, at this stage services including wiring and plumbing and installed.

- Internal wall and ceiling lining is installed. If there are requirements for internal walls to be fireproofed, sound proofed or insulated, this is done prior to internal lining.
- The external lining, roofing windows and doors are installed.
- All other internal fittings and fixtures are then installed including the waterproofing of wet areas and floor coverings.

At around 95% completion, the structure is transported to site via truck, placed and tied into footings and completed onsite.

The USA and UK construct modular housing within a similar manner. A study into modular housing within the UK (Pan, Gibb & Dainty, 2007) determined that the advantages of cost, time, productivity and quality were the key drivers for using this method. However, health and safety benefits and sustainability are also integral benefits. This construction method is becoming increasingly popular, however traditional construction methods still triumph. This is in compression to Scandinavia, who are the leaders in advancing modular construction techniques (Modular Building Institute, 2010). Within Scandinavia, it is estimated that 90% of the times constructed include some form of prefabrication.

2.4.4 Similar and Comparable Existing Construction Methods

As displayed within the following table, there are various levels of off-site construction within a modular house, with the level utilized varies on the need and project.

Table 2.2: Prefabrication Level (Steinhardt, 2013)

Prefab. level	Type	Definition
High	Complete	Box-form, volumetric, completed buildings delivered to a building site
	Modular	Structural, volumetric, potentially fitted-out units delivered to site and joined together onsite
	Pods	Volumetric pre-assembly. Fully fitted-out units connected to a structural frame onsite, such as bathroom or kitchen pods
	Panels	Structural, non-volumetric frame elements which can be used to create space, such as Structural Insulated Panels (SIPs) and precast concrete panels
	Component sub-assembly	Precut, preassembled components such as doors, and trusses not feasible to produce on site
Low	Materials	Standard building materials used in onsite construction

This extends to different forms of residential housing solutions present within the market today which are further detailed below.

- Modular housing refers to simple configurations that pose various possibilities regarding expansions that can be compared to a Lego-like design. Modular houses are typically simple and elegant, with customizable designs available depending on the budget and requirements.
- Pods consist of one room, being smaller in size and suited to a self-contained room such as a kitchen or bathroom. They follow the same ideal as modular housing however are fit out prior to installation with all fixtures, ready for use on-site.
- Prefabricated homes are inclusive of design and construction with fixed pricing and delivery programs. They possess significant cost savings, options for customization, sustainability, logistics and access benefits. Prefabricated homes require substantial planning and site preparation prior to installing on-site.
- Panelised structures possess a flat pack like ideal, in which the walls and roof are delivered to site almost entirely constructed. This includes all linings, plumbing and electrical services which are only required to be lifted into place and tied into the services. Although they can be constructed quickly, this method tends to possess plain external cladding and a skillion roof.

- Kit homes can be in the form of shed-kid homes or readily available simple designs, with limited to no personalization available. The features of this option include affordability, easy installation and fire resistance with common applications being for holiday homes and shed houses. All the material quantities are supplied and delivered to the site ready for construction.
- Mobile homes, also known within the USA as trailer homes are prefabricated and prebuilt off site on a transportable chassis, enabling them to be relocatable. Due to this, limited to no personalization is available, and the size and height is restricted. This form of construction occurs to a different set of standards from the 1970's, making them not very energy efficient and of low resell value. The homes often contain an eclosed subfloor which has a cosmetic covering around the outside to hide the chassis, axel, and wheels.
- Shipping container homes are constructed using decommissioned shipping containers which increases sustainability and the lifecycle of the product. While the structure poses various design and refurbishment opportunities, there are legislated decommissioning requirements which must be completed prior to occupation.
- Completely transportable structures are those which are commonly used on work sites as a site office. They are commonly transported following completion which occurs repeatedly over the lifespan of the structure.
- Prefabricated components are partially built prior to arriving on site, consisting of walls, frames, and roof trusses. Once on site, the walls and roof must be moved and fastened into position. The frame is then constructed, and traditional construction methods including the installation of the external lining and roof follow for the remainder of the project.
- Processed materials consist of precut materials such as cladding and framing which are delivered to site ready for installation. This reduces the requirement to cut any material on site, reducing labour requirements and construction time.

Each of these existing construction methods poses their own benefits and limitations, with varying levels on onsite and off-site labour being required. A combination of forms can be used within various situations to achieve a desired outcome and should be considered when developing and proposing a solution.

Existing comparisons between traditional construction methods and modular construction are evident, with the following detailing some of the major contributing factors. These comparisons were studied within a research paper that compared modular construction and stick-built construction, in relation to multi-family buildings in the USA (Fray, 2010). The findings of this study are transferable to this instance and can be utilized to base further assessment upon.

- Cost: When comparing traditional and modular construction, the study determined that there can be savings of between 15 – 20%. However, the saving can usually be offset by transport and cranage costs which therefore, when comparing the costs from design to completion, there is no major savings (Cheverton, cited in Fray 2010, p. 19). The major difference in costs throughout the project is in relation to allocation throughout each stage. Modular construction methods possess more upfront costs in relation to traditional construction, where costs are spread more evenly throughout the process. However, modular construction has the advantage of being able to be removed and reused which enables them to maintain their value (Lawson & Richards, 2010).
- Time: Upon comparison of traditional construction methods and modular construction, it is evident that modular construction is much quicker due to reduction in the likelihood of client and contractor delays. Once modular construction begins, the client has no access or control over the construction which reduces the amount of preliminary design uncertainty and potential variations. The second key benefit is site installation, in which modular building components are able to be transported and craned into place on site resulting in faster delivery times (Mohsen, 2008).

- Safety: Through using a combination of off and onsite construction, safety has evidently been improved. The study demonstrated that reportable accidents were reduced by over 80% in comparison to traditional construction methods (Lawson, Ogden, & Bergin, 2012). This is due to greater safety precautions being implemented and monitored within a factory setting in relation to onsite.
- Sustainability: The waste produced by modular construction is significantly reduced by 10 – 15% on a building site and less than 5% within an off-site facility (Lawson & Richards, 2010). Within off-site facilities, there is also greater opportunity for recycling to occur, along with utilization of efficient lightweight materials which reduced construction materials embodied energy. Additionally, due to construction techniques, a higher level of thermal performance can be achieved through increased airtightness which will therefore improve the buildings energy efficiency.

2.4.5 Modular Capabilities and Limitations

Modular capabilities pose significant improvements and benefits regarding planning and construction of residential homes. Through utilizing a combination of on-site and off-site construction, with aspects being completed in parallel, a decrease in time and cost can be achieved. The cost-effective capabilities of modular construction can be achieved through effective planning, waste minimization, and reducing preliminary and overhead construction costs. As modular construction is mass produced, room for error is reduced, and increased efficiency regarding onsite tasks is reduced due to the repetitive nature of the design is achieved. Although, due to the repetitive nature and reduction in customization, aesthetics can be reduced which could potentially defeat the cost and time saving benefits, dependent upon the application. By minimizing on site establishment costs and time, the project as an entirety will be completed earlier. This creates various opportunities for different organizations which are required to remain open but would like upgrades, renovations or alterations made to their space. By results in reduced interruptions, less site established and progressive costs.

Application of modular construction within remote locations has been successful within residential and commercial settings. The cost of transportation is analysed against local labour and material rates which determined the construction method preferred. However, through reducing the risk and site disturbance when using modular construction, especially in sites of high value, the capabilities of modular construction can be utilized.

Within the construction industry, job security is a major component in which modular construction provides benefits within. As the industry as a whole functions on a needs basis, there are often factors such as contract durations, stakeholders and weather conditions which impact employment duration and opportunities. Through moving the majority of labour requirements into a control environment such as a factor, it enables the staff to continue with work regardless of the weather conditions. This reduces delays which previously occurred during these events and manages risk associated with onsite construction. This enables job security to be provided within an industry which is renowned known for its inconsistency.

On the contrary, prefabricated construction options do possess limitations (Ryan E Smith, 2010, p 83). If not managed correctly, the following factors which impact time and cost effectiveness of -prefabrication construction incur, resulting in limitations.

- Overhead costs which include staff requirements, factory costs, establishment costs, maintenance, utilities, and equipment.
- Profit margins which are imposed upon large companies may be determined as disproportionate to smaller companies which have a limited profit margin, although the larger organization require larger profits to cover overhead costs.
- The transportation of components, panels and modules may not comply with typical

transportation requirements. This may result in additional labour to fasten and transport components during off peak times.

- Cranage of modular construction may result in complex installation methods which increase risk and skill required.
- The fees associated with technical design from engineers, compliance officers and architects.
- Quality of modular components which have been imported from other countries.

Therefore, although modular construction has not achieved the same level of success in Fiji as it has in other countries (Murray-Parkes, 2017, pg. 15), it poses significant opportunities within developing countries. The limitations of this construction method need to be assessed and weighed with the opportunities it can provide. Through correct planning and implementation, a majority of the limitations can be mitigated to an extent which improves the opportunities this construction method can impose on the industry.

2.5 Modular Housing Construction Standards

2.5.1 Fijian Construction Standards

As defined within section 2.1.8 of this dissertation, a standard is defined by Standards Australia (2022) as “a published document which sets out specification and procedures to ensure that a material, product, method or service is fit for purpose and consistency performs the way it was intended.” Within Fiji, the construction sector operates under regulations and standards which have been developed and implemented in order to ensure durability, sustainability and safety within building design, construction and occupation. The Building Code of Fiji (BCF) and the Fijian Town Planning Act, 1946 are the two primary legislations governing the Fijian construction industry (Government of Fiji, 2020). These documents detail the requirements for various aspects of the design and construction process, including environmental considerations, electrical and plumbing installation, fire safety and structural integrity.

The Building Code of Fiji details the legislative, required minimum design and construction standards of buildings within Fiji. This code has been developed in line with international standards and draws from New Zealand and Northern Australian standards, due to its geographic locational similarities. The code has been developed and adapted to suit Fijis geographic and climatic conditions, including the nation's high susceptibility to earthquakes and cyclones (Government of Fiji, 2020). Within the code, specific provisions are details for wind load restraints which complement the intensity and frequency of tropical cyclones which occur within the nation (Sika and Chand, 2019), and material and construction technique requirements which assist in further enhancing structures resistance to national disaster events (Lad and Holland, 2019).

The Town Planning Act, 1946, details regulations of land use and development. This act ensures proposed developments are consistent with the urban planning objectives within Fiji for the projects specific region and building class. Within the Act, planning approval is mandated which ensures proposed designs are in adherence with environmental regulations and zoning laws (Ministry of Local Government, Housing and Environment, 2017). By doing so, the rapid urbanization which is occurring within Fijians urban areas is able to be regulation to ensure planning objectives are abided by and environmental impact is mitigated and reduced were possible.

The adoption of the Green Building Councils of Fiji's (GBCF) guidelines demonstrates the nations continual focus and commitment on ensure sustainable development is practiced. These guidelines focus on incorporation of sustainable construction practices, energy efficiency, water conservation and utilisation of renewable resources (Green Building Council of Fiji, 2021). The GBCF is a non-profit organisation within Fiji which was established with the goal of promoting sustainable building practices, established in response to a growing need for environmentally sustainable and responsible building practices. The GBCF advocated for education, training, green building initiatives and influences policy development through collaboration with government bodies, international organisations and industry stakeholders (Green Building Council of Fiji, 2021). Through implementation of these guidelines, a growing awareness of the need for sustainable building practices is achieved, assisting in transitioning Fijis construction industry into a sustainable, built environment.

However, although these standards, codes and guidelines are being implemented across Fiji, the enforcement of such is not being upheld or being completed to the required standard to ensure compliance. This is due to various limiting factors such as limited regulatory agencies resources and skilled employees, and the requirement for standards to continually evolve to align with technology and legislative advancements (Narayan and Prasad, 2020). Through addressing these challenges, Fijis construction industry will continue to develop in the right direction, focusing upon sustainability, resilience and quality structures, enabling safe housing to be providing to Fijis growing population.

2.5.2 Modular Construction Standards

The standards which govern modular construction are critical to ensure durability, quality and safety of the structures. Due to the technology and processes of modular construction being a new concept and continuing to develop, within many countries, specific standards for modular construction have not been developed. Therefore, modular construction must comply with the traditional construction method standards and building codes. Within recent years, additional regulations which address specific aspects surrounding modular construction, such as the requirements surrounding the transportation and assembly of modules, have been developed.

The Internation Code Council (ICC) provides guidelines which have been developed under the International Residential Code (IRC) which have been applied within the United States to modular construction. The ICC guidelines assess modular constructions structural integrity, material and connection method of the modules (International Code Council, 2021). Within Australia, the National Construction Code (NCC) performs a similar function, detailing requirements of sustainability, health, amenity and safety for construction (Australian Building Codes Board, 2022). Another example is the Building Standard Law of Japan. Similarly to the United States, this law is not specific for modular construction, but details required design characteristics to ensure the structure is resilient to seismic activity, due to the countries high susceptibility to earthquakes (Ministry of Land, Infrastructure, Transport and Tourism, 2019).

Construction specifications are defined as documents which contain details regarding the quality, material, installation and construction of a building. In regard to modular construction, these specifications provide additional, process specific details surrounding the structural components, fabrication process, transportation and installation of the modules. As modular construction consists of an offsite fabrication process within a controlled factory environment, the building specifications include a high level of quality control measures which ensures that each module is constructed as per the standard prior to leaving the factory (Smith, 2020). One example of this is within the United States where the construction specification references organizational standard which must be adhered to. These standards can include organizations such as the National Electrical Code (NEC) for electrical works and installation, and the American Society for Testing and Materials (ASTM) for material testing (ASTM International, 2021).

The existing construction codes which are in relation to modular construction vary between different countries, with an extensive number of countries still relying upon codes developed for traditional construction methods. However, the variations between existing codes are primarily in relation to traditional building methods, climate and the countries susceptibility to national disasters and seismic activity. Within the United Stated, the IRC primarily regulates modular construction standards. As detailed above, the IRC contained a comprehensive specification for residential construction and extends into modular construction specific inclusions surrounding manufacturing, transportation and installation (International Code Council, 2021). This code provides assurance that traditional and modular construction methods are both withheld to the same performance and safety standards. These specifications are consistent with those detailed above for Australia and Japan.

Through this investigation, it is evident that the level of detail contained in different countries' legislation and guidelines in relation to modular construction significantly varies. However, consistency is evident with each country's codes focus upon quality, durability and safety which is adapted to suit local construction practices and environmental conditions.

2.5.3 Case Study – PrefabAUS

PrefabAUS, or previously known as prefab Australia is one of the leading modular construction industry bodies who represent the interests of the offsite or prefabrication construction sector, including modular construction, within Australia. PrefabAUS plays an intriguing role within shaping Australia's construction industry, promoting development and innovation of modular and prefabricated building techniques and technologies. One of the industry bodies' most significant contributions is the development and publication of the Modular Construction Handbook (PrefabAUS, 2024). This handbook acts as a comprehensive guideline detailing standards, best practice and technical details for professionals including engineers, architects, developers and builders who are involved within the modular construction industry.

A variety of topics in regard to modular construction are contained within the handbook, and include material selection, design and manufacturing considerations and processes, transportation and installation of the modules. Through developing the handbook, the knowledge of various industry experts is able to be contained and provided to all involved within the modular construction industry. This document was developed in the aim to serve as basis for establishing a standardized modular design and construction practice within Australia (Prefab AUS, 2024). The integration of traditional and modular construction methods is one of the key aspects focused upon within the handbook. This includes highlighting the importance of preliminary stakeholder collaboration to ensure all modular components are able to be seamlessly integrated within the building's overall design. By doing so, it ensures issues such as material inconsistencies, misalignment of the modular components or delays within the assembly phase are eliminated.

The associated regulatory requirement's for modular construction are also addressed, providing further insight and evaluation into the application of the NCC and other relevant standards for this construction method. The NCC's flexibility is highlighted which ensures performance and safety requirements are met while still enabling modular innovation to occur. Technical guidance is also provided, with a key focus on sustainability and renewability within the design and construction process. This includes strategies that have been developed to incorporate sustainable practices for every stage of the design and construction process, including minimizing environmental impact, improving energy efficiency, renewable materials, and reducing waste.

The following are therefore some of the key requirements and recommendations which are detailed within the Modular Construction Handbook by Prefab Aus (PrefabAUS, 2024):

- Design considerations: emphasis is placed on early integration of modular components within the design process and discussions with key project stakeholders. This ensures that the modular components can be manufactured in alignment with the overall buildings design requirements and technical specifications. Modular components are also recommended to be developed to a standard size and with standard connection points, enabling flexibility to accommodate client and site-specific requirements and conditions. In regard to structural design, the handbook outlines the required load bearing capability, seismic considerations and wind resistant design requirements. Additionally, the stresses the modules experience during transportation and installation should be considered and designed to account for.

- Material Selection: It is recommended within the handbook that the material utilized pose longevity and durable characteristics, which can withstand transportation and any site-specific environmental conditions, such as sea salt spray. There is a large emphasis on the utilization of locally available, renewable and sustainable materials to assist in the minimization of the proposed buildings' environmental impact.
- Off-site Manufacturing processes: Strict quality control measures are detailed to be implemented during the off-site manufacturing process of the modulars. These measures include, but not limited to, testing of materials, regular inspections and adherence to manufacturing tolerances ensuring the required construction standards are met. Due to the nature of off-site construction, advanced fabrication techniques, for example CNC machining, are able to be utilized. This enables a high level of accuracy to be achieved, essential to ensure the installation of the modules is seamless onsite.
- Transportation and Logistics: The preparation and transportation of modules is detailed, to ensure components are secured correctly to prevent damage occurring during transport. This could include planning transportation routes to accommodate overside vehicle loads and use of protective coverings on the modules. There are also environmental strategies which should be considered during the transportation process, such as energy-efficient transportation methods, optimization of loads and coordination of site deliveries.
- On-site installation: Site preparation requirements are detailed which are required prior to the arrival and installation of modules. This includes ensuring foundation and utility

installation compliance and completion. A inspection and test plan, with required witness and hold points should also be developed for the installation of the modules onsite. This will include the requirements and expectations surrounding lifting equipment, module alignment and securing techniques. Within the handbook, emphasis is placed on the importance of correct connections between modules. This not only includes the structural components but all plumbing, electrical and mechanical systems and services, and finishing works such as joint sealing and installation of exterior finishes to ensure a seamless visual appearance is achieved.

- Regulatory Compliance: The handbook outlined requirements for modular construction to meet the NCC and other applicable standards, such as structural performance, fire safety and energy efficiency. The recommendation is also made to seek certification and approval as per the local council's governance and requirements throughout the process.
- Sustainability Practices: Methods for waste minimization within the fabrication and installation phases are detailed, including strategies which include the incorporation of material off-cuts into the design and ensuring waste materials are recycled. The modules should also be designed with energy efficiency as a key design factor, which could include the incorporation of renewable energy systems, optimizing installations and using double or triple glazed windows.
- Work, Health and Safety: The safety of workers within the fabrication, transportation and installation of the modular components is outlined within the handbook, including recommendations for the required PPE, manual handling and onsite safety protocols. The handbook details the importance of designing modules which are focused upon the wellbeing and health of the occupants, placing consideration of aspects such as indoor air quality, terminal comfort and natural lighting.
- Innovation and Future Trends: The utilization of new technology such as BIM and automatic fabrication process is encouraged to enable efficiency and accuracy of the modular construction to be improved. The modules should also be designed with the future in mind,

considering extensions, adaptability and integration of new technologies.

Therefore, it is evident that the introduction of the Modular Construction handbook by PrefabAUS within Australia has provided significant impacts to the modular and prefabrication construction industry. This handbook assists in ensuring that modular construction can be utilized to its full potential to meet demands associated with increasing population and urbanization, while withholding a high standard of safety, sustainability and quality. This has not only occurred through providing a platform for wider adoption of construction techniques associated with off-site construction methods, but also provides standard practice guidelines and promotes advancement for the industry. Through providing a benchmark for modular construction quality and innovation, Prefab AUS has enabled Australia to be a leader within the modular construction market globally.

2.6 Safety

Within the construction industry, safety is one of the most important and critical concerning factors, impacting all within the construction and occupancy phase. Modular construction presents its own unique safety advantages and challenges as opposed to traditional constructions methods, due to the differing assembly and fabrication circumstances.

Within the design phase of a modular building design, portions of the building are able to be designed to be prefabricated within a controlled factory environment. By doing so, the controlled setting enables an increased level of oversight in relation to employees' compliance with safety standards (Gibb and Izack, 2013). This is in comparison to traditional construction methods which focus their safety risk assessment primarily upon on-site hazards, posing additional safety measures and an increased likelihood of accidences. Additionally, the nature of a modular buildings design process enables an increased level of planning and implementation of safety features, such as structural reinforcements, fireproofing and soundproofing, to occur. Safety elements are able to be incorporated and constructed within the off-site fabrication phase, reducing the potential for onsite hazards (Lawson, Ogden and Goodier, 2014). In comparison to traditional construction methods, these features would be installed onsite which results in an increase of risk and potential for injury.

The methodology utilizing modular construction methods provides a safter working environment as opposed to traditional construction methods. This is, similarity to the design considerations, due to the nature of the off-site fabrication processes as opposed to onsite methods. As the amount of work to be completed onsite is reduced, exposure to hazards associated with construction sites, such as inclement weather exposure, plant, working at heights and other high-risk activities (Smith, 2020). As modular construction enables a repetitive construction process to be achieved, workers are able to undertake standardized and repetitive processes. The skill sets of modular construction employees is high within the project specific tasks, reducing the likelihood of errors and injury. Upon comparison to traditional construction methods, which utilize problem solving which can increase the risk of unsafe practice, it is evident that modular construction methodology reduces safety risks.

Modular construction often utilizes cranes to relocate and place modules, providing task specific safety challenges. Lifting operations are commonly used within traditional construction methods, however, the precision and scale required for modular construction is significantly greater. This is as the modules which were constructed off site, are transported to site and require precise lifting and positioning. Modern equipment and highly trained operations reduce the risks associated with cranes, there are still significant safety risks which need to be considered and mitigated for. Within the design stage of modular construction, pre-planned lifting points can be determined and designed for, along with the controlled nature of lifting will assist in the reduction of risks associated with modular construction (Tatum and Liu, 2017). However, if errors occur, the consequence and severity due to the size and weight of the modular components will be significant, causing damage and injury if not handled correctly (Lawson, Ogden and Goodier, 2014).

The safety conditions for site managers and trades are typically increased within a factory environment, due to being controlled and offering consistent conditions, including consistent ventilation, lighting, and ergonomic conditions. Within these environments, work related illness and Injury and exposure to potential hazards is reduced.

For the occupants, modular construction techniques ensure the modules and overall buildings are constructed in a controlled, off-site environment, to a high-quality standard. By doing so, the risk of defects occurring that could lead to safety issues, such as structural failures, inadequate fire safety measures and poor indoor air quality are reduced (Blismas and Wakefield, 2009). This risk can be reduced to a higher level of quality control and testing requirements during the fabrication stages of work, ensuring safety standards are met prior to being delivered onsite.

Therefore, it is evident that modular construction offers various safety related advantages as opposed to traditional construction methods. Although unique challenges are posed in relation to the operation of utilizing a crane to place modules, modular construction provides significant safety advantages throughout all phases and for all personal involved within the construction and occupation of the building.

2.7 Materials

2.7.1 Modular Construction Primarily Materials

The materials utilized within modular construction primarily consist of wood, steel, and concrete.

However, this has been expanded into sustainable materials such as bamboo, hybrids, and composites. The determination of materials implemented is based upon factors such as locality and resources availability, building characteristics including structural load andwind requirements and the building component (Goodier, C, Lawson, M & Ogden, R 2014). Furthermore, the maintenance of buildings is dependent upon material availability which can pose significant impacts within countries possessing limited resources (Manish, Charles, Sarel, & Rose, 2014). New technology is constantly emerging with 3D-printed modular construction being explored with the purpose of providing fast, low waste construction and providing viable construction alternatives to remote environments (Delorit, J, Hoisington, A, Jagoda, J & Schuldt, S 2021).

The materials used within a building system pose impact upon energy consumption, ongoing repair and maintenance, overhauling or replacement costs. Through using robust materials and construction technology which assists with minimizing cyclical maintenance costs and requirements, the requirement for maintenance and disturbance impact will be mitigated. This can occur through the use of alternative methods that are present within the modular construction industry as follows:

- Framing that consists of steel or timber, studded framed walls and roof trusses is commonly used within construction. Steel poses opportunities due to its lightweight nature in comparison to timber.
- Precast concrete panels act similar to flat pack housing in which of reconstructed and transported to site where they are attached to a steel framed building. This method is not very adorable due to transportation costs and onsite assembly requirements.
- Sandwich polystyrene panels are a new technology being implemented more commonly into modular construction. The benefits of this material include its lightweight, energy efficient due to insulation properties and opportunities for use within the walls and roof.
- Composite panels can be used, including pre-attached cladding or veneer that further attached to steel frames offer opportunities surrounding efficiency and reduced construction time.

2.7.2 Global and Innovative Alternative Construction Materials

Within the global construction industry, the exploration of alterative construction materials has increased with the common goal of sustainability, renewable and efficient resources. As a result, materials from a recycled or renewable source are often used as a substitute for traditional construction materials, such as timber, steel or concrete. The following are examples of alternative construction materials which pose potential and have begun to be implemented within the industry.

- Hempcrete: A bio-composite material which is composed of a lime-based binder mixed with the inner hemp plant fibers. This material possesses a low carbon footprint, high thermal insulation properties and is very breathable, resulting in an increase in popularity in European countries (Lawrence et al., 2020). Additionally, the material is fire resistant, lightweight and absorbs carbon dioxide while it cures, being a sustainable option for utilization as an insulating infill material within a timber framed structure, noting it is unable to be used as a load bearing material.
- Rammed Earth: A traditional construction technique displayed within Australia, involving the compaction of soil, sand and stabilizers to form solid walls. Rammed earth provides thermal pass properties, is durable, energy efficient and poses a low environmental impact (Venkatarama Reddyy and Gupta, 2006). The techniques utilized for this construction method have been developed to increase aesthetic and structural integrity for application with modern architectural buildings.
- Mycelium-Based Materials: Utilization of Fungi root structures as a biodegradable material is currently being tested within Europe and the USA. The mycelium forms a dense root network when grown upon agricultural waste which has the ability to be shaped and dried to develop an insulating, lightweight and fire resistant material (Jones et al., 2020). The utilization of this material is currently being tested for application within structural components of experimental buildings, insulation panels and acoustic tiles.
- Cross-laminated timber (CLT): CLT is a form of engineered wood which consists of solid

timber which is glued together perpendicularly. This material provides stability and high strength, posing advantages within the duration of construction, carbon sequestration and reduces material waste (Mallo and Espinoza, 2015). CLT has functions within residential and commercial buildings, with it being used in Europe and Northern America as an alternative to concrete and steel for structural applications.

- Recycled Plastic: Recycle plastic is being utilized within various application, such as within the development of interlocking bricks within India and bicycle path construction within the Netherlands. This enables durable and versatile products to be produced from materials which otherwise would be placed within landfill, posing characteristics which include durability, high thermal insulation and light weight (Yuan et al., 2021).

There is therefore significant opportunity within the construction industry for innovation and continual evolution within the materials utilized. The development of materials is primarily focused on sustainability, cost effectiveness and performance, with key areas for innovation as follows:

- Biodegradable Materials: Biodegradable building materials can be developed, reduce construction waste and minimize the materials' environmental footprint, and can include algae-derived plastics and mycelium-based composites. When these materials reach the use of their useful life, they pose the ability to biodegrade naturally without harming the environment, providing a sustainable option to traditional construction materials.
- Hybrid Materials: Through the use of new technology and materials, hybrid materials are being developed with the aim of providing improved material performance. This can include bamboo combined with polymers or bio-resins to create a material which has increased durability and strength characteristics for use within structural building components. Therefore, by developing hybrid materials, enhancement of traditional materials is able to occur (Smith and Green, 2022).
- 3D Printing of Local Materials: With advances within 3D printing technology the

application has also extended to enable materials to be utilized in different ways. This method enables the production of components and geometries which can pose difficulty to fabric using traditional methods (Buswell et al., 2018). One example of this includes the utilization of cement and volcanic ash to create individualized building components onsite. This assists in reducing waste and transportations costs

- Energy Efficient Manufacturing: Through using renewable energy sources or efficient production techniques within the manufacturing process, the impact of producing construction materials can be reduced. Furthermore, advanced robotic and automation processes can reduce material wastage and increase precision, resulting in a more sustainable manufacturing process (Huang et al., 2017). An example includes factories which utilize solar or wind energy to produce materials, reducing the production processes carbon footprint.

2.7.3 Local Fijian Material's within Modular Construction

Within Fiji, there are various natural resources which can be utilized as materials for modular construction. Utilizing local materials, such as the following, can assist with reducing costs, supporting local economies and enhance sustainability.

- Bamboo: Due to its fast growing and renewable nature, Bamboo has been utilized within traditional Fijian architecture and within modern engineering techniques. Bamboo is able to be used within structural applications, such as trusses and framing once it is treated and processed (Laroque et al,. 2020). The utilization of bamboo within modular construction can occur through the development of prefabricated bamboo modules or panels which are light and easy to transport and install onsite. Due to its rapid growth rate and renewable ability, it can be planted and harvested within a 3 – 5-year turnaround period. This is in comparison to traditional hardwood which require a 20 – 50-year turnaround period. In addition, bamboo plantations assist in improving the quality of soil and prevention of erosion (vann der Lugt et al., 2006).

- Coconut Timber: Derived from senile coconut palms which are unable to produce fruit and would otherwise be waste material, coconut timber is a sustainable material which is durable, dense and has a fine grain (Coronal, 2016). This makes coconut timber suitable for both decorative and structural purposes, and can be utilized as paneling, flooring or furniture. Deforestations impact can be mitigated, and local economy can be supported by processing and transporting the palms locally (Coronel, 2016).
- Coral Stone: Used within traditional Fijian construction methods, coral stone have abundant availability and poses the potential to be repurposed as a construction material. Coral stone has been utilized for foundations, walls and decorative features after being cut into shape, posing features, such as being naturally porous, good thermal installation, and reduces the demand for importing materials, supports the local economy and assists in promoting sustainability (Rao et al., 2019). However, when harvesting coral stone, care should be taken to ensure that the extraction process does not pose any damage to the marine ecosystem.
- Volcanic Ash: Due to Fiji's volcanic origin, there is an abundance of volcanic ash which can be utilized as pozzolan, a material which when mixed with lime and water form cementous properties, within concrete (Sarker, 2013). Through including volcanic ash within concrete, the amount of portland cement that is required can be reduced, lowering the materials carbon footprint, enhancing durability and reducing the requirement for repairs and replacements, continuing to enhance sustainability (Habert et al., 2012). Volcanic ash cement also poses benefits regarding enhancement of durability and increased resistance to chloride, assisting in the mitigation of saltwater exposure effects.

2.8 Manufacturing

2.8.1 Manufacturing Practices

Manufacturing practices vary between different countries and are often influenced by the available resources, technology, regulations and workforce. Within highly developed countries such as Japan, the USA and Germany, the technology associated with manufacturing processes are advanced. This can include artificial intelligence (AI), 3D printing and robotics to assist with the automation and increase the quality of the products. Within the modular construction industry in Germany for example, factories utilize the Internet of Things (IoT) and cyber-physical systems to enable optimization of the manufacturing process (Kagermann, 2015). These technologies provide the capability for the factory to be self-monitoring and will make automatic amendments to manufacturing lines to ensure waste is reduced and efficiency enhanced.

Another example is the concept of “Monozukuri” from Japan’s manufacturing systems which values high quality and precision and combined modern technology with traditional craftmanship methods. Lean construction principles such as just in time (JIT) production and continuous improvement (Kaizen) are implemented within Japanese manufacturing, to assisting in ensuring efficiency is improved and waste is reduced (Shad & Ward, 2019). Within the USA, modular construction companies utilize robotics and advanced automation to enable the construction of highly consistent and precise components. This enabled assembly time to be increased and labor costs to be reduced (Weller et al., 2015).

2.8.2 Sustainability Considerations within Manufacturing

One of the key considerations globally within manufacturing is sustainability, being a priority to focus upon the use of renewable energy and resources, proactive and efficient technologies, minimise waste and comply with energy regulations. This is with the goal of achieving and circular economy and reducing the reliance upon non renewable energy sources.

Within Germany, the utilisation of on-site renewable energy generation has been implemented into modular construction plants. This has occurred through the construction of wind turbines or solar panels which are integrated into the manufacturing systems and power manufacturing activities. A 'closed loop' production system has also been implemented (Geissdoerfer et al., 2017) which recycled waste materials back into the manufacturing process, reducing the fabrication processes environmental Impact. Furthermore, Plant Prefab and other USA modular construction companies have begun to utilise ecofriendly materials, such as FSC timber, and using renewable energy resources (Generate Electric, 2019) to reduce their environmental impact and demonstrate their commitment to sustainability.

An 'Eco-Factory' initiative within Japan processes similar characteristics, were modular construction manufacturing pants aim to implement practices surrounding green procurement to reduce waste and energy consumption. One example of this is Sekisui House, a modular construction company who has implemented sustainable materials and energy efficiency technologies into their manufacturing processes (Sakae and Lindahl,2015) to assist in reducing the environmental impact of their products.

Although there is significant focus on ensuring sustainability within manufacturing practices in Fiji, there is still significant potential for sustainability to be enhanced through reducing and reuse waste materials, the adoption of energy efficiency processes, and optimising the resources which are utilised. The reliance upon imported fuels is one of the major aspects within Fiji which pose issues in regard to sustainability. This is due to the associated high production costs and greenhouse gas emissions which could be eliminated if renewable energy sources were integrated. The Fiji Sugar Corporation (Fiji Sugar Corporation, 2020) has begun to explore the new of renewable energy sources for its sugar mills, through utilisation of biomass. Through doing so, they aim to be a model for the Fijian manufacturing industry and present opportunities which could be adapted and implemented into modular manufacturing facilities. However, there are various strategies which could be further implemented to assist in improving the sustainability of manufacturing processes within Fiji as follows:

- Energy Efficiency: Through implementing energy-efficient plant which assist in optimising production process, energy consumption can be reduced.
- Renewable Energy: Integration of wind, solar, wind, and/or biomass renewable energy sources to provide power to manufacturing plants.
- Waste Reduction: Development of waste reduction systems to assist in reusing waste into the production process, with the aim of reducing the amount of waste which ends up in landfill.
- Sustainable Sourcing: Utilization of locally sourced and renewable materials to assist in reduction of transport, reducing associated emissions.

Therefore, it is evident that sustainability within manufacturing has become a key component due to the increase of legislative requirements and global transition to renewable energy sources and reducing wastage. Examples were provided from the USA, Germany and Japan manufacturing systems which demonstrate how the processes have been adapted to integrate renewable energy sources and materials, reduce waste and act in a closed loop production system. These examples exist the global commitment of reducing dependence upon non-renewable energy and materials and increase the drive for circular economy within manufacturing systems.

2.8.3 Manufacturing Innovation

Innovation within the manufacturing sector is essential in ensuring costs are reduce and, stability and productivity are increased. There are various emerging technologies which pose opportunities within the manufacturing industry, as detailed below.

- 3D Printing: 3D printing technology which is also known as additive manufacturing enables customised and complex modular components to be fabricated quickly, with minimal wastage and high precision. Within the modular construction industry, 3D printing has become increasingly popular to fabric fixtures, fittings and structural elements for modules (Weller et al., 2015).
- Robotics and Automation: Expensive benefits can be reaped when utilising automation and robotics within the modular construction industry due to its increased level of safety, speed, consistency and reduction of labour requirements and cost (Bahrin et al., 2016). This technology has been implemented within German and Japanese modular construction manufacturing plants, which have utilised robotics to assemble modules, resulting in increased precision outputs and accelerated construction times.
- Artificial Intelligence (AI) and Machine Learning: Serving various functions, machine learning and AI can assist in automatically predicting outcomes and identifying patterns in large data sets (Lee et al., 2018). By doing so, supply chains and quality can be optimised, and maintenance requirements predicted, reducing the requirements for plant downtime and manual labour.
- Sustainable Processes and Material: Innovative development within the sector of materials has led to the development of sustainable and renewable materials which can act as a substitute for traditional construction materials (Jones et al., 2020). An example of this, as discussed previously in this dissertation, is utilisation of mycelium-based composites or biodegradable plastics which provide an eco-friendly alternative for traditional materials for utilisation within modular construction.

2.8.4 Manufacturing Practices within Fiji

The manufacturing practices within Fiji are not extensive and have focus upon furniture manufacturing, timber processing and garment production. There is heavy reliance upon manual labor, locally sourced materials and a mix of semi-modernized manufacturing techniques and traditional craftsmanship (Fiji Ministry of Industry, Trade and Tourism, 2020). One example is the furniture and timber industry, where products are locally produced and designed specifically to suit the local market's needs using locally sourced resources. Therefore, though application of advanced and innovative manufacturing technologies and practices, Fiji's modular construction manufacturing industry can be enhanced, as detailed within the following.

- Resource Availability: As previously discussed, there are various challenges surrounding the availability of resources within Fiji due to its geographic position, size and climate. By utilising material readily available and fast-growing materials, and adapting technologies to assist in the enhancement of such, opportunities are evident. This could include the utilisation of 3D printing to convert recycled or bioplastic materials into readily available materials for incorporation into modular construction processes. Through implementation of this technology locally, the materials can be produced, utilised effectively and efficiently, reducing emissions related to extensive transport and assisting in providing economic development.
- Labor (safety and availability of skilled labour): AI can assist in automation of the manufacturing industry which can alleviate the strain on nation imposed due to the limited availability of skilled labour. This provides an opportunity for education to be offered surrounding these technologies to provide an enhanced skill set to the industry which aligns with advancements in the technology. The implementation of automative technology also assists is reducing safety risk to the workers. This is as the high-risk work can be replaced by automative plant which removed the labourers from harm's way.
- Infrastructure: Ensuring the available infrastructure is to the required level prior to incorporating manufacturing technologies is essential. This includes ensuring there is reliable energy sources, transportation networks for materials and the produced product, and digital connectivity. Within Fiji, development and investment into manufacturing infrastructure is

key in order to provide a foundation for sector growth (Fiji Roads Authority, 2020).

- Cultural and Environmental Considerations: Within Fiji, the manufacturing practices need to consider the environmental and cultural factors specific to the nation. This can include ensuring material which is locally sourced is utilised and cultural traditions and building practiced are respected. The Fijian government has a key goal of promoting sustainable practice and ensuring no harm occurs to the environment, including reducing risk to sensitive or threatened ecosystems (Fiji Ministry of iTaukei Affairs, 2020). By placing consideration into these factors, the goals of the government are strived towards, and impact is elevated.

2.9 Transportation

2.9.1 Modular Construction Transportation

Use to the nature of modular construction consisting of a primarily off-site manufacturing process, the transportation of the constructed modular units is a key component of the modular construction process. This includes ensuring the modules are designed to a standard that they are able to be transported efficiently and safely, without the need for extraordinary measures. The transportation of the modules possesses direct impacts to the cost, timeline and feasibility of the project, with the main transportation methods being air and truck freight.

Truck freight, consisting predominantly of the use of heavy rigid, and in some cases land trains, is the most used transportation method within modular construction. This is due to the availability and low cost compared to alternative methods, such as air freight. There are several regulatory and technical factors which need to be considered and designed for when using truck freight, including the following:

- Route: the proposed route for transport needs to be planned prior to delivery to ensure the road conditions, load dimensions and weight, and infrastructure constraints (e.g. tunnel clearances and bright weight capacities) are abided by and in line with what is being transported (Smith, 2016). Without planning, or utilization of roads which do not comply with these needs, detours or redesign of modules will be required to comply with the limitations present.

- Load weight and dimensions: there are regulatory requirements surrounding the weight and dimensions of a load which can be transported via truck. If these limits were exceeded, overside load permits are required which involve additional coordination, cost and planning prior to transportation (Bureau of Transportation Statistics, 2020).
- Load security: To ensure safety of the roads and road users during transport, the security of the modules during transport is critical (Gould and Newton, 2018). This involves placement of the load onto the truck, reinforcement framing and the method of securing (e.g. anti slip mats or tension straps). The dynamic loads the modules would experience during transport need to be considered during the planning and implemented during the fabrication phase. Thid includes breaking, corners and acceleration, specifically within reinforcement or connection points of the modular components.

Air freight is an alternative method of transport and poses significant benefits as opposed to trucks. However, this method is not used as frequently due to the cost, weight and size limitations, with opportunities and limitations explored below.

- Size and weight limitations: Within air freight, there are weight and size limitations which are deemed more strictive then those of trucks. This therefore means that larger modules are either planned around the limitations or are often disassembled prior to transport and reassembled onsite.
- Accessibility and speed: Air freight poses a significant benefit to its speed being significantly faster than ground transportation. This therefore means it is ideal for projects which have a

tight deadline or where it is impractical to access the site via ground. This includes locations which are removed, have a limited or unpredictable road network or where response is urgent in a natural disaster response circumstance (Miller and Wallis, 2019).

2.9.2 Transportation within Fiji

Fiji faces various challenges in relation to transportation due to its geographical conditions and location, and infrastructure development limitations. The road network within Fiji consists of winding, narrow roads with poor surface quality within urban and highway locations. Within rural or remote areas, the road network consists of unsealed and unmaintained roads which are not up to the required standard for large truck fright deliveries. This therefore significantly reduces the use of large trucks to transport modules (Naidu, 2020). The weather also poses significant impacts to Fijis road network as heavy rains pose damage to unsealed and sealed roads. Flooding and landslides, especially within the mountainous areas of Fiji are frequent and can impose further complications surrounding transportation logistics. This therefore poses the need for all-terrain, robust and powerful vehicles which can ensure remote sites can be accessed, and the use of temporary road enhancements such as importing road base or gravel to assist in ensuring the site is accessible (Pacific Infrastructure Facility, 2021).

The geographic location, as mentioned above, also poses difficulties for transportation between the islands. As there are many smaller islands which are only accessible by sea, the logistics required to access these sites are extensive and alternative transportation methods need to be considered in order to ensure efficient and cost-effective delivery can be achieved. This includes sea vessels which require adequate port infrastructure. Within smaller islands, the infrastructure is not to a high standard which could withstand the requirements of large ships. This therefore means that use of smaller vessels with an increase in the required manual handling, as cranes or other lifting machines aren’t always available, is required (Naidu,2020). RoRo ferries, also known as roll-on-roll-off ferries are an example of sea vessel availability in Fiji for small module transportation (Fiji Ports Corporation Limited, 2018). These vehicles are 3.5 m in width and could be utilized to transport ‘flat packed’ modules.

This therefore equates to additional complexity in regard to transportation complexity as there are various ‘steps’ required before the module reaches the works site. This includes, for example, truck transportation to a port, loading of the modules onto a ship or barge and then loaded onto a truck, increasing the risk of damage occurring. Additional sustainability concerns are then raised in relation to reliance upon diesel powered freight and maritime methods due to the associated pollution and greenhouse gas emissions (Pacific Islands Forum Secretariat, 2019). Through infrastructure investment and integration of renewable energy sources, such as electric trucks or solar powered barges, this impact could be mitigated. Therefore, as the modular construction industry is developed and invested within Fiji, addressing transportation concerns will be a high priority to ensure sustainably and viability of the method.

2.9.3 Case Study – Transportation of Mining Houses within Australia

The mining industry within Australia provides insight into the transportation methods, opportunities and constraints of modular units. This often occurs within remote and challenging conditions such as Pilbara, Western Australia which exhibits remote and rough terrain, being isolated and inhospitable. Pilbara is home to an iron ore mining base, where modular houses are utilized to accommodate the employees. The transportation of such modules presented significant challenges due to the logistics of the area associated with the limited infrastructure, harsh environment, increased temperatures and frequent dust storms.

Utilization of truck freight to transport these modules involves transversing through unsealed and rough roads, requiring a specialized, offroad vehicle. The trucks used were fitted with reinforced chassis and advanced suspension systems to withstand the terrain and prevent damage to the modular components (Anderson and Lucas, 2017). Load sharing axes were also used to ensure the load of the axles was distributed evenly, with the aim of reducing the transportations impact on the road surface. In areas where access was not possible, heavy-lift helicopters were also used. However, this method is costly and was used as a last resort (Miller and Wallis, 2019).

Figure 2.7: Building transportation, Pilbara Western Australia (Mayall, 2017)

The modules were required to be adapted in order to ensure they comply with the limitations evident surrounding the method of transportation. This includes developing modules in smaller components to enable efficient transportation and onsite assembly. The components were designed and constructed with modular connectors and reinforced joints to ensure the transportation stresses could be withstand with no compromise to the building's structural integrity (Smith, 2016). This includes utilizing a 'flat pack' form of modular construction to reduce volume and improve efficiency.

Therefore, through evaluation of this case study, the importance of ensuring the transportation of modules to be customized for the project sites limitations is evident. Valuable lessons for implementation within the context of Fiji are demonstrated which requires similar adaptation to ensure successful design, fabrication, transportation and installation of modular residential housing within difficult to access and remote areas.

2.10 Sustainability

It has been determined that modular construction poses significant advantages in relation to duration, cost and wastage which contribute to sustainable construction. However, sustainability accounts for the environmental, economic, and social impacts of a product and therefore all three must be considered. This includes transportation constraints and the increase of coordination, communication engineering and planning processes, higher initial investment, and consumers negative perceptions upon new construction methods (Hewage, K & Kamali, M, 2016). These factors require analysis in order to determine the sustainability of modular construction over its lifecycle in comparison to traditional construction techniques.

Environmental performance is one of the most critical factors in regard to sustainability, due to construction accounting for a significant portion of environmental burden. A lifecycle performance review was conducted, and it is evident that the most critical phase of a building's lifecycle is during operation (Hewage, K & Kamali, M, 2016). In order to reduce energy consumption over the duration of a building's life, the building materials energy, both directly and indirectly needs need analysed. This included the energy used to acquire, process, and manufacture the materials which is referred to as indirect and the transportation and assembly of the materials which is referred to as the direct. Therefore, in order to ensure a building material is sustainable it is essential to consider the modular factory location and labour availability (Choi, B, Kim, K, Nam, S & Yoon, J 2020), impacting embodied energy consumption and the subsequent environmental impact.

Globally, varying materials are being utilised for the construction of residential modular houses. One sustainable example of resource selection is within the Philippines, where it is observed that bamboo is being utilised within various elements of a build, including structural components and insulation. Bamboo is a fast growing, readily accessible resource within this region and therefore, by utilising such it enabled the environmental impact of the building to be reduced and offers more scope and availability for the products.

In regards to the waste produced, upon analysis it has been determined that modular construction poses a reduction in overall weight of waste by up to 83.5% and homes constructed using modular methods was determined to use 20% less material overall (Barati, K, Li, B, Loizoi, L & Shen, X 2021). This includes 75% less material waste in the forms of wood and plasterboard then traditional methods. In demonstrates that modular construction impacts are on average lower than traditional construction methods with a reduction in greenhouse gasses of 30% (Quale, K 2017).

A significant opportunity that modular construction poses in regard to reducing environmental impact is the ability to relocate the entirety of a building. Due to the modular nature of the building, deconstruction and reuse of a building can be conducted easily and efficiency. This ideal extends to maintenance and repairs to the structure. The entirety of the structure will not have to be replaced rather portions can be removed and replaced, with repairs and reuse enabled for the once damaged elements. Therefore, all components can enter a circular lifecycle consisting of construction, use, removal, maintenance, and reuse, extending the useful life of each component.

A methodical lifecycle analysis study was conducted for residential modular buildings which outlined sustainability performance criteria (SPC's). The SPC's were then utilised to validate and determine benchmark-based sustainability performance indicators (SPI's) (Hewage, K, Kamali, M & Milani, AS, 2018). The SPC's were broken down into three subcategories which include environmental, social, and economic and list the defining and performance factors for each SPI. This paper provides benchmark and consideration factors which will be utilised to define performance criteria and identify constraints surrounding the utilisation of modular construction.

Therefore, it is evident, that due to modular construction requiring less labourers, fewer materials, reduced duration and pose a tighter building envelope, a positive sustainable impact is presented. However, factors surrounding the embodied energy factors of transportation, and the locality of the site and factory need to be analysed to ensure the sustainability of the construction method is not being significantly impacted.

2.11 Energy Efficiency

Within modular construction, there are various methods to assist with improving the thermal performance of a building. This should ideally occur through an assessment of the building's energy rating and design to ensure it is optimized. However, this will look different within the modular construction industry due to the mass production of components.

The following are possible measures which can be considered and implemented within the design and construction process:

- Increasing insulation properties or the thermal mass of the materials being used.
- Ensure the entirety of the design during construction is draught proof.
- Analysis of the floor coverings to ensure the best fit for the desired outcomes.

- Insulation in the floor, walls, ceiling and roof, with a variation in required R value dependent on the desired outcomes.
- Alteration of roof and cladding colors, depending on the desired outcomes.
- Implementation of passive cooling within the building through increasing natural ventilation.
- Implementation of passing heating within the building through increasing thermal mass.
- Alterations to lighting to reduce air leaking through the ceiling.
- Alterations to the structure and site location to reduce solar exposure and overshadowing from neighbors.
- Alterations to the layout and zoning of the building to optimize and avoid solar gains.
- Alterations to the window size, location, opening and frame, along with window coverings.
- Shading elements such as eaves, awnings, and pergolas.
- Planting and landscape design.

These measures will be assessed and implemented as required within the proposed design to ensure the produced structure poses efficient benefits within modular housing. Some aspects are limited and some obsolete within this setting, however by conducting further analysis, it will ensure the proposed outcome is sustainable and energy efficient which is specifically important in villages that result on passive heating and cooling due to possessing little or no electricity.

2.12 Innovation within Modular Construction

Renco Interlocking Modular Building Blocks are an innovation within the modular constriction and sustainable construction industry. Renco blocks are designed to be reused and upgraded to enhance performance while reducing environmental impact, being a part of a circular economy model which is adaptable, efficient and environmentally sustainable. The blocks are manufactured using a composite material which utilises bio-based polymers that are produced using agricultural by-products and recycled industrial waste, such as slag and fly ash. The utilisation of these materials ensures that what would otherwise be deemed was waste is reused for a fulfilling purpose, while providing excellent acoustic and thermal insulation properties (Renco, 2022). In relation to embodied carbon, an estimated reduction of these blocks as opposed to traditional concrete blocks is up to 40% (Green Building Council, 2023).

Figure 2.8: Renco Interlocking Blocks (Built Offsite, 2014)

The composite material utilised for the construction of the blocks therefore provides significant opportunities while also being ideal for use in diverse climatic conditions. The material is able to be customised for the project's specific needs and application. This includes the surface texture, colour and density, making it transferable for use in load bearing walls and internal partitions depending on the density. The interlocking design also eliminates the need for mortar which is traditionally used in brick and block construction. This reduces the need for additional materials which would pose additional wastage, energy and an increase construction duration (Smith and Taylor, 2023).

Additionally, the interlocking design increases the buildings structural stability and ensures precise alignment and construction is obtained. This is particularly advantageous within areas that are frequently exposed to seismic activity in which traditional constriction methods may fail. The blocks also pose characteristics for easy disassembly and reuse which further increases the products sustainability. One example is within Lombok Indonesia where Renco blocks were used to construct housing for displaced communities following an earthquake. This equated to a low-cost housing method which was resilient to subsequent events, while being able to be rapidly assembled within weeks as opposed to months (Anderson and Wilson, 2024). The community were trained and assisted within the construction of the houses due to the low skill set required for assembly. This enabled the community to have a sense of purpose, ownership and enhance their resilience, empowering the population through employment availability and skill development (Baker et al., 2024).

This construction method therefore poses significant cost saving opportunities across the building’s lifecycle. This is due to a reduction in material and labour costs, construction time and ability to be reused. This blocks insulation properties can also assist in reducing the building occupants’ expenses through lower heating and cooling costs (Miller and Zhang,2023). Renco Modular building blocks therefore demonstrate significant innovation and advancements within the modular construction industry. The blocks are highly sustainable, while still offering design flexibility and resilience within natural disaster events.

2.13 Case Studies

The implementation of modular residential construction techniques has been demonstrated within various counties, including Nepal and the Philippines. Due to the technology's principal characteristics, modular construction is becoming a preferred technique due to its fast construction times and affordability, identified within the case studies analyzed (Bhattacharjee, 2016). The evaluation of such case studies has determined through utilization of modular construction in response to housing market crises, it has provides an opportunity for the nations to develop.

2.13.1 United Kingdom

The United Kingdom (UK) residential construction completion rate has fallen to 125,000 annually while the expected target identified by the Government has been raised to 300,00 (Davies, 2018). The construction factors impacting this fall include a reduction in available and skilled construction workers, profitability being reduced, time constraints and pressure, and the frequent nature of exceeding budgets. Therefore, it is evident to analyze whether current construction processes are appropriate and if implementation of alternate construction methods such as modular could assist with the current housing crisis (Edwards, El-Gohary, Nazir, Shelbourn and Thwala, 2020). A bibliometric analysis was conducted in order to determine trends and findings relevant regarding the advantages and disadvantages to utilizing modular construction. The analysis determined that the UK is within a housing market crisis due to population rise and failure rate of housing delivery.

Additionally, modular construction outperformed traditional construction in regard to time, quality, and cost identified as being 22% less than traditional construction (Construction Magazine UK, 2019). Modular housing was utilized by CenterPoint, which is a charity which aims to assist with homelessness. The charity constructed over 300 modular homes within Manchester and London in 2021. Each dwelling consisted of a single bedroom unit which was fully transportable, enabling them to be relocated to different sites. Therefore, all the significant factors impacting the delivery of UK residential housing can be alleviated by the use of modular construction, promising a strategic solution.

2.13.2 Philippines

Within the Philippines, the Government encourages modular residential construction to be utilized due to its fast completion rate. However, the technology is evidently not well-known or practiced, with traditional construction methods continuing to be the preferred option. A feasibility study was conducted which concluded that although modular construction was identified as a faster method, in some instances the project duration does not vary significantly (IEEE,2022). However, when analyzing the duration of manufacturing and construction it was evident that modular housing posed a significant shorter turnaround time. A market search determined that there has been an increase in businesses offering sustainable modular housing within the Philippines, with many constructed using Bamboo. This study therefore demonstrates that modular construction poses significant benefits and increasing popularity regarding assisting with the Philippines housing crisis due to a reduction of construction duration.

2.13.3 Nepal

The developing nation of Nepal have utilized the application of modular construct for post disaster reconstruction. Following an earthquake in 2015, modular construction gained popularity due to efficient construction and reduced cost in comparison to traditional concrete and brick construction. The opportunities identified regarding implementation of modular construction included a reduction in construction time, increased labor productivity, reduction in rework, development of standardized and environmentally sustainable product and lastly, projects with better suitable space and time constraints. Additionally, the challenges of implementation of modular construction were also identified (Kisi, Mani and Shrestha, 2019). Challenges include construction competition with traditional techniques, the community's limited knowledge of the method and lack of workers qualified with the skills required for the technology. However, it was identified that through government-initiated training and information sessions, two of those challenges could be alleviated, which will in turn create additional jobs and offer more opportunities. Various companies such as Prefab House Nepal have begun to construct insulated modular homes within Nepal which use passive heating and cooling to reduce the heat gain in summer and loss within winter. Therefore, it is demonstrated that the challenges associated with implementation of modular construction are greatly outweighed by the opportunities. Additionally, the challenges can all be resolved through initiatives, providing increased opportunity for the diverse advantages of the construction method to be obtained by the broader community.

2.13.4 America

Within Northern America, construction of modular houses is evident which range from 3.9-46m wide and 12-15m long, possessing a floor area between 40 – 60 m^2. These houses are fully fitted, cladded and delivered with a pitch roof, enabling the formation of a sizable single-story house. The construction occurs predominantly off-site, presenting great opportunities for regional areas where transportation restrictions are present. The framing commonly used within construction is either timber or light steel framing if termites have been identified as an issue within the area. The structure is supported by concrete bored piers or helical screw piles following a similar methodology to traditional construction methods.

2.13.5 Japan

Japan has utilized modular construction since the early 1970's in which they have adopted advanced manufacturing techniques to improve efficiency and constructability. The leading supplies currently present within Japan include Sekisiui heim, Misawa, Daiwa and Toyota Homes which demonstrates the market demand for this form of construction. Sekisui Heim is known for their highly automated factories and use a range of standardized components enabling houses to be constructed in 6 days which is revolutionary within the construction industry. The Japanese utilize modular construction within various application which include 2 - 3 story homes. These designs use up to 12 modules to make large homes which are built with open sides to enable a penalized construction method to be implemented. This enables a range of layout and fixture design choices, increasing design, manufacturing, and installation times. The systems commonly use concrete raft slab foundations to support a fully welded framing systems, which is inline with traditional construction methods.

2.13.6 Qatar

Within Qatar, a prototype has been released for a new hospital district which has been designed by the engineering and architecture firms Buro Happold and OMA. The design includes modular units, a perimeter section, loop, villas and crosses which all serve unique purposes. Through utilizing modular units, the health organization is able to move and alter the buildings design based on demand while remaining operational. Using automation and 3D printing, the hospital is able to construct itself and remarkably produces the same amount of energy it consumes. Although this example is not in relation to residential housing, the same concept can be applied to enable interchangeable and efficient design and construction at a large scale.

2.13.7 Australia

Architect Peter Myers designed modular housing for indigenous Australians in remote communities within the early 2000's as form of utilizing readily available materials to construct low-cost housing. The building costs were kept as low as $125,000 and provided energy efficient designs unique to the remote Australian environment. The homes consisted of thermal insulation through use of reflective membrane insulation located on all of the walls, floors and ceilings. Additionally, constant ventilation was enabled through using a double roof which ensure the structure remained cool during the heat and warm during the night (David Handson, 2008). After launching this initiative, the local community raised concerns regarding the impact this construction method would have on construction jobs and training opportunities, in which was addressed through education and opportunities. Within Australia today, various single dwelling modular companies are present within the construction market. These companies include Glendale Homes, Remote Building Solutions, Austwide Homes and Tassie Homes. More recent initiatives include the Queensland Government utilizing modular construction for social housing due to its efficient construction time and adaptability.

2.13.8 Modular Construction: Natural Disaster Response Opportunities

Within current circumstances, the post-disaster reconstruction response consists of temporary shelters with permanent housing taking extended durations to reconstruct (Armin, Samia, Golstein and Markus, pp. 10 & 32). However, these situations are deemed as time critical in order to enable the effected communities to return to their livelihoods. Investigation into the timeframe for reconstruction post disaster historically highlighted that reconstruction took around five years. For example, following an earthquake experienced in Japan during 2005, reconstruction took four years to complete (Ruwitch, 2011), and following a tsunami in Indonesia during 2004, reconstruction was completed within five years (Silva, 2010).

The duration of response and reconstruction is due to post disaster reconstruction being a complex process as a result of the scale, underlying issues, material availability, construction skills shortage, funding, and management (Llyod-Jones, 2006). This is further outlined within figure 1 below which demonstrates that it is predicted by the Federal Emergency Management Agency (FEMA) that it can take wards of five years to establish permanent housing from the time of the disasters impact. However, this timeline does not consider subsequent disasters which could occur within the following years.

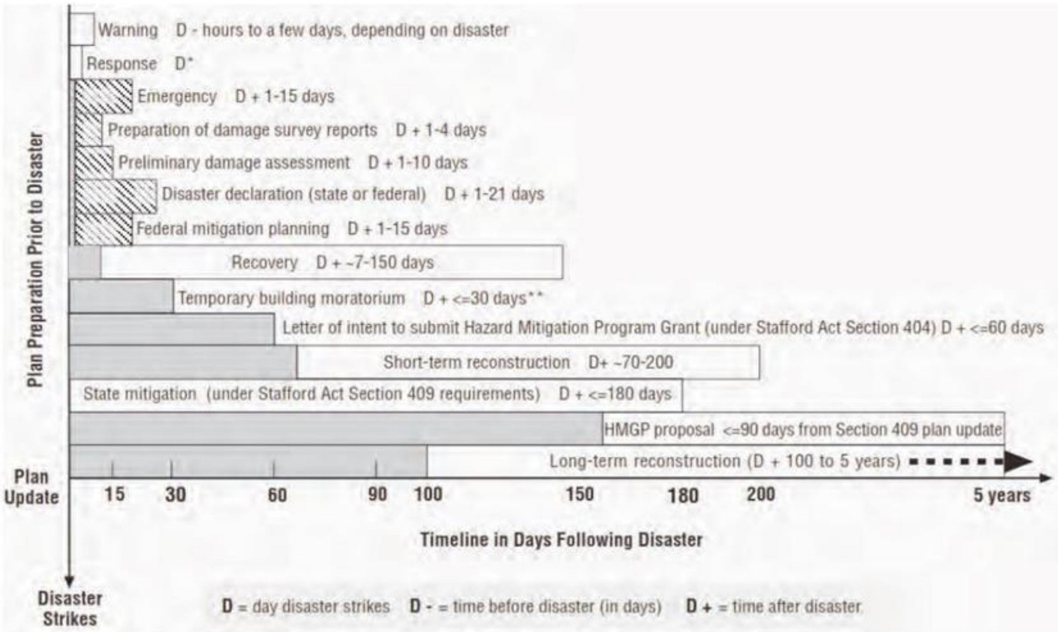

Figure 2.9: Post-Disaster recovery and reconstruction timetable (FEMA, 2005)

The definition of housing is identified as a permanent dwelling, where shelter is defined as a habitable covered living space providing security, a healthy environment and provides privacy and dignity to those occupying it (Corsellis, T & Vitale, A 2005). Although temporary shelters can be occupied for extended durations due to the timeframe of construction post disaster, speed is key principle of disaster recovery. Queensland's Emergency Recovery Guidelines suggest "following an event, effective recovery arrangements should help re-establish resilience within individuals and communities and the natural assets that support them as soon as possible" (The Queensland Recovery

Guidelines, 2011).

Due to this, modular construction is identified as a strategy which could be utilised as a time effective solution for residential shelter construction post disaster. This is due to the construction method containing modules for all building components which are prefabricated and can be repaired or replaced as a result of damage. These modules are easily customisable and are mass produced and quality controlled which produces economic benefits and a higher standard of housing quality produced overall (Aye, Crawford, Gunawardena, Mendis, and Ngo, 2014). Additionally, minimal onsite construction is required, resulting in reduced construction times and lower level of construction skills required.

Modular construction has previously been utilised within this context, providing significant benefits for the community. One example of this was within Haiti following a 2010 earthquake as post disaster temporary housing. This initiative involved the Haiti Canadian Embassy installing 46 modular housing units to provide temporary shelter for 75 individuals (Kelly, 2017). The utilisation of modular housing as a response to this disaster readily provided shelter and was able to be occupied until permanent housing was construct greatly benefiting the community and ensuring they could progress with their lives in a safe environment.

Therefore, it can be determined that modular construction is proven to be a suitable solution to providing post-disaster relief shelter. Implementation of modular construction technology for this purpose has been successful in a variety of situation's, with additional opportunities to expand the implementation of this construction method within housing and long-term shelters due to its time efficient construction and modular nature making replacement of damaged parts streamline. This technology therefore enables disaster effected communities to return to their livelihoods increasingly quicker and significantly reduces the impact upon communities and the nation during the recovery phase. Additionally, the case studies determined that implementation of modular residential construction has proven successful and poses significant opportunities within varying counties for differing needs. Through comparison with traditional construction methods, the benefits of modular significantly triumphed above traditional methods in all situations. This was especially noted within comparison during reconstruction post-disaster due to efficiency, cost, and availability of resources. Additionally, all challenges associated with modular housing could be alleviated efficiently with correct education being provided. This concluded that modular construction poses significant opportunities within various circumstances due to the technologies nature and demonstrates extensive opportunities to be implemented into developing and disaster-prone countries.

2.14 Requirement for Research

The literature review conducted on the Fijian culture, housing and construction industry, and modular housing demonstrates that the majority of previous research has focused on the construction system. There is no evidence of existing research being conducted into the design and manufacturing of modular housing within the context of the Fijian construction industry. Due to the nature of modular housing, implementation of this construction method into developing countries such as Fiji could pose extensive benefits. This design and manufacturing method demonstrates opportunities to counteract challenges currently experienced such as resource availability, quality, and skilled labor. This can occur through providing a more suitable, sustainable, and economical approach to designing and constructing residential housing in Fiji. Investigation into the growth forecast that modular construction can impose within the industry and the opportunities it can provide within Fiji can be investigation which will assist in determining the key factors for driving growth.

Although there is already modular construction solutions present within Fiji, the exploration into betterment of the design, materials utilized and manufacturing systems in regard to the constrains present and ensuring the solution is sustainable will pose significant improvement along with reducing construction costs and increasing safety. By extension, standardizing a design for modular housing which caters for the extreme weather conditions, cultural requirements and needs of the Fijian communities is essential to ensure success. Therefore, this research will investigate solutions modular construction can provide for the current challenges faced.

Housing providers within Fiji can work together with material, manufacturing and transportation companies to enable the delivery of a more sustainable and long-lasting housing solution. Throughout this research project, focus will be placed upon the early design stages of modular housing for the context of Fiji. This will ensure a sustainable design that is fit for purpose within Fiji's climate, cultural requirements and transportation restriction is obtained. International modular construction trends provide a basis for design development which can be customized for the implementation into various Fijian contexts. This extends to the development of design codes and standards within Fiji which address modular construction within Fiji.

As a result, the following research questions are posed:

- In the context of the Fijian construction industry, what benefits can modular construction pose in comparison to traditional construction methods?
- What are the innovative advantages modular construction can pose within the Fijian construction industry in regard to sustainability, cost, manufacturing and development?
- What benefits can modular construction pose within Fiji in relation to natural disaster recover response?

Therefore, this research project will pose significant benefits to the construction industry within Fiji through providing a sustainable, fit for purpose and context modular residential housing solution. The research project will aim to answer the outlined questions regarding implementing modular construction within Fiji, benefits and determining logistical factors which otherwise create limitations.

2.15 Conclusion

After conducting this literature review it is evident that the implementation of modular housing within the construction industry can pose significant benefits for developing counties as well as reducing environmental impact, construction costs, construction and assisting in providing affordable and safe housing. The case studies demonstrate the various situations in which modular housing can offer an effective solution. The research aims to address all aspects identified within the requirements for research, with the goal to produce a design which can be utilized in country.

Therefore, undertaking this research in relation to the concept of modular housing within the residential sector of Fiji and the positive benefits this could have in regard to natural disasters have been made evident. Through implementation of modular construction within Fiji, reduced displacement and reaction time post disaster in regard to shelter can occur, with the overall aim for future planning and sustainable development to begin occurring within the region.

Chapter 3

Methodology

Throughout the duration of the proposed research project, various methodologies will be implemented in order to determine a sound conclusion following an in-depth literature review. Methodology as detailed within “method and methodology in housing user research” by Furbey R and Goodchild B (Furby and Goodchild, 1986) and “methodology within housing research” by Vestro D.U (Vestro, 2005) will be utilised to conduct the proposed research, to ensure the required project outcomes are achieved. Through the mixed method approach of methodology formats, including quantitative and qualitative methods, it will ensure all aims of my project are fulfilled and a variety of perspectives and understanding is obtained to enable detailed analysis and non-bias determination.

3.1 Literature Review

A comprehensive literature review will be conducted within the preliminary stages of the research project to provide a detailed understanding of the current state of modular residential housing and the impact it has upon the construction industry. This review will include topics such as the historical development, applicable standards, recent innovation, design trends and manufacturing technologies currently being utilised within the industry.

Case studies will be examined to demonstrate modular housing construction projects globally and the impact the construction method has had upon communities. The framework, which is proposed by Bilau, Witt and Lill (2018) within their publication “research methodology for the development of frameworks for managing post-disaster housing reconstruction" will be utilised to review the adaptability and resilience of the examined locations and innovative modular construction techniques. This publication provides emphasis on content specific mythologies which are relevant within evaluation of the construction methodology utilised and the surrounding environmental conditions. This is in extension to the methodology detailed by GjaffarianHoseini et al. (2011) within their publication which demonstrates the evaluation of housing solutions in diverse setting and in relation to sustainability requirements through field research and data.

Lastly, sustainability within the construction method will be investigated to determine how this construction method can contribute to enhancing sustainability within the housing industry and opportunities present within innovation and manufacturing systems. The publication "eco-cultural design assessment framework and tool for sustainable housing scheme: by Qtaishatm, Adeyeye and Emmitt (2020) will be utilised for evaluating sustainability in relation to cultural connect. The assessment framework within this publication is adapted in order to assess environmental impact and cultural requirements to ensure both are considered in relation to design and construction methodologies.

Keywords will be used to ensure an extensive literature review is undertaken to gather and evaluate the required information. This will include evaluating the references of the journals to validate the reliability of the research articles which will be obtained from recommended research engines which includes Google Scholar, Scopus, and ScienceDirect. An internet search will also be conducted to review other publications and grey literature from other organizations. This information will include case studies, reports, and policies.

3.2 Questionnaire

A questionnaire will be constructed utilizing Microsoft forms in which a preliminary, statistical investigation will be undertaken. The participants of this questionnaire will include industry professionals such as engineers and non-government organizations (NGO's), the community, construction workforce, local councils, students, and educators within higher learning institutions. This will enable a broad range of data to be obtained from various individuals with different backgrounds and skill levels. The methodology will follow the eco-cultural design assessment framework proposed by Qtaishat, Adeyeye, and Emmitt (2020) to ensure that cultural and environmental factors are appropriately addressed. This information will be analyzed, and conclusions drawn which will form the basis of the investigative questions within the industry and community engagement and consultation sessions.

The questionnaire will explore currently held knowledge regarding the construction technique, the identified opportunities and challenges, questions surrounding the method and whether they would be likely to utilize this construction method. Further questions surrounding the impact natural disasters have incurred upon the individual, the consequent challenges experienced, and whether implementation of this construction method could/can assist will be asked. This methodology will be undertaken within the preliminary stages of the project to enable additional information surrounding key points raised to be obtained and queries to be addressed throughout the remainder of the research project. Prior to dispersing the questionnaire via email, ethics approval from the university is required to be obtained, with an information sheet contained in Appendix C.

3.3 Industry Expert Consultation

Occurring online via zoom, industry expert consultation will occur with a variety of government, non-government, and private organizations. Connections were previously obtained during the engineering study tour with various organizations relevant to this research project. Connection and proposition of my project and the involvement of such individuals will be established within the preliminary project stages. This includes individuals from private engineering consultancy firms, engineers Fiji representatives, Housing and development Fiji department, Red Cross, Fijian Universities, and the National Disaster Recovery Agency. These consultations will align with the context-specific methodologies discussed by Bilau, Witt, and Lill (2018), ensuring that the resilience and adaptability of modular residential construction methods are effectively evaluated.

Interviews will occur with recorded audio in order to refer back to points and statements made during analysis. All names, private and sensitive information will be protected. Questions asked will include preliminary opinion-based questions regarding the implementation of the technology within the proposed situation along with additional questions surrounding the technologies roles in a reconstruction post disaster response setting, as contained in Appendix C. The element of sustainability and cultural requirements will also be addressed along with identified constraints this project aims to investigate and the proposed solution modular construction aims to fulfill.

3.4 Comparative Analysis

A comparative analysis will be undertaken in order to compare the findings from the literature review and other findings. This analysis will aim to compare the efficiency, sustainability, and cost-effectiveness of modular houses and materials used within Fiji in comparison to traditional construction methods. By doing so, the analysis will assist in determining whether modular construction actually poses the benefits advertised or if the construction method is better suited to other applications. The analysis will also consider a range of comparative criteria including sustainability, cost, labor, safety, sustainability and quality, incorporating the methodological insights of Vestbro et al. (2005) to ensure a comprehensive evaluation.

3.5 Case Study Analysis

A case study analysis will be undertaken to conduct an in-depth analysis into modular housing projects which have a focus on design, manufacturing, and implementation aspects. The purpose of this analysis is to determine the feasibility, benefits, and outcome of the application such elements in Fiji based upon other applications in similar circumstances. The case study methodology, as outlined by GhaffarianHoseini et al. (2011), will be used to evaluate projects in remote and rural communities and situations with limited resources or short construction timeframes. The benefit of using this construction method in comparison to traditional methods will be analysis, enabling a detailed and thorough analysis to occur in order to determine if this construction method will be fit for purpose within the proposed situation.

3.6 Modular Housing Design Proposed Solution

Through conducting this research project, a modular building design solution will be proposed. This design will encompass the findings of the literature review, questionnaires, interviews, and analysis to propose a solution to the issue preliminarily identified. The outcomes, benefits, and key design elements of the design will be detailed and proposed plans presented using CAD software. The design process is therefore a critical element of this project which will utilize all the findings of the project to pose a solution. The goal of the project is to determine how modular construction methods benefit the Fijian construction industry and communities, focusing on sustainability, resources, accessibility and developing a solution which is fit for in country use. The design will focus on sustainability, resource accessibility, and developing a solution suitable for in-country use. The selected materials and manufacturing systems will be thoroughly evaluated to prevent potential issues, guided by the principles of eco-cultural design (Qtaishat, Adeyeye, and Emmitt, 2020) and culturally responsive building practices (GhaffarianHoseini et al., 2011).

3.7 Design Feedback Questionnaire

A questionnaire will be constructed utilizing Microsoft forms in which feedback on the proposed design will be obtained. The participants of this questionnaire will be a focus group of engineering study tour participants who have experience and understanding of the cultural beliefs, limitations and opportunities of the Fijian construction industry. This will enable a review of the proposed design to identify further opportunities, possible constraints and amendments which could be made to assist in the improvement of the design and application. The responses to this questionnaire will be analyzed, discussed and implemented were possible in the design in order to present the best possible outcome as a result of this dissertation.

3.8 Project Planning

In reference to the project schedule contained within Appendix A.2, there are key milestones which are requires to be reached throughout the duration of this project. This includes the literature review, methodology, draft dissertation containing preliminary results, presentation, and the completion of the final dissertation. Prior to commencing the research component of the dissertation, the resources which would be required to undertake the project needed to be identified, as contained within Appendix A.1 and a risk assessment needed to be undertaken and approved by the dissertation supervisor, as contained within Appendix A.3.

3.8.1 Key Considerations

When undertaking the proposed research project, the key considerations required include safety and ethics. This will not only ensure the successful outcome of the project, but also ensure the researchers' safety is maintained. Safety issues will be identified, and mitigation strategies outlined within the risk management assessment contained in Appendix A. Within the circumstance of the proposed research project, the ethical considerations which require analysis and approval include protection of sensitive information and ensuring participants are provided their right to confidentiality. Therefore, in order to safeguard a participant's confidentiality and provide legal jurisdiction regarding data protection, the researcher is required to continually uphold the ethical code of conduct. This includes adhering to all polies and rules regarding the code. Therefore, aspects of this project will need to be approved by the University of Southern Queensland Human Ethics committee such as the survey questionaries to ensure the code of conduct is abided by. Ethics clearance was sought and further details and supporting documentation can be found within Appendix C.

This ensures no participants will be subject to potential physiological or physical harm as a result of the undertaken research. This demonstrates that throughout the entirety of the research project it is essential that consideration regarding ethics and safety occurs. Within various stages, differing ethical issues, constraints and requirements are prominent and must be complied with. It is essential that if in doubt, to refer to the University of Southern Queensland Human Ethics Committee for guidance. A preliminary risk assessment has been undertaken, however upon initiation of this project and throughout various phases it is essential to re-evaluate the risks, their mitigation measures and identify any additional risks which require further analysis. Through doing so, it will ensure that the proposed research project has been undertaken safely and ethically and no harm will be or is intended to be posed upon the participants and community.

3.8.2 Safety

The majority of the tasks associated with conducting this research project can occur behind a computer in one form or another. Therefore, on the basis of personal safety, limited issues will arise. Safety issues which could occur include repetitive stress injuries, eye strain or heath issues due to prolonged screen use and seated work. These issues can be mitigated through implementing correct workplace ergonomics and by taking regular breaks.

When conducting questionnaires or interviews, the safety of both oneself and the other participants needs to be considered. This includes both physical and emotional safety in which the university's ethics department is required to review and make an assessment of the proposed research questions to eliminate harm from occurring, as contained in Appendix C.

Therefore, the potential harm this project could pose upon myself and those involved is minimal. By ensuring the mitigation measures addressed in the following section are implemented and ethics of the proposed questionnaire and interview questions are evaluated, the projects risks can be significantly elevated, and safety enhanced.

3.9 Conclusion

In conjunction with a comprehensive literature review surrounding opportunities for materials, sustainability, and project management due to modular construction in the Fijian context, the identified methodologies will be undertaken. The outcome of the proposed methodologies formats varies dependent upon the scope identified. The objectives and associated problems previously identified will be targeted within the questioning aspects of each methodology format. This will provide a relevant and detailed response from industry professionals and the community who are the end consumers being engaged to identify risks, opportunities, and restraints regarding modular construction. The benefit of doing so is to prevent a one-sided, biased conclusion from occurring by addressing all stages of the process and engaging industry professionals to provide insight upon the projects feasibility. Additionally, by engaging the community and engineering study tour participants, it will address whether this construction method is accessible and obtainable, along with being fit for purpose and culturally aligned. Therefore, the aim of the project will be addressed in a beneficial format enabling the outcomes to be determined upon analysis of the data and information collected.

Chapter 4

Comparative and Case Study Analysis

A comparative analysis is used to evaluate the performance of two or more things to determine what they have in common to assist in developing an understanding of similarities and differences. Within this dissertation, a comparative analysis will be completed for traditional and modular construction methods, specifically within the context of the Fijian construction industry. Various criteria will be determined and utilized for the analysis, looking at varying factories such as time efficiency, maintenance needs, sustainability and transport logistics for example. Case studies will also be analyzed in order to provide real world examples and application of the discussed construction methodologies. This will enable the strengths, limitations and innovative applications of such to be determined with the ultimate goal of determining which construction method is best suited to address the challenges and opportunities present within the Fijian construction industry.

4.1 Methodology

4.1.1 Data Sources

This comparative case study analysis will utilize data which is within industry reports, field research and academic literature. The key resources utilized include a report on housing research methodologies by Goodchild and Furbey (1986), modern construction logistics by Smith (2016) and the eco-cultural design in sustainable housing by Adayeye, Emmitt and Qtaishat (2020). Additional sources are referenced as utilized and contained within the dissertation references.

4.1.2 Analytical Framework and Comparative Metrics

Within the analysis, various criteria such as time efficiency, durability, maintenance requirements and transport logistics are utilized as the analytical framework. To conduct this analysis, the comparative metrics which will be used in order to compare and measure traditional and modular constructive performance is dependent on the associated analytical framework. Examples include the cost per square meter for materials, environmental impact in relation to utilization and wastage of resources and safety, including adherence to regulations and number of incidences.

4.2 Comparative Criteria

4.2.1 Cost-Effectiveness

4.2.1.1 Initial Construction Costs

Within Fiji, traditional construction methods typically possess lower initial construction costs and are viewed as more cost effective due to the reliance upon available labour and materials. Within Fiji, traditional construction utilises locally sourced materials such as timber and do not require importing of vast and specific materials (Naidu, 2020). This in turn, reduces transport and import costs significantly, being beneficial due to Fiji's geographic location.

The construction cost, using traditional construction methods, of a single-story house in Fiji that utilises local materials and labour is between FJD 1,500 – 2,500 per square metre (AUD $984 - $1,640). Therefore, for a standard 100m^2 house, the total cost would be between FJD 150,000 - 250,000 (AUD $98,370 - $163,950). This consists of local materials, with the cost of locally sourced material being between FJD 300 – 400 per cubic meter (AUD $197 - $262). When imported materials such as steel or prefabricated components are utilised, this is significantly more expensive due to transportation, import and labour costs. The Fijian construction workers typically receive lower wages, with the daily average rage of a construction worker in Fiji being between FJD 20 – 30 (AUD $13 - $19) (Naidu, 2020). Therefore, this demonstrates the expected initial construction costs of a home within Fiji using traditional construction methods.

This is in contrast to modular construction, which poses higher initial costs due to the requirements for specialised manufacturing plant and equipment, and greater extents of transportation logistics. The initial costs associated with procuring and installing a modular construction manufacturing plant is high, estimated at costing between FJD 2 – 3 million (AUD $1.3 - $1.97 million) depending on the complexity and size of the facility. This venture will be especially pricey within the initial stages due to the current manufacturing infrastructure within Fiji not consisting of any local manufacturing capacity for modular components. Due to this, in the current state of Fijis manufacturing infrastructure, modular components would require manufacturing in specialised facilities being imported. This extends to the transportation and logistics requirements associated with transportation of prefabricated modules to site. This poses additional initial costs, due to the island geography and, shipping and handling costs if the component is imported from overseas which is estimated at upwards of FJD 20,000 – 30,000 per container from Australia (AUS $13,116 - $19,674).

From this analysis, it is evident that although modular construction poses higher initial costs, there are long term savings that can be reaped through modular construction. This includes faster construction time and efficiency, and reduced waste and labour requirements. This demonstrates that, although the capital investment for modular technology is high, the production of the modular components offsets this difference (Smith, 2016).

4.2.1.2 Lifecycle Costs

When evaluating construction methods lifecycle costs, the initial construction expenses and ongoing costs, including operation, maintenance and energy consumption all need to be considered for the life of the building. Within the context of the Fijian construction industry, the logistical constraints and climate pose a significant impact upon the lifecycle costs. Although typically cheaper in regard to initial construction costs as explored within section 4.2.1.1 of this dissertation, traditional construction methods tend to incur a higher level of ongoing costs. This is due to a higher level of maintenance requirements, longer construction timelines and a lower level of energy efficiency.

Within traditionally constructed buildings, the requirement for more frequent maintenance is evident due to the materials utilized. One example is timber, which is prone to warping, rot and insect damage within Fiji's climate. Annually, maintenance costs of a traditional Fijian home can range from FJD 3,000 – 5,000 (AUD $1,967 - $3,279) depending on the quality of construction (Naidu, 2020). This is in extension to the higher duration of construction as a result of reliance upon availability of materials, local labor and weather conditions. As a result, the time required for the property to begin generating value is prolonged, resulting in higher financing and opportunity costs. Project delays between 3 to 6 months are common, resulting in additional interest costs of between FJD 10,000 – 15,000 (AUD $6,558 - $9,837).

Within Fiji, the buildings constructed using traditional construction methods often lack the level of precision or insulation required to optimize energy efficiency. As a result, higher cooling costs are experienced due to Fijis hot and humid climate due to the use of air conditioning which is commonly installed and used, accounting for a significant portion of Fijis electricity costs. This is in extension to homes which are poorly insulated, utilizing between 15 – 25% higher cooling costs annually (Fiji Electricity Authority, 2024).

The lifecycle cost of modular construction therefore poses cost savings which are associated with lower waste generation, reduced construction time, and enhancements with water and energy efficiency. By undertaking off-site manufacturing of the modules, a level of precision is above to be achieved which assists within the reduction of cooling and heating costs due to the tightness of the building envelope (Miller and Zahang, 2023). Modular houses are also typically designed to comply with higher thermal efficiency standards, reducing cooling costs resulting in an estimated energy saving of between 20-30% annually.

Construction timeframes are also significantly reduced by an estimated 30 – 50% as a result of the off-site manufacturing processes associated with modular construction. As a result, labor and financing costs can be reduced, enabling the building to enter into operation sooner. This leads to a potential saving of between FJD 15,000 – 25,000 (AUD $9,837 - $16,395) within a construction loans interest due to a shorter project construction period (Miller and Zahang, 2023). During the construction, 10-15% less waste material is produced, reducing the material cost and environmental impact. This is estimated at a waste saving of the project being around FJD 400,000 (AUD $262,320) (Smith, 2016). As the construction of modular houses involves precise manufacturing techniques and use of durable materials, the requirement for maintenance is reduced. One example is composite materials or treated steel which are less prone to insect damage or weathering in comparison to traditional timber (Smith, 2016). Therefore, it is estimated that the annual maintenance cost of a modular residential building within Fiji would range between FJD 1,500 – 2,500 (AUD $1,000 – $1700) being significantly less than traditional methods.

From the above analysis, a comparison of the lifecycle costs of traditional construction methods as opposed to modular construction can be determined. Please refer to the following table which captures a comparison of the costs over a 30-year period in FJD, showing the lower and upper limits.

Table 4.1: Comparison of lifecycle costs over a 30-year period

Cost Category	Traditional Construction (FJD)	Modular Construction (FJD)
Initial Construction Cost	$150,000 – $250,000	$300,000 – $450,000
Waste Savings	$0	$40,000 – $60,000
Construction Loan Interest	$10,000 – $15,000	$5,000 – $10,000
Energy Cost	$30,000 – $50,000	$15,000 – $25,000
Maintenance Cost	$90,000 – $150,000	$45,000 – $75,000
Total Lifecycle Cost	$280,000 – $465,000	$405,000 – $620,000

The above analysis demonstrates that whole traditional construction methods utilized within Fiji present lower initial costs, they incur a higher lifecycle cost due to longer construction timelines, an increase in maintenance requirements, and higher energy consumption during operation. As demonstrated within the above table, over a 30-year period the total lifecycle cost for a typical 100m^2 home ranges between FJD 280,000 to 465, 000 (AUD $187,000 - $310,000) (Naidu, 2020).

This is in comparison to modular construction which poses an initial high construction cost but offers greater long term savings over the buildings lifecycle as a result of short construction timelines, reduced material wastage. maintenance requirements, and energy consumption (Smith, 2016). This ranges between FJD 405,000 – 620,000 (AUD $270,000 - $415,000) over the 30-year period as demonstrated in the above table (Miller and Zahang, 2023).

Therefore, as the aims of the project and the Fijian governments construction initiatives are in relation to providing a sustainable and efficient design, it is evident that modular construction provides a better outcome in relation to lifecycle costs.

4.2.2 Time Efficiency

4.2.2.1 Construction Timeframes

The evaluation of construction timeframes is essential to ensure limitations and benefits are identified in relation to traditional and modular construction methods. This is increasingly applicable to the focusing on Fiji, which experiences various weather conditions, labour shortages and logistically challenging which can pose significant impact to a project's timeline.

Due to the parallel manufacturing of the modular components offsite, and site preparation occurring when utilising modular construction, significant time efficiency advantages are evident. This assists in reducing the overall project timeline as opposed to traditional construction methods where all construction phases follow a sequential process, increasing the likelihood of delays. This simultaneous process has been determined to half construction time. This is evident within a modular construction project which occurred in New Zealand (Baker et al., 2024), in which a building was completed within 6 months as opposed to 12 months. Within Fiji, this construction approach could pose benefits due to the unpredictable, tropical weather conditions, reducing the impact of site delays. This is due to the majority of manufacturing occurring in an off-site, controlled environment, reducing vulnerability to weather delays. As Fiji is prone to heavy rains and cyclones, construction can be disrupted for prolonged periods at a time. Through utilisation of modular construction, work is able to continue off site, presenting a significant time saving advantage (Baker et al., 2024).

A typical modular construction building timeline ranges between 4 to 8 months dependent on the size and complexity of the project. The stages of this project would include site preparation, modular transportation and on-site assembly. By running the manufacturing of the modular components and preparation of the site in parallel, projects are able to be complete 30 – 50% faster than traditional construction methods (Anderson and Wilson, 2024). This poses benefits in situations where urgent housing is required, such as following a natural disaster or in housing crisis.

As stated above, traditional construction methods occur in a sequential manner, leading to longer construction time when factoring in risks such as material availability, labour shortages and weather conditions. The average construction time for a traditional building within Fiji ranges from 12 to 18 months depending on complexity and size (Smith, 2016) and if frequently impacted by such risks. Projects frequently face construction halts of between 1 – 3 months as a result of adverse weather conditions, including between the country's rainy season, extending the overall projects duration (Naidu, 2020).

From the above analysis, a comparison of the construction timeframes of traditional construction methods as opposed to modular construction can be determined, demonstrated within the following table.

Table 4.2: Construction Timeframe Comparison

Construction Method	Typical Construction Timeframe	Weather Impact	Material and Labor Constraints
Traditional Construction	12 – 18 months	High impact, potential delays between 1 – 3 months	Subject to labor and material shortage delays
Modular Construction	4 – 8 months	Minimal impact as a result of off-site fabrication	Impact reduced due to off-site processes

Therefore, modular construction poses significant time saving advantages as opposed to traditional construction methods within Fiji. This is due to the ability for modules to be manufactured off-site while the sites is simultaneously being prepared. This results in a 30 – 50% reduction of the projects overall duration (Baker et al., 2024) posing significant benefits in time critical situations (Anderson and Wilson, 2024).

4.2.2.2 Impact of External Factors

Within Fiji, external factors majorly impact the construction industry. These factors include, but are not limited to resource availability, logistical constraints and weather delays, which pose impacts within traditional construction methods project timelines and cost increases. In order to mitigate the impact of external factors, utilizing off site construction and manufacturing processes, such as through modular construction, poses significant advantages (Naidu, 2020).

Fiji is located within a tropical maritime climate, characterized by heavy, unpredictable rainfall and, during the wet season between November and April, a high frequency of cyclones. As a result of these conditions, onsite construction delays are often experienced, with an estimated expected 1 – 3 months of delays during the wet season. This particularly poses issues when preparing the site and completing foundational and framing work which requires dry conditions, and the sequential nature of residential construction processes. As modular construction utilities of site manufacturing, a majority of the building modules are able to be manufactured within a factory environment and transported to site for onsite assembly, resulting in a quick and efficient onsite construction process. The controlled nature of this manufacturing technique mitigates risks associated with on-site delays related to the weather and reduces the timelines vulnerability to unpredicted weather events (Anderson and Wilson, 2024).

Traditional construction methods are also heavily reliant upon the availability of material and labor, which can also be impacted due to external factors such as supply chain issues and geopolitical events. Due to the geographic location of Fiji and the remote locations of some projects, transportation of materials poses its own challenges. Expected delays can range between 3 - 6 months within the project's duration (Smith 2016). The following table demonstrates the impact of external factors on traditional and modular construction method durations.

Table 4.3: Construction Durations, Impact of External Factors

Construction Method	Typical Construction Timeframe	External Factor Vulnerability (Labor, Materials and Weather)
Traditional Construction	12 – 18 months	High: Material Shortages, labor issues and weather delays can increase the construction timeline by 3 – 6 months.
Modular Construction	4 – 8 months	Low: Off-site construction in control environmental while working parallel to onsite construction preparation mitigates potential delays.

Therefore, due to the unpredictable nature of Fiji's climate and weather pattern, the ability for an alternative construction method to assist in mitigating construction delays poses a significant advantage. Modular construction enables this risk to be mitigated through off site manufacturing within a control environment. In addition, through the ability to manufacture modules and prepare the site simultaneously, the duration of the construction can be reduced by as much as 50% (Baker et al., 2024), demonstrating the benefits modular construction can impose within the Fijian Construction Industry.

4.2.3 Sustainability

4.2.3.1 Environmental Impact

Within the Fijian construction industry, an increased emphasis upon sustainability and the environmental impact of proposed developments is evident due to the nations geographical location and vulnerability to environmental degradation and climate change. Key focus areas include waste generation, the use of sustainable materials and energy consumption, with the impact of traditional construction methods as opposed to modular construction analysed below.

Overall, traditional construction methods have a higher energy consumption and waste production in comparison to modular construction (GhaffarianHoseini et al., 2011) due to on-site inefficiencies and less precise material usage. Traditional construction methods typical utilise materials such as concrete, steel and timber which are not always sourced sustainably. One commonly used material is concrete blocks which possesses a high embodied carbon level as a result of the cement production process which is highly energy intensive, emitting 410kg of CO_2 per $1m^3$ (Green Building Council, 2023). In addition, the amount of waste produced onsite which is up to 15-20% of raw materials due to inefficiencies and poor planning when fitting, cutting and assembling can result in a large amount of left over or ‘off cut’ quantities (GhaffarianHoseini et al., 2011). As a result, this waste often goes to landfill which increases the environmental footprint of the construction process. As prefabricated building components are utilised within modular construction, the precise use of materials within a controlled environment can assist in the reduction of waste by 60 – 90% as opposed to traditional construction (Smith and Taylor, 2023).

As the construction duration within Fiji is typically between 12 to 18 months, the prolonged onsite activity increases the environmental impact of the activity through extended noise, air pollution and fuel consumption (Naidu, 2020). This in addition to increased levels of dust and debris which is released into the atmosphere as a result of an extended construction duration, contributing to environmental degradation. Material transportation, manual labour and equipment operation utilise on-site energy, in which inefficiency of site processes can result in a high level of energy consumption (GhaffarianHoseini et al., 2011). This is particularly evident when utilising heavy machinery and equipment such as compressors, concrete mixers and cranes. One example of this is within onsite concrete production, significant carbon emissions as a result of fossil fuel-powered machinery and cement production are released, contributing to global CO_2 emissions. This is in comparison to modular construction which utilising off site manufacturing within a controlled environment, resulting in significant energy savings. Due to the nature of off-site manufacturing, the requirement for onsite heavy machinery is reduced by up to 50%, resulting in decreased emissions and fuel consumption and increased efficiency (GhaffarianHoseini et al., 2011).

The implementation of renewable energy sources within factors such as solar power is also becoming increasingly standardised, further assisting in the reduction of emission and environmental impact of the construction industry. The energy efficiency of modular building is often increasingly higher due to the use to insulative technologies, for example high performance insulation panels. By doing so, the operational carbon footprint of the residence can be reduced, minimising the demand of cooling and heating. Through case studies it has been found that operational energy use within modular residential buildings can be reduced by 30 – 40 % due to increased thermal insulation and airtight construction (Smith and Taylor, 2023).

The following table demonstrates the sustainability impact of various key aspects between traditional and modular construction methods as discussed above. It is evident that traditional construction methods are generally associated due to higher level of material wastage, energy consumption and environmental degradation as a result of reliance on high carbon materials and on-site inefficiencies. This is opposed to modular construction which utilises off-site manufacturing, resulting in reduced waste, utilisation of eco-friendly materials and lower energy consumption levels.

Table 4.4: Sustainability Impact of Traditional and Modular Construction

Construction Method	Material Usage	Waste Production	Construction Timeframe	Operational Energy savings	Embodied Carbon (concrete)
Traditional Construction	Timber, concrete, steel – high level of embodied carbon	15-20% of materials wasted (Naidu, 2020)	12 – 18 months (Naidu, 2020)	N/A	410 kg CO_2/m^3 (Green Building Council, 2023)
Modular Construction	Eco-friendly material usage	Waste reduction of 60-90% (Smith and Taylor, 2023)	4 – 8 months (Baker et al., 2024)	30 – 40% reduction (Smith and Taylor, 2023)	40% lower embodied carbon (Renco Blocks)

Therefore, modular construction possesses less of an environmental impact as a result of its off-site manufacturing methods and potential for use of eco-friendly materials. Renco Modular Blocks pose a significant reduction of embodied carbon in comparison to traditional concrete blocks (Green Building Council, 2023). Additionally, by undertaking off site construction within a control environment, a higher level of efficiency is able to be achieved within the use of material, resulting in less waste being produced. When designing modular units, efficiency energy use is a key aim which can be achieved through the incorporation of sustainable and advanced insulative technologies which assist in reducing the operational carbon footprint of the building (Smith and Taylor, 2023).

4.2.3.2 Resource Utilisation

Within the construction industry, the management and utilisation of resources, particularly in regions such as Fiji in which environmental vulnerability and material scarcity, pose significant challenges. As traditional construction often involved on site material adjustments being made, there is an increase in wastage, resource use and construction duration. This is in comparison with modular construction which poses an increased efficient use of resources and sustainability through the utilisation of offsite manufacturing and therefore reduces wastage.

Excess materials within traditional construction methods is classified as waste, as a result of inaccurate measurements and cuts from onsite adjustments. Within a standard residential construction project, the level of waste can range between 15 – 20% of the total construction material quantity (GhaffarianHoseini et al., 2011). Due to the geographical location of Fiji, a majority of the construction material are imported and are of limited quantities. As a result, this level of material wastage is not sustainable (Naidu, 2020). However, modular construction poses the ability to precisely cut materials within a control environment which therefore reduces wastage by 60 -90% (Miller and Zhang, 2023). Typically, computer numerical control (CNC) machines are utilised to cut the modular components to the exact specification, enabling exact measurements and minimal error. The utilisation of a control environment also eliminates down time as a result of weather and increases the ability for the integration of sustainable materials (Green Building Council, 2023).

As discussed in section 4.2.3.1 Environmental Impact, other key factors relating to resource utilisation include the requirement for traditional construction methods to make onsite adjustments, resulting in inaccurate and inefficient measurements and material usage. The off-site, manufacturing nature of modular construction combats this, through utilisation of a controlled environment to monitor and optimise material usage. This also extends into a reduction of required cooling and heating costs within modular construction as a result of enhanced thermal performance, improving the resident's sustainability and energy efficiency. Additionally, external factors such as weather events can impose upon resource utilisation, requiring additional labour, materials and construction duration. The following table details a comparison between the resource utilisation in traditional and modular construction methods.

Table 4.5: Traditional and Modular Construction, Resource Utilization Comparison

Construction Method	Construction Timeframe	Timber Usage ($100m^2$ residential)	Embodied Carbon	Material Wastage	Thermal Performance
Traditional Construction	12 – 18 months (Naidu, 2020)	20 m^3 (Naidu, 2020)	410 kg CO_2m^3 traditional concrete	15-20% waste due to onsite alterations	Poor – high energy use
Modular Construction	4 – 8 months (Baker et al., 2024)	15 m^3 (Miller and Zhang, 2023)	Up to 40% reduction using alternatives	60-90% reduction (Miller and Zhang, 2023)	High performance, e.g. high performance insulation reduce energy use 30-40%

Renco Modular Blocks are a sustainable material example which is a block system which can reduced embodied carbo by up to 40% as opposed to traditional concrete blocks (Green Building Council, 2023). A case study utilising Renco Modular Blocks was conducted within Fiji, analysing a 150 m^2 residential building. It was found that embodied carbon had been reduced by 40% or 15 tonnes of $C0_2$ emissions due to utilisation of Renco Modular Blocks as opposed to traditional concrete blocks.

Additionally, due to the nature of the modular blocks being precision cut, there was no requirement for on-site adjustment further reducing the generated wastage.

Precision cutting technique case studies have also been conducted in Suva, Fiji in a 50-unit residential housing project. It was determined that $200m^3$ of timber was saved as a result of utilising precision cutting techniques, reducing the generated wastage. The project duration was estimated to be completed within 12 months but was achieved within 6 months, resulting in a significant time, fuel and water usage resource saving (Nadiu, 2020).

Therefore, it is evident that the utilisation of traditional construction techniques results in higher material wastage and resource utilisations as a result of onsite adjustments and efficiency. Within countries such as Fiji where the bulk of the materials are imported, expensive and scarce, the issues associated with resource utilisation are extensive. This is in comparison to modular construction methods which utilise off site manufacturing to enable precise material usage and a reduction in generated wastage. Additionally, residential buildings have an improved thermal performance and lower operational energy use (Miler and Zhang, 2023) which demonstrates that modular construction is a more resource efficient and sustainable construction technique.

4.2.4 Quality and Durability

4.2.4.1 Structural Integrity

Numerous challenges are experienced regarding structural durability and integrity as a result of Fiji's tropical climate and geographical location. Traditional methods of construction utilise on-site assembly and locally soured materials, enabling for on-site adjustments to be made in relation to adapting to unforeseen site conditions, in which modular construction is unable to do so (Anderson and Lucas, 2017). However, due to the heavy reliance on site specific variables and manual labour, the structural integrity of the building can be affected, specifically in relation to regions that are exposed to high winds, earthquakes and tropical storms.

Quality control is a major issue within traditional construction methods due to the inconsistency experienced as a result of on-site construct. The requirement for manual measurements, cutting and assembly results in human error, and weakened structural elements (Anderson and Lucas, 2017). Within traditional construction, this can be evident through variations within the depths of piers, misalignment of reinforcement, and inconsistences within concrete mixes. These errors can impact the buildings strength and therefore results in an increase in vulnerability and likelihood of failure within weather events. Furthermore, the harsh environmental conditions experienced, such as humidity, rainfall and saltwater, also pose impact upon the building's structural integrity. Through exposure to these external conditions, building materials can deteriorate overtime and reduce the lifecycle of certain elements, increasing the frequency of major maintenance to every 5 – 10 years (Naidu, 2020). An example is within coastal areas, timber is prone to termite infestation and rot, and concrete structure steel reinforcement are prone to corrosion, reducing the buildings structural capacity.

The NBCF and other related structural standards, such as AS/NZS:1170 Structural Design Actions, must be abided by withing the design and construction of residential buildings within Fiji. Adherence to these standards onsite is majorly reliant upon the material and workmanship quality. Additionally, many of the traditional structures built within Fiji are not constructed to these standards, posing variability within construction quality and increased risk during cyclone-prone periods (Naidu, 2020). A study was conducted into the cyclone damage imposed upon traditional Fijian residential homes. It was determined that close to 25% of the homes which were constructed utilising timber and concrete blocks experienced significant structural damage as a result of foundational movement and wind loadings. An investigation into the buildings structural components identified that the quality of the reinforcement and concrete mix varied and failed to comply with the NBCF's cyclone resistant standards (Naidu, 2020), resulting in cracked foundations and weakened walls.

As modular components are constructed in a precise, off-site environment, higher quality is able to be achieved, equating to an increase in consist structural integrity, as opposed to traditional construction methods (Miller and Zhang, 2023). Within a factory setting, quality control processes such as CNC machining are implemented which are unable to be achieved on site, producing components which are more durable and can withstand hash weather conditions (Anderson and Wilson, 2024). This is significantly important within disaster prone regions, such as Fiji, to ensure the structures are able to withstand varying weather conditions.

Advanced and composite materials, such as composite panels and galvanised steel are frequently utilised within modular construction, offering increased resistance to the environmental conditions, such as saltwater, pests and humidity, experienced within Fiji (Anderson and Wilson, 2024). Through implementation of these materials, an increased level of structural durability is achieved, requiring minimal maintenance and extending the buildings lifespan by 30 – 50 years. The opportunity to utilise systems, such as interlocking panels, and modular steel frames, which assist in load distribution are also achievable through modular construction. This enables the buildings resistance to lateral forces, such as those experienced within a cyclone or earthquake, to be increased, significantly improving the buildings structural integrity.

As detailed, compliance with the NBCF and AS/NZS.170 is required, in which modular buildings are designed to meet or exceed the cyclone-resistant structure requirements. This practice has been implemented to ensure the structures are able to withstand high wind speeds, with modular homes within Fiji being designed to comply with category 5 cyclone standards of wind speeds up to 250 km/h (Anderson and Wilson, 2024). As off-site manufacturing enables for high levels of quality control and as a result, struct design compliance, these design standards are able to be repeatedly achieved. Within Suva, a steel frame modular house was designed and constructed to meet AS/NZS:1170.2 and remained structurally sound following a category 5 cyclone. A post-disaster structural evaluation occurred on the building, and it was determined that there was no significant structural damage imposed on the building, identifying modular construction to pose superior resilience within extreme weather conditions (Miller and Zhang, 2023).

Therefore, it is evident that as a result of manual, onsite, variable, inconsistent and inaccurate process, traditional construction methods are not as structurally resistant and durable as modular construction methods. Traditional construction methods however do enable accommodations to site specific conditions, this flexibility can result in a variability within the buildings structural performance. This is particularly important due to Fijis high susceptibility to natural disasters, in which a precision-manufactured components with advanced materials results in a more highly favoured construction method.

4.2.4.2 Adaptability to Local Conditions

In order to ensure long term sustainability, durability and quality, the adaption of construction methods which align with cultural conditions and the environmental is critical within Fiji. Traditional and modular construction methods have both adapted in order to respond and comply with Fiji's geographical requirements, climate and heritage conditions. The application of these elements however, different between the two construction techniques.

Traditional and cultural construction methods which have been developed to suit the environmental conditions and available materials, such as the Fijian Bure. This includes the utilisation of bamboo, coconut timber, which is naturally resistant to decay and thatched roofs, which are easily repairable, are all abundant and durable materials within Fiji (Naidu, 2020) resist decay. Traditional Fijian buildings also incorporate features such as wide eves for providing shade and elevated floor levels to act as a mitigation measure against flooring to align with the local climate (Naidu, 2020). Additionally, natural ventilation systems such as thatched roofs and open walls assist in reducing the requirements for artificial cooling and enable the interior to stay cool. Cultural construction methods are therefore highly adaptable to Fiji's climate and weather events. However, traditional building are less resistant within major events such as earthquakes and cyclones and often require regular repairs and maintenance as a result (Naidu, 2020).

As discussed within the previous section, on-site construction enables adaptability and adjustments to be made easily in order to accommodate for specific environmental or site conditions. This can include, the foundational height of the building being adjusted in order to accommodate for flood risk and terrain. Flexibility within the construction process is therefore obtained (Naidu, 2020), which can be important when constructing in rural and coastal areas which pose unpredictable terrain conditions.

While modular construction poses opportunities for development to account for the local conditions, additional design and preparation will be required in order to account for flood risks, unpredictable terrain and other site-specific conditions. This can include designing buildings with an increased reinforced structure when located within seismic areas (Smith and Taylor, 2023) or increasing the level of insulation for cold climates. The utilisation of thermal insulation within modular construction is one example of increasing the level of insulation in order to improve the buildings energy efficiency and reduce the requirements for heating and cooling costs.

Therefore, cultural construction methods and buildings, such as the bure, offer significant benefits and teaching which can be implemented into modern design methods to mitigate the risks experienced within Fiji. Although, traditional construction methods are generally requiring more frequent maintenance and are less durable as a result of the materials utilised, the ability to adapt onsite is beneficial. As modular construction has to be adapted during the design phase in order to comply with the sites terrain or climatic conditions, increased energy performance and material durability is achieved. This demonstrates that both forms of construction are able to adapt to local conditions, with modular conduction adapting during the design process and traditional construction adapting while on site.

4.2.5 Social and Cultural Acceptability

4.2.5.1 Community Perception

The social and cultural acceptability of construction methods within Fiji plays a major role within the acceptance of a technique and the communities perception. Traditional construction methods are significantly more accepted, often due to the deep roots of the associated local practices. While modular construction is an emerging technique and not as widely utilised or accepted. Therefore, the community and cultural perceptions of the construction methods varies significantly which poses impact upon their adoption and implementation within the construction sector.

The utilisation of traditional and cultural construction methods is deeply engrained within Fijis identity and community practices. Often, practices and construction techniques are passed down through generations, being reflective if the cultural craftsmanship and being highly socially acceptable. One example within Fijian housing is the utilisation of timber and traditional hatching, and the construction of the bure. These materials and construction methods do not only provide practical application, but also represent the connect of Fijians to local and Heritage craftsmanship (GhadderianHoseini et al., 2011). Additionally, the materials utilised within these construction methods are often sourced locally, being renewable and sustainable. This is favoured by the Fijian people due to the embodied relationship between the people and their land. This can include the utilisation of coconut wood for example, a renewable resource which has been utilised within traditional Fiji homes for centuries. The elders within a village emphasise the importance of heritage craftsmanship to ensure cultural continuity is maintain, identifying the construction process as an act of community collaboration (Naidu, 2020). This practice demonstrates that the act of construction within Fiji is not solely about creating shelter, rather continuing traditional and maintaining community ties.

This belief extends to the involvement of the community within traditional construction methods. Often, villages will work together in order to construct homes and community structures, nurturing the social bonds, enhancing the shared responsibility, and reflects the Fijian value of solesoleveki. Solesoleveki is the emphasis of mutual aid and cooperation within the community, in which the construction of the bure, consisting of various families working together, sharing knowledge and labour, is a prime example. The implementation of this value therefore assists in preserving the community's sense of ownership and connection to the building (Naidu, 2020). Therefore, due to the deep cultural roots within construction methods, the Fijian people take pride in continuing these practices. The buildings produced as a result are often more in line with the environmental, being more desirable within rural and cultural contexts (GhaffarianHoseini et al., 2011).

As modular construction is an emerging building technique, resistance is often faced when trying to implement in a local, cultural context as this not achieved the same level as cultural integration and traditional methods. Communities are often sceptical due to modular construction being perceived as a disconnected or foreign in relation to local traditions. This is particularly evident within rural areas where culturally based construction methods are still highly utilised and there is a strong hesitation to adopt emerging and unfamiliar materials and designs (Anderson and Wilson, 2024). However, adaption of modular construction techniques within cultural preferences, particularly in relation to disaster recovery, is becoming widely accepted and implemented. One example is following the earthquakes experienced by Lombok Indonesia, modular units where designed, with cultural requirement in mind to display a locally focused architectural style for residential and commercial spaces (Anderson and Wilson, 2024). Due to the utilisation of locally inspired design, such as through the utilisation of traditional rooflines and natural local materials such as bamboo cladding, the units were perceived as culturally appropriate while still being resilient to disasters. The implementation of a similar approach into Fiji, could assist in modular construction gaining wider acceptance within the community.

4.2.5.2 Cultural Compatibility

Construction methods within Fiji consist of a significant social and cultural symbolism due to traditional construction practices being deeply integrated within the communities identify and cultural practices. Traditional construction practices, such as the bure, are a symbol of community identity and cultural continuity. The practices demonstrate shared commitment to sustainable practices and generations of knowledge which align with the Fijian communities' cultural values. This demonstrates that the structures are more than physical. They are a cultural icon which represents the people and the village. The bure is recognised as the meeting house, being a centralise and versatile point within a village, acting as a location to host ceremonies, discussions and events. This structure and its recognition demonstrate the social status, continuity and cohesion throughout the village's generations.

Collaboration within traditional construction methods is commonly practices, with the construction of a bure involving the entire village. Through undertaking construction in this approach, a sense of collaboration and collective effort is achieved, fostering sense of pride and ownership, enhancing social ties and reinforces cultural values. This method is in alignment with the Fijian ethos 'solesolevaki' (Naidu, 2020), emphasising the requirement for cooperation and support within the community. The alignment of construction practices with the cultural values of sustainability and respect for the environment is also evident through traditional construction methods. This can include the utilisation of natural and local resources that are biodegradable and renewable. The design of such structures, including the utilisation of open floor plans for gatherings and wide eves for cooling, aims to enhance comfort and foster social interaction (GhaffarianHoseini et al., 2011).

Modular construction is an emerging construction method which poses the potential to incorporate cultural requirements through design adaptation and community consultation in order to ensure it is culturally compatibility. This can include features such as wide eves for cooling and elevated floors to reflect traditional Fijian architecture. Designs can also be adapted to mirror traditional buildings, such as a bure, and help reduce the perceived perceptions of the construction methods through ensuring modular construction is deemed cultural acceptable to the community.

One key method to ensure the proposed modular construction is culturally compatible, is through involving the stakeholder, i.e., the community, within the design phase of the project This can include enabling local villages to participate in engagement sessions in order to provide input which can then be translated into the designs to incorporate aesthetic and cultural elements which align with Fijian cultural traditions (Anderson and Wilson, 2024). This could include a second door for the elders to enter through and open communal spaces to ensure the proposed design supports family interactions and social gathering. Within the context of disaster recovery, modular construction has demonstrated its high adaptability in order to elevate the displacement experienced by the community. Through incorporation of traditional design elements and Fijian motifs, the cultural compatibility and therefore acceptance can be achieved.

Therefore, it is evident that construction is a key pillar within the cultural context of Fiji and the acceptance of modular construction Is based on the integration of these elements into the proposed design. This includes through inclusion of cultural elements, locally sourced and adaptable materials and open spaced which enhance the community's utilisation of the space. This demonstrates that through careful planning and consultation, modular construction poses the opportunity to become culturally acceptable within Fiji.

4.2.6 Materials

4.2.6.1 Material Types and Sources

The materials utilised and their subsequent sources, availability, cost and sustainability varies between construction methods. Traditional methods of construction generally, utilise naturally occurring and locally sources materials while modular construction gravitates towards the incorporation of advanced materials which generally require importation and have different economic and environmental impacts.

Within Fiji, traditional construction methods favour the use of locally sourced materials which are readily available and fit for purposes within the local climate. Through utilisation of these materials, importation and transport costs and emissions are reduced, local economies are supported, and the resources utilised and best fir for the tropical climate of Fiji. The common materials utilised are as follows:

- Bamboo is a rapid growing, sustainable material found locally within Fiji, making it sustainable with a low carbon footprint. The materials natural properties make it ideal for withstanding earthquakes and high wind events which are common in Fiji (Naidu, 2020), while having high strength, flexibility and pest resistance.
- There are a variety of different forms of timber utilised within Fiji such as native hardwoods and coconut timber within framing, flooring and roofs. These timbers are sustainably sourced and suitable for Fijis climate due to being resistant to high humidity and termites (Naidu,

2020).

- Coral stone is a locally sourced material which is utilised within the Fijian construction industry as foundational walls and within base structures. The stone is naturally abundant and naturally resistant to moisture, making it ideal for utilisation within Fiji's climate.
- Concrete within Fiji is combined with natural gravel and sands to be utilised as a reinforcement within structures. However, the production process of cement is not sustainable and poses significant environmental impact due to the level of CO_2 emissions emitted during manufacturing.

The sustainability elements of the material utilised within traditional construction methods in Fiji, as discussed above, therefore varies depending on the source and manufacturing of the material. However, the industry has a high focus upon sustainability and green footprint and therefore gravitate towards the utilisation of materials which require low processing and are able to be locally sourced. This includes coconut timber, coral stone and bamboo as detailed, which grow abundantly within Fiji and therefore assists in ensuring limited environmental degradation and impact (Naidu, 2020). Additionally, by sourcing these materials locally, costs, emissions and other impacts associated with transportation are reduced, lowing the materials carbon footprint. One example of utilisation of locally sourced materials within Fiji's construction industry is within a Naidu village who constructed a meeting hall. The village utilised approximately 30m^3 of coconut timber and 700 bamboo poles which equated to FJD 50,000 (AUD $33,155). Souring these materials enabled the local economy to be benefited, reduced transport emissions by an estimated 15% as opposed imported alternatives (Naidu,2020) and produced a durable structure as a result of the materials properties.

This is in comparison to modular construction which utilised advanced and sustainable materials which often require importation due to being sourced internationally. This occurs due to the need for high quality and durable materials but can increase the carbon footprint and cost of the product due to the requirement for long distance transportation (Renco, 2022). This can include sustainable materials such as eco-friendly insulation, FSC timber and recycled steel, which is often sourced from global suppliers, as detailed below.

- Forest Stewardship Council (FSC) timber is a sustainable alterative to timber which is sourced and manufactured in a manner to ensure environmental responsibility. FSC timber is termite resistance, durable and has a higher lifespan compared to traditional timbers. This material however is imported, which increases the carbon footprint and costs, being between FJD 500 – 700 (AUD $332 - $464) per m^3.
- Recycled steel is a refabricated alternative to traditional steel, used within the framing of buildings due to its durability and strength. Through utilising recycled steel, the environmental impact is reduced as opposed to sourcing new material, however it often needs to be imported increasing transport emissions and cost. Within Fiji, recycled steel costs between FJD 1,200 – 1,500 (AUD $796 - $995) per tonne (Renco, 2022). Although alternatives such as bamboo or timber are cheaper for structural application, steel has greater structural integrity properties which make it a preferred choice for implementation to mitigate against disaster events such as cyclones.
- Various eco-friendly insulation alternatives such as plant-based foam insulation and recycled cellulose are utilised within modular construction to increase the thermal performance and reduce energy consumption of the structure. This therefore enables a stable internal temperature to be achieved, reducing artificial cooling costs and being beneficial within tropical climates such as Fiji (Renco, 2022). Sourcing of eco-friendly alternatives require importation which increases transport emissions and costs, however the energy efficiency savings across the lifespan of the structure elevates the upfront investment.

Therefore, while the alterative materials utilised within modular construction have increased sustainability properties, there is additional carbon emissions released, transportation and costs involved. However, the material properties excel in regard to energy efficiency and durability which can assist in offsetting the environmental impact over the lifecycle of the product. When comparing modular homes and traditional homes, modular homes demonstrate a reduced energy consumption level of 30% which enhances the long-term sustainability of the method (Smith and Taylor, 2023). Within Suva, Fiji, a modular house was constructed using FSC certified timber, plant-based foam insulation and recycled steel frames. The overall initial cost of the materials for a 100m^2 home, was FJD 150,000 (AUD $99,465) and had 20% higher carbon emissions associated with the transportation of the materials. However, the life cycle saving due to reduced requirements for maintenance and energy, provide lifetime emissions savings (Smith and Taylor, 2023).

From the above analysis it is evident that traditional construction methods within Fiji utilise locally sourced materials which are valued for their local availability, cultural relevance, sustainability and high level of adaptability to the climate. However, modular construction materials, while posing high energy efficiency and durability properties, are imported, resulting in a high carbon footprint.

4.2.6.2 Material Efficiency

As detailed within the above section's, traditional construction poses significant disadvantages regarding material efficiency due to inaccuracies in on-site cutting and fitting that leads to material wastage. Additional, changes occur more frequently during onsite construction which can result in materials being discarded (Naidu, 2020). Additionally, through utilisation of locally grown and sustainable materials, such as coconut and native hardwoods, or bamboo, the environmental impact can be reduced through a low level of processing and transportation. An example of material efficiency is within Nadi, Fiji, where a community centre was constructed using locally sourced timber and bamboo. The transportation related costs and emissions were reduced as a result of being locally sourced, saving around FJD 15,000 (AUD $9,950). However, due to the requirement for on-site adjustments and therefore manual cutting, 10% material wastage occurred (Naidu, 2020).

Modular construction utilisation of off-site manufacturing techniques enables cuts to occur precisely and, reducing the environmental impact and increasing material efficiency through optimising material usage, reducing on-site alteration and enabling the reuse of materials. This leads to a high efficiency and reduced wastage of between 60 – 90% as opposed to traditional construction methods (Smith and Taylor, 2023). In regions that have limited availability to affordable materials, such as Fiji, modular construction methods regarding the efficiency of materials, poses a significant advantage.

4.2.7 Transport

4.2.7.1 Logistics and Costs

The cost and logistics which are associated with the transportation of materials need to be considered for any form of construction. However, the geographic location and infrastructure within Fiji poses its own challenges in regard to transportation, costs and logistics. Traditional and modular construction methods both pose distinctive cost and logistic implication in regard to materials, handing and sustainability, posing benefits and disadvantages to the methods.

Traditional construction methods utilise smaller, manageable loads which in turn, make logistic simple and cost effective. Additionally, locally sourced materials are favoured which enable a short distance of transportation to be required, offering enabling a standard vehicle with no special handing methods being required (Smith, 2016). This poses advantages including lower transportation costs of between 30 – 40% less as opposed to importing or long-hauling prefabricated modules (Naidu, 2020). This is beneficial within remote or rural areas in which access for heavy duty equipment or plant may be limited. The logistical requirements for transporting smaller or more local loads is therefore less. Standard vehicles which do not require special considerations, permits or route planning are able to be utilised, enabling flexibility and reduce possible delays. This is significantly advantageous due to the unpredictability nature of the road infrastructure network within Fiji. However, traditional construction methods may require an increased number of deliveries due to smaller loads or a reduced level of forward planning. This can result in an increase in emissions and fuel costs over the duration of a project (Smith, 2016).

This is in comparison with modular construction, in which entire modules are required to be transported from fabrication factories to the project site and materials are often required to be imported in country. This can pose significant complexities and costs, especially in countries with an unreliable road network, and limited infrastructure, such as Fiji (Naidu, 2020). The large components may require oversized vehicle permits and careful route planning which can lead to large costs. Due to the long-distance nature of transporting modular components, a higher carbon footprint due to a higher level of fuel consumption is achieved. However, through using modular construction methods, the transportation conditions are able to be controlled. This can be achieved through weatherproof packaging or customised contained which ensures no damage occurred to the modules (Naidu, 2020). This is particularly beneficial due to the unpredictable nature of Fiji's climate. Additionally, efficient delivery of fully assembled modules reduces the on-site construction period, minimises labour costs and requirement for additional transportation of materials (Smith, 2016).

Therefore, while traditional construction methods pose benefits within the logistics and cost implications of transportation due to simplified methods and increased flexibility, the emissions generated due to increased number of loads and inefficient planning poses sustainability constraints. Modular construction on the other hand often requires larger vehicles and additional planning, yet reduces the required onsite construction time, labour costs and provide an increased level of efficiency. This demonstrates that both methods of construction pose advantages and disadvantages in regard to transportation logistics and costs, and the application of such needs to be considered to determine which method is best fit.

4.2.7.2 Environmental Impact of Transportation

The environmental impact of transporting modular components is higher than traditional construction, due to the requirement of moving a larger load that requires larger or more specific freight methods over a long distance. This can include ships or aircraft for transportation of modules between islands, offsetting significant greenhouse gas emissions (Fiji Ports Corporation Limited, 2018) which are typically three to five time higher then locally sourcing the materials (Smith, 2016). This demonstrates that modular construction results in higher carbon emissions, fuel costs and a higher level of route planning. Additionally, road widening or adjustments may be required in order to enable the required vehicles to utilise the road network. This has significantly environmental impacts due to increased materials, construction and other related costs.

Within traditional methods of construction, materials are able to be locally sourced and transported in smaller qualities. This equates to a less energy intensive means of transport which poses a reduction in the carbon emissions environmental impact of this method (Naidu, 2020). However, a higher frequency of trips may be required, increasing the level of emissions and fuel consummation, and construction is limited by the availability of local materials.

4.2.8 Equipment and Tools

4.2.8.1 Specialised Equipment

The types of tools and equipment varies significantly between traditional and modular construction methods. The requirement for specialised equipment also significantly varies, posing impact upon the availability, cost and complexity of the project. Within traditional methods of construction, basic tools which are generally very familiar to the local workforce are required. This enables the equipment required to be easily accessible and the reduces the requirement for specialised training. This enhances the benefits of traditional construction methods within rural or remote location as supply, purchasing, transportation or training of use of specialised equipment is not required due to the familiarity of traditional equipment. Local availability also eliminates the requirement for transporting specialised equipment which therefore reduces transport emissions and costs (Smith and Taylor, 2023). There are however limitations as the tools utilised pose limited precision, resulting in inconsistencies and material wastage. The equipment also poses a high level of labour intensively, requiring more labour and increased costs.

This is in comparison to modular construction where specialised manufacturing equipment is required to enabled precise assembly, and specialised plant or vehicles are required for transport. This increases the logistics and costs associated with the project, such as the requirement to purchase CNC machines, laser cutters, cranes, heavy duty lifting equipment and specialised transportation vehicles. The initial and operational costs of the equipment is also generally a lot more expensive and is often in limited availability, especially in rural or remote areas. The reliance on such equipment could pose delays or increase the projects costs if required to import or rent specialised equipment (Miller and Wallis, 2019). The requirement for specialised equipment within modular construction does pose advantages in relation to a higher level of quality and production, and also reduces the requirement for on-site labour. This enables wastage, labour costs and material costs to be reduced, and durability to be increased.

4.2.8.2 Maintenance and Availability

The availability and maintenance of tools and equipment within Fiji pose great significance within the cost, feasibility and efficiency of differing construction methods, particularly within rural and remote regions. Traditional construction methods utilise basic equipment and tools, such as drills, concrete mixers and saws which are easily sourced and maintained. This poses an advantaged within rural areas in which specialised equipment may not be easily accessible or available. Due to a higher level of availability, downtime is reduced, and repairs are easily accessible. This enables disruptions to the construction duration to be reduced and increases the affordability of the project (Anderson and Lucas, 2017).

The workforce is also familiar with the use and maintenance requirements of such tools, reducing the requirement for specialised training, maintenance equipment and costs. This enables maintenance work to be completed on site, posing significant benefits when working in remote or rural regions. This demonstrates that there are significant benefits which include lower maintenance costs, higher adaptability within remote locations and readily accessible and available replacement parts, reducing potential delays.

However, modular construction requires an increased level of specialised equipment, requiring a higher level of specialised maintenance activities. This can incur additional maintenance costs and poses difficulties when requiring replacing parts, especially in remote areas (Miller and Wallis, 2019). Dependence on specialised labour and imported components also occurred, posing as a disadvantage and potential delays.

4.2.9 Labour Requirements

4.2.9.1 Skilled Labour

Evaluation into the labour requirements, and the need for skilled labour services, is essential in order to determine the projects feasibility. This is especially important within regions such as Fiji in which the availability of skilled labour and costs associated with training or externally sourcing specialise expertise poses great impact on a projects budget or timeline.

Traditional construction methods rely upon utilisation of locally available about and skills which is sustainable and cost-effective long term. The utilisation of traditional methods of construction within Fiji poses an advantage due to the workforce being familiar with local and cultural building materials and techniques, reducing the requirement for additional education or employment of labour which have specific expertise (Naidu, 2020). This includes traditional methods of constructions, such as bamboo weaving, and the knowledge associated with such, passed down through generations, to be increasingly available within communities. However, Fiji often loses a large sum of their workforce to neighbouring countries such as Australia and New Zealand due to the higher pay rates and desire to move outside of Fiji. This poses the availability of skilled labour to be limited or unpredictable. The costs associated with labour in country are affordable, however skilled labour rates are significantly higher (Naidu, 2020) yet not generally required.

On the other hand, modular construction by nature requires a skilled workforce with knowledge in assembly and fabrication techniques. This includes the requirement for project managers, supervisors', fabricators and assemblies which are trained and experienced within modular construction. This could increase training opportunities and the importation of workers with this specific skill; however, this comes at an additional cost (Bilau, Witt and Lill, 2018). Due to the nature of modular construction being completed with precise manufacturing techniques, when small errors occur, there are significant consequences, highlighting the requirement for a specialised and skilled workforce. This therefore incurs higher initial costs and a high experience on a skilled labour force. If delays are experienced within finding or importing skilled workers, impact to the overall construction timeline occurs, reducing the benefits of modular construction.

4.2.9.2 Labour Intensity

The level of manual labour required within modular or traditional construction poses impact upon the efficiency, cost and time of a project. Modular construction utilised off-site factory settings where machinery acts in the place of traditional labourers. This reduces the requirement for on-site labour costs, however, can impact sources of employment (Bilau, Witt and Lill, 2018). The benefits associated with labour intensity within modular construction include time efficiency, as projects are able to be completed in a reduced timeframe with limited risk of delays, and to a higher level of quality and precision. However, the requirement for skilled labours increases the projects labour costs, yet less labour is required overall. Modular construction, as previously discussed, is depended on skilled labour, which can delay a project if not available.

Traditional construction methods are labour intensive and require long periods of on-site work. This can assist in providing more local jobs, increase community engagement and benefits the economy, but can also increase the construction cost and timeline (Smith, 2016). The labour costs associated with hours per day across the project's duration is significantly greater than that of modular construction. The efficiency of such labour is also reduced and is more prone to project delays such as labour availability and weather due the sequential nature.

4.2.10 Maintenance Requirements

4.2.10.1 Long-Term Maintenance

The tropical climate of Fiji poses a significant impact to a buildings long-term maintenance requirement. This is due to the humid conditions, high level of rainfall and susceptibility to pests. Traditional construction methods utilise locally sourced materials, which while are locally sourced and sustainable, pose susceptibility to weather and decay (Naidu, 2020). This therefore increases the requirement for maintenance which results in a higher cumulative cost over the lifespan of the building. However, as the communities are educated within the maintenance of these structures, low cost and routine activities are easily accessible and able to be completed within the village. One example is the bure which is constructed throughout Fiji as a traditional building. Every three years, the timber is required to be resealed to prevent decay as a result of salt exposure, accumulating to FJD 12,000 (AUD $8,000) over a 20-year period (Naidu, 2020).

On the contrast, due to their precise fabrication techniques and use of advanced, durable materials, modular construction provides a lower requirement for maintenance. Due to the off-site, fabrication process, a controlled environment enabled an increase in quality control, reducing the need for frequent repairs and increases the structural longevity of the building (Miller and Zhang, 2023). This therefore is advantageous due to the reduced requirement for maintenance and associated costs because of increased durability and resistance to environmental factors. However, the initial cost of materials utilised within modular construction is at a higher price point. The availability to replace such materials may also pose increased costs and delays because of requiring importing.

This demonstrates that although modular construction poses higher initial costs, the associated maintenance costs and requirements over the lifecycle of a building is reduced. This is due to the increased level of durability and quality of the materials and high level of precision during the manufacturing and assembly of the structure. On the contrast, traditional construction methods require frequent repairs because of natural materials being prone to weathering, decay and pests. However, the materials and resources required to conduct maintenance, increase the cumulative costs over the building’s lifecycle.

4.2.10.2 Availability of Maintenance Services

The availability of maintenance services within Fiji is greatly dependent on the location and poses significant long-term impacts upon the durability and upkeep of a building. The maintenance services available for traditional construction methods is extensive due to the nature of the region and high availability of skilled local contractors and materials. The requirements associated are also greatly understood, enabling skilled labour for repairs and upkeep to be easily accessible within Fijian communities. This enables the souring of materials and contractors to be cost effective and costing 30-50% less then modular maintenance tasks (Smith and Taylor, 2023), eliminating the requirement to outsource or import materials or assistance. However, the frequency requirement and durability of such materials is higher than modular construction, increasing the cumulative maintenance costs over the building's lifespan.

This is in comparison to modular construction where the maintenance services are not as well known or accessible, incurring higher long term maintenance costs (Anderson and Wilson, 2024). This poses challenges in relation to accessibility and availability of maintenance services, posing reliance on specialised contractors and imported components, increasing costs and complexity. However, the frequency of repairs is often far less over a buildings lifecycle as a result of higher quality materials and controlled fabrication.

4.2.11 Safety

4.2.11.1 On-Site Safety

Varying construction methods pose impact to the project's efficiency and workers safety and wellbeing. Due to onsite nature of traditional construction methods, workers are exposed to a higher level of risks which are associated with manual labour, equipment, plant and weather (Naidu, 2020). Weather related incidents are at a higher risk within tropical climates such as Fiji due to frequent and unpredictable rain and storms, and a high level of humidity. Workers are outdoors, posing risks to heat exhaustion, slips and falls. Additionally, various plant, tools and equipment are utilised on site which require manual operation. Physical tasks including working at heights, heavy lifting and handling of tools increase risk related to falls, cuts and manual handling (Smith and Taylor, 2023).

The requirement for standard personal protective equipment (PPE) sch as boots, eye protection, gloves and helmets within general tasks can cost between FJD 300 (AUD $200) per person. When undertaking specialised tasks, such as working from heights, specialised PPE is required increasing associated costs. The costs associated with training workers and supervisors in work, health and safety matters are also cumulative, but essential to assisting the reduction of risk (Anderson and Wilson, 2024).

When undertaking on-site, traditional construction, there is a high advantage of being able to adapt safety practices based on protocols, legislation and familiarity. Accessing generalised PPE is also easily accessible, enabling works to continue without delay or impact to workers safety (Naidu, 2020). However, there is a higher risk of injury and increased costs associated with safety compliance.

Onsite safety is increased when utilising modular construction due to the reduction in the amount of work and elimination of high-risk activities. This is as the majority of the high-risk work is completed within a regulated factory setting in which standards can be efficiently enforced. This therefore reduces the risk of injuries, falls and weather exposure which can impact the safety of on-site labours Smith and Taylor, 2023). However, specialised safety equipment is required due to the nature of off-site manufacturing. This includes PPE suited to tasks such as cutting, welding and heavy machinery, costing between FJD 500 -700 (AUD $330 - $646) per person due to the specialised nature of the equipment.

However, significant advantages are evident due to lower risks associated with the onsite construction component and a higher level of consistent compliance with the safety standards. As the manufacturing facilities require strict safety protocols to be followed, incurring a higher level of training and compliance, and a reduction in human error. The initial investment of the required safety equipment is higher, posing a disadvantage.

4.2.11.2 Compliance with Safety Regulations

Ensuring compliance with safety regulations is essential within construction projects in order to ensure the safety of the workers and to maintain building standards. Due to the nature of modular construction consisting of off-site manufacturing, the ability to achieve consistent regulatory compliance due to a controlled factory environment is significantly advantages. This can be completed through efficient monitoring, routine inspections and immediate corrective actions if standards are breached (Miller and Whallis, 2019). This enables a standardized approach to safety, enabling consistent compliance and a reduction in on-site compliance requirements. As a majority of the high-risk work is completed off site, the onsite assembly as a reduced number of safety measures (Smith and Taylor, 2023).

This is opposed to traditional construction methods which although generally aim to comply with safety regulations, the enforcement of such varies and therefore risk to laborers increases (Bilau, Witt and Lill, 2018). Compliance with safety regulations depends on the oversight of the project, and enforcement capacity of the project managers. This is often dependent on available resources, location and weather, with challenges imposed upon the consistency of safety standard implementation and enforcement. This leads to a decentralized compliance oversight, where compliance inspectors may not travel to remote or rural areas leading to inconsistencies withing safety standard implementation. Additionally, within projects which have limited resources or may be community run, the compliance and oversight of regulatory standards will be limited or not existent. This can include the utilization of safety measure such as scaffold, to wearing PPE such as safety glasses and hardhats (Naidu, 2020).

4.3 Case Studies

4.3.1 Traditional Construction Methods

4.3.1.1 Case Study – Fijian Rural Housing Project

Traditional construction methods have been utilised within rural Fiji in order to construct residential housing which is well suited to the surrounding local environment, cultural and economic requirements of the community. This method of construction utilised locally sourced materials, including thatch, timber and bamboo which are easily accessible and abundant within Fiji in order to ensure sustainability and efficiency (Naidu, 2020).

The Fijian Rural Housing Project was initiated to assist in addressing rural housing needs within Fiji. The project aimed to target remote villages across the main islands of Vanua Levu and Vita Lavu, specially focusing on communities vulnerable to tropical storms and flooding. Through this multistage project, community engagement occurred to ensure skills were transferred, sustainability and local ownership of the project was achieved. The project was able to construct approximately 100 residential houses was completed in late 2020.

The buildings were designed using traditional Fijian architecture methodology and designs, focusing on cultural appropriateness and climate adaptability. This includes key features such as an elevated floor to act as a safeguard against flooding and an open and naturally ventilated interior to enable a reduction in the requirement for artificial cooling costs. When determining materials, it was essential they aligned with the design requirements to enable natural ventilation and insulation, along with ensuring they will withstand Fijis climate. This includes bamboo which is utilised within Fiji due to its high abundance, strength and flexibility, enabling it to be beneficial for use within areas prone to cyclones and high winds (Naidu, 2020). The use of bamboo and other locally sourced materials so assisted in maintaining ecological balance and supporting local industries through encouraging the use of indigenous resources (Bilau, Witt and Lill, 2018). Through doing so, material and transportation costs were kept low, and the residential buildings were environmentally sustainable and culturally appropriate.

Utilization of traditional construction methods within rural areas of Fiji also poses significant benefits regarding cost efficiency. Due to local materials being less experienced as opposed to alterative imported materials, the material costs associated with construction are kept low. Additionally, through relying upon traditional construction materials and techniques, housing is able to be kept accessible and affordable to communities which have limited economic resources. Additionally, the requirement for specialised labour is reduced to the knowledge possessed within the community (Anderson and Wilson, 2024).

As traditional construction methods and indigenous techniques are inherently sustainable, by utilisation of renewable resources and designing structures which align with the environmental conditions, the residential homes were able to possess a lower carbon footprint to those built using conventional materials (Smith and Taylor, 2023). This includes a reduced requirement for transportation and associated carbon emissions, and inclusion of design elements which contribute to social sustainability. By maintaining traditional practices, local heritage was able to be preserved and a sense of pride and ownership within the community was instilled (Naidu, 2020).

Therefore, it is evident that the Fijian Rural Housing Project demonstrates key advantages to utilising traditional construction methods to promote cultural and community cohesion while addressing local housing needs in a sustainable and culturally appropriate manner. Through utilisation of traditional designs and locally sourced materials, the project was successfully able to provide affordable housing which is in line with the communities cultural and social requirements.

4.3.1.2 Case Study - Australian Outback Housing

Australian outback communities face challenges in relation to the extreme, harsh environmental conditions. His includes aridity, extreme heat and limited access to materials. In response to this challenge, traditional methods of construction have been adapted in order to suit these conditions and incorporate site specific features (Anderson and Lucas, 2017). This can include deep, shaded verandas, and insulation techniques for hot climates. Though the adaption of these features, the resilience and flexibility of traditional construction techniques is evident within challenging environmental.

Within Alice Springs, a rural housing project initiative occurred within 2018 with the aim of providing culturally appropriate and sustainable housing to the indigenous communities which were experiencing housing shortages (Smith and Taylor, 2023). Throughout the project, traditional construction methods were utilised and adapted to be able to withstand the harsh outback climate, including deep verandas and rammed earth. Additionally, the houses were required to provide comfort and energy efficiency for the residents (Anderson and Lucas, 2017). The project was completed within 2020 and successfully constructed 40 houses within various Alice Spring Communities that was tailored to the residents cultural and specific environmental requirements.

This project demonstrated the potential to utilise traditional construction methods in order to address economic, environmental and cultural issues experienced within rural areas. The implementation of traditional construction methods such as rammed earth, and local labour enabled the project to produce climate appropriate and affordable housing which supports the lifestyle of the occupants.

4.3.2 Modular Construction Methods

4.3.2.1 Case Study – New Zealand Modular Housing Project

A modular housing project occurred within New Zealand which demonstrated the environmental and efficiency benefits of the alterative construction technique. The project commenced within 2023 and concluded within 2024, constructing 60 modular homes across various urban areas within New Zealand. The project aimed to address housing shortages experienced within a sustainable and efficient manner.

The project was successful completed in half the time traditional construction methods take, which is due to the parallel programming of site preparation and modular fabrication. As the modules are fabricated in a controlled environment, environmental benefits include a reduction in waste and enhanced insulation properties, along with high precision being achieved (Baker et al., 2024). Delays were experienced within the initial stages of the project due to a limited skilled labour shortage of individuals familiar with modular construction techniques. This was mitigated through the implementation of additional training to provide individuals with the required level of expertise.

Overall, the New Zealand Housing Project was able to demonstrate the benefits of modular construction in regard to accelerating project timelines and the environmental benefits. Although there were initial high levels of commencement costs and logistical challenges, the project demonstrated high advantages regarding reduction of waste, increased precision and energy efficiency. This enabled modular construction to be classified as a value construction method alternative within upcoming projects, enabling efficiency and sustainability to be balanced,

4.3.2.2 Case Study – Post Earthquake Rebuilding in Lombok, Indonesia

Lambok, located in Indonesia was subjected to a severe earthquake which impacted significant areas of residential housing and displacing thousands of residents. A total of 250 modular units deployed in 2018 shortly after the event throughout the locality to provide durable residential housing for residents who were displaced in an efficient timeframe (Anderson and Wilson, 2024). By doing so, the construction of resilient and safe home, in a quick timeframe was able to be achieved.

When designing these modules, local architectural styles were incorporated along with the development of community use spaces. This included local architectural styles such as traditional roof shapes and layouts, and community spaces to encourage social connection and support community functions, enabling the buildings to assist within the social and physical recovery of the community. This case study demonstrates the high level of adaptability that modular construction encompasses, enabling designs to be developed based on local conditions and cultural requirements, and demonstrates its successful use within disaster recovery.

4.4 Discussion of Results

4.4.1 Key Findings

Through undertaking the comparative analysis, it was evident that both modular and traditional construction methods pose display advantages and disadvantages. Traditional construction techniques offer an increased utilisation of local resources, adaptability to environmental and cultural conditions, being a resilient construction choice for continued utilisation within Fiji. On the other hand, modular construction is significantly efficient om regards to materials and time and upholds a high level of quality and safety. This makes modular construction well suited for projects which require a tight turnaround time or highly precise construction methodology. However, the initial costs associated with the required specialised equipment and logistical concerns within the connect of Fiji may pose limitations to the construction method.

The following table offers a summary of each factor which is compared within this analysis and details the outcome of all identified comparative criteria.

Table 4.6: Detailed Summary of Comparative Criteria

Cost Effectiveness	Initial Construction Costs	Traditional construction methods generally have lower initial construction costs, particularly within Fiji, due to the locally sources materials and less reliance on specialized manufacturing and transportation logistics.
	Lifecycle Costs	Modular construction methods offer increases lifecycle cost savings due to reduced waste and construction time, improved energy efficiency and maintenance. Traditional construction methods, although cheaper initially, will incur higher costs overtime due to inefficiencies and higher maintenance requirements.
Time Efficiency	Construction Timeframes	Modular construction methods offer significantly shorter construction timeframes due to offsite fabrication and onsite preparation occurring simultaneously.
	Impact of External Factors	Modular construction methods are less impacted by external factors (e.g. weather-related delays) due to the use of off-site construction methods.

Sustainability	Environmental Impact	Modular construction methods have lower impact due to reduced energy consumption, less waste production, and use of eco-friendly materials.
	Resource Utilization	Modular construction utilizes resources more efficiently due to precise off-site manufacturing methods, reducing waste and improving sustainability.
Quality and Durability	Structural Integrity	Modular construction offers greater structural integrity due to precise off-site manufacturing methods, and increased quality control.
	Adaptability to local conditions	Both construction methods can be adapted to local conditions, with traditional methods, e.g. bure, incorporating culturally developed features suited to the environment and materials, while modular construction requires additional design and preparation to address specific conditions such as seismic activity or climate.
Social and Cultural Acceptability	Community Perception	Traditional construction methods are widely more accepted due to heritage and cultural connections, while modular construction is a new technique which can be altered to align with traditional architectural styles.
	Cultural Compatibility	Traditional construction methods are widely

		more compatible due to deep integration within social and cultural practices (e.g. bure), while modular construction can be adapted to meet cultural requirements.
Materials	Material Types and Sources	Traditional construction uses locally sources material which are well suited to local conditions, adorable and have a lower environmental impact.
	Material Efficiency	Modular construction is very efficient in regards to materials due to precise off site manufacturing and controlled environmental which aim to minimize waste.
Transport	Logistics and Costs	Traditional construction methods offer simpler and more cost-effective logistics by using smaller, locally sourced materials transported via conventional methods.
	Environmental Impact of Transportation	Traditional construction methods have a lower environmental impact due to the use of locally sourced materials which are able to be transported in smaller, less energy intensive loads.
Equipment and Tools	Specialist Equipment	Traditional construction methods require commonly available tools, whereas modular construction require specialized fabrication, transportation and installation equipment

		increasing costs and complexity.
	Maintenance and Availability	Traditional construction methods are easier and cheaper to maintain, with materials and parts available and the workforce is trained to install such.
Labor Requirements	Skilled Labor	Traditional construction methods rely on locally available, familiar skills.
	Labor Intensity	Modular construction requires reduced labor by utilizing off-site fabrication.
Maintenance Requirements	Long Term Maintenance	Modular construction offers better long-term benefits due to the use of durable materials and off-site manufacturing.
	Availability of Maintenance Services	Traditional construction methods offer better availability due to the widespread presence of skilled contractors and materials.
Safety	On-site Safety	Modular construction poses better safety due to reducing high risk activity and exposure to hazards through off-site construction in a controlled environment.
	Compliance with Safety Regulations	Modular construction ensures increased compliance due to close monitoring and control within off site environments.

4.4.2 Implications for the Fijian Construction Industry

The utilisation of modular and traditional construction methods in Fiji will be primarily based on the project's requirements and constraints. Within urban areas or post disaster event scenarios, where efficiency and speed are key factors, modular construction is the preferred choice. Within rural and culturally sensitive projects, the balance traditional construction methods can officer in relation to sustainability, cultural relevance and cost is superior. This demonstrates that the implementation and utilisation of both methods poses advantages within Fiji and the determination of what method should consider the analysis's outcomes.

4.4.3 Recommendations

Based on the comparative and case study analysis conducted, the following is recommended as a result:

- Disaster Recovery: Modular Construction should be utilised due to its speed and resilience. Prefabricated components have the ability to be stockpiled and utilised within emergency for a quick response.
- Urban Development: Modular Construction should be utilised due to its quality and efficiency, reducing transportation costs and assisting in supporting the local economy.
- Rural and Cultural Projects: Traditional construction methods should be used, focusing on local labour and materials.

4.5 Conclusion

4.5.1 Summary of Analysis

Through undertaking this analysis between traditional and modular methods of construction, the advantages and disadvantages of each were able to be identified, within the context of the Fijian construction industry. Although modular construction poses significant benefits in relation to safety, sustainability and efficiency, traditional methods have their value within their high level of adaptability and integration within the cultural roots of the Fijian industry.

4.5.2 Final Assessment Determination

Within Fiji, both traditional and modular construction methods have their place. The determination of which method for use should be determined based upon the project's needs, opportunities, location and limitations. Consideration should be made into the time, cost, sustainability and cultural requirements of the project to ensure the best method is chosen. Alternatively, a hybrid approach which utilizes both the strength of both techniques can also be implemented and poses as an effective solution to addressing the challenges currently faced within the Fijian construction industry. If implementing modular construction within Fiji, measures need to be implemented to counteract the aspects in which traditional construction methods triumph. This can include the following examples:

- Materials: utilisation of locally sourced and sustainable materials as imposed to specialised materials.
- Skilled labour: offering subsidised training to increase the number of skilled labourers within the modular construction sector.
- Maintenance costs: implementation of initiatives to ensure modular components are easily accessible and readily available.

4.5.3 Future Research Recommendations

From the above analysis, it has been identified that there are further research areas which are recommended to be completed in order to support this analysis. This includes on-site investigation and data collection in order to assist in the validation of the literature review and analysis findings. As a part of this dissertation, funding was applied for in order to revisit Fiji and conduct in country investigations. However, this funding was not successful, being a known project risk, and due to limited response from Fijian contacts, no in country work was able to be completed to support the dissertation findings. Utilisation of the study tour peer group to evaluate this project outcome was aa planned contingency and enabled educated individuals to assess the solution and research.

Additionally, it would be recommended that investigation into case study applications occurs in order to determine possible opportunities, shortfalls and applications. This could include Fiji, remote Australia or other similar countries such as the Philippines or Nepal. It is important to note when conducting in country case study investigation, that Fiji does pose specific limitations regarding resecures availability and transport infrastructure which is varying from country to country.

Chapter 5

Modular Housing Design Proposed Solution

This proposed modular residential design solution for Fiji's construction industry has been developed in line with traditional Fijian building layouts and inclusions and would be considered a base model. Site specific and geotechnical conditions have not been specifically considered or designed for within the proposed solution. There is a further possibility of expansion with this model, including the addition of bedrooms or increasing the size of the living space, as demonstrated within the proposed alterative configuration. The plan set for the proposed design contains the following:

- Floor Plan: scaled diagram which displays the room arrangements in the building, demonstrating the room and spaces relationships, path of traffic and location of fixtures.
- Elevations: 2D representation of the building from a vertical orthographic plane, illustrating the exterior façade of the structure.
- Alternative configurations: floorplan diagrams which display potential alternative layouts which can be developed using the proposed modules.
- 3D Representation: demonstrates the proposed design to assist in the visualization of the finished product.
- Finishes and Fixtures Schedule: A list of the required major fixtures and fittings, such as cladding and framework and their associated specification.
- Environmental Safeguards: mitigation measures required to be implemented to act as a safeguard towards the environment in which a project occurs within.

Through providing the above, an overall picture of the proposed modular design is able to be achieved, supporting the key comparative and case study analysis findings and proposed mitigation measures. The design is further evaluated with key components highlighted within section 5.7 of the dissertation.

5.1 Floor Plan

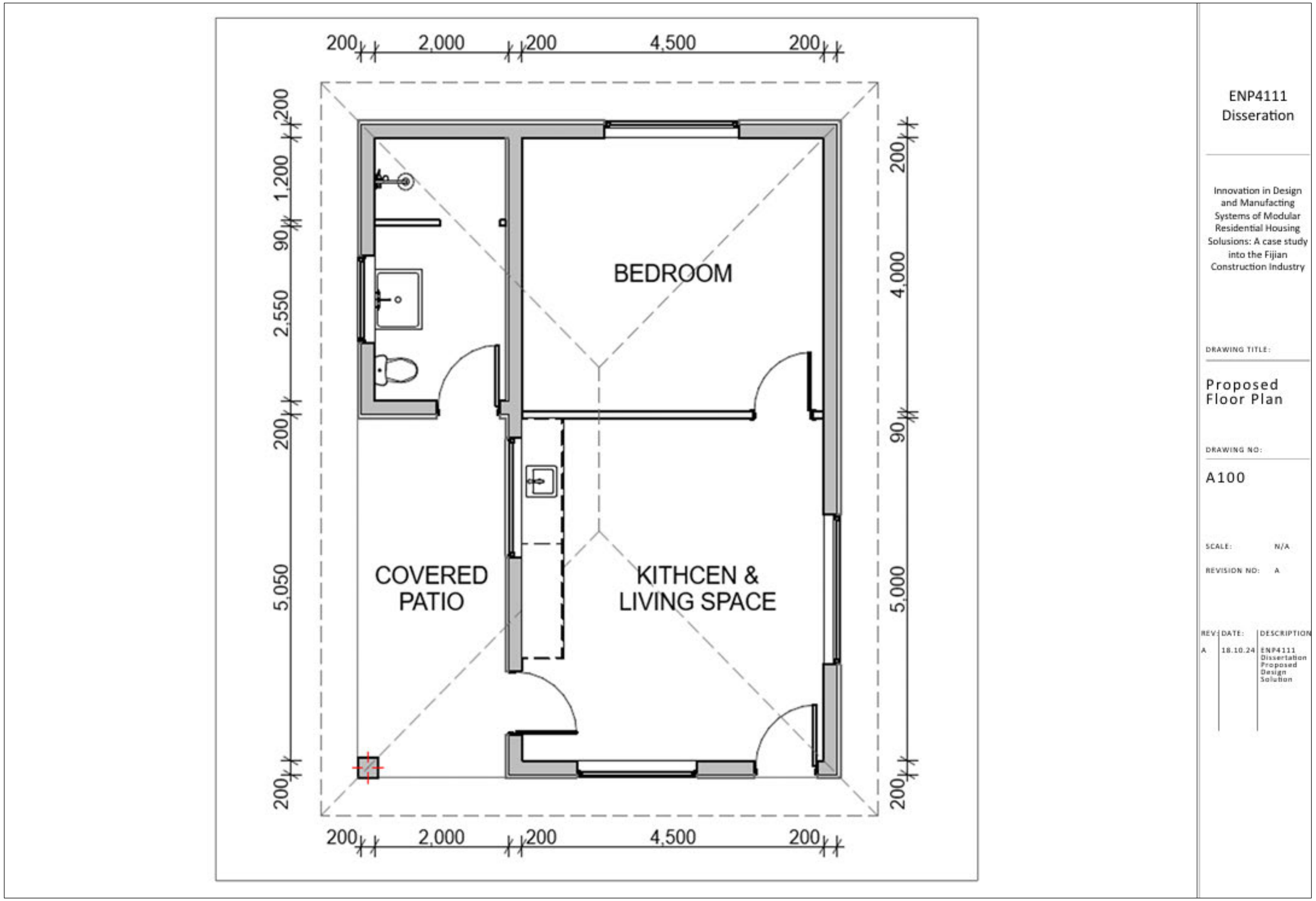

Figure 5.1: Proposed Modular Construction Floor Plan (Battersby, 2024)

5.2 Elevations

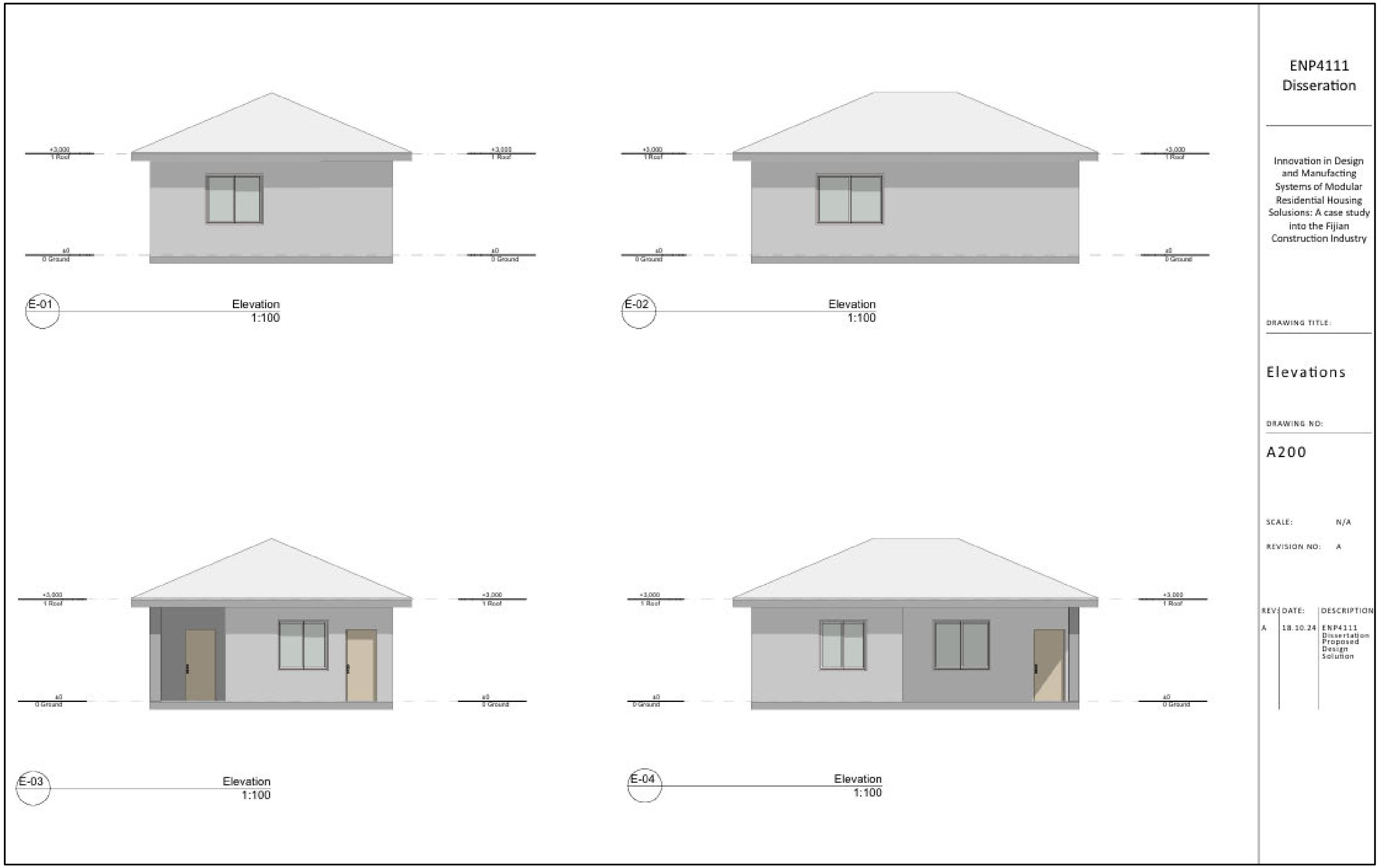

Figure 5.2: Proposed Modular Construction Elevation (Battersby, 2024)

5.3 Alternate Configurations

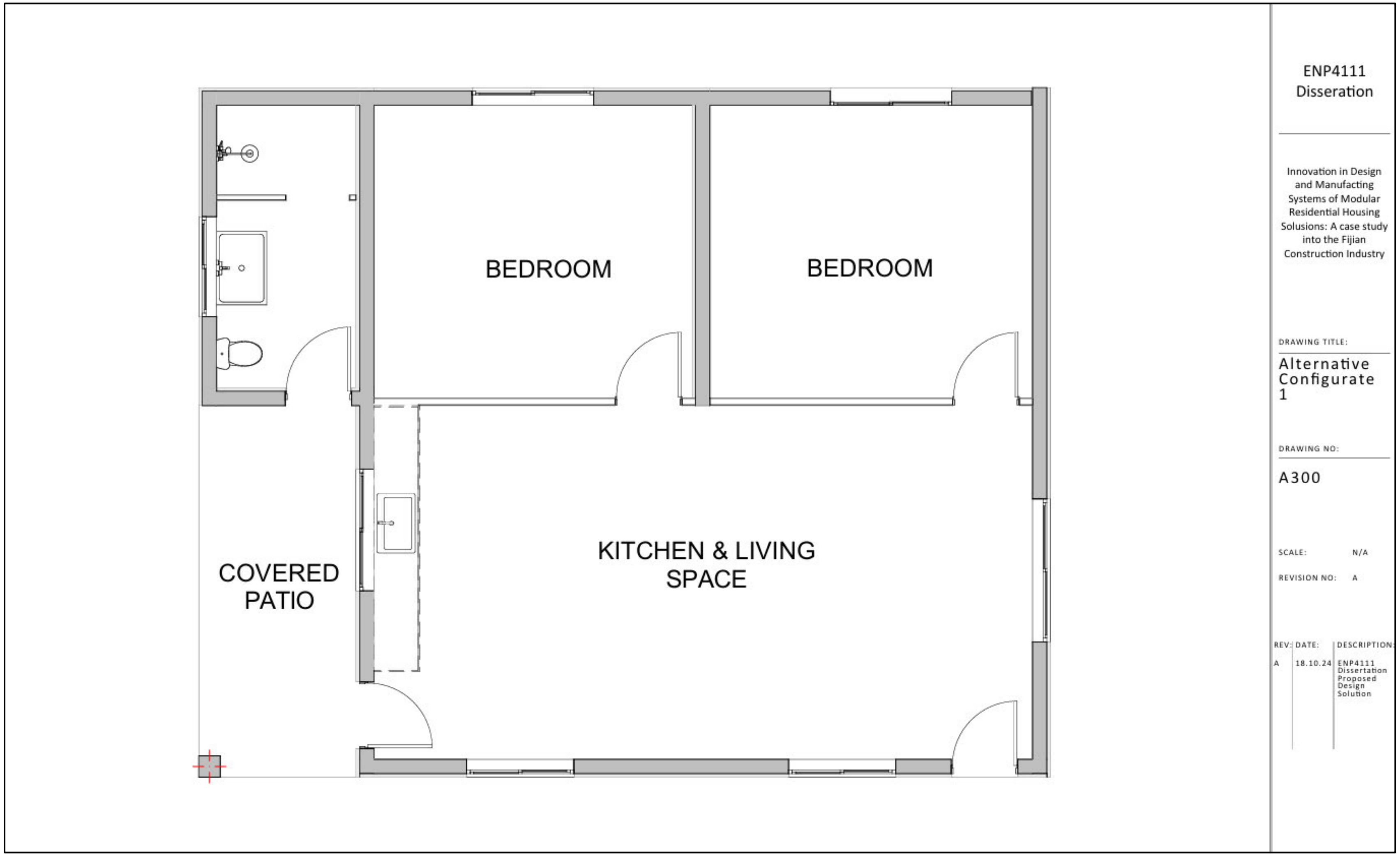

Figure 5.3: Proposed Modular Construction Alternative Configurate 1 (Battersby, 2024)

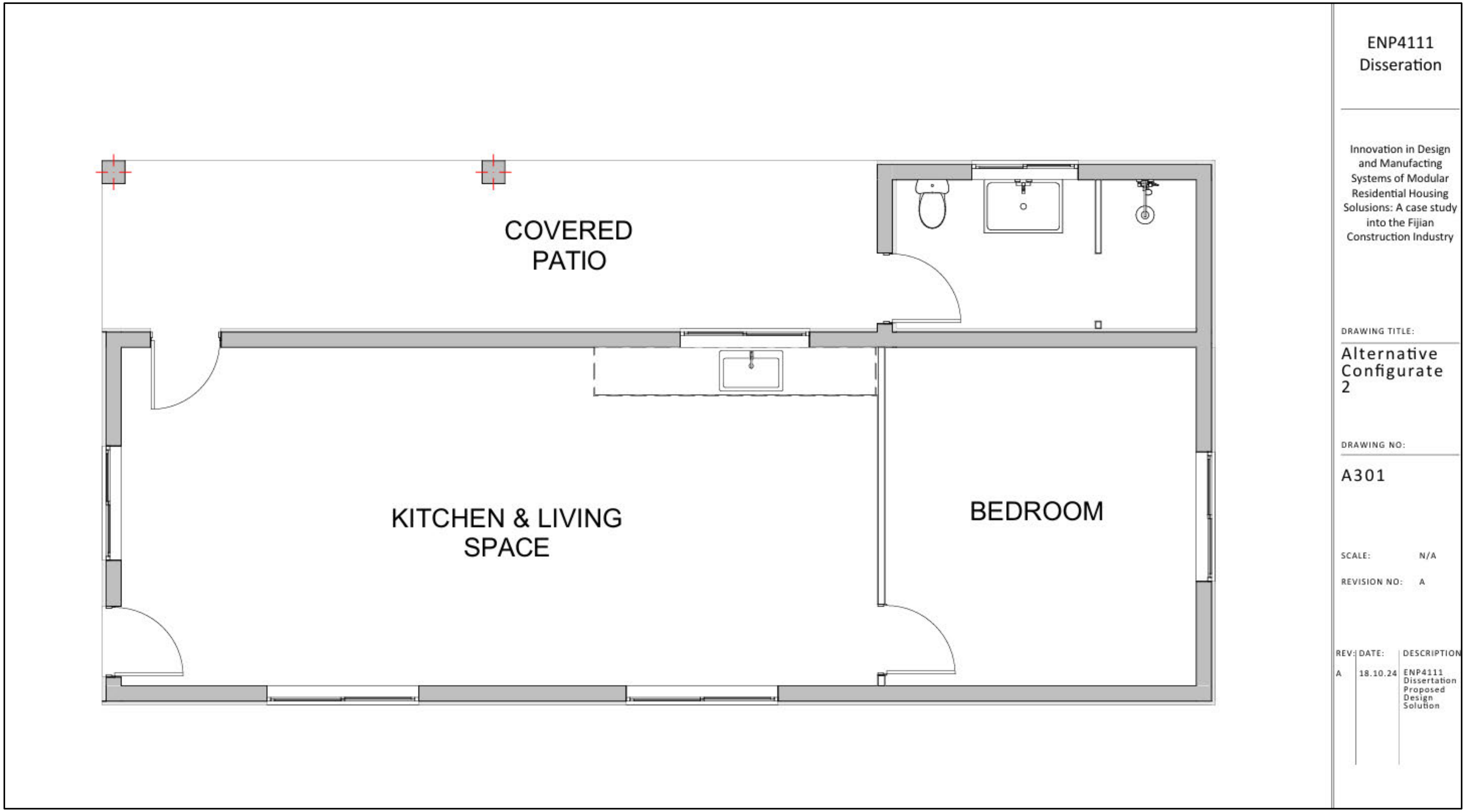

Figure 5.4: Proposed Modular Construction Alternative Configurate 2 (Battersby, 2024)

5.4 3D Representation

Figure 5.5: Proposed Modular Construction 3D Representation – Front (Battersby, 2024)

Figure 5.6: Proposed Modular Construction 3D Representation – Rear (Battersby, 2024)

5.5 Proposed Fixtures and Finishes Schedule

The below proposed fixtures and finishes schedule has been developed with the aim to utilise local, readily renewable materials, and ensure the fixtures dictated are to an environmentally efficient level. The aim is for the schedule to act as a base line for the fixtures and a guideline for the finishes based upon the research which has been conducted within this dissertation and the opportunities evident for innovation and growth within this sector of the Fijian construction industry.

Table 5.1: Finishes and Fixtures Schedule

Item	Material	Specification
External Cladding	Bambo CLT Nano-tech bamboo fibreboard Light Colour	Require treatment for pest and humidity resistance, and reinforcement to meet Fiji's cyclone building codes
Internal Walls	9mm Plasterboard	Moisture resistant with anti-mould coatings, compliant under NBCF
Framework	Bamboo	Require pressure-treatment for pest and rot, and marine-grade protective coating for moisture resistance as per NBCF
Insulation	Coral Stone	Locally sourced, as per NBCF
Floor Coverings	Coconut Timber	Require treatment for pests and humidity, seal with high-quality polyurethane or water-resistant finish
Reinforced Slab	Concrete with volcanic ash	Ensure MPa and reinforcement to NBCF and Fiji's cyclone building codes
Window Frames	Steel Frames	Power coated or galvanised, meet Fiji's wind pressure standards

Window Glazing	Double Glazed	Impact resistant glass (tempered or laminated), compliance with NBCF glazing requirements
External Doors	Bamboo CLT, hollow core	Require reinforcement and treatment for pest and humidity, wind resistant fixtures
Internal Doors	Bamboo CLT, hollow core	Require treatment for pest and humidity, include seals
Electrical Systems	-	Compliance with AS/NZS 3000 (Wiring Rules) to ensure safety and functionality
Plumbing Systems	Piping	Compliance with AS/NZS 3500 for Water and sanitary plumbing and drainage
Cabinetry	Kitchen	Kitchen floor cabinet with stainless steel sink and vinal countertop.
Appliances	Kitchen	To be supplied by the client – energy efficiency and water saving appliances recommended.

5.6 Environmental Safeguards

The environmental safeguards contained in the below table are applicable to all construction projects and consider various factors for the proposed work. It is recommended that the listed safeguards and associated documentation is adhered to and produced for and within the on-site construction process to prevent environmental impact from occurring, and to align with the Fijian Governments sustainability goals.

Table 5.2: Recommended Environmental Safeguards (Local Government NSW, 2024)

Safeguards for the proposed work	
General	• An environmental management plan is prepared and implemented prior to the commencement of works. • No new access tracks to be created for the works without approval and necessary due diligence occurring. • Parking of vehicles and storage of plant/equipment is to occur on existing paved areas. Where this is not possible, vehicles and plant/equipment are to be kept away from environmentally sensitive areas and outside the dripline of trees. • All project staff and contractors will be inducted on the environmental sensitivities of the work site(s) and relevant safeguards prior to commencement. • The Project Manager will be notified immediately of any complaints relating to management of environmental issues • The Building Manager must be notified of any pollution incidents that have caused or threaten material harm to the environment. • The Asset Manager will be notified if damage occurs to an area (vegetation, etc.) outside of the nominated work area
Soil	• Site management will incorporate best management erosion and sediment control practices such as those found in the Landcom's "Blue Book (4th Edition) on erosion and sediment control. • Linear silt stop fencing to be installed down slope of all affected areas and stockpiles. Silt fencing will be installed before any excavation begins. • Sandbags, hay bales wrapped in geotextile fabric etc. will be used to slow water flow and trap sediment. No straw bales are to be used.

	• All erosion and silt control devices will be visually inspected weekly to ensure effectiveness as well as after each rainfall event. • The rehabilitation of disturbed areas and stockpile locations will be carried out progressively as construction stages are completed, and in accordance with Landcom's "Blue Book (4th Edition) on sediment and erosion control. • Construct temporary drainage structures in accordance with the associated specification. • Overburden will be placed in the form of a bund upslope of the site where necessary to reduce surface water entering the site. • If it is anticipated that Potential Acid Sulfate Soils will be disturbed, an Acid Sulfate Management Plan will be prepared. • If contaminated areas are encountered during construction, appropriate control measures will be implemented to manage the immediate risks of contamination. All other works that may impact on the contaminated area will cease until the nature and extent of the contamination has been confirmed and any necessary site-specific controls or further actions identified in consultation with relevant government agencies.
Waterways and water quality	• Visual monitoring of local water quality (ie turbidity, hydrocarbon spills/slicks) is to be undertaken on a regular basis to identify any potential spills or deficient erosion and sediment controls. • Water quality control measures are to be used to prevent any materials (eg. concrete, grout, sediment etc) entering drain inlets or waterways. • Wash down should use potable water and excess debris removed using hand tools. Wash down waste must be filtered before release, and away from all waterways.

	• No dirty water may be released into drainage lines and/or waterways. • Prevent sediment moving off-site and sediment laden water entering any water course, drainage lines, or drain inlets. • Reduce water velocity and capture sediment on site. • Minimise the amount of material transported from site to surrounding pavement surfaces. • Divert clean water around the site. • Store fuels, chemical and hazardous materials in secure, bunded areas within temporary construction ancillary facilities, and at least 50m from all waterways. • Capture and dispose of spill and contaminated materials from temporary construction ancillary facilities at a licensed facility. • Provide spill kits around temporary construction ancillary facilities. • Measures to control pollutants from stormwater and spills will be investigated and incorporated in the pavement drainage system at locations where it discharges to the receiving drainage lines. Measures aimed at reducing flow rates during rain events and potential scour will also be incorporated in the design of the pavement drainage system.
Air quality	• Measures to minimise or prevent air pollution or dust are to be used including watering or covering exposed areas. • Works are not to be carried out during strong winds or in weather conditions where high levels of dust or air borne particulates are likely • Vegetation or other materials are not to be burnt on site. • Vehicles and vessels transporting waste or other materials that may produce odours or dust are to be covered during transportation

	• Vehicles and equipment are to be maintained in good working order. • Monitor work areas and stockpiles for dust generation and seed/cover/spray to suppress. • Measures (including watering or covering exposed areas) are to be used to minimise or prevent air pollution and dust • Do not leave vehicles idling

Biodiversity	<u>General:</u>
	• Prepare a Vegetation Management Plan (VMP) to:
	    • Identify measures to manage vegetation within the road reserve;
	    • Detail restoration, regeneration and rehabilitation of areas of native vegetation that will be removed to accommodate the proposed works.
	    • Detail appropriate management for the potential habitat of threatened flora and fauna species that will be indirectly impacted by the proposal. This may include fencing and signage.
	    • Identify weed management strategies.
	• As part of the site induction process, provide all site personnel with information on the biodiversity values of the study area, including threatened species, no-go areas and responsibilities under relevant environmental legislation and associated management plans for individual species.
	• Should unexpected, threatened fauna be located at any time during construction, cease work immediately in the area to prevent further harm to the individual. Contact the Environmental Officer and a suitably qualified ecologist to determine if further assessment or management plans are required.

	<u>Clearing of Vegetation: Pre-clearing:</u>
	• Qualified fauna experts are required to conduct pre-clearing surveys and undertake fauna handling if required. This may include:
	  ◦ Hollow bearing tree survey;
	  ◦ Stag-watching survey (targeted threatened species) in order to identify the number and type of nest boxes required and appropriate locations to install them.
	• Where clearing is required, establish exclusion zones to ensure clearing does not extend beyond the approved area.
	• Trees that are to be trimmed (or removed if necessary) will be clearly marked. Any vegetation to be protected adjacent to the work area will be protected with exclusion fencing.
	• Exclusion fencing will be placed at or beyond the drip lines of the protected vegetation so as to prevent damage to their root systems.
	• Any trees with hollows are to be checked for native fauna prior to being removed. If any fauna is found, works will stop and wildlife protection services will be contacted. Refer to any company specific policy requirements for hollow bearing trees and amend mitigation measures accordingly.
	<u>Clearing of vegetation – general safeguards</u>
	• Remove minimum required vegetation and minimise disturbance to remaining vegetation
	• If any damage occurs to vegetation outside of the boundaries of the work site as a result of the implementation of the proposal, the Project Manager will be notified and will establish strategies for mitigation of impacts and site restoration.
	<u>Loss of threatened species and their habitats:</u>
	• Minimise removal of native vegetation and fauna habitat.

	• Implement exclusion zones to protect threatened ecological communities and threatened species habitat. • Remove trees in the presence of a qualified ecologist or wildlife expert experienced in the rescue of fauna. • Where reasonable and feasible, retain mature and hollow bearing habitat trees, including dead stags. • If hollow bearing trees are being removed, provide nest boxes to mitigate impacts, as determined by the pre-clearing survey. • Works are not to harm threatened fauna. • Works are not to create a barrier to fauna movement. Invasion of Exotic Species: • Manage vegetation within the road reserve and adjacent to areas of vegetation clearing to reduce invasion of noxious weed species. • Use weed-free topsoil in landscaping and revegetate disturbed sites with locally indigenous species. • Construction machinery should be washed prior to entering and leaving site to ensure weed propagules are not transported. Stockpiling: • Only place stockpiles in low value vegetation, where cleared sites are unavailable. • Stockpiles should be no taller than 2m height. • Use existing stockpiles before creating new ones. Site Restoration: • The rehabilitation of disturbed areas will be carried out progressively as construction stages are completed.
Traffic and transport	• Where possible, current traffic movements and property accesses are to be maintained during the works. Any

	disturbance is to be minimised to prevent unnecessary traffic delays. • If traffic disturbance is unavoidable, a Traffic Management Plan (TMP) will be prepared and implemented on site. • Comply with Council requirements regarding traffic control, access and road/ pedestrian access. • Erect signs regarding proposed works, temporary road closures, diversions etc.
Noise and vibration	Notification: • All sensitive receivers (e.g. local residents) likely to be affected will be notified at least five working days prior to the start of any works associated with the activity that may have an adverse noise or vibration impact. Standard Hours of Operation: • Works to be carried out during normal work hours (i.e. 7am to 6pm Monday to Friday; 8am to 1pm Saturdays). Any work that is performed outside normal work hours or on Sundays or public holidays may not be permitted and, if permitted, works are to minimise noise impacts. Out of hours: • Where out-of-hours activities are required, a Noise and Vibration Management Plan will be prepared and implemented in consultation with sensitive receivers.
Socio-economic	• Contain all work within the boundaries designated on the site plan • Restore work sites to as close to their original condition as possible • Display public information signs until site restoration is complete

	• Carry out community and stakeholder consultation before works start • Notify the Works Supervisor and Asset Manager immediately of any complaints or any accidental damage to property • Locate services and peg out no-go areas to avoid service-disruption • All staff will exercise courtesy in dealing with the community
Landscape character and visual amenity	• Contain all work within the boundaries designated on the site plan • Restore work sites to as close to their original condition as possible • Minimise spread of stockpiles, waste, and parking
Waste	• All surplus material, off cuts, and other debris resulting from the work shall be removed from site and disposed of by a licensed contractor to a licensed waste management facility. • Waste material, other than vegetation and tree mulch, is not to be left on site once the works have been completed. • Working areas are to be maintained, kept free of rubbish and cleaned up at the end of each working day.

5.7 Design Evaluation

5.7.1 Modular Construction Method

This design has been developed on the basis that the nodules are constructed in an off-site manufacturing facility and transported to site for construction. The detail component of this design has not been developed; however, it is proposed the modules fit together in an interlocking system. The modular construction method therefore has the following proposed steps:

- Design review and approval by client: The client is given the opportunity to alter the standard design, as demonstrated within the proposed alternative configurations. All room sizes are standard dimensions which enables additional bedrooms to be included or the living space to be expanded.
- Source materials: Locally soured materials are proposed for the majority of the components, as detailed within the fixtures and finishes schedule.
- Off-site manufacturing of modules: The modules are manufactured within an off-site facility, in which a high level of quality control is undertaken to ensure all modules are compliant with the relevant standards. This includes a heavy focus on work, health and safety, waterproofing, and ensuring the modules are able to withstand disaster events such as cyclones and heavy rain events.
- Site preparation: the site is prepared in conjunction with the modules being manufactured. This includes the installation of erosion and sediment controls. excavation works, and preparation of either a base slab or piers, depending on the ground conditions engineers design, and flood risk.
- Transportation of modules to site: The modules are transported to site flat pack style via a standard medium rigid (MR) vehicle with a built-in crane.
- Placement of modules: The modules, which includes all internal and external walls, doors, windows, ceiling and roof elements, are cranes off the rear of the MR vehicle and into secured into position on site. This enables the home to reach the ‘lock up’ stage within a standard day of work.
- Internal fit out: The internal fit out of the building, including kitchen, sanitary, electrical and plumbing works are than completed. This can be completed in conjunction with the modular home (recommended), or client supplied.
- Hand over: the building is then ready for occupancy, with a final walk through with the client, and official hand over.

By utilising this method of construction, the onsite construction duration and associated labour requirements, costs and delays are able to be reduced significantly. Additionally, a high level of quality control and compliance is able to be achieved due to the nature of off-site manufacturing as opposed to on-site constriction. This is particularly important due to Fiji's high susceptibility to natural disasters and limited accessibility to regulatory bodies and compliance checks within rural and remote areas.

5.7.2 Material Selection

The materials selected and identified within the fixtures and finishes schedule for the proposed modular design have a key focus upon sustainability and structural integrity. The majority of the materials are able to be sourced locally within Fiji, eliminating the requirement for additional freighting costs and emissions. Additionally, the materials are therefore naturally favourable for utilisation within Fiji's climate, having high flexibility and resistance to winds, pests and humidity. Through off-site manufacturing, the utilisation of materials is able to be completed optimally. This occurs through precise measurements, reducing wastage and increasing the productivity of the materials.

5.7.3 Required Fabrication Plant, Tools and Equipment

The requirements for fabrication plant, tools and equipment varies between the different stages of the project. This is broken down into the following stages, with the aim of all works being completed in Fiji to support the economy and reduce potential carbon emissions. While an initial investment, the benefits of being able to fabricate all components within Fiji is extensive. All associated PPE for the subsequent tasks will also be required to ensure all work is being completed as per the relevant work, health and safety standards.

- Manufacturing: Manufacturing plant, such as a CNC machine or other alternative technology powered by an energy efficient power source, and lifting equipment such as a crane will be proposed for development within Fiji.
- Site Preparation: Site preparation will include plant such as an excavator, skid steer and trucks, and hand tools such as a shovel.
- Transportation: A MR truck (at a minimum) with a fitted crane is required, along with all other supporting items such as straps, and supports, and water methods, e.g. Roro Ferry.
- On-site installation: The truck as detailed above will be required to assist in the movement of the modules. Standards hand tools such as a drill will be required to fit the modules to the base structure.
- Fit out: Standard hand tools will be required to fit out the structure, this includes a drill, wrench and pliers for example based upon the required actions.

From the above, it is evident that specialised tools and equipment will only be required within the manufacturing stage of the project. The remainder of the tasks, including the on-site installation, will utilise standard tools and equipment. This has been determined based on the potential limitation surrounding specialised equipment on site and alleviate some of the specialised on-site labour requirements. This is especially important within rural and remote areas and the extent of equipment required to be transported will be reduced as the availability of standard tools is increasingly higher.

5.7.4 Required Labour

The labour requirements will be split between the off-site manufacturing, and on-site construction components of the project. During off-site manufacturing, skilled labour who are competent within modular manufacturing will be required. Labour which are licenced to operate the nominated plant and vehicles, including excavators during on-site preparation and MR licenced drivers to transport the modules to site, will be required. Lastly, during the on-site construction process, including the installation and internal fit out, will required skulled labour within general construction duties and modular construction.

Due to the efficient nature off-site, the required number of labourers required will be required as apart of this project. This will enable less workers being required per project, increasing the amount of work which is able to be completed. Additionally, as additional education within modular construction will be required to assist within the construction of this projects, it will be proposed that fee-free education is provided to the workforce. This will enable upskilling and skilled labour to be obtained for the on and off-site components, reducing the likelihood of labour relayed delays.

5.7.5 Transportation Method

The materials required for manufacturing the modules will be sourced locally were possible, reducing the requirement for international freight. All modules have been designed to be contained within the bed of a standard medium rigid (MR) vehicle with the maximum panel being 5m x 2.4m. Due to the high availability on the main island and condition of the road network, this method of transport will be deemed efficient for transport. However, when transporting modules into rural or remote areas of the main islands, when the road infrastructure may be unreliable, or to alternative islands, other methods of transport need to be considered. This include helicopters, sea plane, roro ferries and boats which will all serve a unique purpose, have their own limitation and be utilised within differing areas. The requirement for modules to be transported via shipping container has been eliminated due to the extensive infrastructure required to enable efficient access and configuration.

5.7.6 Maintenance

The modules have been designed to withstand disaster events; however, it is also proposed that they are designed to be sacrificial. Due to the realistic nature of receiving residential maintenance, the modules have been designed with long lasting materials and additional coating/finishes in order to extend the lifecycle of each component. The design and construction of the modules has kept in mind traditional construction techniques and aims to mirror traditional methods to assist in village based maintenance works. Additionally, as the modules are made in a standard size, replacement of a module is easily obtainable. The notion of when a module requires maintenance (beyond general wear and tear) and requires replacement, this module will be removed and replaced with an identical. The old modules will then be returned to the manufacturing facility for repair and utilised to repair another home.

5.7.7 Sustainability

The proposed modular construction design aims to promote a high level of energy efficiency during operation, and circular lifecycle for the modules. The proposed materials are to be sourced locally, were possible, and manufactured in Fiji. The manufacturing plants are proposed to have renewable energy alternatives, such as solar panels, to assist in reducing the environmental impact of manufacturing. Additionally, through off-site manufacturing, material wastage is able to be reduced, and efficient material use planning achieved to enable all components to be used. Through one large load being transported to site, the transport relayed emission and impact are also able to be reduced. Lastly, due to the replacement/interchangeable nature of the modules, the repair and reuse is able to extent the useful lifetime of the product. This assists in reducing landfill and ensures the lifecycle of the materials are able to be utilised to their fullest extent. Through this approach it is evident that carbon emissions and material wastage will be reduced, and the modules are able to continually serve a practical function within the community.

5.8 Natural Disaster Application

The proposed modular construction design has been developed with an application in assisting with disaster resilience in mind. As analysed, modular construction has been utilised within various applications globally to assist in alleviating the impact disaster events have upon a community. This has been considered in the following key aspects:

- All components are to be designed to meet and exceed the applicable standards in relation to wind load and earthquakes.
- All components are to be designed to be sacrificial within a major event, this is to prevent any additional damage occurring which could have been avoided if one component (e.g. roof element) was designed to give way.
- All components are to be designed to be interchangeable and easily replaceable.

Based on the above, it is proposed that initiatives are implemented to construct modular housing within highly impacted communities prior to events occurring. The Red Cross have an initiative in which shipping containers full of essentials are scatters throughout the island to provide communities with essentials in the event of a natural disaster. A similar initiative can be applied within a modular construction related context. This includes the implementation of containers throughout the islands which contain modular construction homes, which contain key modules such as roof elements and wall components. In the event of a natural disaster, when components become damaged, communities are able to access these containers and utilise the modules to repair their homes. The old modules will then be collected by the manufacturing plant for repair and reuse.

Throught the above proposed application, the impact disaster events have upon residential houses will then be reduced due to the increased efficiency of repair works. Traditionally, homes could go months or even years without receiving the required repair works to enable the shelter to be deemed as habitable again. By providing the communities with ‘replacement parts,’ homes are able to be repaired quickly and efficiency, reducing the amount of time required to be spent on reacting and increasing the amount of time the communities have for developing and living.

5.9 Design Feedback

Feedback was requested from the participants of the 2023 Fiji Engineering Study Tour in regard to the proposed solution. This enabled further evaluation to occur on the design to ensure it is deemed fit for purpose for implementation in Fiji. From the feedback provided, the design itself was considered to be simple, and effective, considering all conditions at hand. Consideration was recommended into the electrical and plumbing components of the design, which would propose a unique set of circumstances depending on the village and services available. It was also suggested additional windows are included for locations which do not have access, or have limited access, to electrical to enable natural sunlight to enter the building.

The cultural elements of the design, such as an open living space and a second doorway for the elders to utilised were also asked to be spoken upon. The participants classed the importance of including cultural aspects into the design as extremely and somewhat important. This was based on the fact that although the major cities are transitioning into a more westernised design style, the communities are still heavily linked to their culture and architectural cultural beliefs. The feedback provided on the proposed design agreed these cultural aspects were sufficient and recommended that further feedback is sought from consultation with Fijian villages.

The transport challenges within Fiji were deemed to be very important by the participants in regard to the consideration of delivery and installation of modular homes. The most practical modes of transportation within Fiji were discussed to be vehicles such as Utes, trucks and boats. The proposed design was developed to be transported via a standard MR truck, in which the responders deemed as good and a commonly available mode of transport. It was suggested that for more rural and remote areas, other forms of transport which are more capable for the terrain, such as a 4x4 are considered, and for transportation between island, boats are considered. The largest challenges noted for implementation within Fiji include establishment and operation of the manufacturing facilities, obtaining educated and skilled labour, the poor road conditions and limit infrastructure, and community and culturally acceptance. The proposed design aimed to mitigate these challenges, with community engagement and consultation proposed to ensure the design is developed inline with cultural requirements to ensure acceptance.

The application of instilling adorable housing which can assist in offering a solution to natural disaster impacts was asked. The participants were in favour of modular construction being utilised for both these benefits, with different funding initiative encouraged to be explored to assist with the implementation of this construction method. While being an initial investment, the construction of manufacturing facilities in Fiji has been deemed as beneficial with the ability to offer the community long term benefits.

5.10 Conclusion

The proposed residential modular construction design has a strong emphasis on sustainability, durability, and cost-effectiveness, making it a model for future developments in Fiji's construction industry. The overall aim of the proposed design was to provide an affordable and transferable design which can be implemented within Fiji to assist in mitigating natural disaster related impacts and assist in progressing the mindset of the nation for reactive to proactive. It is believed that this design has achieved this goal, through offering interchangeable modular components and a strong focus on ensuring the lifecycle of the product is circular, this construction method can be determined as an efficient and sustainable way forward for the Fijian construction industry.

Chapter 6

Conclusion

6.1 Summary and Discussion of Project Outcome

In conclusion, through conducting a detailed literature review, comparative and case study analysis, a proposed modular construction design was able to be developed for implementation within Fijian villages. Through conducting a diverse literature review into modular construction, the opportunities, innovations, sustainability and manufacturing properties were able to be determined. This includes the existing challenges of modular construction and the proposed solutions to alleviate such issues. Additionally, the case studies evaluated within the literature review discussed the opportunities and various alternative applications of modular construction. This enabled the confirmation to be made that modular construction has extensive application and benefits in disaster related contexts.

Industry and engagement with industry professionals within Fiji was proposed for completion to assist in gaining further insight into the challenges faced and opportunities present for modular housing. However, due to limited response from industry connections, this aspect of the research methodology was not able to be completed. It is suggested that further research and consultation is conducted with industry experts in order to gain a variety of feedback that considers all areas of the project, including cultural, transportation, education and application.

The comparative and case study analysis enabled a determination to be made as to weather the implementation of modular construction would be beneficial, as opposed to traditional construction methods. Based on this analysis, although modular construction poses significant benefits in relation to safety, sustainability and efficiency, traditional methods have their value within their high level of adaptability and integration within the cultural roots of the Fijian industry. It was therefore recommended that modular construction should be utilized within a disaster recovery context and within urban development due to its quick construction time and high level of structural integrity and resilience. Through correct implementation of the construction method, costs and carbon emissions associated with transportation can be reduced and by manufacturing in Fiji, the economy can be supported.

The modular nature of the proposed design will enable the occupant's accessibility to frequent and readily available maintenance to be significantly increased and duration for remediation to significantly decreased following a disaster event. Damages or defected components of a structure have the ability to be swapped out for a new component, such as roof or wall module, to provide safe and secure housing. The damaged component is them able to be repaired and reused within another structure, extending the lifecycle and interchangeability of the components to significantly improve the sustainability and renewability of the components.

Therefore, despite industry engagement not being successful, the outcome of this dissertation was able to be achieved. The proposed design aims to address the issues currently being experienced within the Fijian construction industry, such as accessibility to skilled labour and construction tools and equipment, frequent and readily available maintenance, and ensuring sustainability and reduction of waste within the design. Though implementation of this alterative design method within Fiji, the aim is that the mindset of industry professionals from reactive, which has been developed as a result of the high level of natural disasters experienced, to proactive, enabling development and innovation to occur.

6.2 Completion of Project Aims and Outcome

This dissertation was able to successfully explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities. This is through providing safe and readily available shelter which can not only withstand natural disasters but be reconstructed and repaired quickly and efficiently post-event, in the form of a proposed modular residential house design, modelled with CAD software. An analysis occurred within the materials, cost and construction process associated with modular construction and benefits obtained through implementation within Fiji.

Additionally, the environmental and sustainability benefits of modular construction in regard to materials, lifecycle and construction were determined. Through implementation of modular construction, which utilized locally sourced materials and manufactured within Fiji, the carbon emissions associated with transport are able to be significantly reduced due to eliminating the requirement for importing. The utilization of off-site manufacturing also reduces the material wastage incurred as a result of on-site adjustments and inefficiencies.

Therefore, through applying modular construction within Fiji, communities are able to have access to an affordable and resilient structure. This includes improving the community's response to disaster events but providing them with structurally integral home to withstand events and, in the instance of damage, providing readily available replacement components. The standard of living throughout Fiji will also be significantly improved due to modular construction. Traditional methods of construction require a high level of maintenance activities in order to increase the lifespan of a structure. Due to limited availability of resources, maintenance works are often not completed. By implementing modular construction, the high-quality materials are able to be utilized reducing the requirement for frequent maintenance.

Additionally, modular construction poses significant benefits within the construction industry regarding natural disasters. Through initiatives similar to those of the red cross, and due to the modular nature of modular construction, communities are able to have easy access to replacement components in the event damage is incurred. This will assist in significantly reducing the repair turnaround time and enable efficient and easy completion of maintenance work.

6.3 Reflection

The motivation behind completing this project stemmed from the engineering study tour I attended in Fiji mid last year. During my time within the village, I was exposed to the living conditions of the Fijian people, and the limitations surrounding development due to disaster events. It was highlighted that the nation struggled to progress due to continual setbacks, weather this be labour shortages, material availability or repetitive damage. Therefore, I was inspired to propose a solution to this issue in able to assist in alleviating the reactive mindset developed.

When completing this project, I was able to conduct a detailed literature review due to the extent of research available online. This included various case studies which detailed the implementation of modular construction within a variety of contexts. This review served as a basis to the remainder of the dissertation, with the key findings being translated within the comparative and case study analysis, and within the proposed design. Industry engagement and consultation with Fijian contacts was unfortunately unsuccessful due to receiving limited to no response. Additionally, the duration of obtaining ethics clearance was extensive, posing impact on this consultation and the completion of the project within the required time frame.

Overall, through completing this project I was able to develop a greater understanding of the Fijian construction industry and modular construction. I believe that the proposed design and additional research contained within this dissertation is able to be utilised in order to provide a basis to assist in the development of Fiji's residential housing industry and their response to disaster events. Through doing so, a big impact would be made to the industry, providing various benefits in which I am proud of achieving through this dissertation.

6.4 Further Research and Recommendations

It is recognised that this dissertation does not provide a comprehensive analysis and investigation into all factors surrounding traditional and modular construction elements due to resource availability and time constraints. To continue and expand upon this dissertation, further analysis can occur into all surrounding factors, as detailed below.

6.4.1 Industry Engagement and Consultation

Undertaking industry engagement and consultation with a range of in country stakeholders, such as Engineers Fiji and the Ministry of Infrastructure, Transport, Disaster Management and Meteorological Services, would enable further development of the design to occur to ensure it is fit for application. Focus groups with construction and engineering agencies, and communities is also suggested to gain a variety of feedback that considers all areas of the project, including cultural, transportation, education and application. The proposed tasks to fulfil this additional area of research include the following:

- Questionnaire: A questionnaire is to be constructed in which a statistical investigation will be undertaken. The participants of this questionnaire is proposed to include industry professionals such as engineers and non-government organizations (NGO's), the community, construction workforce, local councils, students, and educators within higher learning institutions. The questions are to explore currently held knowledge regarding the construction technique, the identified opportunities and challenges, questions surrounding the method and whether they would be likely to utilize this technology. Further questions surround the impact natural disasters have incurred upon the individual, the consequent challenges experienced, and weather implementation of this technology that could/can assist is recommended.

- Industry expert consultation: Proposed to occur with a variety of government, non-government, and private organizations. Connections that were previously obtained during the engineering study tour with various organizations relevant to this research project including individuals from private engineering consultancy firms, engineers Fiji representatives, Housing and development Fiji department, Red Cross, and the National Disaster Recovery Agency. Questions asked can include preliminary opinion-based questions regarding the implementation of the technology within the proposed situation along with additional questions surrounding the technologies roles in a reconstruction post disaster response setting. The element of sustainability and cultural requirements is also to be addressed along with identified constraints this project aims to investigate, and the proposed solution modular construction aims to fulfill.
- Community Engagement Focus Groups: The community is proposed to be engaged in order to obtain their perspective regarding the construction method. This will highlight weather the technology would be utilized within Fijian villages based upon economic, locality and cultural constraints. This can be undertaken by visiting a number of villages in which a focus group will be constructed. The construction method can be explained, scope of implementation within Fiji discussed, the opportunities, benefits and constraints identified, and therefore will provide an opportunity for feedback and questions to be obtained, asked, and answered. This will enable a determination regarding feasibility to occur and consumer feedback and queries to

be obtained. This can be completed in conjunction with on-site investigations to enable examples to be shown and practical application to be explored.

- Onsite Investigation: Onsite investigations are an essential aspect of developing an understanding of the issue at hand and often the severity and impact the proposed technology could instate. The proposed sites to investigate include an established community, a newly constructed subdivision, a slum community within the outskirts of Suva and a community which has recently been impacted by a nature disaster currently in the reconstruction phase. The Red Cross provides containers throughout the island which provide essential items for communities to access post disaster. The capacity and situation surrounding the container would be important to investigate with a site visit proposed for various shelter locations both regional and rural. The conduction of these onsite investigations can be in conjunction with community engagement sessions which therefore enable the living conditions, impact, construction techniques and nature of the sites to be determined. Additionally, the constraints and benefits modular construction could bestow can be identified posing a rounded, unbiased perspective and understanding of the current and desired living conditions.

In conjunction with the research presented within this dissertation, by undertaking this further research it will ensure that relevant and detailed collaboration with industry progressional and the community, who are the end consumers are being engaged. This will ensure that identifications of risks, opportunities and restraints in regard to modular construction is able to occur. The benefit of doing so is to prevent a one-sided, bias conclusion from occurring by addressing all stages of the process and engaging industry professionals to provide insight upon the projects feasibility. Additionally, by engaging the community it will address weather this construction method is accessible and obtainable, along with being fit for purposed and culturally aligned. Therefore, the aim of the project will be addressed in a beneficial format enabling the outcomes to be determined upon analysation of the collected data and information.

6.4.2 Collaboration and Inclusion of Innovative Sustainable Practices

The Sungai Watch is a family-run nonprofit organisation which collects tones of plastic waste from within Indonesia's rivers over the past three years (Visram, 2024). Sungai Design is the offset organisation which utilizes the waste material for repurposing into furniture. The principles displayed within this organisation could be transferable to Fiji and the waste management issues they are currently facing and align closely with Fijis sustainability and waste reduction initiatives. Research into a partnership or into the methods of repurposing the materials that Sungai Design utilise could occur to determine the adaptability of this method within Fiji (Anderson, 2023). This could impose significant benefits within the modular construction sector through, instead of developing furniture, utilising the same design procedures to fabricate non-structural modular or roof components, fittings such as doors or fixtures such as kitchen or bathroom cabinetry.

Through undertaking this research, focuses could be placed on the feasibility and opportunities of incorporating repurposed plastic waste materials within the modular design and construction within Fiji. This research could entail a detailed analysis into the different types of waste materials which are evident within Fiji and could be collected and the methods of processing required to transform these materials into functional building components, fixtures, fittings or furniture. The required level and reliance upon Fiji importing construction materials and furnishings will also be reduced as a result of this initiative, enabling local economics to be supported and contribution to Fijis sustainability goals to be achieved. Employment, education and training will also increase as a result of implementing this waste management and repurposing solution, further assisting in the contribution of social economic development within Fiji. This would enable the development of a unique, environmentally sustainable and culturally relevant product which will assist in enhancing the renewability and sustainability of modular construction within Fiji.

6.4.3 Further Analysis into Alternative Sustainable Materials and Fabrication Processes

Another critical area which could incur further research as an extension of this dissertation, is an in-depth analysis into the material types utilised within modular construction and optimisation of fabrication processes.

The selection of materials is a key contributing factor to a buildings level of sustainability. By undertaking research which focuses upon the identification of sustainable materials which suit Fijis climate and have low carbon footprint and environmental impact within their lifecycle. This includes the scope for development or alteration of existing materials utilised within modular and traditional construction methods to ensure sustainability and renewability is achieved. For example, as Fiji does not possess excess land which can be used for vegetation growth like Australia and America, fast growing, space efficient and native species need to be explored and adapted. This will assist in reducing the number of imported materials required for construction. This can further extend into materials traditionally used for construction within Fiji, to determine them functionally within modern design and construction.

The fabrication and manufacturing process utilised within Fiji, for not only modular construction but all manufacturing purposes should be analyses to investigate opportunities to offset the associated energy consumption and cost. This could occur through an investigation into the implementation of renewable energy sources, which includes wind, water or solar power, to operate these facilities. By doing so, the carbon footprint of the produced product will be significantly reduced, and sustainability will be increased (Smith and Green, 2022), as per Fijis sustainability goals. Additionally, seeking opportunities to implement energy efficient technologies within the fabrication and manufacturing process, for example installation of LED lighting, and energy efficient plant and machinery, should be considered. The overall process should also be evaluated to ensure production is optimised, reducing energy consumption and fabrication duration.

In order to analyse and compare the materials and fabrication process, a Life Cycle Assessment (LCA) could occur. This assessment will assist in comparing varying environmental impacts of proposed solutions and will enable a comprehensive view of the environmental consequences of such throughout the lifecycle of a product to be determined. This data is essential to ensure informed decisions are being made and the proposed materials and fabrication processes align with Fijis sustainability goals.

This research could be extended into an analysis into the socio-economic consequences and implications of the proposed material and fabrication solutions. This includes the implication of utilising locally sourced materials and energy efficient factories. By doing so, it is proposed that the environmental sustainability of modular construction will be significantly increased, as well as providing economic development opportunities for the nation, providing more opportunities for employment and education. Therefore, through a dual focus on environmental and economic sustainability and development, the benefits of modular construction as opposed to traditional construction methods will align with Fijis sustainability goals, as well as enabling affordable and durable residential housing to be provided to the expanding nation.

6.4.4 Further Analysis into Transport Methods and Infrastructure

Transport methods and associated infrastructure, such as ports and road networks within Fiji are recommended to be further researched and analysis. Transportation is a major enabler to ensure that the implementation of modular construction is able to be completed efficiently, cost effectively and with minimal environmental impact. In order to implement modular construction successfully within the Fijian construction industry, examination into the transportation options between the Fiji Islands and within rural and remote areas, where there are significant logistical constraints due to underdeveloped or limited infrastructure is essential.

Additional research should preliminarily include an evaluation of the current infrastructure and transport methods. This should extend to an analysis of weather in their current condition, they have the capacity to withstand the demands of modular construction. This includes port and cargo handling facilities having the capacity to manoeuvre prefabricated modules and the road network providing the required access for the specified vehicles. The sustainability of such transportation methods and the evaluation of other options which assists in the reduction of the environmental impact and carbon emission should also be evaluated to ensure that the proposed methods are in line with Fiji's environmental goals.

Through conducting a comprehensive analysis of the existing systems, a better understanding of the associated challenges and feasibility associated with modular construction in Fiji can be determined. Furthermore, strategies can be proposed in order to improve accessibility and streamline the logistical process of modular construction. The findings of the proposed additional research could further assist in the formation of modular construction related polies and identify areas for improvement within the Fijian transport infrastructure. By doing so, collaboration with various stakeholders in the aim for assisting in the investment of Fiji's infrastructure is able to be achieved, assisting in supporting the implementation of modular construction throughout Fiji.

6.4.5 Further Analysis into Residential Service Integration

Analysis into the integration of residential services is essential in ensuring the proposed modular construction alternative is successful for integration within the Fijian construction industry. This includes meeting the required local needs for health, liveability and sustainability, and infrastructure such as wastewater, water, sewer, electricity and telecommunications. Communities within Fiji have varying access to residential services, with geographically challenging and rural villages often being without. Therefore, innovative approaches are required to ensure all needs are met and the proposed modular design solution is developed which best fits the needs of the community.

One the key services which requires an adaptable solution for integration within the proposed modular design is the water and wastewater network. In regions where this service is not available, a decentralised system which fulfils the needs of the community and environment should be proposed. This includes the inclusion of water saving and recycling technologies and treatment systems which could help address issues associated with limited resources or reliance on old, inefficient systems. Through undertaking further research, the feasibility of the proposed solutions can be determined and a solution proposed to assist in bridging the gap within isolated communities.

Additionally, electricity should be considered, especially within regions which do not have reliable access. As the Fijian's have a key focus upon sustainability, it is proposed that further research is to occur within renewable energy sources and battery systems which can be incorporated into the modular houses. This includes wind or solar which can assist in providing a sustainable, self-sufficient energy supply. This would assist in reducing dependence on power grids, enhance energy and reduce long-term operational costs.

Therefore, by conducting further analysis into the integration of residential services in regard to the proposed modular residential design, it will ensure that the communities receive all necessary services to meet the needs regarding health, liveability and sustainability. The proposed solutions are able to have a heavy focus upon sustainability, and include renewable energy and recycled water to reduce long-term environmental impacts. This will assist in reducing the reliance upon town infrastructure and ensure the longevity and integration of the proposed design.

6.4.6 Structural Detail and Design Analysis for Modular Construction

Another critical area which further research is recommended in within structural detail and design analysis. As determined within this dissertation, modular construction is a promising residential housing alternative within Fiji, posing benefits to combat the issues currently faced within the industry. However, further analysis into structural designs relating to wind loads and design elements such as ventilation and moisture retention are required to ensure success and sustainability within this region. All proposed design is required to adhere to Fiji's National Building Code (NBCF) and relevant standards in order to ensure compliance is met with safety requirements and local regulations.

Due to Fiji's high susceptibility to high wind speed and cyclones, a detailed structural design analysis into wind loads of the proposed design is essential. Within the NBCF, the structural requirements for buildings in cyclone prone regions is detailed to need to be designed for wind speeds of up to 44m/s. In addition, the unique stresses related to modular components need to be designed for, in which current standards have not yet been adapted. As a result, further research is recommended to be focused upon development of modular design structural design and components which fulfil wind load standard requirements. The utilisation of structural reinforcements and advanced materials in order to ensure forces are withstands without compensation the performance or safety of the users. Regional wind intensity data is recommended to be incorporated into the design, which is further beneficial for coastal and elevated regions of Fiji to ensure the proposed design is fit for purpose and designed to withstand Fiji's unique conditions.

The high humidity and rainfall experienced within Fiji as a result of its tropical climate is another ongoing challenge which can result in moisture retention within materials, compromising the structures durability over its lifetime. Within Fiji's current building standards, moisture control is addressed but there is limited understanding or requirements into modular construction specifically.

Through investigation into moisture control mechanicians which could include incorporation of water-resistant materials and enhanced sealing techniques, the durability of modular construction can be increased.

Furthermore, the incorporation of passive design principals including shading, orientation and ventilation can significantly assist in reducing the demand of artificial cooling and heating, improving the structure energy efficiency and sustainability. It is recommended that further research should investigate the incorporation of passive design principals to fulfil the climatic conditions of Fiji, while adhering to sustainability goals and energy efficiency standards.

Within the NBCF, natural and mechanical ventilation requirements are specified to ensure occupant comfort is obtained and indoor air quality is high. Within modular construction systems, due to the nature of sealed panels and compact designs, air flow and ventilation can be reduced. As a result, it is recommended that further research occurred into hybrid systems or cross ventilation techniques to ensure efficient natural and mechanical ventilation is achieved through air circulation in modular residential construction.

Fire resistant standards within Fiji detail the requirement to utilise fireproofing materials within residential construction. Due to the nature of prefabricated modules, further research should explore design solutions and materials which will be compliant with regulations and are fit for use within a modular context. The inclusion of smoke alarms and other monitoring systems should also be evaluated to ensure the building is designed to the required wet and dry fire standards applicable to the region and application.

Water management within Fiji is essential due to the tropical climate resulting in heavy rainfall and flash flooding. Within the NBCF, basic water management and drainage requirement are detailed in relation to traditional construction methods. Further research is recommended to occur to determine the application of the codes standards into modular construction, including but not limited to flood resistant materials, drainage systems and elevated foundations, in order to mitigate water related risks. Through investigation and evaluation into water management, the proposed design solution is ensured to be resilient within the flood prone regions of Fiji and be in line with the NBCF's provisions regarding site specific design adaptations and flood resilience.

Therefore, as determined within this dissertation, modular construction presents vast and significant opportunities within the residential construction sector of Fiji. However, further research is required into structural detail and design in order to ensure the key challenges faced within Fiji, such as wind load, water management and moisture retention are mitigated. By doing so, the proposed modular design will meet the requirements of the NBCF and other applicable standards, offering a safe, sustainable residential construction solution. Through conducting target research within these areas, the demand for affordable and sustainable residential housing fit for purpose within Fiji can be achieved.

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Appendices

Appendix A – Project Plan

A.1 Resources

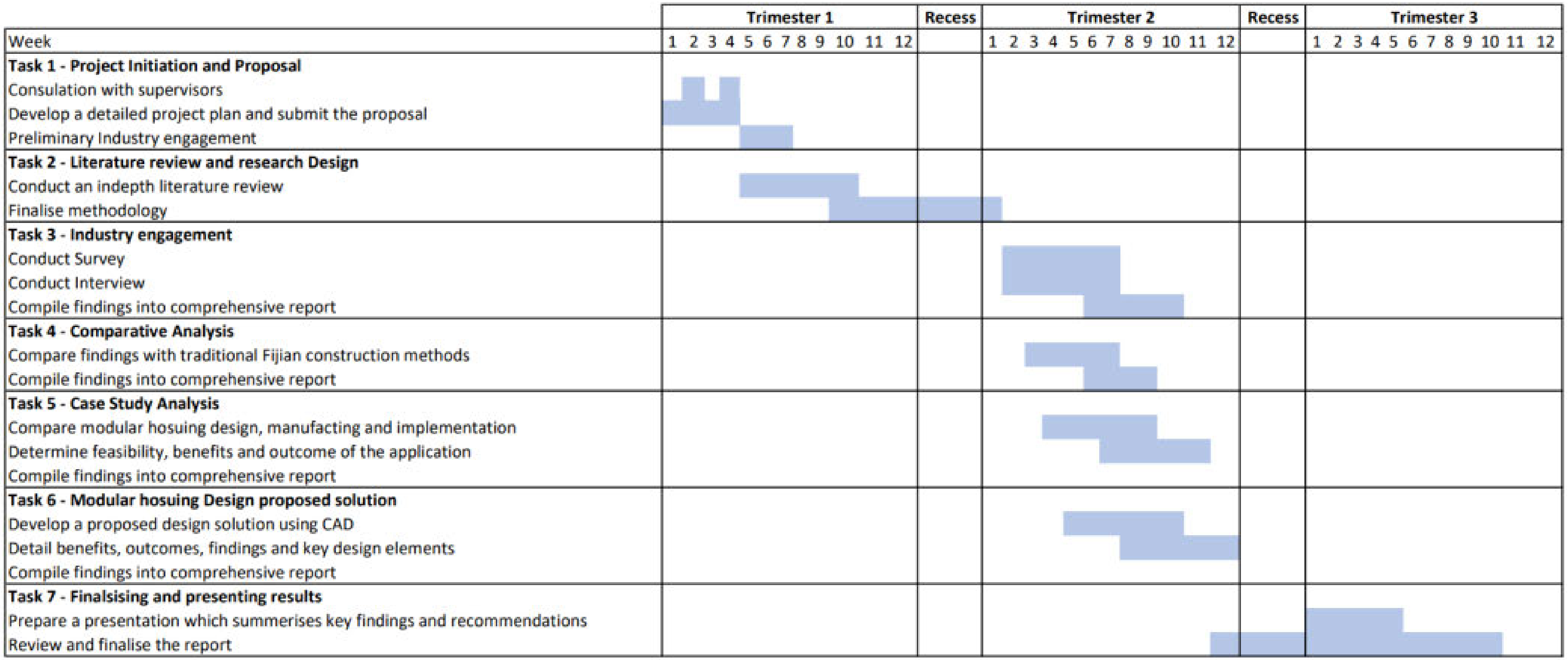
The resources required to undertake the proposed research project are outlined within table 1 below. All identified resources are obtainable upon the basis that the funding can be granted and organization and scheduling with the country experts and community can be aligned.

Table A.1: Resources Required to Undertake Research Project

Task	Resource	Quantity	Source	Cost	Comment
All	PC with Microsoft Windows	1	Student	N/A	Already Owned
	iPhone	1	Student	N/A	Already Owned
	Microsoft 365	1	Student	N/A	Already available
	Pen and Paper	1	Student	N/A	Already Owned
Literature Review	Professional Resource Databases	1	University	N/A	Available through the university
	Reference Manager – Citation Tools	1	University	N/A	Available through the university
	Industry expert's engagement	10	Student	N/A	Scheduling required Time Constraints
	Data from Industry	-	Student	N/A	Access of Data
	Community Engagement	3	Student	N/A	No costs associated
External Consultation	Survey Participants Involvement	40*	Student	N/A	Involvement by participants
	Microsoft forms	1	Student	N/A	Already available
Design	ArchiCAD	1	University	N/A	Available through the university

A.2 Project Schedule

The required milestones and short-term goals were assessed in order to develop a suitable timeline which displays the desirable completion time. The project schedule below demonstrates a visual framework of the project structure and desired completion dates for the primary tasks.



A.3 Risk Assessment

A risk assessment was conducted for this research project in order to determine the potential risks and hazards associated. The following risk assessment was developed on the basis that in country investigations were to be conducted, and has been approved by Steven Goh following completion of the methodology assessment task of this course. Development of a risk assessment is one of the most important aspects of a project, ensuring that all potential risks are mitigated.

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland Offline Version

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Research Project 1 & 2 - Proposal	Assessment Date:	11/10/2023
Workplace (Division/Faculty/Section):	Faculty of Engineering and Surveying	Review Date:(5 Years Max)	11/01/2024

Context			
Description:			
What is the task/event/purchase/project/procedure?	Determining if Modular Construction is suitible within the FIji Contect		
Why is it being conducted?	To determine an outcome for the Proposed Research Project		
Where is it being conducted?	Combination of online and in county (Fiji)		
Course code (if applicable)	ENG4110, ENG4111 & ENG4112	Chemical name (if applicable)	N/A
What other nominal conditions?			
Personnel involved	Caitlin Battersby and external engaged individuals		
Equipment	iPhone 13 pro, PC, paper and pens.		
Environment	Online, office enviroment		
Other	N/A		
Briefly explain the procedure/process	Combination of online and incountry interviews and engaement with industry professional and the community.		

Assessment Team - who is conducting the assessment?	
Assessor(s)	Caitlin Battersby
Others consulted:	Steven Goh

Eg 1. Enter Consequence

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide

E=Extreme Risk – Task ***MUST NOT*** proceed

H=High Risk – Special Procedures Required (See USQSafe)

M=Moderate Risk – Risk Management Plan/Work Method Statement Required

L=Low Risk – Use Routine Procedures

Eg 2. Enter Probability

Eg 3. Find Action

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:*			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Unethical research	Legal issues, unuseful information/data	Major	Implementing the Ethical code of Conduct	Possible	High	No	Approved questions by the University of Southern Queensland Human Ethics committee, sign non-discolures & blank out/exclude all sensitive information and names from documents	Minor	Unlikely	Low	Yes
Exposure to Covid-19	Subsequent illness from contacting the Virus	Major	Compliance with covid safety plans, wearing marks, 1.5m rule and isolating from the sick	Unlikely	Moderate	No	If unwell, self isolate and do not contact with other individuals. If someone else notes they are unless, resechule meetings and take required procortuions if been in contact	Minor	Rare	Low	Yes
Access/trip hazards due to terrian or equipment	Injury to student or public due to terrain being uneven or equipment being inappropriately placed	Major	Obsticals are to be relocated, minimised or physically flagged prior to occupation. Uneven terrain to be avoided and utilise footpaths when available.	Likely	High	No	Taping of uneven ground levels/surface to identify hazards when applicable. Tape chords and leads to the floor or reroute to avoid trip hazards. Ensure access is identified prior to meetings and events to prevent time delays and disruptions or rushing leading to injury	Major	Unlikely	Moderate	Yes
Interaction with People	Lanuage barrier, different cultural values, arguments	Major	Learn basic language, be polite and don't engage in arguments	Likely	Extreme	No	Travel with a group and in country contacts, do not enter situations or areas subject to disgrimination or arguments, avoid unsafe areas. Ensure clothing is acceptible for the situation	Major	Unlikely	Moderate	Yes

<table>
<tr><th colspan="5">Step 6 - Approval</th></tr>
<tr><td>Drafter's name:</td><td colspan="2">Caitlin Battersby</td><td>Draft date:</td><td>5/10/2023</td></tr>
<tr><td>Drafter's comments:</td><td colspan="4">Prelminary Risk assessment to be reviewed prior to arriving incountry</td></tr>
<tr><td>Approver's name:</td><td>Steven Goh</td><td>Approver's title/position:</td><td colspan="2">Research Project Supervisor</td></tr>
<tr><td>Approver's comments:</td><td colspan="4"></td></tr>
<tr><td colspan="5">I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.</td></tr>
<tr><td>Approver's signature:</td><td colspan="2"></td><td>Approval date:</td><td>Click here to enter a date.</td></tr>
</table>

Appendix B – Questionnaire Data

This following data is drawn from the questionnaire completed, as detailed within the body of this dissertation. Six anonymous responses were received from the UniSQ 2023 Fiji Study Tour Group, with the following graphs and details being drawn from Microsoft forms. No alterations have been made to participants responses.

ENP4111 – Modular Housing Design Proposed Solution Review and Feedback

This questionnaire aims to gain feedback on the proposed design solution as apart of the dissertations methodology.
Thesis Title: Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry.

This project is being undertaken as part of a Bachelor of Engineering (Honours), Civil Engineering Research Project through the University of Southern Queensland. The purpose of this project is to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

B.1 Traditional Architecture and Cultural Values

Question: How important do you believe it is for the modular housing solution to reflect the Traditional Fijian architecture and cultural values?

Response:

Figure B.1: Question 1 Response

B.2 Application of Cultural Beliefs in Design

Question: How do you believe from your experience at the Study Tour in 2023, that the design of modular homes should reflect and incorporate cultural beliefs?

Response:

- I found that whilst the inner cities of both Suva and Nadi had more modern outlooks on daily life, outskirts and villages immediately reflected more cultural values. The leaders are trying to retain cultural beliefs and as such it is best practice to help them in this goal by providing solutions that reflect a strong cultural way of life.
- The main aspect to assist in incorporating cultural beliefs should be a living area with the separate entrances for the elders and using materials that assist in matching the architecture to traditional buildings.
- Incorporating local artwork, design, and aesthetics will assist in reflecting cultural beliefs. The general building layout should also be designed to incorporate communal areas, such as those experienced within the village, to remain consistent with local infrastructure.
- I believe it should be definitely taken into account and considered, however if we are wanting to establish reliable houses to live in we should not comprise on the longevity and livability of the house. I'm particular to integrate it into the 21st century.
- There is still a strong cultural link and identity present in their society so key aspects associated with their housing and their culture need to be retained in so far as is possible. This includes consideration of individual roles and position and the associated expectations that surround these e.g. location of the various "areas" in the house.
- The layout should reflect the "open home" culture. There should be areas to eat/lounge on the ground in an open room. There should be options to access electricity and running water in areas where these are available too.

B.3 Transportation Challenges

Question: How significant do you believe the transportation challenges (e.g. road conditions, island access) are when considering the delivery and installation of modular homes within Fiji?

Response:

Figure B.2: Question 3 Response

B.4 Modes of Transportation

Question: What do you believe is the most practical mode of transportation for modular housing materials and components within Fiji?

Response:

- By vehicle such as a Ute is most applicable to current transportation methods when considering vehicles on the island and the availability of people or workers. The only downside to this is some lack of quality main roads throughout the island that may experience loss or damage of modular housing panels during transportation.
- Boat to the closest port/jetty then small trucks with portions of the structure
- Large vehicle transport will be the most practical mode of transportation, considering the large number of villages located within the centre of the main island. This is followed closely by boat transportation, to access smaller offshore settlements.
- There is only one blue mettle ‘tarmac’ road backed road. And this is a 2 lane road which could prove sufficient transport via a truck or other heaving vehicle.
- Realistic via road, acknowledge this will likely mean on trucks down pit hole filled narrow back roads
- Large trucks similar to what we travelled in

B.5 Road and Infrastructure Limitations

Question: How do you believe the current road and infrastructure limitations in Fiji influence the size and structure of modular housing units?

Response:

- As previously mentioned, the quality of roads is not ideal to ensure 100% damage free goods and as such there may be losses there. Additionally, this may also reduce the volume of goods particularly to villages away from ports and airports (mountainous regions). It may be prudent for research to investigate common travel routes to perform a logistical analysis.
- Structures will have to be small enough to fit on smaller trucks to access areas with poor or narrow roads
- Due to the poor road conditions, a limit on the size for the modular housing would be appropriate due to transportation requirements.
- There are 2 lane road with quite narrow sections and no room off either side whilst going through mountainous regions which little alternatives for congestion.
- There will be limitations on size and consideration needed around packing to prevent damage during transport.
- The housing will need to be structurally sound / robust to withstand the bumpy road conditions. It should be able to break into pieces small enough to fit within a standard truck.

B.6 Modular Construction Implementation Challenges

Question: What do you see as the largest challenges in implementing modular housing in Fiji, and what solutions would you propose?

Response:

- One of the biggest challenges will be the establishment and operation of manufacturing facilities as well as trained personnel. To best reflect cultural beliefs and values, it would be ideal to manufacture on Fiji using the locally utilized materials however this would be a large undertaking especially if the solution becomes popular.
- Cost and the notion of change. To alleviate this the cost would have to be mainly or completely offset by governments or charity, and the designs would have to emulate traditional architecture.

- The generally poor road conditions would provide challenges when transporting modular housing. Furthermore, troublesome weather conditions would require considerable effort into the structural integrity of the units. I would propose a sturdy base structure, with the ability to extend if needed. Limiting the size of these units would assist in transportation on main roads.
- I'd say the transportation as well. I'd propose compact solutions in particular solutions that are centered around what transport is available rather than trying to find the appropriate transport to fit the builds.
- I think you have identified them above, though cost will also be a consideration. Smaller panels that pack tightly allowing assembly of structures that are considerate of Fijian cultural heritage would be my proposal. Possibly made from recycled materials to help keep costs a down provided these are safe and have no health or safety concerns to human or environmental health.
- Community acceptance - do education programs/positive word of mouth Accessing resources, materials and labor - source locally (look at what materials are readily available). Potentially customize materials for particular areas - for example if a village farms bamboo nearby then use this. Also train locals/ make it easy to build.

B.7 Initial Design Feedback

Question: Please see the floor plan. Please note the following:

- Components have been designed to fit easily on a standard MR truck.
- The rooms can be interchangeable and additional bedrooms/living space can be added - this design is a base design.
- Goal for implementation would be within rural and urban communities, with a focus on lower demographic housing development.
- Ideally, key components such as roof elements would be stored at key locations (similar to the red cross container initiatives) for easy access and maintenance practices in the event of a natural disaster).
- The proposed solution has been designed to be sacrificial, and modules easily replaceable to combat issues experienced for natural disasters.

What are your initial thoughts on this design?

Response:

- The initial design appears thorough, with a strong emphasis on combatting outcomes of natural disasters as well as the leveraging of existing infrastructure such as the red cross relief initiative. Further design examples may be important to include to convey how the modularity operates. Otherwise, the design is thought out for the conditions at hand.
- Looks good, where does the modularity of additional rooms apply? Is a slab required or what ground prep is needed?
- This unit covers the essentials very well, and has been thought out effectively!
- Simple, efficient and good.
- Generally good though have you considered how you would extend such a building while retaining all key elements? Thinking about where and how you would add a second bedroom for example.
- The design caters for a range of conditions specific to implementation in Fiji. Perhaps consider electricity, water and other services and how these will interact with the design - particularly as the level of access will differ between villages

B.8 Cultural Design Factors

Question: The design takes into key cultural design factors such as a second door for elders and a open, family orientated layout. Do you believe these factors are sufficient or are there improvements you can suggest.

Response:

- From my experience, respect and community are both major aspects to Fijian village way of life, and the design appears to provide both of these for the residents. The only issue would be further concepts to relay how this idea can be maintained for multiple bedrooms for example.
- None at this time from that perspective
- These factors appear sufficient in covering the cultural aspects of Fiji.
- That seems good, I think form here it would interesting to see the feedback from the communities in Fiji.
- From memory they were the big two that I recall in most village houses.

- Yes this is a good idea. Also consider many windows (similar to what you have) for areas with little electricity that rely on natural light

B.9 Materials

Question: The proposed design utilizes materials such as Bamboo CLT for the external cladding, coconut timber for framing, coral stone for insulation and volcanic ash within concreting purposes. These offer a sustainable edge and utilization of locally sourced and renewable materials. Can you please detail your thoughts and provide feedback of improvements or shortfalls.

Response:

- Not being familiar with other alternatives, these all appear to be viable solutions so long as the access routes for them have been established or are simple to establish. The large undertaking in manufacturing and developing acquisition or trade routes may be a pitfall if not considered.
- Seems good, does working with these materials cause any cost prohibitive issues? Ie. if these are meant to be super cheap and charity or gov funded?
- Locally sourced materials is always a large benefit in these remote locations with high transport costs and limited availability to resources. While the building is designed to be sacrificial, I would only suggest rigorous structural testing to ensure the building is safe using these sorts of materials.
- This is great in particular could provide some education on how they locals could use their very own materials to build a house more in tune with modern technology, and methodology.
- I think that’s a great start. What about flooring? Also are there any opportunities for use of coconut husk or possibly materials that are byproducts of local industries?
- This is good. Have you considered how the Bure at the village was raised with stones/concrete/soil. Could this inspire the base of the house too?

B.10 Transportation

Question: The components of this design will be constructed off site in a factory and transported to site. Each component can be transported on the back of a standard MR truck. Do you identify any further transportation issues with this design, and if so, please detail.

Response:

- I found that LR and MR trucks were common place on roads, as well as some prevalance in villages as passing through. Vehicular transportation will be the most effective method of transportation, apart from between coastal locations for ports.
- Are they proposed to be constructed in Fiji to employ Fijians? In some areas MR trucks may still be too big, thoughts on options for component supply and in place construction where required?
- This solution seems ideal for the majority of the mainland. Based off what I have heard, a standard MR may have difficulty navigating the most rural areas of Fiji. This would be a difficult challenge to manage, and may involve a transfer to a more capable 4WD vehicle.
- No, same as above, unless it was built in Australia or something like than you would need a sufficient ship.
- Nothing I can think of
- This is good

B.11 Manufacturing Facility

Question: The construction of the manufacturing facility to construct modular construction will be an initial costly investment. However, if this construction method was implemented, do you believe this investment would be worthwhile and beneficial within the residential construction sector? Detail why or why not.

Response:

- I think that the investment would be worthwhile as monsoon season can also bring cyclonic weather on top of torrential downpour and any benefits to disaster relief should be investigated. The current disaster relief appears effective but any assistance would be ideal to improve safety and normalcy response times.

- Given the correct funding it certainly could be, there is always going to be a construction cost that the majority of Fijians may not be able to afford
- While the financial challenges may be stressful for a small economy nation, I fully support this idea due to the high impact that natural disasters have each year. Transportable and modular housing would considerably benefit the people of Fiji in the long term.
- Yes because you would reduce coasts in the long run as a posed to a bandage solution that would be taxing over time.
- I think it may depend on how resilient the structures prove to be to weather and pest damage. In theory, being modular, cost should come down over time with improvements in the production process. But ade of transport and construction should also pay off in the long term
- Yes. Have you considered an alternative approach at using local villages that farm/live close to the materials and using local labour to construct the housing? This might be cheaper and a way to get more community acceptance but it might not be the best quality or as per standards, maybe? Just an idea to consider.

B.12 Education

Question: Education of the workforce on the manufacturing and construction of modular construction methods will be an initial investment. It will be proposed that fee-free training will be offered to the workforce to upskill and provide jobs within this sector. Do you believe this will be beneficial for the community and what issues do you foresee?

Response:

- Overall it will be beneficial to the community, but may face resistance from those that may oppose change and may not see the housing concept as necessary. Fee-free training will also be beneficial so long as it is consistently fee-free over time to ensure that knowledge is passed down and a new cultural norm for construction methods is established.
- Yes it will be, there are no issues to upskilling and jobs provision. Proper training should be prioritized.
- Adding jobs in any economy will strengthen the nation. Outside of the previously mentioned financial stresses and planning factors, I don't see any issues.
- Absolutely. Get them involved, trained practicing but also promoting an effective work ethic.

- Yes, provided those trained don’t try and take advantage of it. Could also consider extra courses for the initial workers to become local trainers who take on apprentices to pass on the skills.
- Yes

B.13 Cultural Workforce Impact

Question: Do you believe this construction method will impact the current, cultural workforce (e.g. family's having certain roles within a village)? Please explain

Response:

- I dont believe it will majorly impact the cultural workforce as the norms of house repair and construction are already known and appreciated on a cultural basis. This will jsut be a different method for those within the village to adapt to. The initial issue will be ensuring the villagers and residents that it is a culturally sensitive design that incorporates sustainability and has their beliefs at heart.
- No, this will never completely replace traditional construction for all people and there will still be a need for cultural buildings and houses for people that want to take a different approach.
- Through my experience with the Bure construction, it appears several community members contributed to completing that task. I would assume a modular housing development would be no different, but challenges of proper training may be presented.
- I think it may reduce the need for the ceremonial straw roofs but we could interstate that into the final solution or just leaving it for their main meeting buildings.
- This does seem to happen but I feel there was a cultural shift already occurring that was starting to move away from this.
- Yes but no. The villages will probably be inclined to have men trained in the construction. Looking at when they took down the bure whilst we were there a bunch of men got involved and it was fine so I think it would be similar with the constructing of houses

B.14 Affordability

Question: In your opinion, based on the proposed design, do you believe modular housing can be made affordable while still maintaining high quality and cultural relevance for Fijian families?

Response:

- Cost may be an issue for transport and initial manufacturing development. The position of material sources should also be understood to reflect how far they have to travel before undergoing modular housing manufacturing. Optimizing location will help reduce overall cost as other costs mentioned will be large.
- With outside charity or government support then yes, otherwise no.
- If designed properly, I do believe the high initial investment will pay off long term, resulting in an affordable option for Fijian families and the broader community.
- Yes
- Yes I think it possible but I don't think it will be easy.
- Yes, maybe there are options for cheaper houses with cheaper materials - potentially you could look at a low quality but cheap option vs a high quality vs expensive option

B.15 Natural Disaster Solution

Question: In your opinion, based on the proposed design, do you believe modular housing can offer a solution to the natural disasters experienced and rapid response of maintenance on housing post disaster event?

Response:

- It was mentioned that the pieces are sacrificial and can be easily replaced. So long as the red cross initiative can house these components on a regular and consistent locational basis, it will reflect current beliefs for housing of designing and building simple for easy repair. Another aspect is through the 'Bula House', which is typically designed to stay upright during bad weather so further consideration may need to be made for this other design.
- Yes, provided the ground preparation is not time prohibitive and there is sufficient stock.
- Definitely, If designed to easily de-construct I believe this would be a revolutionary solution to a very prevalent problem in Fiji.
- Yes

- Yes I think it has a role to play. Hopefully such dwellings would be quite resilient but being modular would be much easier and quicker and therefore in theory cheaper to fix after more severe events.
- Yes the natural disaster considerations are good. Potentially considered a raised foundation as discussed in 9

B.15 Additional Feedback and Comments

Question: Please provide any other additional feedback, concerns or comments.

Response:

- Overall the modular system appears to be culturally sensitive, considered low cost, viable and productive for the Fiji Economy, and its people. Most necessary developments were identified in the context to questions, and does not need major changes apart from those listed from my responses above.
- No further comments, looks great!
- Nothing further I can think of sorry.
- Great work!

Appendix C – Ethics Clearance

The following documentation is in relation to ethics clearance application ETH2024-0748. It should be noted that clearance was originally sought for the industry consultation questionnaire and interview, but was later amended due to a change of scope to a questionnaire sent to the study tour group participants.

Ethics ETH2024-0748 (HREC): Miss Caitlin Battersby (Student) (Low risk)

Academic/Researcher	Miss Caitlin Battersby (Student) A/Pr Steven Goh
Project	Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry
Division	Academic Division
Faculty/Department	Academic Affairs

This is a draft version

Ethics application

Overview

Application initiated by:
Miss Caitlin Battersby (Student)

Ethical Considerations

Are you working with animals or humans?
Humans, human data or human tissue

Do you have a current approval from another Ethics Committee to conduct this project?
No

Project title
Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Project Type
Undergraduate/Honours project

Project summary
Modular construction has proven to offer an effective and sustainable solution to housing shortages globally. This resolution is through decreasing labor costs and requirement for skilled laborers, increase in productivity and decrease in construction duration. Therefore, it poses as a functional solution to post-disaster relief shelter and the ability to provide safe, dependable, and sanitary housing within developing nations. Due to this, this research project is to explore the utilization of modular construction within the context of Fiji.

This will occur through an analysis of design innovation of the current design trends within modular housing, including the materials utilized, and sustainability of the design. The advancement of manufacturing systems will also be analyzed, which includes 3D printing and supply chain optimization, the determine how to ensure efficiency and reduce the timeline of the project. The challenges which are currently faced within the Fijian construction industry will be addressed and solutions proposed in relation to modular housing. This will pave the future direction for potential innovation and aim to fast-track construction in Fiji which is not only up to standard but also provides a method of reducing the impact natural disasters place upon the community.

Through this research project, the benefits, and outcomes regarding modular construction evident determined will have significant impact upon the nation. This project aims to assist with the development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development.

Host department

School of Engineering

Project duration

1 year

Is your research being conducted within Australia?

Yes

Select all that apply:

New South Wales

Queensland

Does this project relate to, and/or extend on a previously approved project.

No

Is this project funded?

No

Investigators

Principal Investigator

□

A/Pr Steven Goh

UniSQ ID

0000106034

Person type

Staff

Organisational area

School of Engineering

Other affiliations
Centre for Future Materials; Centre for Health Research;

Field of Research (FoR)
400303. Biomechanical engineering; 400304. Biomedical imaging; 400308. Medical devices; 400310. Rehabilitation engineering ; 401001. Engineering design; 401002. Engineering education; 401003. Engineering practice; 401006. Systems engineering; 401703. Energy generation, conversion and storage (excl. chemical and electrical); 401704. Mechanical engineering asset management;

Co-investigator (UniSQ Staff)

Co-investigator (UniSQ Student)

□□
Miss Caitlin Battersby (Student)
UniSQ Student ID
0061146648

Type of student
UGRD Student

Program
BENH - Bachelor of Engineering (Honours)

Organisational area
School of Engineering

Field of Research (FoR)

Does the project involve co-investigators from another university or organisation?
No

Conflict of interest

Does the Principal Investigator or any other members of the research team have an actual, perceived, or potential personal or financial Conflict of Interest (CoI) in relation to the project?
No

Do any of the Co-Investigators or External Investigators have an actual, perceived, or potential personal or financial Conflict of Interest (CoI) in relation to the project?
No

Outline the Conflict of Interest (CoI) and advise on how it will be managed.

Qualifications and Experience

Principal Investigator - qualifications and experience

Principal Investigator

A/Pr Steven Goh

Qualifications relevant to project

BEng(Hons) Qld , MBA Deakin , MProfAcc USQ , DEng USQ

Experience relevant to project

Completed engineering study tour in 2023 at Fiji

Co-Investigator - qualifications and experience

Co-Investigator

Miss Caitlin Battersby (Student)

Qualifications relevant to project

Currently completing bachelor of engineering (honors) in civil engineering

Diploma of Building design

Experience relevant to project

Completed engineering study tour in 2023 at Fiji

Operational Items

Does this project include:

not applicable

The following options were available for selection:

- *Genetically Modified Organism (GMO)*
- *biological material (non-GMO), e.g. work with toxins, mutagens, teratogens, carcinogens etc.*
- *biological material native to Australia that was (or will be) collected in Queensland for commercial purposes*
- *radioactive substances and/or ionising radiation? (e.g. DXA, X-ray)*

Does this project include:

not applicable

The following options were available for selection:

- *the export, supply, publishing, or brokering of controlled goods, software, or technology*
- *an arrangement with a foreign government or foreign university that does not have institutional autonomy not applicable*
- *not applicable*

If you have not previously submitted an Research Data Management Plan (RDMP) please provide details around 1. Storage, 2. Access, 3. ownership and 4. sharing research data.
Data for this project is in reference questionnaire responses obtained throughout the duration of this project.

1. All data will be contained upon my personal laptop which is always under passcode lock and secured

2. Raw data will only be available to myself (Caitlin Battersby) and Steven Goh

3. Data will remain in my possession, on a locked laptop which is recured

4. Research data will only be shared in the form of this research project, no name or identifying information is being collected at the time of questionnaire

Note: I am unable to access the RISE software, if this is still deemed required, please advise

Additional Information

Do you have a UniSQ Risk Management Plan relating to the activities being undertaken in this project?
Yes

RMP Reference number
See attached

UniSQ RMP Project Title
See attached - all work in country, no work in Fiji (change of scope)

Status of approval
Current

Date of Approval
05 Jun 2024

Upload a copy of the RMP

Ethical considerations - Human

Participant involvement

In what way are human participants involved in your project:

Direct recruitment and/or observation of human participants
Yes

How many participant groups will be involved in this research project?
9

Existing data sets and/or archival data
No

Existing Human biospecimens

No

Genomic research (includes full scope of genetic research)

No

Clinical trials

No

Aims and significance

Background

Modular construction has proven to offer an effective and sustainable solution to housing shortages globally. This resolution is through decreasing labour costs and requirement for skilled labourers, increase in productivity and decrease in construction duration. Therefore, it poses as a functional solution to post-disaster relief shelter and the ability to provide safe, dependable, and sanitary housing within developing nations. Due to this, this proposed research project is to explore the utilisation of modular construction within the context of Fiji.

As a part of an engineering study and cultural emersion experience in June 2023, I was exposed to the challenges currently experienced due to constraining factors. These factors include resource cost and availability, lack of skilled workers and engineers, and in-efficient project and waste management. Additionally, Fiji is highly susceptible to a high intensity and frequency of natural disaster which has led to the development of a reactive mindset, preventing the nation from forward planning, and developing. This project will aim to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

This will occur through an analysis of design innovation of the current design trends within modular housing, including the materials utilised, and sustainability of the design. The advancement of manufacturing systems will also be analysed, which includes 3D printing and supply chain optimisation, the determine how to ensure efficiency and reduce the timeline of the project. The challenges which are currently faced within the Fijian construction industry will be addressed and solutions proposed in relation to modular housing. This will pave the future direction for potential innovation and aim to fast-track construction in Fiji which is not only up to standard but also provides a method of reducing the impact natural disasters place upon the community.

Therefore, the benefits and outcomes regarding modular construction evident determined through the proposed research project will have significant impact upon the nation. This project aims to assist with the development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development.

Aims

Objectives and aims

The aim of the research project is to propose a suitable solution in the form of modular housing which can be implemented within developing countries as a method of improving living conditions and response to natural disasters. Modular housing is becoming an increasingly common construction technique within countries such as Australia due to its flexibility, fast construction time, high quality, and cost-effective nature. This project will be a case study on Fiji, an island located within the South Pacific region, with the aim to determine the impact and opportunities of implementation of modular construction within the developing country. By doing so, the benefits on the community and how the construction process will improve the counties development will be identified. This project will aim to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be reconstructed and repaired quickly and efficiently post-event.

Therefore, the objectives of the research project are as follows:

1. Research: Conduct diverse research into modular housing and the opportunities, innovations, sustainability, design, manufacturing, and existing case studies. This will enable challenges to be identified and solutions to be proposed.

2. Comparative analysis: Compare the efficiency, sustainability, and cost-effectiveness of modular houses and materials used within Fiji in comparison to traditional construction methods.

3. Case study analysis: an in-depth analysis into modular housing projects which has a focus on design, manufacturing, and implementation aspects. The fundings are to reflect the feasibility, benefits, and outcome of the application such elements in Fiji.

4. Proposal of a modular housing solution to be implemented in Fiji: develop a proposed modular building housing solution design which encompasses the findings of the research and analysis.

5. Review of proposed modular housing solution by study tour participants

Expected outcomes

The expected outcome of this research project is to develop a modular housing design which is suitable to be manufactured and implemented within Fiji. This design will assist with providing resilience to the community and development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development. A comparative analysis and case study analysis will assist in providing reasoning and data as to why the proposed outcome will be beneficial. Furthermore, the expected outcomes determined through this investigation will include the following:

· Evaluation of the materials, cost and construction process associated with modular construction and benefits obtained through implementation within Fiji.

· Determination of the environmental and sustainability benefits of modular construction in regard to materials, lifecycle and construction.

· Understanding of modular construction application and benefits that if implemented, could be bestowed upon Fijian communities.

· Determination of the benefit's modular construction post natural disaster regarding repair turnaround, availability of materials for maintenance and completion efficiency/ease.

· Development of a design which could me manufactured and implemented within Fiji to reap the benefits determined through this project.

Justification and significance

The literature review conducted on the Fijian culture, housing and construction industry, and modular housing demonstrates that the majority of previous research has focused on the construction system. There is no evidence of existing research being conducted into the Design and manufacturing of modular housing within the context of the Fijian Construction Industry. Due to the nature of modular housing, implementation of this construction method into developing countries such as Fiji could pose extensive benefits. This design and manufacturing method demonstrates opportunities to counteract challenges currently experienced such as resource availability, quality, and skilled labor. This can occur through providing a more suitable, sustainable, and economical approach to designing and constructing residential housing in Fiji. Investigation into the growth forecast that modular construction can impose within the industry and the opportunities it can provide within Fiji can be investigation which will assist in determining the key factors for driving growth.

Although there are already modular construction solutions present within Fiji, the exploration into betterment of the design, materials utilized and manufacturing systems in regards to the constrains present and ensuring the solution is sustainable will pose significant improvement along with reducing construction costs and increasing safety. By extension, standardizing a design for modular housing which caters for the extreme weather conditions, cultural requirements and needs of the Fijian communities is essential to ensure success. Therefore, this research will investigate solutions modular construction can provide to the current challenges faced.

Housing providers within Fiji can work together with material, manufacturing and transportation companies to enable the delivery of a more sustainable and long-lasting housing solution. Throughout this research project, focus will be placed upon the early design stages of modular housing for the context of Fiji. This will ensure a sustainable design that is fit for purpose within Fiji's climate, cultural requirements and transportation restriction is obtained. International modular construction trends provide a basis for design development which can be customized for the implementation into various Fijian contexts. This extends to the development of design codes and standards within Fiji which address modular construction within Fiji.

Therefore, this research project will pose significant benefits to the construction industry within Fiji through providing a sustainable, fit for purpose and context modular residential housing solution. The research project will aim to answer the outlined questions regarding implementing modular construction within Fiji, benefits and determining logistical factors which otherwise create limitations.

Has your project been peer reviewed?

No

Type of Research

Do you have adequate resources available for this research project?

Yes

What type of research are you undertaking in this project?

case study

The following options were available for selection:

- *medical (can be interventional, observational or lab-based)*
- *clinical*
- *biomedical*
- *epidemiological*
- *clinical trial*
- *use of drug or therapeutic device*
- *mental health*
- *public health*
- *dental*
- *action*
- *quantitative*
- *qualitative*
- *case study*
- *social science*
- *oral history/biographical*
- *other*

Identifying participant group/s

Will there be direct recruitment or use of existing data and/or tissue from any of the following participant groups?
n/a (none of the participant groups above are target groups for this project)

The following options were available for selection:

- *women who are pregnant, the human foetus, or human foetal tissue*
- *children or young people under the age of 18 years*
- *people with a cognitive impairment, an intellectual disability, or a mental illness*
- *people considered to be a forensic or involuntary patient*
- *people with impaired capacity for communication*
- *prisoners or people on parole*
- *people highly dependent on medical care, including a person who is unconscious*
- *military personnel*
- *military veterans*
- *people who would not usually be considered vulnerable but would be considered vulnerable in the context of this project*
- *Aboriginal and/or Torres Strait Islander peoples*
- *hospital patients*
- *people residing outside Australia*
- *people who would be considered to use English as a Second Language (ESL)*
- *people who would be considered to use English as a Foreign Language (EFL)*
- *n/a (none of the participant groups above are target groups for this project)*

Benefits and Risks

Benefits

The potential benefits of the project are:

- gains in knowledge, insight and understanding
Yes

Explain how this benefit will be achieved as a result of this research being conducted
This project will aim to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

- improved social welfare
Yes

Explain how this benefit will be achieved as a result of this research being conducted
Propose a new method of residential construction which could improve living conditions, availability and repair time following disaster events This design will assist with providing resilience to the community and development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development.

- improved individual wellbeing
Yes

Explain how this benefit will be achieved as a result of this research being conducted
Propose a new method of residential construction which could improve living conditions, availability and repair time following disaster events This design will assist with providing resilience to the community and development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development.

- Other
No

Risks

The following types of risks (either short or long term) may occur due to participation in this project:

- physical (including injury, illness, pain or death)
No

- psychological (including feelings of worthlessness, distress, guilt, anger or fear related, for example, to disclosure of sensitive or embarrassing information)
No

- social (including damage to social networks or relationships with others; discrimination in access to benefits, services, employment or insurance; social stigmatisation)
No

- devaluation of personal worth (including being humiliated, manipulated or in other ways treated disrespectfully or unjustly)
No

- economic (including the imposition of direct or indirect costs on participants)
No

- legal (including discovery and prosecution of criminal conduct)
No

- inconvenience (including taking the time to fill in the survey, participate in an interview etc)
Yes

Expand on this risk and its relevance to your project. Outline arrangements you will put in place to minimise this risk
Minimal, provide survey to participants to complete when they see fit/have availability to reduce pressure/time constraints.

- discomfort (including minor side-effects of medication, the discomforts related to measuring blood pressure, and anxiety induced by an interview)
No

- Other
No

Is there a physical, psychological, social, economic, and/or legal risks identified above that holds a risk greater than inconvenience or discomfort, in either the short or long term, resulting from participation in, or use of data in this project
No

Will you be collecting and/or analysing any biological material obtained from a person (e.g. tissue, blood, urine, sputum, or any derivative of these such as cell lines) in laboratory-based research
No

Will you be generating, gathering, collecting, conveying or using genomic data, information, or biological materials (such as germline/germ cells or somatic cells) that has hereditary

implications and/or is predictive of future health in research involving participants, relatives and other family members?

No

Are you intending to study and/or expose illegal activity?

No

Does your project contain sensitive and/or contentious issues (e.g. suicide, eating disorders, body image, trauma, violence, abortion, etc.)?

No

Does your project include deception of participants, concealment or covert observation?

No

Are you seeking disclosure of information which may be prejudicial to participants?

No

Are there any other high risk factors (not already disclosed above)?

No

Project Team

What is the level of risk for the project team?

Low

Outline the strategies that you have in place to address the level of risk to the project team?

N/A no risk

Data collection and access

Data Collection

Data Collection considerations

None of the above apply to this project

The following options were available for selection:

- *collection of data in a rural and remote setting*
- *travelling overseas to collect data*
- *physiological or psychological testing of participants*
- *none of the above apply to this project*

Data Access

Will any research data be made available or shared via open access, restricted access, mediated access or as metadata only?

No

Provide further details about the data that will be made available/shared, and via what method.
Data is specific to project, no current inquires or desire for it to be shared.

Will any individual or organisation external to UniSQ (i.e. a third party) have access to the research data during the project?
No

Other Considerations

UniSQ Course projects

Are you a course leader intending to undertake this project as a UniSQ Course project?
No

Upload any relevant or supporting documentation

Course information

Permissions to access participants

Are you required to obtain permission to access your group/s of participants?
No

Does your project include the recruitment of UniSQ staff or students?
No

Evidence of approval/endorsement

Monitoring your project

What will you do in cases where unexpected events or emergencies occur as a result of participation in this project?
Notification to the project supervisor (Steven Goh)

Notification to relevant UniSQ ethics

Cease project until further ethics clearance or approval to progress is obtained

Communication of findings

Publishing your findings

Method of Communication
research thesis

If providing individual test results to each participant, what arrangements will be in place to deal with participant's distress in the case of adverse results?

The following options were available for selection:

- *research thesis*
- *journal article*
- *book or book chapter conference presentation (not published in a proceedings)*
- *open access dataset*
- *published report to organisation or community group*
- *private report to organisation or community group*
- *report to all participants*
- *executive summary of results*
- *individual test results to each participant (eg from physiological or psychological testing)*
- *media (eg article in "The Conversation")*
- *creative output*
- *other*

Will the participants and/or other interested stakeholders be able to access these findings and/or request a copy of the summary of results?
Yes

Provide further information with regards to accessibility of these results
Students who answered questionnaire will be able to see published results through university software

When disseminating your findings, will participants be
non-identifiable (i.e. no individual or organisation can be identified)

The following options were available for selection:

- *non-identifiable*
- *re-identifiable*
- *identifiable or presented in a manner which may allow some participants to be identified.*
- *other*

Participant - Group 1

Group 1 name
Questionnaire

How many individual participants are expected to be recruited in this group?
10

Describe the participants in this group:
University Students (UniSQ)

Where will this group of participants be recruited from?
Met previously in study tour and engaged for project

Will any potential participants in this group be under 18?
No

Is there a pre-existing relationship between the participants and anyone involved in recruiting and/or collecting data from this group
Yes

What is the nature of the pre-existing relationship and will you be implementing any special precautions if these are unequal pre-existing relationships
Met previously during Fiji study tour and stayed in contact following (see each other at residential schools) no risk to research

Do these participants have any cultural needs?
No

Recruitment of Participants

How will you recruit participants?
Other

If other, explain how these participants will be invited to be involved in the project.
Facebook group chat from residential school

Indicate how you will obtain the contact details of these participants
other

Further explain how you are obtaining contact details as per the source/s selected above.
Obtained previously from engineering study tour

Provide details of who will be inviting participants and further explain the method/s they will use, as identified above.
Via message sent by Caitlin Battersby explaining project, what's involved (e.g. questionnaire)

Will you be offering payment or any other incentives to this group of participants?
No

Invitation/s for recruitment, not participant information sheet.

Upload Recruitment Information

Data Collection

Method of collection

survey/questionnaire

Provide further details for this data collection method

Microsoft forms

Administered and returned online

Are particular qualifications required to use this method?

No

Will you be recording participants?

No

Documents you have referred to for this group which may include: Survey instrument, question list, protocol for administering a substance

Data Collection documentation specific to this group

Participation

What are you asking participants in this group to do or what is to be done to them?

Link is provided to students to complete questionnare when they have the chance

How much time are you asking of participants in this group and when will this time be required?

20 minutes when available

Specifically, where will this data be collected?

Online - Microsoft forms

Does the research involve measures or procedures that are diagnostic or indicative of any medical or clinical condition, or any other situation of concern?

No

Will a Participant Information Sheet (PIS, or similar) be provided to the participants?

Yes

Please upload your participant information document. It is strongly recommended that you use the UniSQ template which has all required fields including purpose, risks, benefits and referral services.

Participant Information Sheet

When and how will you be distributing the participant information sheet (or similar) to participants?

via messages

If you are not using a Participant Information Sheet (or similar), how will this project be communicated to participants?

Via engagement message and within a blurb at the start of the survey

Will participants be referred to support services?
No

Consent

Are these participants able to consent for themselves?
Yes

Will participants be fully informed about the true nature of the research?
Yes

Consent type

How will you obtain consent from this group of participants?
Consent form

Participant Consent Type - Group 1

Consent form

Outline the process by which the participants will give consent and how they return the consent form to the researchers.
Consent form as attached

Needs to be completed and signed

Attach consent forms

Consent form/s

Participant - Group 2

Group 2 name
N/A not occuring anymore

How many individual participants are expected to be recruited in this group?
1

Describe the participants in this group:
N/A not occuring anymore

Where will this group of participants be recruited from?
N/A not occuring anymore

Will any potential participants in this group be under 18?
No

Is there a pre-existing relationship between the participants and anyone involved in recruiting and/or collecting data from this group
Yes

What is the nature of the pre-existing relationship and will you be implementing any special precautions if these are unequal pre-existing relationships
N/A not occuring anymore

Do these participants have any cultural needs?
No

Recruitment of Participants

How will you recruit participants?
Email
Other

If other, explain how these participants will be invited to be involved in the project.
N/A not occuring anymore

Indicate how you will obtain the contact details of these participants
other

Further explain how you are obtaining contact details as per the source/s selected above.
N/A not occuring anymore

Provide details of who will be inviting participants and further explain the method/s they will use, as identified above.
N/A not occuring anymore

Will you be offering payment or any other incentives to this group of participants?
No

Invitation/s for recruitment, not participant information sheet.

Upload Recruitment Information

Data Collection

Method of collection
interview

Provide further details for this data collection method
N/A not occuring anymore

Are particular qualifications required to use this method?

No

Will you be recording participants?
No

Documents you have referred to for this group which may include: Survey instrument, question list, protocol for administering a substance

Data Collection documentation specific to this group

Participation

What are you asking participants in this group to do or what is to be done to them?
N/A not occuring anymore

How much time are you asking of participants in this group and when will this time be required?
N/A not occuring anymore

Specifically, where will this data be collected?
N/A not occuring anymore

Does the research involve measures or procedures that are diagnostic or indicative of any medical or clinical condition, or any other situation of concern?
No

Will a Participant Information Sheet (PIS, or similar) be provided to the participants?
No

If you are not using a Participant Information Sheet (or similar), how will this project be communicated to participants?
N/A not occuring anymore

Will participants be referred to support services?
No

Consent

Are these participants able to consent for themselves?
Yes

Will participants be fully informed about the true nature of the research?
Yes

Consent type

How will you obtain consent from this group of participants?
Consent form

Participant Consent Type - Group 2

Consent form

Outline the process by which the participants will give consent and how they return the consent form to the researchers.
N/A not occuring anymore

Attach consent forms

Consent form/s

Participant - Group 3

Group 3 name
N/A

How many individual participants are expected to be recruited in this group?
1

Describe the participants in this group:
N/A

Where will this group of participants be recruited from?
N/A

Will any potential participants in this group be under 18?
No

Is there a pre-existing relationship between the participants and anyone involved in recruiting and/or collecting data from this group
No

Do these participants have any cultural needs?
No

Recruitment of Participants

How will you recruit participants?
Other

If other, explain how these participants will be invited to be involved in the project.
N/A

Indicate how you will obtain the contact details of these participants

other

Further explain how you are obtaining contact details as per the source/s selected above.
N/A

Provide details of who will be inviting participants and further explain the method/s they will use, as identified above.
N/A

Will you be offering payment or any other incentives to this group of participants?
No

Invitation/s for recruitment, not participant information sheet.
Upload Recruitment Information

Data Collection

Method of collection
other (not outlined above)

Provide further details for this data collection method
N/A

Are particular qualifications required to use this method?
No

Will you be recording participants?
No

Documents you have referred to for this group which may include: Survey instrument, question list, protocol for administering a substance
Data Collection documentation specific to this group

Participation

What are you asking participants in this group to do or what is to be done to them?
N/A

How much time are you asking of participants in this group and when will this time be required?
N/A

Specifically, where will this data be collected?
N/A

Does the research involve measures or procedures that are diagnostic or indicative of any medical or clinical condition, or any other situation of concern?
No

Will a Participant Information Sheet (PIS, or similar) be provided to the participants?
No

If you are not using a Participant Information Sheet (or similar), how will this project be communicated to participants?
N/A

Will participants be referred to support services?
No

Consent

Are these participants able to consent for themselves?
Yes

Will participants be fully informed about the true nature of the research?
Yes

Consent type

How will you obtain consent from this group of participants?
Waiver of the requirement for consent is required

Participant Consent Type - Group 3

Waive requirement for Consent

Provide a justification as to why the requirement for consent should be waived
N/A

Participant - Group 4

Group 4 name
N/A

How many individual participants are expected to be recruited in this group?
1

Describe the participants in this group:
N/A

Where will this group of participants be recruited from?
N/A

Will any potential participants in this group be under 18?
No

Is there a pre-existing relationship between the participants and anyone involved in recruiting and/or collecting data from this group
No

Do these participants have any cultural needs?
No

Recruitment of Participants

How will you recruit participants?
Other

If other, explain how these participants will be invited to be involved in the project.
N/A

Indicate how you will obtain the contact details of these participants
other

Further explain how you are obtaining contact details as per the source/s selected above.
N/A

Provide details of who will be inviting participants and further explain the method/s they will use, as identified above.
N/A

Will you be offering payment or any other incentives to this group of participants?
No

Invitation/s for recruitment, not participant information sheet.

Upload Recruitment Information

Data Collection

Method of collection
other (not outlined above)

Provide further details for this data collection method
N/A

Are particular qualifications required to use this method?
No

Will you be recording participants?

No

Documents you have referred to for this group which may include: Survey instrument, question list, protocol for administering a substance

Data Collection documentation specific to this group

Participation

What are you asking participants in this group to do or what is to be done to them?
N/A

How much time are you asking of participants in this group and when will this time be required?
N/A

Specifically, where will this data be collected?
N/A

Does the research involve measures or procedures that are diagnostic or indicative of any medical or clinical condition, or any other situation of concern?
No

Will a Participant Information Sheet (PIS, or similar) be provided to the participants?
No

If you are not using a Participant Information Sheet (or similar), how will this project be communicated to participants?
N/A

Will participants be referred to support services?
No

Consent

Are these participants able to consent for themselves?
Yes

Will participants be fully informed about the true nature of the research?
Yes

Consent type

How will you obtain consent from this group of participants?
Waiver of the requirement for consent is required

Participant Consent Type - Group 4

Waive requirement for Consent

Provide a justification as to why the requirement for consent should be waived

N/A

Participant - Group 5

Group 5 name

N/A

How many individual participants are expected to be recruited in this group?

1

Describe the participants in this group:

N/A

Where will this group of participants be recruited from?

N/A

Will any potential participants in this group be under 18?

No

Is there a pre-existing relationship between the participants and anyone involved in recruiting and/or collecting data from this group

No

Do these participants have any cultural needs?

No

Recruitment of Participants

How will you recruit participants?

Other

If other, explain how these participants will be invited to be involved in the project.

N/A

Indicate how you will obtain the contact details of these participants

other

Further explain how you are obtaining contact details as per the source/s selected above.

N/A

Provide details of who will be inviting participants and further explain the method/s they will use, as identified above.

N/A

Will you be offering payment or any other incentives to this group of participants?
No

Invitation/s for recruitment, not participant information sheet.

Upload Recruitment Information

Data Collection

Method of collection
human biospecimens

Provide further details for this data collection method
N/A

Are particular qualifications required to use this method?
No

Will you be recording participants?
No

Documents you have referred to for this group which may include: Survey instrument, question list, protocol for administering a substance

Data Collection documentation specific to this group

Participation

What are you asking participants in this group to do or what is to be done to them?
N/A

How much time are you asking of participants in this group and when will this time be required?
N/A

Specifically, where will this data be collected?
N/A

Does the research involve measures or procedures that are diagnostic or indicative of any medical or clinical condition, or any other situation of concern?
No

Will a Participant Information Sheet (PIS, or similar) be provided to the participants?
No

If you are not using a Participant Information Sheet (or similar), how will this project be communicated to participants?
N/A

Will participants be referred to support services?
No

Consent

Are these participants able to consent for themselves?
Yes

Will participants be fully informed about the true nature of the research?
Yes

Consent type

How will you obtain consent from this group of participants?
Waiver of the requirement for consent is required

Participant Consent Type - Group 5

Waive requirement for Consent

Provide a justification as to why the requirement for consent should be waived
N/A

Participant - Group 6

Group 6 name
N/A

How many individual participants are expected to be recruited in this group?
1

Describe the participants in this group:
N/A

Where will this group of participants be recruited from?
N/A

Will any potential participants in this group be under 18?
No

Is there a pre-existing relationship between the participants and anyone involved in recruiting and/or collecting data from this group
No

Do these participants have any cultural needs?
No

Recruitment of Participants

How will you recruit participants?
Other

If other, explain how these participants will be invited to be involved in the project.
N/A

Indicate how you will obtain the contact details of these participants
other

Further explain how you are obtaining contact details as per the source/s selected above.
N/A

Provide details of who will be inviting participants and further explain the method/s they will use, as identified above.
N/A

Will you be offering payment or any other incentives to this group of participants?
No

Invitation/s for recruitment, not participant information sheet.

Upload Recruitment Information

Data Collection

Method of collection
other (not outlined above)

Provide further details for this data collection method
N/A

Are particular qualifications required to use this method?
No

Will you be recording participants?
No

Documents you have referred to for this group which may include: Survey instrument, question list, protocol for administering a substance

Data Collection documentation specific to this group

Participation

What are you asking participants in this group to do or what is to be done to them?
N/A

How much time are you asking of participants in this group and when will this time be required?
N/A

Specifically, where will this data be collected?
N/A

Does the research involve measures or procedures that are diagnostic or indicative of any medical or clinical condition, or any other situation of concern?
No

Will a Participant Information Sheet (PIS, or similar) be provided to the participants?
No

If you are not using a Participant Information Sheet (or similar), how will this project be communicated to participants?
N/A

Will participants be referred to support services?
No

Consent

Are these participants able to consent for themselves?
Yes

Will participants be fully informed about the true nature of the research?
Yes

Consent type

How will you obtain consent from this group of participants?
Waiver of the requirement for consent is required

Participant Consent Type - Group 6

Waive requirement for Consent

Provide a justification as to why the requirement for consent should be waived
N/A

Additional Groups

You have indicated that you are using more than 6 groups of Human Participants, Existing Data Sets; or Existing Biospecimens.

This application form can only collect up to 6 groups. Please attach additional groups of data here.

Attach additional groups of data here.

Additional groups

Additional Documentation

Do you need to upload any additional documentation?

No

Attached files

RMP Approved.pdf

ENP4111_CBattersby_Methodology.pdf

CB Transcript 15.05.2024.pdf

Recruitment Email.pdf

Consent form Questionnaire v12 280923.pdf

Information Sheet Questionnaire v13 151123.pdf

ENP4111 - Modular Housing Design Proposed Solution Review & Feedback.pdf

Information Sheet Questionnaire - updated.pdf

Consent form Interview v12 280923.pdf

Information Sheet Interview v13 151123.pdf

Methodology - interview and survey questions.pdf

Consent form Interview v12 280923.pdf

Information Sheet Interview v13 151123.pdf

Information Sheet Questionnaire v13 151123.pdf

Consent form Questionnaire v12 280923.pdf

Information Sheet Questionnaire v13 151123.pdf

Information Sheet Questionnaire v13 151123.pdf

Information Sheet Questionnaire v13 151123.pdf

Information Sheet Questionnaire v13 151123.pdf

Information Sheet Questionnaire v13 151123.pdf

Information Sheet Questionnaire v13 151123.pdf

Professional Engineer Research Project

Methodology

✔ Done

Opened: Monday, 22 January 2024, 12:00 AM
Due: Monday, 20 May 2024, 11:59 PM

Assignment

Submission status

Submission status	Submitted for grading
Time remaining	Assignment was submitted 2 hours 15 mins early
Last modified	Monday, 20 May 2024, 9:43 PM
File submissions	ENP4111_CBattersby_Methodology.pdf 20 May 2024, 9:43 PM

Submission comments	▸ Comments (1)

Feedback

Grade	Satisfactory
Graded on	Wednesday, 5 June 2024, 8:29 PM

Feedback comments

Would be good to see some methodology literature being cited for each of the methods used in 1.1 to 1.8, as well as an overall methodological approach. This is to show that you have grounded your methodology and methods in literature.

For example,

Furbey, R. and Goodchild, B., 1986. Method and methodology in housing user research. Housing Studies, 1(3), pp.166-181.

Vestbro, D.U., Hurol, Y., Wilkinson, N., Lawrence, R., Horelli, L., Johansson, R., Lans, V., de Jonge, T., Iwarsson, S., Steinfuhrer, A. and McGrath, N., 2005. Methodologies in housing research. The Urban International Press.

Bilau, A.A., Witt, E. and Lill, I., 2018. Research methodology for the development of a framework for managing post-disaster housing reconstruction. Procedia engineering, 212, pp.598-605.

Qtaishat, Y., Adeyeye, K. and Emmitt, S., 2020. Eco-cultural design assessment framework and tool for sustainable housing schemes. Urban Science, 4(4), p.65.

GhaffarianHoseini, A., Ibrahim, R., Baharuddin, M.N. and GhaffarianHoseini, A., 2011. Creating green culturally responsive intelligent buildings: Socio-cultural and environmental influences. Intelligent Buildings International, 3(1), pp.5-23.

Consider your RMP as approved by me.

Caitlin J. Battersby

Student ID: [redacted]
Course: **ENP4111**
Class: 10533

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Faculty: Academic Affairs
Assessment: **Assignments, Written, Planning document 2**
Due Date: **20-May-2024**
Examiner: Belal Yousif

13076792

Marker Signature: ____________________ **Mark Given (Office Use Only):** ____________________

Have you previously submitted the assignment electronically? Yes ☐ No ☐

☐ I have been granted an assignment extension (supporting documentation attached).

☐ I wish to be granted an assignment extension (supporting documentation attached).

☐ Application Accepted ☐ Application Denied Lecturer ____________

STUDENT DECLARATION:

I hold a copy of this assignment which I can produce if the original is lost or damaged.

I hereby certify that no part of this assignment has been copied from any student's work (including previous work by me) or from any other source except where due acknowledgement is made in the assignment. No part of this assignment has been written for me by any other person except where such collaboration has been authorised by the Course Team Leader or the examiner concerned.

Signature: [redacted] ________ **Date:** 20/05/2024

Notes:
1. An Examiner or a Course Team Leader has, and may exercise, the right not to mark this assignment if the above declaration has not been signed.
2. If the above declaration is found to be false, further appropriate action will be taken.

Make sure that you have used the **CORRECT** Assignment Cover for your assignment. Incorrect assignment cover sheets will cause delays.

DATE RECEIVED

(Office Use Only)

University of Southern Queensland

Faculty of Engineering and Surveying

Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Dissertation Methodology by

Caitlin Battersby

[redacted]

In fulfilment of the requirements of

ENP4111 Professional Engineer Research Project

towards the degree of

Bachelor of Engineering (Honors) (Civil)

Under the supervision of

Steven Goh and Janith Jeewantha

Table of Contents

Introduction and Background

Modular construction has proven to offer an effective and sustainable solution to housing shortages globally. This resolution is through decreasing labor costs and requirement for skilled laborers, increase in productivity and decrease in construction duration. Therefore, it poses as a functional solution to post-disaster relief shelter and the ability to provide safe, dependable, and sanitary housing within developing nations. Due to this, this research project is to explore the utilization of modular construction within the context of Fiji.

As a part of an engineering study and cultural emersion experience in June 2023, I was exposed to the challenges currently experienced due to constraining factors. These factors include resource cost and availability, lack of skilled workers and engineers, and in-efficient project and waste management. Additionally, Fiji is highly susceptible to a high intensity and frequency of natural disaster which has led to the development of a reactive mindset, preventing the nation from forward planning, and developing. This project will aim to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

This will occur through an analysis of design innovation of the current design trends within modular housing, including the materials utilized, and sustainability of the design. The advancement of manufacturing systems will also be analyzed, which includes 3D printing and supply chain optimization, the determine how to ensure efficiency and reduce the timeline of the project. The challenges which are currently faced within the Fijian construction industry will be addressed and solutions proposed in relation to modular housing. This will pave the future direction for potential innovation and aim to fast-track construction in Fiji which is not only up to standard but also provides a method of reducing the impact natural disasters place upon the community.

Through this research project, the benefits, and outcomes regarding modular construction evident determined will have significant impact upon the nation. This project aims to assist with the development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development. Therefore, the objectives of the research project are as follows:

1. Research: Conduct diverse research into modular housing and the opportunities, innovations, sustainability, design, manufacturing, and existing case studies. This will enable challenges to be identified and solutions to be proposed.
2. Industry engagement and consultation: conduct surveys and interviews with industry professionals within Fiji to gain further insight into the challenges faced and opportunities present for modular housing.
3. Comparative analysis: Compare the efficiency, sustainability, and cost-effectiveness of modular houses and materials used within Fiji in comparison to traditional construction methods.
4. Case study analysis: an in-depth analysis into modular housing projects which has a focus on design, manufacturing, and implementation aspects. The fundings are to reflect the feasibility, benefits, and outcome of the application such elements in Fiji.
5. Proposal of a modular housing solution to be implemented in Fiji: develop a proposed modular building housing solution design which encompasses the findings of the research and analysis.

Therefore, the expected outcome of this research project is to develop a modular housing design which is suitable to be manufactured and implemented within Fiji. This design will assist with providing resilience to the community and development of Fiji as a nation through diverting the agencies attention from a reactive approach, providing a means which they can start planning for future development.

Literature Review

To develop and propose a modular housing solution applicable to Fiji, it is important to first identify what modular housing is and its benefits. Housing availability, longevity and affordability are key characteristics of modular construction which not only will ensure the communities can reap the benefits of the construction alternative, but also reduce ongoing maintenance costs and repair duration. The following literature review investigates the Fijian culture regarding housing requirements and practices, details modular housing and investigate case studies and opportunities for the construction method. This review will serve as a basis for my proposed methodology and analyses, enabling a suitable design to be proposed.

The literature review conducted on the Fijian culture, housing and construction industry, and modular housing demonstrates that the majority of previous research has focused on the construction system. There is no evidence of existing research being conducted into the Design and manufacturing of modular housing within the context of the Fijian Construction Industry. Due to the nature of modular housing, implementation of this construction method into developing countries such as Fiji could pose extensive benefits. This design and manufacturing method demonstrates opportunities to counteract challenges currently experienced such as resource availability, quality, and skilled labor. This can occur through providing a more suitable, sustainable, and economical approach to designing and constructing residential housing in Fiji. Investigation into the growth forecast that modular construction can impose within the industry and the opportunities it can provide within Fiji can be investigation which will assist in determining the key factors for driving growth.

Although there are already modular construction solutions present within Fiji, the exploration into betterment of the design, materials utilized and manufacturing systems in regards to the constrains present and ensuring the solution is sustainable will pose significant improvement along with reducing construction costs and increasing safety. By extension, standardizing a design for modular housing which caters for the extreme weather conditions, cultural requirements and needs of the Fijian communities is essential to ensure success. Therefore, this research will investigate solutions modular construction can provide to the current challenges faced.

Housing providers within Fiji can work together with material, manufacturing and transportation companies to enable the delivery of a more sustainable and long-lasting housing solution. Throughout this research project, focus will be placed upon the early design stages of modular housing for the context of Fiji. This will ensure a sustainable design that is fit for purpose within Fiji's climate, cultural requirements and transportation restriction is obtained. International modular construction trends provide a basis for design development which can be customized for the implementation into various Fijian contexts. This extends to the development of design codes and standards within Fiji which address modular construction within Fiji.

Therefore, this research project will pose significant benefits to the construction industry within Fiji through providing a sustainable, fit for purpose and context modular residential housing solution. The research project will aim to answer the outlined questions regarding implementing modular construction within Fiji, benefits and determining logistical factors which otherwise create limitations.

After conducting this literature review it is evident that the implementation of modular housing within the construction industry can pose significant benefits for developing counties as well as reducing environmental impact, construction costs, construction and assisting in providing affordable and safe housing. The case studies demonstrate the various situations in which modular housing can offer and effective solution. The research will aim to address all aspects identified within section 13, requirements for research, with the goal to produce a design which can be utilized in country.

Further investigation is still required before this literature review is complete as identified within this submission. These points will ensure the proposed design solution has considered all elements of modular construction and limitations in which the method could impose. It will also ensure that the design is fit for construction and purpose within Fiji, addressing all cultural requirements of the indigenous people.

Therefore, undertaking this research in relation to the concept of modular housing within the residential sector of Fiji and the positive benefits this could have in regard to natural disasters have be made evident. Through implementation of modular construction within Fiji, reduced displacement and reaction time post disaster in regard to shelter can occur, with the overall aim for future planning and sustainable development to begin occurring within the region

Methodology

Throughout the duration of the proposed research project, various methodology will be implemented in order to determine a sound conclusion following an in-depth literature review. Through the various methodology formats, it will ensure all aims of my project are fulfilled and a variety of perspectives and understanding is obtained to enable a detailed analysis and non-bias determination. Certain aspects of the methodology are subject to alteration or being void on the basis of weather funding is able to be obtained from the university. On the basis I am not successful in this endeavor, the following proposed tasks will be altered to include interview conducted on teams and removal of all in country activities. This will be further amended on the submission of the final project report.

1.1 Literature Review

A comprehensive literature review will be conducted within the preliminary stages of the research project. The purpose of the literature review will be to understand the current state of modular residential housing and the impact it has upon the construction industry. This will include topics such as the historical development in relation to how modular housing has evolved over time, standards applicable to modular construction, recent innovation within modular housing and the cutting-edge design trends and manufacturing technologies which are being utilized in the industry currently. Case studies will be examined to demonstrate modular housing construction projects globally and the impact the construction method has had upon communities. Lastly, sustainability within the construction method will be investigated to determine how this construction method can contribute to enhancing sustainability within the housing industry and opportunities present within innovation and manufacturing systems.

Keywords will be used to ensure an extensive literature review is undertaken to gather and evaluate the required information. This will include evaluating the references of the journals to validate the reliability of the research articles which will be obtained from recommended research engines which includes Google Scholar, Scopus, and ScienceDirect. An internet search will also be conducted to review other publications and grey literature from other organizations. This information will include case studies, reports, and policies.

1.2 Questionnaire

A questionnaire will be constructed utilizing Microsoft forms in which a preliminary, statistical investigation will be undertaken. The participants of this questionnaire will include industry professionals such as engineers and non-government organizations (NGO's), the community, construction workforce, local councils, students, and educators within higher learning institutions. This will enable a broad range of data to be obtained from various individuals with different backgrounds and skill levels. This information will be analyzed, and conclusions drawn which will form the basis of the investigative questions within the industry and community engagement and consultation sessions. The questions will explore currently held knowledge regarding the construction technique, the identified opportunities and challenges, questions surrounding the method and whether they would be likely to utilize this construction method. Further questions surrounding the impact natural disasters have incurred upon the individual, the consequent challenges experienced, and weather implementation of this construction method could/can assist will be asked. This methodology will be undertaken within the preliminary stages of the project to enable additional information surrounding key points raised to be obtained and queries to be addresses throughout the remainder of the research project. Prior to dispersing the questionnaire via email, ethics approval from the university is required to be obtained. This process will occur over the coming weeks to ensure adequate time is available to evaluate the response and dictate further questions for the next step based on identified topic areas.

1.3 Industry Expert Consultation

Occurring both online via zoom and in person dependent upon the situation, industry expert consultation will occur with a variety of government, non-government, and private organizations. Connections were previously obtained during the engineering study tour with various organizations relevant to this research project. Connection and proposition of my project and the involvement of such individuals will be established within the preliminary project stages. This includes individuals from private engineering consultancy firms, engineers Fiji representatives, Housing and development Fiji department, Red Cross, Fijian Universities, and the National Disaster Recovery Agency. Consultation interviews will be scheduled which will include both in country and online dependent upon availability, location, and constraints. Interviews will occur, with recorded audio in order to refer back to points and statements made during analysis. All names, private and sensitive information will be protected. Questions asked will include preliminary opinion-based question regarding the implementation of the technology within the proposed situation along with additional questions surrounding the technologies roles in a reconstruction post disaster response setting. The element of sustainability and cultural requirements will also be addressed along with identified constraints this project aims to investigate and the proposed solution modular construction aims to fulfill.

1.4 Community Engagement Focus Groups

The community will be engaged in order to obtain their perspective regarding the construction method. This will highlight weather the technology would be utilized within Fijian villages based upon economic, locality and cultural constraints. This will be undertaken by visiting several villages in which a focus group will be constructed. The construction method will be explained, scope of implementation within Fiji discussed, the opportunities, benefits and constraints identified, and therefore will provide an opportunity for feedback and questions to be obtained, asked, and answered. This will enable a determination regarding feasibility to occur and consumer feedback and queries to be obtained. This will be completed in conjunction with on-site investigations to enable examples to be shown and practical application to be explored.

1.5 Onsite Investigation

Onsite investigations are an essential aspect of developing an understanding of the issue at hand and often the severity and impact the proposed technology could instate. The proposed sites to investigate include an established community, a newly constructed subdivision, a slum community within the outskirts of Suva and a community which has recently been impacted by a nature disaster currently in the reconstruction phase. The Red Cross provides containers throughout the island which provide essential items for communities to access post disaster. The capacity and situation surrounding the container would be important to investigate with a site visit proposed for various shelter locations both regional and rural. The conduction of these onsite investigations will primarily be in conjunction with community engagement sessions which therefore enable the living conditions, impact, construction techniques and nature of the sites to be determined. Additionally, the constraints and benefits modular construction could bestow can be identified posing a rounded, unbiased perspective and understanding of the current and desired living conditions.

1.6 Comparative Analysis

A comparative analysis will be undertaken in order to compare the findings from the literature review and other findings. This analysis will aim to compare the efficiency, sustainability, and cost-effectiveness of modular houses and materials used within Fiji in comparison to traditional construction methods. By doing so, the analysis will assist in determining whether modular construction actually poses the benefits advertised or if the construction method is better suited to other applications. This analysis will also touch upon construction standards and the requirements surrounding modular construction in comparison to standard methods within Fiji.

1.7 Case Study Analysis

A case study analysis will be undertaken to conduct an in-depth analysis into modular housing projects which has a focus on design, manufacturing, and implementation aspects. The purpose of this analysis is to determine the feasibility, benefits, and outcome of the application such elements in Fiji based upon other applications in similar circumstances. Case studies from remote and rural communities will be evaluated along with implementation within situations that have limited resources or short construction timeframes. The benefit of using this construction method in comparison to traditional methods will be analysis, enabling a detailed and thorough analysis to occur in order to determine if this construction method will be fit for purpose within the proposed situation.

1.8 Modular Housing Design Proposed Solution

Through conducting this research project, a modular building design solution will be proposed. This design will encompass the findings of the literature review, questionnaires, interviews, and analysis to propose a solution to the issue preliminarily identified. The outcomes, benefits, and key design elements of the design will be detailed and proposed plans presented using CAD software. The design process is therefore a critical element of this project which will utilize all the findings of the project to pose a solution. The goal of the project is to determine how modular construction council benefit the Fijian construction industry and communities, focusing on sustainability, resources, accessibility and developing a solution which is fit for in country use. When developing the design, the materials selected and manufacturing systems proposed need to be evaluated to prevent issues from arising.

2. Outcome and Benefit

In conjunction with a comprehensive literature review surrounding opportunities for materials, sustainability, and project management due to modular construction in the Fijian context, the identified methodologies will be undertaken. The outcome of the proposed methodologies formats varies dependent upon the scope identified. The objectives and associated problems previously identified will be targeted within the questioning aspects of each methodology format. This will provide a relevant and detailed response from industry professionals and the community who are the end consumers being engaged to identify risks, opportunities, and restraints regarding modular construction. The benefit of doing so is to prevent a one-sided, bias conclusion from occurring by addressing all stages of the process and engaging industry professionals to provide insight upon the projects feasibility. Additionally, by engaging the community it will address whether this construction method is accessible and obtainable, along with being fit for purpose and culturally aligned. Therefore, the aim of the project will be addressed in a beneficial format enabling the outcomes to be determined upon analysis of the collected data and information.

3. Project Planning

Please refer to the timeline located in section 3.3 which outlines the stages of the research project. The key dates for this project are as follows:

- Literature review due by the 2nd of April 2024
- Methodology due by the 20th of May 2024
- Draft Dissertation containing preliminary results due by the 9th of September 2024
- Presentation during the residential school beginning the week of 14th of October 2024
- Dissertation due by the 4th of November 2024

3.1 Resources Required

The resources required to undertake the proposed research project are outlined within table 1 below. All identified resources are obtainable upon the basis that the funding can be granted and organization and scheduling with the country experts and community can be aligned.

Table 1: Resources Required to undertake proposed research project

Task	Resource	Quantity	Source	Cost	Comment
All	PC with Microsoft Windows	1	Student	N/A	Already Owned
	iPhone	1	Student	N/A	Already Owned
	Microsoft 365	1	Student	N/A	Already available
	Pen and Paper	1	Student	N/A	Already Owned
Literature Review	Professional Resource Databases	1	University	N/A	Available through the university
	Reference Manager – Citation Tools	1	University	N/A	Available through the university
In-country (Fiji) Investigation & Consultation	Round trip flights Sydney – Fiji	1	UniSQ International Funding	$800*	Obtaining Grant
	Accommodation in Country	14	UniSQ International Funding	$2000*	Obtaining Grant
	Transportation in Country	14*	UniSQ International Funding	$150*	Obtaining Grant
	Other in country expenses	1	Student	$400*	Self-Funded
	Industry expert's engagement	10	Student	N/A	Scheduling required Time Constraints

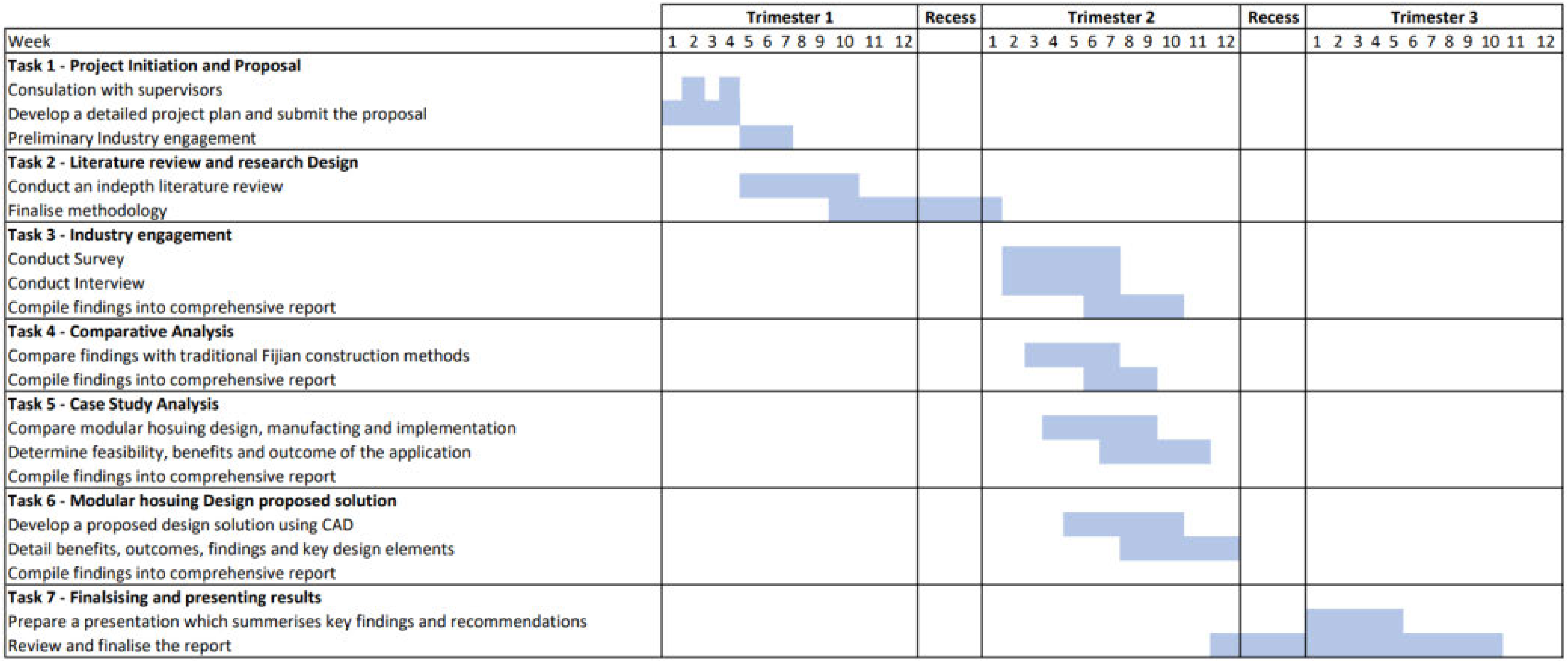
	Data from Industry	-	Student	N/A	Access of Data
	Community Engagement	3	Student	N/A	No costs associated
	On-site investigations: • Steel Cap boots • High vis • Hard Hat • Safety Glasses	1 1 1 1	Student Student Student Student	N/A N/A N/A N/A	All required PPE must be worn onsite, all items are already owned by student
External Consultation	Survey Participants Involvement	40*	Student	N/A	Involvement by participants
	Microsoft forms	1	Student	N/A	Already available
Design	AutoCAD	1	University	N/A	Available through the university

3.2 Key Considerations

When undertaking the proposed research project, the key considerations required include safety and ethics. This will not only ensure the successful outcome of the project, but also ensure the researchers' safety is maintained. Safety issues will be identified, and mitigation strategies outlined within the risk management assessment however, the task posing the highest risk is the in-country visit to Fiji. Previously I participated within a study tour located in Fiji, therefore a preliminary understanding regarding the safety concerns of the proposed stay have been obtained. This ensures preparation can occur and appropriate measures can be taken to prevent hazardous situations from occurring. Within the circumstance of the proposed research project, the ethical considerations which require analysis and approval include protection of sensitive information and ensuring participants are provided their right to confidentiality. Therefore, in order to safeguard a participant's confidentiality and provide legal jurisdiction regarding data protection, the researcher is required to continually uphold the ethical code of conduct. This includes adhering to all polies and rules regarding the code. Therefore, aspects of this project will need to be approved by the University of Southern Queensland Human Ethics committee such as the survey questionaries to ensure the code of conduct is abided by. This ensures no participants will be subject to potential physiological or physical harm as a result of the undertaken research. This demonstrates that throughout the entirety of the research project it is essential that consideration regarding ethics and safety occurs. Within various stages, differing ethical issues, constraints and requirements are prominent and must be complied with. It is essential that if in doubt, to refer to the University of Southern Queensland Human Ethics Committee for guidance. A preliminary risk assessment has been undertaken, however upon initiation of this project and throughout various phases it is essential to re-evaluate the risks, their mitigation measures and identify any additional risks which require further analysis. Through doing so, it will ensure that the proposed research project has been undertaken safely and ethically and no harm will be or is intended to be posed upon the participants and community.

3.3 Project Schedule

The required milestones and short-term goals were assessed in order to develop a suitable timeline which displays the desirable completion time. The project schedule below demonstrates a visual framework of the project structure and desired completion dates for the primary tasks.



3.4 Safety

The majority of the tasks associated with conducting this research project can occur behind a computer in one form or another. Therefore, on the basis of personal safety, limited issues will arise. Safety issues which could occur include repetitive stress injuries, eye strain or heath issues due to prolonged screen use and seated work. These issues can be mitigated through implementing correct workplace ergonomics and by taking regular breaks.

When conducting questionnaires or interviews, the safety of both oneself and the other participants needs to be considered. This includes both physical and emotional safety in which the university's ethics department is required to review and make an assessment of the proposed research questions to eliminate harm from occurring. This weeklong process will be undertaken in preparation for conducting this research and will ensure the ethics of the project are maintained.

In the instance in country investigations occur within Fiji, a larger risk will arise and require mitigation measures implements to ensure the safety of myself and participants. A risk assessment was conducted and contained within section 3.5 of this report. For example, when attending construction sites or manufacturing facilities, it is essential to abide by all work, health, and safety requirements such as wearing standard PPE such as steel cap boots, fluorescent vests, and a hard hat. This extends to sites in country, in which standard PPE as per an Australian construction site requirements will be exercised for one's own personal safety. Dependent on the site, undertaking a site induction, signing in and out and sighting of one's white card may be required. This credential will be carried on my person at all times during these visits to ensure all necessary credentials are available and one will ensure that all identified points within the site induction are abided by.

Therefore, the potential harm this project could pose upon myself and those involved is minimal. By ensuring the mitigation measures addressed in the following section are implemented and ethics of the proposed questionnaire and interview questions are evaluated, the projects risks can be significantly elevated, and safety enhanced.

3.5 Risk Assessment

A risk assessment was conducted for this research project in order to determine the potential risks and hazards associated. The following risk assessment was developed on the basis that in country investigations were to be conducted. This will be further amended based upon the funding outcome. Development of a risk assessment is one of the most important aspects of a project, ensuring that all potential risks are mitigated.

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland **Offline Version**

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Research Project 1 & 2 - Proposal	Assessment Date:	11/10/2023
Workplace (Division/Faculty/Section):	Faculty of Engineering and Surveying	Review Date:(5 Years Max)	11/01/2024
Context			
Description:			
What is the task/event/purchase/project/procedure?	Determining if Modular Construction is suitible within the Fiji Contect		
Why is it being conducted?	To determine an outcome for the Proposed Research Project		
Where is it being conducted?	Combination of online and in county (Fiji)		
Course code (if applicable)	ENG4110, ENG4111 & ENG4112	Chemical name (if applicable)	N/A
What other nominal conditions?			
Personnel involved	Caitlin Battersby and external engaged individuals		
Equipment	iPhone 13 pro, PC, paper and pens.		
Environment	Online, office enviroment, onsite visits and investigations		
Other	N/A		
Briefly explain the procedure/process	Combination of online and incountry interviews and engaement with industry professional and the community.		
Assessment Team - who is conducting the assessment?			
Assessor(s)	Caitlin Battersby		
Others consulted:	Steven Goh		

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide

E=Extreme Risk – Task ***MUST NOT*** proceed

H=High Risk – Special Procedures Required (See USQSafe)

M=Moderate Risk – Risk Management Plan/Work Method Statement Required

L=Low Risk – Use Routine Procedures

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Unethical research	Legal issues, unuseful information/data	Major	Implementing the Ethical code of Conduct	Possible	High	No	Approved questions by the University of Southern Queensland Human Ethics committee, sign non-discolures & blank out/exclude all sensitive information and names from documents	Minor	Unlikely	Low	Yes
Exposure to Covid-19	Subsequent illness from contacting the Virus	Major	Compliance with covid safety plans, wearing marks, 1.5m rule and isolating from the sick	Unlikely	Moderate	No	If unwell, self isolate and do not contact with other individuals. If someone else notes they are unless, resechule meetings and take required procortuions if been in contact	Minor	Rare	Low	Yes
Access/trip hazards due to terrian or equipment	Injury to student or public due to terrain being uneven or equipment being inappropriately placed	Major	Obsticals are to be relocated, minimised or physically flagged prior to occupation. Uneven terrain to be avoided and utilise footpaths when available.	Likely	High	No	Taping of uneven ground levels/surface to identify hazards when applicable. Tape chords and leads to the floor or reroute to avoid trip hazards. Ensure access is identified prior to meetings and events to prevent time delays and disruptions or rushing leading to injury	Major	Unlikely	Moderate	Yes
Flight to/from	Lost baggage, miss flight,	Major	Luggage insurance and tracking decives, leave with lots of spare time	Possible	High	No	Pack spare change in hand luggage and keep all necessary items to complete tasks while in country on my person. Leave in plenty of time, specially in Fiji due to transport delays and uncertainty.	Moderate	Unlikely	Moderate	Yes
Transport	Unrealiable, unlawful, unsafe driving	Catastrophic	Allow lots of time, only get in legitiment transport service vehicles	Possible	High	No	Orgnaise transport through accomodation or through in country contacts to ensure the means will be safe.	Major	Unlikely	Moderate	Yes
Vehicles	Hit by car, unlawful driving, unsafe driving	Catastrophic	Walk away from road when possibly, do not get in any vehicle	Possible	High	No	Wear visable clothing, avoid walking beside roads, not travel by ones self, organise transport through accomodation or legitiment transport service vehicles	Major	Unlikely	Moderate	Yes
Interaction with People	Lanuage barrier, different cultural values, arguments	Major	Learn basic language, be polite and don't engage in arguments	Likely	Extreme	No	Travel with a group and in country contacts, do not enter situations or areas subject to disgrimination or arguments, avoid unsafe areas. Ensure clothing is acceptible for the situation	Major	Unlikely	Moderate	Yes

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35º C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
							and abideds by the cultural requirements of the community.				
Weather	Hot and wet season - possible heatstroke and disasters	Catastrophic	Chilled water available, check weather before traveling, long/loose clothing	Likely	Extreme	No	Seek shade and shelther, always stay hydrated. Stay up to date with weather notifications and act/reschedule acordingly/	Catastrophic	Unlikely	Moderate	Yes
On-site hazards	Structures not being build to specifications, trip hazards, machinery handtools and plant	Catastrophic	Wear PPE, avoid standing on structures that are unsafe, be inducted on site	Likely	Extreme	No	Be firm when in a situation which does not feel safe and do not engage, if machinery is being used avoid that area if the correct PPE or training has not been provided/aquired, do not distrupt workers and undertand that I am a guest to this space and need to listen and react as required.	Catastrophic	Unlikely	Moderate	Yes
Commun-ity disatisfac-tion	Disatisfaction, arguments, physical violence	Major	Open communication and discussion, listen to concerns, approach sensitive topics carefully	Possible	High	No	Have a in country buddy who can assit with language barrier issues and convey messages when required discusses sentisive or topics to avoid prior, avoid individuals not interested in enaging in the disucssion, don't force	Major	Unlikely	Moderate	Yes
Living standard hazards	Unsanitiary and unhyganic conditions leading to illness	Major	Wash hands regularly, avoid eating in these conditions	Likely	Extreme	No	Use hand sanitiser regulary and provide own sanitiary items when required, not consiming items made within these conditions, consume only filtered and purfied water	Major	Unlikely	Moderate	Yes
Ceoliac	Injesting food containing or contaminated by Gluten leading to illness	Major	Prepare own food and seek advice when eating out from chef's on cooking techniques	Possible	High	No	Discuss with locals who can advise on restrants/takeout that will be safe, take medication when eating out, ensure sanitary eviroment when preparing own food.	Major	Unlikely	Moderate	Yes
Disoriten-tated in Fiji	Lost, unable to return to accomodation, miss out on scheduled meetings	Major	Maps, only travel from A - B via taxi service	Possible	High	No	Obtain a buddy or guide (possibly from think pacific), ensure someone always knows my location and keep phone on person at all times, stick to well known areas	Major	Unlikely	Moderate	Yes

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
PPE for construction site visits	Hard hat, high vis, steel cap boots, safety glasses and earplugs	Student	9/02/2024
Obtain in country buddy	UPS and TP connections	Student	1/03/2024
Sunscreen and hat	Local chemist and clothing store	Student	9/02/2024
Culturally appropriate clothing	Local clothing stores	Student	16/02/2024
Travel Insurance	NRMA and/or Quantas Insurace	Student	22/03/2024
Phone with maps and service	iPhone 13 and International roming	Student	22/03/2024
Obtain Ceoliac Medication	Local Chemist - GluteGuard	Student	9/02/2024
Hand sanitiser and sanitiery items	Local Chemist	Student	9/02/2024
Organise in country transport services	Connections and ceritifed providers	Student	1/03/2024

Step 6 - Approval			
Drafter's name:	Caitlin Battersby	Draft date:	5/10/2023
Drafter's comments:	Prelminary Risk assessment to be reviewed prior to arriving incountry		
Approver's name:	Steven Goh	Approver's title/position:	Research Project Supervisor
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.

University of Southern Queensland
Consent form
Questionnaire

UniSQ HREC Approval number: **ETH2024-0748**

Project Title

Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Research team contact details

Principal Investigator details

Prof Steven Goh
Email: [redacted]

Co-investigator details

Ms Caitlin Battersby
Email: [redacted]

Statement of consent

By signing below, you are indicating that you:

- Have read and understood the information document regarding this project. ☐ Yes / ☐ No
- Have had any questions answered to your satisfaction. ☐ Yes / ☐ No
- Understand that if you have any additional questions, you can contact the research team. ☐ Yes / ☐ No
- Are over 18 years of age. ☐ Yes / ☐ No
- Agree to participate in the project. ☐ Yes / ☐ No

Name (first & last)			
Signature		**Date**	

Thank you for taking the time to help with this research project.

Please return this document to a research team member before undertaking the questionnaire.

Project Title

Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Research team contact details

Principal Investigator details

Prof Steven Goh
Email: [redacted]

Co-investigator details

Ms Caitlin Battersby
Email: [redacted]

Description

This project is being undertaken as part of a Batchelors of Engineering (Honours), Civil Engineering Research Project through the University of Southern Queensland.

The purpose of this project is to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

Participation

Your participation will involve completion of an online questionnaire that will take approximately 20 minutes of your time.

Questions will include: The Fijian construction industry, Modular Construction, Natural disaster event impacts on residential housing and implementation of Modular construction within Fiji.

Your participation in this project is entirely voluntary. If you do not wish to take part, you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You may also request that any data collected about you be withdrawn and confidentially destroyed.

If you do wish to withdraw from this project or withdraw data collected about yourself please contact the Research Team (contact details at the top of this form).

Your decision whether you take part, do not take part, or take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

Expected benefits

It is expected that this project will benefit the Fijian construction industry and aims to propose a uitable solution in the form of modular housing which can be implemented within developing countries as a method of improving living conditions and response to natural disasters.

Risks

In participating in the questionnaire there are no anticipated risks beyond normal day-to-day living.

Privacy and confidentiality

All comments and responses are confidential unless required by law.

The names of individual persons are not required in any of the responses.

Participants data will not be made available for future research purposes. The data will be stored within a secure locked laptop and when shared, will be non-identifiable.

A copy of the completed research project can be provided to participants upon request. Additionally, if a summary of the project results is requested by the participant, a non identifiable summary can be provided.

Any data collected as a part of this project will be stored securely, as per University of Southern Queensland's Research Data and Primary Materials Management Procedure.

Consent to participate

Clicking on the 'Submit' button at the conclusion of the questionnaire is accepted as an indication of your consent to participate in this project.

Questions

Please refer to the Research team contact details at the top of the form to have any questions answered or to request further information about this project.

Concerns or complaints

If you have any concerns or complaints about the ethical conduct of the project, you may contact the University of Southern Queensland, Manager of Research Integrity and Ethics on +61 7 4687 5703 or email researchintegrity@unisq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can address your concern in an unbiased manner.

Thank you for taking the time to help with this research project. Please keep this document for your information.

ENP4111 - Modular Housing Design Proposed Solution Review & Feedback

This questionnaire aims to gain feedback on the proposed design solution as apart of the dissertations methodology.

Thesis Title: Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

This project is being undertaken as part of a Bachelor of Engineering (Honours), Civil Engineering Research Project through the University of Southern Queensland. The purpose of this project is to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

* Required

1

How important do you believe it is for the modular housing solution to reflect the Traditional Fijian architecture and cultural values? *

- ◯ Extremely important
- ◯ Somewhat important
- ◯ Neutral
- ◯ Somewhat not important

2

How do you believe from your experience at the Study Tour in 2023, that the design of modular homes should reflect and incorporate cultural beliefs? *

3

How significant do you believe the transportation challenges (e.g. road conditions, island access) are when considering the delivery and installation of modular homes within Fiji? *

- ◯ Extremely Important
- ◯ Somewhat important
- ◯ Neutral
- ◯ Somewhat not important

4

What do you believe is the most practical mode of transportation for modular housing materials and components within Fiji? *

5

How do you believe the current road and infrastructure limitations in Fiji influence the size and structure of modular housing units? *

6

What do you see as the largest challenges in implementing modular housing in Fiji, and what solutions would you propose? *

7

Please see the floor plan. Please note the following:

Components have been designed to fit easily on a standard MR truck.

The rooms can be interchangeable and additional bedrooms/living space can be added - this design is a base design.

Goal for implementation would be within rural and urban communities, with a focus on lower demographic housing development.

Ideally, key components such as roof elements would be stored at key locations (similar to the red cross container initiatives) for easy access and maintenance practices in the event of a natural disaster)

The proposed solution has been designed to be sacrificial, and modules easily replaceable to combat issues experienced for natural disasters.
What are your initial thoughts on this design? *

8

The design takes into key cultural design factors such as a second door for elders and a open, family orientated layout. Do you believe these factors are sufficient or are there improvements you can suggest. *

9

The proposed design utilizes materials such as Bamboo CLT for the external cladding, coconut timber for framing, coral stone for insulation and volcanic ash within concreting purposes. These offer a sustainable edge and utilization of locally sourced and renewable materials. Can you please detail your thoughts and provide feedback of improvements or shortfalls. *

10

The components of this design will be constructed off site in a factory and transported to site. Each component can be transported on the back of a standard MR truck. Do you identify any further transportation issues with this design, and if so, please detail. *

11

The construction of the manufacturing facility to construct modular construction will be an initial costly investment. However, if this construction method was implemented, do you believe this investment would be worthwhile and beneficial within the residential construction sector? Detail why or why not. *

12

Education of the workforce on the manufacturing and construction of modular construction methods will be an initial investment. It will be proposed that fee-free training will be offered to the workforce to upskill and provide jobs within this sector. Do you believe this will be beneficial for the community and what issues do you foresee? *

13

Do you believe this construction method will impact the current, cultural workforce (e.g. family's having certain roles within a village)? Please explain *

14

In your opinion, based on the proposed design, do you believe modular housing can be made affordable while still maintaining high quality and cultural relevance for Fijian families? *

15

In your opinion, based on the proposed design, do you believe modular housing can offer a solution to the natural disasters experienced and rapid response of maintenance on housing post disaster event? *

16

Please provide any other additional feedback, concerns or comments - Thank you!

University of Southern Queensland

Participant Information Sheet

Questionnaire

UniSQ HREC Approval number: ETH2024-0748

Project Title

Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Research team contact details

Principal Investigator details

Prof Steven Goh
Email: [redacted]

Co-investigator details

Ms Caitlin Battersby
Email: [redacted]

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Participation

Your participation will involve completion of an online questionnaire that will take approximately 20 minutes of your time.

Questions will include: The Fijian construction industry, Modular Construction, Natural disaster event impacts on residential housing and implementation of Modular construction within Fiji and review of a proposed design.

Your participation in this project is entirely voluntary. If you do not wish to take part, you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You may also request that any data collected about you be withdrawn and confidentially destroyed.

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Your decision whether you take part, do not take part, or take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

Expected benefits

It is expected that this project will benefit the Fijian construction industry and aims to propose a uitable solution in the form of modular housing which can be implemented within developing countries as a method of improving living conditions and response to natural disasters.

Risks

In participating in the questionnaire there are no anticipated risks beyond normal day-to-day living.

Privacy and confidentiality

All comments and responses are confidential unless required by law.

The names of individual persons are not required in any of the responses.

Participants data will not be made available for future research purposes. The data will be stored within a secure locked laptop and when shared, will be non-identifiable.

A copy of the completed research project can be provided to participants upon request. Additionally, if a summary of the project results is requested by the participant, a non identifiable summary can be provided.

Any data collected as a part of this project will be stored securely, as per University of Southern Queensland's Research Data and Primary Materials Management Procedure.

Consent to participate

By signing the consent form, you consent to participating in this questionnaire

Questions

Please refer to the Research team contact details at the top of the form to have any questions answered or to request further information about this project.

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Thank you for taking the time to help with this research project. Please keep this document for your information.

University of Southern Queensland
Consent form
Interview

UniSQ HREC Approval number: ETH2024-0748

Project Title

Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Research team contact details

Principal Investigator details

Prof Steven Goh
Email: [redacted]

Co-investigator details

Ms Caitlin Battersby
Email: [redacted]

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Questionnaire

Preliminary information:

- Occupation and title (deidentified)
- Locality (rural or urban)
- Experience in civil construction industry and nominate years

Construction in Fiji

- Are you involved in the Fijian construction industry? (yes/no)
  If yes, Please provide details
- What are some key cultural factors you identify which play a role within shaping the construction industry?
- What are the shortfalls do you see?
- What impacts do you forecast surrounding upcoming generations moving towards different industries or outside of there communities?
- What are the constraints you see?
- What opportunities do you see?
- What areas of improvement do you see?
- What differences have you observed within the construction industry for urban and rural communities/locations?

Construction and culture in Fiji

- What are essential construction factors within Fiji
- What are typical building layouts or inclusions?
- Are there any cultural beliefs/customs which are implemented within construction/building design within Fiji

Modular construction

- What is your knowledge of modular construction?
- Have you seen modular construction implemented within Fiji? (yes/no)
  If yes, please provide details
- Do you see modular construction having a good impact if implemented within Fiji?
- Does this differ between urban and rural communities?
- What cultural implications do you see with implementing modular construction in Fiji?
- What limitations do you see associated with implementing modular construction?

Modular construction – natural disaster event

- What limitations do you see regarding maintenance and construction surrounding natural disaster events?

- What organisations or assistance are available to assist with maintenance and repairs of residential housing following disaster events?
- What benefits do you see if modular construction was implemented?
- What limitations do you see if modular construction was implemented?

Interviews

Interview will be led by natural flow with guided questions as below, along with pulling from further queries or details which are risen within the questionnaire responses.

Preliminary information:

- Introduce yourself
- Introduce what you do for work
- What is your involvement within the construction industry?

Construction in Fiji

- Discussion surrounding the current status of the Fijian construction industry, limitations, issues and opportunities for improvement.

Construction and culture in Fiji

- Cultural requirements for construction, discussion around beliefs, inclusions (e.g. two separate doors), differences between urban and rural, village chief housing, different roles within villages and families (e.g. construction family).

Modular construction

- Participants knowledge, explanation of what modular construction is and an overview of potential benefits, discussion into what modular construction could do in Fiji and possible constrains evident.

Modular construction – natural disaster event

- Discussion around current evident natural disaster impacts in regards to housing and repairs, and what modular construction could offer in this space.

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Please refer to the Research team contact details at the top of the form to have any questions answered or to request further information about this project.

Concerns or complaints

If you have any concerns or complaints about the ethical conduct of the project, you may contact the University of Southern Queensland, Manager of Research Integrity and Ethics on +61 7 4687 5703 or email researchintegrity@unisq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can address your concern in an unbiased manner.

Thank you for taking the time to help with this research project. Please keep this document for your information.

University of Southern Queensland

University of Southern Queensland
Participant Information Sheet
Questionnaire

UniSQ HREC Approval number: ETH2024-0748

Project Title

Innovation in Design and Manufacturing Systems of Modular Residential Housing Solutions: A case study in the Fijian Construction Industry

Research team contact details

Principal Investigator details

Prof Steven Goh
Email[redacted]

Co-investigator details

Ms Caitlin Battersby
Email: [redacted]

Description

This project is being undertaken as part of a Batchelors of Engineering (Honours), Civil Engineering Research Project through the University of Southern Queensland.

The purpose of this project is to explore how modular residential housing construction methods could impact and improve response to natural disasters for the Fijian communities, providing safe and readily available shelter which can not only withstand natural disasters but be prepared quickly and easily post-event.

Participation

Your participation will involve completion of an online questionnaire that will take approximately 20 minutes of your time.

Questions will include: The Fijian construction industry, Modular Construction, Natural disaster event impacts on residential housing and implementation of Modular construction within Fiji.

Your participation in this project is entirely voluntary. If you do not wish to take part, you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You may also request that any data collected about you be withdrawn and confidentially destroyed.

If you do wish to withdraw from this project or withdraw data collected about yourself please contact the Research Team (contact details at the top of this form).

Your decision whether you take part, do not take part, or take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

Expected benefits

It is expected that this project will benefit the Fijian construction industry and aims to propose a uitable solution in the form of modular housing which can be implemented within developing countries as a method of improving living conditions and response to natural disasters.

Risks

In participating in the questionnaire there are no anticipated risks beyond normal day-to-day living.

Privacy and confidentiality

All comments and responses are confidential unless required by law.

The names of individual persons are not required in any of the responses.

Participants data will not be made available for future research purposes. The data will be stored within a secure locked laptop and when shared, will be non-identifiable.

A copy of the completed research project can be provided to participants upon request. Additionally, if a summary of the project results is requested by the participant, a non identifiable summary can be provided.

Any data collected as a part of this project will be stored securely, as per University of Southern Queensland's Research Data and Primary Materials Management Procedure.

Consent to participate

Clicking on the 'Submit' button at the conclusion of the questionnaire is accepted as an indication of your consent to participate in this project.

Questions

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