University of Southern Queensland

Faculty of Health, Engineering and Sciences

Evaluation of Issues in Using Advanced and Sustainable Engineering Materials

A dissertation submitted by

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Abstract

For decades advanced engineering materials have been promising to expand and transform the engineering design and construction field. Materials such as fibre composites, geopolymers and cross laminated timbers boasting to impact the sustainability, economic cost, environmental resilience and energy management of the built environment in an effort to aim toward achieving sustainable development. However, their take up by industry leaders such as; consulting design engineers, construction contractors and local government has not been nearly as rapid as anticipated.

The construction industry is considered to be one of the major contributor to global greenhouse gas emissions with research conducted in the United Kingdom estimating that the construction industry is attributing to approximately 50% of greenhouse gases (Akan, et al., 2017). Therefore it is detrimental that sustainable materials and practices be implemented into the construction industry.

The methodology used for this research project involved a thorough literature review into the following advanced engineering materials: Carbon Fibre Reinforcing Polymers, Cross-laminated timber and Geopolymers used in-lieu of cement in concrete. Findings from the literature review were then summarised and tabulated in report format. Relevant local case studies were found where these materials had been used and a cost-benefit analysis was undertaken to determine the extent of proposed benefits and costs.

A questionnaire was then designed and distributed to focus on issues that have impacted the take-off of Advanced Engineering materials – particularly in the North West NSW region. Results from the questionnaire were critically analysed and summarised in report format so that issues effecting the take-up by industry could be easily evaluated.

Finally, the critical issues or factors that have arisen across the board from the research that was conducted for all three materials researched include; the lacking premonition for sustainable development, lack of relevant training and awareness, lack of Australian design standards, lacking material availability, durability and cost.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Jacob Deryck Tan

[redacted]

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Contents

Abstract ii

Limitations of Use iii

Certification of Dissertation iv

Acknowledgments v

List of Figures: viii

List of Tables: ix

Chapter 1 – Introduction 1

1.1 Introduction 1

1.2 Idea 1

1.3 Aims 2

1.4 Outline of Objectives 2

1.5 Expected Outcomes 3

Chapter 2 – Literature Review 4

2.0 Introduction 4

2.1 Sustainable Development 4

2.1.1 The Problem 4

2.1.2 What is Sustainable Development 5

2.1.3 Sustainable Development Implementation 6

2.2 Advanced Fibre Composites 6

2.2.1 Introduction – What are Composite Materials 6

2.2.2 FRP Composite Materials Used in Industry 6

2.2.3 FRP Sustainability 8

2.2.4 FRP Relative Cost 8

2.2.5 FRP Case Study – Wellingrove Creek Bridge 9

2.3 Geopolymers 14

2.3.1 Introduction – What are Geopolymers 14

2.3.2 Geopolymers Used in Industry 14

2.3.3 Geopolymer Sustainability 15

2.3.4 Geopolymer Relative Cost 15

2.3.5 Geopolymer Case Study – Brisbane West Wellcamp Airport 15

2.4 Cross Laminated Timber 18

2.4.1 Introduction 18

2.4.2 Cross Laminated Timber – Sustainability 18

2.4.4 Cross Laminated Timber – Relative Cost 20
2.4.5 Cross Laminated Timber Case Study 20
2.5 General Conclusions 22
3.1 Research Methodology 23
3.1.1 Research Scope 23
3.1.2 Literature Data Collection 23
3.1.3 Cost Benefit Analysis 24
3.1.3 Questionnaire Design 26
3.1.4 Questionnaire Submission to Human Ethic Review Panel 27
3.1.5 Questionnaire Distribution 27
3.1.6 Summarise and Discuss Findings 28
3.2 Resource Requirements 28
3.3 Consequences 29
3.4 Ethics 29
3.5 Risk Assessment 30
Chapter 4 – Research Results 31
4.1 Cost Benefit Analysis Results 31
4.1.1 Wellingrove Creek Bridge 31
4.1.2 West Wellcamp Airport 37
4.1.3 Browns Road Bridge 41
4.1.4 Summary of Cost-Benefit Analysis 46
5.1 Questionnaire Results 49
Chapter 6 – Discussion 61
Chapter 7 – Conclusion 64
Chapter 8 – Future Work 65
Chapter 8 – References 66
Appendix A 69
Appendix B 71
Appendix C 73
Appendix D 81
Appendix D 87
Appendix E 89

List of Figures:

Figure 1: Reinforcement Corrosion in Concrete (Markham, 2016) 7
Figure 2: Wellingrove Creek Bridge 10
Figure 3: FRP Retrofit Design Detail (Wood, Research and Development, 2018) 12
Figure 4: FRP Retrofit as Constructed 13
Figure 5: Pavement Design by Airport Consulting Group 16
Figure 6: Cross-Laminated Timber Panels. (Evans, n.d.) 18
Figure 7: Construction of Browns Road Bridge 21
Figure 8: Completed Browns Rd CLT Bridge 22
Figure 9: Country Bridge Solution Type 1 Typ. Section (Roads and Maritime Services, 2016) 32
Figure 10: Present day life cycle cost line graph for both alternatives 33
Figure 11: Present day life cycle cost line graph for both alternatives 39
Figure 12: Country Bridge Solution Type 2 Typ. Section (Roads and Maritime Services, 2016) 42
Figure 13: Present day life cycle cost line graph for both alternatives 43
Figure 14: Cost Benefit Comparison - Wellingrove Bridge Upgrade 46
Figure 15: Cost Benefit Comparison - West Wellcamp Airport 47
Figure 16: Cost Benefit Comparison - Browns Rd Bridge Upgrade 48
Figure 17: Pie Chart showing distribution of Respondents 49
Figure 18: Pie Chart showing distribution of Results for Question 1 50
Figure 19: Pie Chart showing distribution of Results for Question 2 51
Figure 20: Pie Chart showing distribution of Results for Question 3 52
Figure 21: Pie Chart showing distribution of Results for Question 4 53
Figure 22: Pie Chart showing distribution of Results for Question 5 54
Figure 23: Chart showing distribution of Results for Question 6a 55
Figure 24: Pie Chart showing distribution of Results for Question 6b 56
Figure 25: Chart showing distribution of Results for Question 7a 57
Figure 26: Pie Chart showing distribution of Results for Question 7b 58
Figure 27: Chart showing distribution of Results for Question 8a 59
Figure 28: Pie Chart showing distribution of Results for Question 8b 60

List of Tables:

Table 1: Benefit-Cost Analysis of Composite Wraps vs Steel Jackets (Hastak & Halpin, 2000) 9
Table 2: Risk Assessment 30
Table 3: Comparison of environmental factors for Wellingrove Creek Bridge upgrade 35
Table 4: Comparison of social factors for Wellingrove Creek Bridge upgrade 36
Table 5: Comparison of environmental factors for West Wellcamp Airport 40
Table 6: Comparison of social factors for West Wellcamp Airport 40
Table 7: Comparison of environmental factors for Browns Road Bridge 44
Table 8: Comparison of social factors for Browns Road Bridge 45

Chapter 1 – Introduction

1.1 Introduction

For decades advanced engineering materials have been promising to expand and transform the engineering design and construction field. Materials such as fibre composites, geopolymers and cross laminated timbers boasting to impact the sustainability, economic cost, environmental resilience and energy management of the built environment in an effort to aim toward achieving sustainable development. However, their take up by industry leaders such as; consulting design engineers, construction contractors and local government has not been nearly as rapid as anticipated. This report will firstly report and summarise previous research that has been conducted in this field in the form of a literature review. The literature review will also review and summarise key aspects of the chosen materials to gain a broad understanding of how these materials can be used and in what situations they can be used. Post the literature review, the report will research 3 particular case studies on projects where these advanced engineering materials have been used especially in regional areas of Australia. The information obtained from the case studies including benefits and costs of the material use, and hence a cost benefit analysis on the materials will be done in comparison to the use of traditional methods. The cost benefit analysis would then provide a good working platform to show the exact areas of benefits and the main areas of cost to aid the design of an industry questionnaire with the goal to uncover and expand the factors behind the lacking take-up, such as; high initial cost, financial risk of using unproven technologies, lack of design standards and how training along with early implementation might affect these results.

1.2 Idea

During my studies for my Bachelor of Engineering Technology through UNE I did extensive research into improving the bond strength of Carbon Fibre Reinforcing Polymers (CFRP) to concrete for maintenance and repair of existing concrete structures. During this previous research I found it intriguing that although extensive research has been done in the field of CFRP's to prove the superior properties of the materials including; strength, durability, environmental sustainability and costings, the take up by industry has lagged behind. Hence, material is not being used as extensively as one would expect. Leaving one to ask the question if all of this previous research is even worth the time and effort put into the area – especially if the take up will never be as desired.

This has been edified as I have begun my journey as a civil and structural designer working in for a consultancy firm in North West NSW. I have had the opportunity to take part in large range of different projects both small and big, and to really start applying the principles of design that I have learnt at university. This not only looks at the technical aspects of design, but also the principles of project management and more importantly to this project, the promotion and implementation of sustainable development.

Sustainable development can easily be dismissed especially in a regional area where the society can be stuck in there ways and or scared of change. But, nonetheless this should not be an excuse to not move forward into a sustainable approach to design and construction.

With this in mind, when I saw the prelisted topic to research Evaluation of Issues in Using Advanced and Sustainable Engineering Materials I immediately could see that there was an opportunity here to expand my horizons and look into the factors that are hindering the adoption of such materials and hopefully conclude with some possible solutions to overcome these issues.

1.3 Aims

The aim of this research project is to research why the take-up of Advanced Engineering Materials has not been as rapid as desired particularly in North West NSW and to identify and evaluate factors that might influence the adoption of such. Due to the vast number of Advanced Engineering Materials, it has been decided to limit the research to Carbon Fibre Reinforcing Polymers, Cross-laminated Timber and Geopolymers.

1.4 Outline of Objectives

The following outlines of objectives of this research, given that this research is assessable it will help keep the project on track so that it can be finished on time:

- Undertake a detailed literature review, including identifying different techniques and materials that promise to revolutionise engineering design and construction.

- Undertake research into and compare economic, environmental social costs and benefits of using these advanced materials as opposed to the traditional methods.
- Conduct one or more surveys to determine what techniques and materials are currently being used for this process in North West NSW, and what might influence the adoption of advanced materials.
- Analyse data obtained from survey to determine the current techniques, systems and materials for engineering design and construction, including cost.
- Identify and evaluate factors that may influence/hinder the adoption of such engineering materials.
- Develop conclusions and identify where more research is needed

1.5 Expected Outcomes

The expected outcome for this project is that the take-up by industry of advanced engineering materials is limited particularly in the North West NSW area due to factors including; perceptions about high initial cost, unproven durability reports, lack of design standards and an unwillingness to change current mind-sets.

Although the research has been limited to three advanced engineering materials (fibre composites, Geopolymers and Cross-Laminated Timber), it is expected that there will be similar factors between the three different researched advanced engineering materials, and such similar factors could then be hypothesised to be similar determining factors limiting the take up by industry for all advanced engineering materials.

Finally it is expected, that although this research is small in comparison to the vast size of this problem worldwide, the mere talking and raising awareness with local engineers via the questionnaire may begin to influence change in the North West NSW area.

Chapter 2 – Literature Review

2.0 Introduction

This chapter will summarise and outline information found during the literature review phase of this study. Information will include details about the current problem of unsustainable development, the future leading towards sustainable development, and a detailed review of how advanced engineering materials will fit into the future of sustainable development. Particular advanced engineering materials reviewed include Fibre Reinforced Polymers, Geopolymers and Cross Laminated Timber. For the individual advanced engineering materials, research has been summarised in the form of current and potential uses of the material, sustainability concepts of the material, general cost comparisons and finally a case study of the material used in the construction industry.

2.1 Sustainable Development

2.1.1 The Problem

The built environment provides a large number of benefits to the way current and future people live. Many parts of the built environment can be invisible to the public eye, but everyone can appreciate the vast benefits.

A small list of typical infrastructure the makes up the built environment and accompanying benefits include:

- Water treatment plants and potable water distribution systems to convey clean safe water to our homes or workplaces for our consumption.
- Waste collection systems and waste treatment plants to convey and treat effluent.
- Roads, bridges, tunnels, railway, runways and ports to transport goods from one end of Earth to the other.
- Electricity plants and distribution systems to convey stable electricity to our homes and workplaces so that we can turn lights on, charge our phone, refrigerate our food.
- NBN or communication network so that we can be connected to anyone at any time from the use of a mobile or laptop.
- Access to hospitals, educational facilities, shopping centres or even the ability to have a luxurious roof over our head.

- Finally, the quality of infrastructure in the built environment directly encourages or discourages the economic growth of a given area (Penn & Parker, 2011).

However, centuries of reaping such benefits without any significant thought into sustaining the environment for the future has now led our environment to be in a state of decline. It is estimated that: 80% of Earths forest have already been destroyed, global warming is predicted to be 4 degrees Celsius warmer by 2100, 8 million tonnes of plastic waste ends up in the ocean at the end of every year and fish stocks are approximately 85% depleted. Obviously none of this is sustainable, and it is detrimental that change occurs sooner rather than later (Engineers Australia, 2017).

Recent studies conducted by the United Nations Department of Economic and Social Affairs indicate that urbanisation is rising, with urban population increasing and rural population decreasing. This shift is putting enormous pressure on existing infrastructure, and is likely to cause more restraint on the environment if a balance between human development and environmental sustainability is not achieved (Penn & Parker, 2011).

2.1.2 What is Sustainable Development

Given the state of the environment and the downward direction that the developing world is pushing the environment, it is detrimental that change comes to head towards sustainable development. Engineers Australia defines sustainability as:

> *"sustainability means that future generations will enjoy environmental, social and economic conditions that are equal to or better than those enjoyed by the present generation"* (Engineers Australia, 2017).

Similarly, the Report of the World Commission on Environment and Development: Our Common Future, defines Sustainable development as:

> *"a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations"* (World Commission on Environment and Development, 1987).

2.1.3 Sustainable Development Implementation

Implementation of sustainable development in many cases largely comes down to the decisions the engineer makes. Such decisions can be made at many different stages of infrastructure development, however commonly are implemented at the start of a project. Sustainable decisions could involve; opting to use Advanced Engineering Materials that are more sustainable then traditional materials, or opting to use recycled building material, or even choosing efficient water and electrical fittings, using materials that create less wastage, and extensive community consultation to positively increase the environmental, social and economic aspect of the project.

Although institution like Engineers Australia promote sustainable development as a value of its Code of Ethics, we are still a long way from fully adopting the mind-set of sustainable development. Generally this might be due to lack of training, an ever-changing or ongoing development of sustainable procedures, or fear that sustainable development might increase the overall cost of the project. It is key to remember that, sustainable development should be a mind-set, not a rule, and therefore should be implicated on all projects, no matter the size (Thorpe, 2018).

2.2 Advanced Fibre Composites

2.2.1 Introduction – What are Composite Materials

A frontrunner innovative material for strengthening and or repairing existing structures is Fibre Reinforce Composites (typically Carbon).

In 2013 Masuelli defined Fibre Reinforced Polymers as an engineered composite material made of a polymer matrix (a variety of short fibres bound together by a polymer). Where the fibres are typically carbon, plastic or glass based due to the low weight, high strength, non-corrosiveness (Masuelli, 2013).

However, this study will compare a variety of peer reviewed journals relating to the sustainability, relative cost and to gain an understanding of where current research is leading in this field. With a final aim to help guide this report into identifying factors that have influenced the take-up of such methods.

2.2.2 FRP Composite Materials Used in Industry

Although the take up by industry has been relatively slow, one of its most common uses in the design and construction industry is its use as an alternative for steel reinforcement in reinforce concrete. Other major uses also include using FRP to rehabilitate existing deteriorated concrete, steel and timber structures.

2.2.2.1 FRP Concrete Reinforcement

Over the past 3 decades FRP reinforcing bars in reinforced concrete as an alternative to steel has been extensively researched. The use of FRP as reinforcement is particularly striking for design of structures in highly aggressive environments where corrosion of typical steel reinforcement is a major problem (See figure 1 below). Other advantages of using FRP reinforcement includes; enhanced construction speeds due to the light weight in comparison, FRP is non-metallic and therefore does not interfere with operations of sensitive electronic devices. FRP bars can be used as a direct replacement of reinforcing steel in concrete beams, slabs, columns and retaining walls. Although the capabilities and uses of FRP reinforcement in concrete is so vast, it is still largely unknown or used by many practicing engineers in Australia. This is unquestionably due to the lacking design standards and criteria available for design engineers (Manalo, et al., 2014).

Figure 1: Reinforcement Corrosion in Concrete *(Markham, 2016)*

2.2.2.2 FRP to Rehabilitate Existing Structures

Many early built structures are facing deterioration, and sometimes a need to support a greater load then initially designed for. The deterioration of the members may be caused by environmental effects or even typical in-service damages. An increase is required in the effort to extend the life expectancy of existing structures because the economic cost to replace large scale structures is generally an exorbitant cost that is not always budgeted for. Retrofitting existing structures with FRP composites may be needed for two different reasons. One type is to increase the yield strength capacity of such member due to an increase in loading post original design. The other type is to retrofit existing deteriorated members that may not meet design load capacities. FRP retrofitting can be applied to most types of materials used in construction but typically reinforced concrete, metal and even timber structures (Bank, 2006). Past studies have provided research into increasing the bond strength of FRP to concrete, anchorage devices associated with such methodology and an analysis of the current status of the problems faced in industry today.

2.2.3 FRP Sustainability

While the mechanical advantages of FRP composite materials are extensively reported in literature, questions remain regarding the sustainability of the materials used to create FRP composites (Lee & Jain, 2009). This becomes a balancing exercise to determine if it more sustainable then other methods.

2.2.3.1 FRP Composites Environmental Advantages

Benefits and advantages of FRP composites can be determined from the characteristics of such:

- The typical light weight of the composite material can result in decreased onsite construction times which results in a reduced impact on the environment.
- The typical high strength of the composite material means that less materials is required to achieve the same strengths resulting in minimal resource use and less waste generated.
- FRP composite materials have the ability to rehabilitate existing structures which increases the life of existing structures. This has significant benefits for the environment.
- The overall construction cost benefits of using FRP materials could potentially increase the allowance for environmental rehabilitation and research.

2.2.4 FRP Relative Cost

It is commonly known that the manufacture and fabrication costs of composite materials is much higher than traditional methods. However, many believe that this is due to the low production volume. When composite materials becomes more of a "Norm" or as the production volume increases then the cost to manufacture and fabricate composite materials would become rather competitive than traditional materials.

When looking at the costing comparison for composite materials and traditional materials Hastak and Haplin found that the only way to accurately compare the costings of composite materials vs alternatives without the need for monetary quantification was to create a Benefit-Cost assessment. This type of assessment basically compares the different materials by giving each benefit a weight or score hierarchy. They observed and found that the subjectivity of the benefit assessment is reduced when more information is available to the user for different materials. To put the model to a test they compared Conventional Steel Jackets with Composite Column Wraps for rehabilitating existing columns. Comparing the benefits of each material with the costing of each material it was determined that:

- The initial cost of using composite materials is higher than using steel jackets
- The benefits of using composite materials is much higher than using steel jackets
- Using the model, it calculates that the additional benefits outweigh the additional costing of using composite materials (Hastak & Halpin, 2000).

Table 1: Benefit-Cost Analysis of Composite Wraps vs Steel Jackets *(Hastak & Halpin, 2000)*

Material type (1)	Material (2)	Benefit score (3)	Benefit comparison (4)	Cost (5)	Cost comparison (6)	BC/CC (7)
Composite	Composite wraps	0.87	1.45	$300,000	1.20	1.21
Conventional	Steel jackets	0.60	1.00	$250,000	1.00	1.00

Note: BC = benefit comparison; CC = cost comparison.

2.2.5 FRP Case Study – Wellingrove Creek Bridge

The following is a case study into the use of FRP strips to strengthen the existing timber bridge that crosses the Wellingrove Creek on Waterloo Rd, to increase the load capacity such that heavy machinery could access the proposed Sapphire Windfarm.

Sapphire Windfarm situated 50km West of Inverell on Waterloo Rd in the Northwest region. Construction of the windfarm occurred during 2017. With the proposed windfarm development set up in the hills, one of the major constraints with this project was site access. Typically the only road to service sapphire windfarm was a deteriorated low travelled gravel road (Waterloo Rd). This road being of low priority to local council meant that little to no resources were available for upgrading existing infrastructure. One of the main deteriorated infrastructure was an old single lane timber bridge crossing Wellingrove Creek (see Figure 2 below). The Wellingrove Creek Bridge is a three span timber structure on concrete piers and abutments.

Figure 2: Wellingrove Creek Bridge

Construction of the windfarm would see large numbers of heavy construction equipment being brought to the site, including; cranes, bulk earthwork equipment, large turbine blades and transformers. Load case estimations for the upgrade of the bridge were as follows (Tingley, 2018).

- Load Case 1, 67 Tonne total load, with a load configuration similar to a typical heavy truck and dog configuration.
- Load Case 2: 188.5 Tonne total load comprising of a 164 Tonne trailer (12 axle configuration) plus 24.5 Tonne Truck (3 axle configuration).
- Load Case 3: 200 Tonne total load comprising a 175.5 tonne trailer (13 axle configuration) plus 2 each 24.5 Tonne trucks (3 axle configuration) one pushing and one pulling).

Considerations into replacing the existing bridge were brought forward by the contractor, which included the following:

- Replacing with a reinforced concrete bridge

- Replacing with a low level culver crossing
- Rehabilitating the existing

Permanently replacing the bridge with a reinforced concrete bridge structure with an estimated constructed price of $750,000. This option would have large time detriments on the completion of the project due to delayed site access. It would also require a new road alignment being adopted within a minimum road reserve width and heritage significant land either side.

Providing a low level culvert crossing with and estimated constructed price of $300,000. Although significantly cheaper than the above option, there would still be a requirement for a new road alignment for the approaches. The culvert option would also be more intrusive on the constant flowing Wellingrove Creek (Hile, 2019).

Another alternative arose which was to rehabilitate and strengthen the existing structure in-situ to cater for such design load cases as above without any significant traffic disruptions or road closure, the contractor proposed to retrofit high strength FRP stiffener strips to the underside of the timber girders and timber knee braces at the end of some of the girders to strengthen against end shear, the combination of the additional tensile FRP reinforcement strips and the knee braces would increase the load carrying capacity of the timber girders (Hile, 2019).

The below figure 3 and 4, shows the design and constructed configuration of the carbon fibre stiffeners. With the design principle being that when load is applied to the timber girders, there is typically tension on the underside of the member and compression on the top side. With the existing situation, the timber girders did not have the required tensile capacity and hence would fail under the applied load. However, once the CFRP stiffeners were applied to the underside, it significantly increased the tensile capacity of the timber girders which allows for higher working loads to be applied.

Due to the complexity of CFRP and the design, trained contractors needed to be brought into retrofit the CFRP to the girders. This in itself was at an inflated cost due to the requirement of the specialised contractors, but still came in at approximately $200 000 which is significantly lower than the cost to rebuild an alternative structure (Hile, 2019).

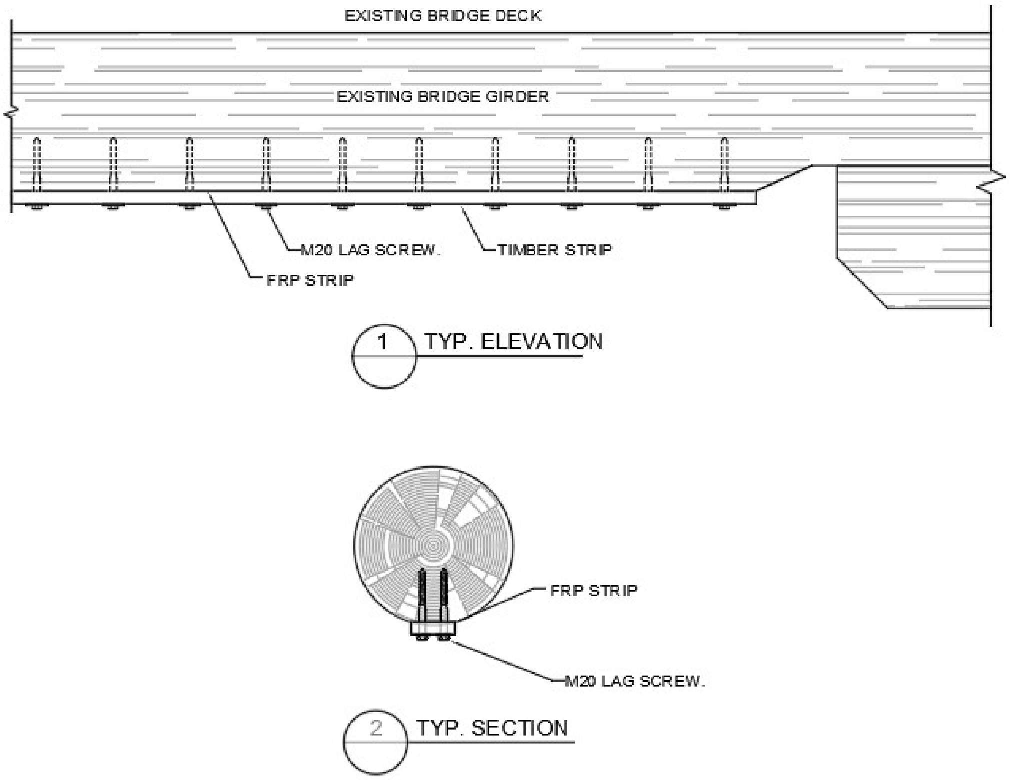

Figure 3: FRP Retrofit Design Detail (Wood, Research and Development, 2018)

Other benefits to rehabilitating the existing bridge with FRP included:

- Reduced time that bridge was not in operation as retrofitment could occur while the bridge was in use.
- Reduced time detriment for site access to the proposed windfarm
- Significantly reduced environmental impacts on the Wellingrove Creek and environmental risks of constructing in constantly flowing water.
- Reduced site disturbance and excavation work required, lowering the risk of erosion.
- No waterway disturbance or contamination.
- Reduced carbon footprint
- Significantly reduced overall Cost
- Social benefits for the local stakeholders that liked the old bridge
- Benefit to the local council for not having to fund for large scale upgrade and extends the life of existing assets and utilises this asset more effectively.

Figure 4: FRP Retrofit as Constructed

Overall in this application, the use of FRP strips was extremely advantageous and economical. The retro fitment allowed the existing bridge to carry the large loads proposed. Decreasing the effects on the social, environmental and economic impacts of this construction, allowing for a step closer to sustainable development for this project. Furthermore, post construction phase of the windfarm, the bridge is still in good repair and does not require near the amount of attention as it did prior to development.

2.3 Geopolymers

2.3.1 Introduction – What are Geopolymers

Consumption of concrete is second most consumed material around the world, second only to water (Cement Industry Federation , n.d.). Along with, the high amounts of greenhouse gas emissions associated with cement, and the high cost of conventional Portland cement it is apparent that there was a need for research into a sustainable alternative (Mehta & Siddique, 2018).

With many options and alternatives researched, the most promising was Geopolymer Concrete.

> Geopolymer Concrete involves the production of binders from alumina and silica which can be obtained from low cost materials or industrial by products such as fly ash, rice husk ash, etc and therefore, this can also be termed as sustainable geopolymer concrete. These source materials react with alkali-activating solutions and form cross-linked three-dimensional alumina-silicate network (Mehta & Siddique, 2018).

The products of this process have high flexural and tensile strength characteristics especially when high temperatures are applied during the curing phase. To a point that in some instances reducing the need for tensile reinforcement.

Durability and potential concrete corrosion is completely different to regular Portland cements given that the geopolymer cements are formed from alumina and silica glass, not hydrates as found in regular Portland cements. Where the geopolymer concrete will act more like a glass rather than a hydrate, meaning that resistance to acid and fire are improved, and resistance to sulphates is not an issue (Concrete Institue of Australia, 2011).

The Concrete Institute of Australia have indicated in the Recommended Practice for Geopolymer Concrete that although the improved material strengths, the provisions given in AS3600 can still be used to design geopolymer concrete until further testing and design standards are available (Concrete Institue of Australia, 2011).

2.3.2 Geopolymers Used in Industry

There are many different uses for geopolymer concrete in the construction industry, typical uses could be as below:

- Footings

- Stormwater pipes
- Bridge decks
- Retaining walls
- Footpaths and bicycle paths

As seen above, Geopolymer concrete can be used to in lieu of nearly all concrete structures made from Portland cement.

2.3.3 Geopolymer Sustainability

As above, high consumption of concrete requires large amounts of Portland cement to be produced. During the production of 1000kg of cement, 125L of fossil fuels and 118kW of electricity is consumed and 1000kg of carbon dioxide is created. Not to mention the added energy to transport of cement around the World. It is clear that using Portland cement is not sustainable for the environment and is a major contributor to the greenhouse effect. (Bondar, 2013)

However, research conducted by Bondar and others suggest that with the use of Geopolymers as an alternative, the carbon dioxide emissions can be reduced to up to a value of 27.5% of the ordinary Portland cement. With this in mind it is extremely relevant to advance this research to help make concrete a green option in construction.

2.3.4 Geopolymer Relative Cost

In 2016 Thaarrini & Dhivya conducted a cost comparison between the production costs of concrete made with Ordinary Portland Cement and concrete made with Geopolymers. It was noted that this comparison was between 1m^3 batch of each concrete type, and all materials required to manufacture the product were bought in bulk from local suppliers. Results indicated for 30MPa concrete the geopolymer concrete was slightly more expensive (1.7%), however for 50MPa concrete the Geopolymer Concrete was significantly cheaper (11%). This suggest that there are potential cost savings for using the geopolymer concrete, however, this would be largely dependent on the availability of the products and having a batching plant that can have this method easily and economically equipped. (Thaarrini & Dhivya, 2016)

2.3.5 Geopolymer Case Study – Brisbane West Wellcamp Airport

The following is a case study into the use of Geopolymer in concrete as a 100% replacement for Portland GP Cement for the aircraft pavements at the Brisbane West Wellcamp Airport located approximately 20km west of Toowoomba. This was a privately funded Greenfield airport that had the opportunity to explore and involve some sustainable development choices. Mainly being the use of geopolymer concrete to replace regular Portland cement concrete. For full construction of the turning area, apron and hanger pavements it was estimated that approximately 40,000m^3 of concrete would be needed to construct this greenfield airport.

Geopolymer concrete for the construction of the 435mm thick concrete pavement in the aircraft turning areas was supplied by Wagners, who are an innovative Australian construction material provider founded in Toowoomba (Wagners, 2019). The construction project saw the supply of 40,000m^3 of geopolymer concrete, which at the time of construction was the largest application of geopolymer concrete in the World.

A detailed trial and testing period and program prior to the works ensured a correct mix design, method of production in the form of a batch plant and the method of placement could be implemented during construction. Once these details had been accurately and efficiently designed, the successful application and commercial production of geopolymer concrete could be commenced (Glasby, et al., 2015).

Following the successful trial and testing period, the pavement could be designed and is shown in the below figure 5.

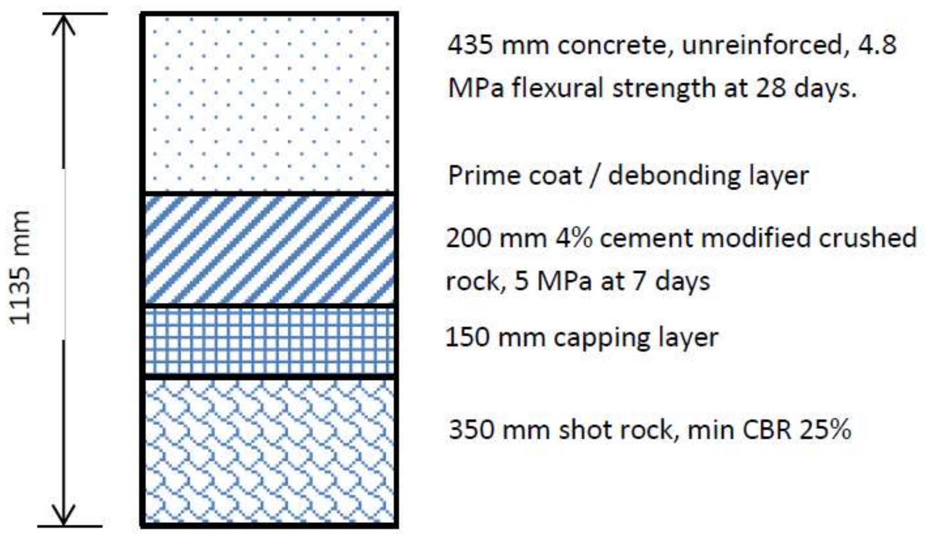

Figure 5: Pavement Design by Airport Consulting Group

One of the key benefits for choosing the geopolymer concrete over the traditional Portland cement was the reduced CO_2 emissions that are typical of geopolymer concrete. It was estimated that in using geopolymer concrete for the construction of the pavements, the CO_2 emissions from construction/development would be drastically reduced by approximately 80%. When considering the project used approximately 40,000m^3 of concrete during construction, this equates to a saving of approximately 8,640 tonnes of CO_2 emissions.

Further benefits of using geopolymer concrete during construction included performance and durability improvements that directly relate to the use of geopolymer concrete. For this project, shrinkage effects and flexural tensile strength properties were of high consideration, given that cracking from shrinkage or from a lack of tensile strength could be potentially disastrous for aircraft. From previous testing it was determined that geopolmer concrete have low shrinkage characteristics and high flexural tensile strength, making it ideal for aircraft pavements (Glasby, et al., 2015).

However, due to the concept of economies of scale, the total cost of using geopolymer in this project was at a premium rate, where it became a concept that only highly motivated or wealthy parties could afford this premium (Glasby, et al., 2015).

Post construction of the Brisbane West Wellcamp Airport, Wagners have continued to develop geopolymer concrete and have been able to contribute some conclusions into this topic. They have found a number of challenges to parties wishing to choose geopolymer concrete:

- Lacking Australian Standard or international standard for design or construction, this means that Small Enterprising Companies wishing to use this product need to spend valuable resources research and designing.
- Cost disadvantages due to economies of scale
- Lack of Availability of structures to confirm long term durability.

Overall, the use of Geopolymer concrete in this project was highly beneficial to the environment due to the reduced carbon dioxide emissions. This would then lead into positive social impacts because society can see a 'greener' approach. However, the choice to use the greener equivalent has led to an increased cost of construction. Where it then becomes a balancing exercise weighing up economic sustainability versus environmental sustainability (Glasby, et al., 2015).

2.4 Cross Laminated Timber

2.4.1 Introduction

Cross Laminated Timber (CLT) is an engineered wood building product designed to complement the light weight properties of soft timbers and the strength of hard timbers (Evans, n.d.). Developed in Europe in the early 1990's to offer a suitable alternative to steel and concrete in multi-family buildings (Espinoza, et al., 2016). CLT is made by laying multiple layers of wood boards orientated perpendicular to adjacent layers see image below.

Figure 6: Cross-Laminated Timber Panels. (Evans, n.d.)

Due to the fact that CLT products are derived from low-value, small diameter and sometimes bug infested timbers means that less forestry is wasted, increasing the yield from each forestry. Although Europe and Canada have already been adopting CLT products for many years, Australia is only looking at the tip of the iceberg (apart from isolated firms who have already developed a few buildings using CLT) similar to America (Mallo & Espinoza, 2015).

2.4.2 Cross Laminated Timber – Sustainability

Many previous studies have shown and proved that when forestry's are sustainably managed, the use of timber as a building product becomes a sustainable alternative to steel or concrete. It is well known that large carbon emissions that are causing detrimental effects to the environment. However, trees convert carbon dioxide into oxygen through the photosynthesis process, therefore it is possible to reduce the amount of carbon in the atmosphere by storing it in timber (Mallo & Espinoza, 2015).

2.4.2.1 Forestry Sustainability

Forestry's produce large amounts of timber for the building and construction industry. Generally there can be substantial amounts of waste generated when the timber from the forestry does not meet guidelines concerning size, density, and general condition. This lower quality timber product is perfect for the cross laminated timber industry as the quality is not as components is not as critical as other timber products. Not only is this better for the environmental sustainability, but it also improves the economic viability of cross laminated timber by making it cheaper for the industry and gives the forestry an option to make money of effectively rubbish material.

2.4.2.2 Operational Sustainability

There has been recent research into the life-cycle environmental performances of Cross Laminated Timber buildings in comparison to traditional steel and concrete buildings. Typical results from the past research indicated:

- Robertson, et al (2012) compared the life cycle environmental impacts of two five story buildings, one built with reinforced concrete and the other built as a hybrid cross-laminated timber building. The results of the study suggested that the timber based building consumed 15% less energy during its life.
- Chen (2012) compared the operation energy requirements for the different types of construction. One being CLT and the other being reinforced concrete. Results suggested that the energy required to operate the CLT building was approximately 10% lesser then the Reinforced Concrete building and this could be further improved through improved technology.
- Hammond & Jones (2008) compared the embodied carbon within a concrete and steel building vs that of the Cross Laminated Timber buildings. Results indicated that the CLT building had less than half of the concrete and steel buildings. The results of the research also indicated that the timber would still be absorbing carbon through most of its life cycle. Meaning that the CLT building would have no carbon dioxide emissions for a substantial amount of time.

In summary, the above research has shown that Cross Laminated Timber buildings consume less energy, require less energy to run and can effectively act as a carbon dioxide sink (Evans, n.d.).

2.4.4 Cross Laminated Timber – Relative Cost

When researching into new innovative materials it is always important to critically compare the costing of alternative methods to determine the economic feasibility of the new product.

In 2017 Burback and Pei performed a comparative cost study between a houses built with typical light weight framed wood vs houses built with cross laminated timber. The results show that for this size construction there is no financial benefit for the builder to use CLT, but alludes to the fact after a certain size of construction this would be reversed. (Burback & Pei, 2017)

In 2016 Mallo and Espinoza performed a cost comparison between Cross Laminated Timber and Concrete/Steel construction using a case study. The comparison consisted of the following options:

- Steel and Concrete
- CLT and Steel beams
- CLT and Glulam timber teams

The comparison depicted that the use of CLT could potentially reduce the total cost by up to 21.7%, depending on the extent of which CLT was used. They concluded that although this study proves the feasibility of CLT, it would be important to do further research into different size and shapes of building to fully determine the extent (Mallo & Espinoza, 2016).

2.4.5 Cross Laminated Timber Case Study

The following is a case study into the effective use of Cross Laminated Timber as the decking for a new bridge in Glen Innes Severn Council. Browns Road crosses Bald Knob Creek approximately 30km east of Glen Innes.

Glen Innes Severn council engaged a contractor to provide a sustainable design for the construction of the proposed bridge over Bald Knob Creek. The proposed single lane bridge was to cater for a T44 design load and to have a design life of minimum 40 years.

The contractor proposed the bridge structural design consisting of concrete abutments, concrete bored piles, engineered timber girders, engineered timber headstocks, engineered timber girders and cross laminated timber bridge decking from a nearby cross laminated timber supplier. The Cross Laminated timber option guaranteed the following:

- The cross laminated timber bridge 7.5m long x 4.5m wide single span estimated to cost approximately $65,000 as opposed to a precast concrete bridge alternative by Roads and Maritime Services (RMS) with similar dimensions which would cost around $210,000.
- The time of construction, or length of construction would be drastically reduced do to the ease of construction and light weight nature of the cross laminated timber materials. With no curing time required other than for the footings.
- Construction would be quite simple requiring less trades, and easier for traditional construction workers who are used to working with timber. This means that there is no requirement for retraining of staff or hiring specialise contractors to build the concrete option. As seen in the figure 7 below, the deck of the bridge is being constructed with an excavator and two labourers.

Figure 7: Construction of Browns Road Bridge

- All concrete bridges use excessive materials (steel reinforcement and concrete) mainly to compensate for the excessive self-weight of the concrete. This can be uneconomical or seem wasteful. Whereas cross laminated timber bridges are much lighter (up to 8 times lighter) and require less material/resources to cater for the standard T44 design load.
- The cross laminated timber is highly acceptable to preservative treatment, hence can be treated to durability Class 1 with a service life of minimum 25

years, with regular maintenance this can be extended up to 50 years. Which is the same class of timber as common species of hardwood like Ironbark, Turpentine and Tallowwood (Roads Maritime Service (NSW), 2008).

Figure 8: Completed Browns Rd CLT Bridge

2.5 General Conclusions

From the above research it can been that there are many benefits and extensive research that has gone into the viability and feasibility of Composite Materials, Geopolymers and Cross-Laminated Timber. Benefits include environmental and economical sustainability for the manufacturing and construction industries, improved characteristics (strength, weight, durability etc), further environmental benefits through the life cycle of the products and even potential cost savings during operations.

Mallo et al. (2015) said that the "rate of diffusion is dependent on the potential product adopters' perceptions of the product attributes". This means that although the potential benefits of advanced engineering materials are so high, there are still reasons as to why the industry has not moved forward with it as desired. Whether it be availability, construction firms and designers stuck in old ways, or even a lack of knowledge there definitely has to be a reason why. The following research will investigate; what factors aid or inhibit the use of the above advanced and sustainable engineering materials?

Chapter 3 – Proposed Research

3.1 Research Methodology

3.1.1 Research Scope

The following methodology will be applied for this research project.

- Gather available information and literature regarding composite materials, geopolymers and cross-laminated timber.
- Summarise literature such that myself and readers can gain a sound understanding of what previous research has been undertaken and provide direction as to what areas need further research.
- Tabulate data from existing research results to help guide a questionnaire.
- Life cycle analysis and cost benefit comparison on each of the materials with a relevant case study.
- Design a questionnaire to focus on issues that have impacted the take-off of advanced engineered materials.
- Prepare an application to the Human Research Committee and have it approved by my supervisor and course coordinator.
- Submit the proposed questionnaire to the Human Research Committee for approval.
- Collate a list of potential candidates for the questionnaire. Looking for a range of people from designers, constructors, councils and even current owners of small businesses.
- Distribute questionnaire to candidates and await response.
- Summarise and tabulate results from questionnaire.
- Critically analyse factors that have been influencing the take-off of advanced engineering materials.
- Write dissertation and submit for grading

3.1.2 Literature Data Collection

For this research project, background literature regarding Carbon Fibre Reinforced Polymers, Geopolymers and Cross-Laminated Timber will need to be thoroughly reviewed. In particular how they relate to sustainable development, cost comparisons and overall benefits of using the above advanced engineered materials. A review into overall sustainable development and the role professional engineers play in delivering such.

There is an abundance of available information regarding this project in published papers, on the internet and in books. However, like all topics there can be unreliable sources of information that can provide false or unproven information. Given that this project is being directly lead by the data found in previous research, false or unproven literature could potentially direct this research project into the wrong direction. Therefore it is critical that only high-calibre reliable material be used in the data collection phase of this project. To ensure that only high-calibre material is used in this research, material will be refined to only include peer reviewed material. Post data collection, the material will be summarised and included in this report in the form of a literature review.

3.1.3 Cost Benefit Analysis

Following the review of literature and particular case studies a high level cost benefit analysis will be undertaken on each of the materials and situation. This will be done to logically quantify the direct cost versus the direct benefit of using each Advanced Engineering Materials against the comparison of using a traditional material or method.

Each material/method of construction analysis will be broken down into three significant areas to determine the sustainability of each material.

Economic

The economic aspect of the analysis will review the overall constructed cost of the project along with design life of the structure and including the maintenance regime of each material alternative. The present day value of the lifecycle cost will be used to determine the economic suitability of the material choice. Hence the overall economic sustainability of using an advanced engineering material for construction compared to the alternative of using the traditional method or material for construction.

The following formula will be used to calculate the present day value (Ahmed, 2018):

$$FV = PV * (1 + r)^n$$

Where:

FV = Future Value based on an applied inflation rate over a number of years

PV = Present Day Value

r = Inflation rate (assumed conservative stable inflation rate of 2% over the length of the design life)

n = Number of periods (years) away from the present day year

The values for constructed price will be taken from the estimated prices provided for each case study, and where needed will be checks against Sydney Construction prices with a regional multiplier of 1.15 applied to all values as described in Rawlinsons – Australian Construction Handbook (Rawlinsons, 2018).

Environmental

The environmental aspect of the analysis will review the overall environmental sustainability of the project, highlighting the extents of environmental impacts of using an advanced engineering material for construction compared to the alternative of using the traditional method or material for construction. The comparison will score each environmental factor on a scale of 1-5. Where a score of 1 will have a very low impact for the corresponding factor and a score of 5 will have a very high impact for the corresponding factor.

I.e. Very Low = 1, Low = 2, Medium = 3, High = 4 and Very high = 5

A similar scaled scoring factor will be used to score the social impacts.

Social

The social aspect of the analysis will review the overall social sustainability of the project, highlighting the extents of social impacts of using an advanced engineering material for construction compared to the alternative of using the traditional method or material for construction.

It can be extremely difficult to quantify exact monetary costs of social and environmental impacts. Hence, this method will only scale the cost or benefit of using the advanced engineering material against not using the material. Engineering judgment will be used to quantify any cost or benefit that cannot be scaled against a control.

The cost-benefit method of analysis will be as described in the 'Cost-benefit Analysis' book by Michael Snell (Snell, 2015).

In order to critically compare the benefits against the costs in a quantitative way, the cost and the benefits will need to be measured by a common unit of measurement. Given that this analysis will be looking into aspects of social, economic and environmental the common unit of measurement will be a score on a range between 0 and 1 for the benefits and above 1 for the costs (in this instance the cost is a detriment and does not necessarily mean the same as economic cost). The score will be modelled to read that the higher score indicates a cost and the lower score indicates a benefit.

3.1.3 Questionnaire Design

The first part of the questionnaire is designed using the Likert Scale.

The Likert Scale is a commonly used questionnaire response type that using predefined categories to measure peoples closes opinion or perception toward the given question (Jamieson, 2019). When using the Likert Scale the following needs to be defined to create the questionnaire:

- Question or statement
- Categories and Number of possible responses

<u>Question or Statement:</u>

It is critical to ensure that the question or statement is thought of critically and worded correctly to convey the correct message. This will ensure that the responses are as accurate as possible and answer the correct question, reducing the risk of unhelpful and unwanted results for the research.

The questions and statements will be critically decided and based off the results from the cost-benefit analysis and the literature review. Where the first stage of the questions will be of a wider overall topic. These questions will be used to get the respondent to begin thinking about the topic as an overall as well as gaining results for the overall topic. Closing in to more detail pinpoint questions further into the questionnaire to get direct responses and results to the research.

<u>Number of Responses:</u>

The number of responses in Likert Scales can vary, where traditionally the research would use a four or five point scale. The number of responses or size of scale adopted for this research will be a four point scale. Broken down into the following categories; always, often, rarely and never. This keeps the initial questionnaire responses simple and relatively easy for the respondent to decide on a response. Previous research has indicated that with the number of responses choices being an even number, means that the respondents are forced to be either for or against and cannot 'sit on the fence' so to speak (Jamieson, 2019).

3.1.4 Questionnaire Submission to Human Ethic Review Panel

Once the draft questionnaire has been prepared, the questionnaires is submitted and approved by the USQ Human Ethics Review Panel via the Research Information Management System (RIMS) on the USQ website.

The application involves detailing the following:

- Project title
- Background data and the potential significance of the research project
- Project aims and hypothesis
- Investigators; primary author and supervisor
- Potential benefits to participants
- Risk; both short term and long term risks of participating in this research
- Proposal to minimise the potentials risks
- The type of research, ie qualitative and quantitative for student honours program
- Any potential conflicts of interest
- Funding requirements for the research
- Secure storage of the data obtained from the questionnaire
- The required length of time that the data needs to be securely stored
- Along with a review of the proposed questionnaire.

Post submission, the application is reviewed by the project supervisor, then the head of the unit and finally it is reviewed by the ethics committee. This is quite an extensive process and should be planned well to decrease the risk of time delays.

3.1.5 Questionnaire Distribution

The questionnaire is distributed to a range of different participant groups in the North West NSW region. Effective and efficient distribution allows for succinct and direct results. Therefore when determining the distribution network, it is key to decide the audience/participants early on in the procedure. There are three main focus groups that this research questionnaire aimed to research:

- Design Engineers:
  Distributing the questionnaire to design engineers will give qualitative insight into the decisions design engineers make when choosing materials for construction.
- Council Engineers:
  Distributing the questionnaire to council engineers will give qualitative insight into the decisions council engineers make when approving designs for construction, or constructing design themselves.
- Construction Engineers:
  Distributing the questionnaire to construction engineers will give insight into the direction regarding advanced engineering materials they see the construction industry going. Along with providing feedback for direct use of advanced engineering materials.

3.1.6 Summarise and Discuss Findings

The results of the literature review, cost-benefit analysis and the questionnaire will be summarised and discussions will be based on the issues in of using advanced and sustainable engineering materials.

Recommendations and suggestions will be presented with the aim to mitigate these issues that have previously impacted the take-up by industry in a hope that the take up of advanced engineering materials are increased so that we can move toward sustainable development.

3.2 Resource Requirements

NOTE: All monetary requirements associated with this project will be supplied by myself – Jacob Tan

- My supervisor is employed by the university, hence any time he spends reviewing and guiding my work should be classified as a resource that will be needed for the project.
- I will need access to online journal paper resources, such that I can adequately and efficiently find data that will be needed.
- I will need access to the USQ library online.

- I will need access to SAI global to find any Australian Standards that might be needed.
- I will need money to supply paper and printer ink to print out the necessary survey material that I will send out. Approximately $20.
- I will need money to supply paper and printer ink to print my final dissertation. Approximately $50.
- I will visit some local sites that have used advanced engineering materials, so I will need to gain permission to do so.
- I would like some sample products of advanced engineering materials that I will be researching. Ie Carbon Fibre Reinforcing material.

3.3 Consequences

Given that this is a university research project typically there would not be many consequences that would affect the community. However, this projects goal is to evaluate factors that influence the take-off of advanced engineering materials. Given that one of the factors that I have already determined is the ‘lack of awareness’. The questionnaire that this research will conduct might actually start to get different people involved with and begin raising awareness of advanced engineering materials.

3.4 Ethics

Engineers Australia says *‘As engineering practitioners, we use our knowledge and skills for the benefit of the community to create engineering solutions for a sustainable future. In doing so, we strive to serve the community ahead of other personal or sectional interests’*. In doing this there are Code of Ethics that we should follow to help guide our values and principles that shape the decisions we make in engineering practice (Engineer Australia, n.d.).

During the course of this project I will:

- ***Demonstrate integrity*** in the decisions that I make by being trustworthy and honest regarding all results obtained.
- Treat all people involved with the respect and confidentiality they deserve without harassment.
- ***Practice Competently*** in developing my knowledge and understanding of this topic.
- Practice and understand all research so that I don’t falsely misinterpret.

- ***Exercise Leadership*** to take account for my actions and efforts put into this research.
- ***Promote Sustainability*** by ensuring that I incorporate social, economic and environmental concerns with the research that I am undertaking

3.5 Risk Assessment

As with any research project there are always potential risks that should be recognised early on in the planning stage. These risks should be categorised into different levels dependant on the harm they pose. Once categorised it is critical to monitor and aim to minimise these potential risks through the life of the project. The following table lists the potentials risks for this project and indicates the measures that will be taken to minimise the risk.

Table 2: Risk Assessment

Risk	Risk Level	Measures to Minimise
Incorrect or invalidated data obtained in literature review	Medium	To minimise this risk I will strive to ensure all reference literature is peer reviewed
Completing the research project within the specified timeline	High	Ensure I follow the proposed project timelines so that I don’t fall behind
Lack of information obtained from proposed questionaries’	Medium	Ensure that there are enough recipients of the questionnaire
Copyright	High	Ensure all research material is correctly referenced

Chapter 4 – Research Results

4.1 Cost Benefit Analysis Results

The following section will summaries and report on the findings from the cost benefit analysis performed to aid the direction of this research. The cost benefit analysis has analysed the three different case studies that were brought to light in the literature review of this report for each advanced engineering material. Each analysis firstly gathers all relevant data and summaries relevant assumptions for the model.

Remembering that the cost benefit analysis will look at economic, environmental and social aspects of the alternative construction methods/materials.

The aim of the questionnaire is to compare each advanced engineering material with a typical traditional material in a way that the output can easily show the critical quantitative benefits and detriments of each material, to aim the questions that will be asked in the questionnaire.

For each analysis an inflation rate of 2% was assumed.

4.1.1 Wellingrove Creek Bridge

This analysis will compare the construction alternatives of either rehabilitating or strengthening the existing of Wellingrove Creek Bridge on Waterloo Rd or replacing the structure with a Precast Concrete bridge.

Economic Comparison:

Initial Assumptions and model setup

- This analysis will use different conditions as stated in the case study described in section 2.2.5 of this report. The case study was mainly looking at the benefits to the proposed windfarm project as described. Whereas this analysis will consider the comparison from a asset management perspective post construction of the windfarm (i.e. ignoring the high design loads that were required for the construction of the windfarm)
- Alternative 1 is to strengthen the bridge with Carbon Fibre Reinforcing strips on the underside of the girder, along with diffusing all structural timber members with Borate salt rods to prevent further deterioration and to greatly reduce the ongoing cost of maintenance. With careful maintenance it has been assumed the design life of this rehabilitation would be 50 years, where further resources would need to be spent. At the 50 year mark, this analysis

will assume that a sustainable cross laminated structure be built with a design life of a further 50 years (to get both alternatives to 100 years).

- ➢ The initial cost of Alternative 1 is $200,000 with an increase maintenance cost over the 50 year design life. The present day constructed cost of the future replacement structure is approximately $350,000.
- ➢ Alternative 2 is to demolish the existing structure and to provide a precast concrete Country Bridge Solution Type 1 structure as shown below in figure 9 consisting of a 2 Lane Bridge 3 x 8m spans (totalling 24m). The design life of the precast concrete structure is 100 years.
- ➢ The constructed cost of Alternative 2 is $750,000 (as estimated in section 2.2.5 of this report) with a regular maintenance regime and cost as described in RMS Country Bridge Solutions Operation and Maintenance Guide (Roads and Maritime Services , 2016).

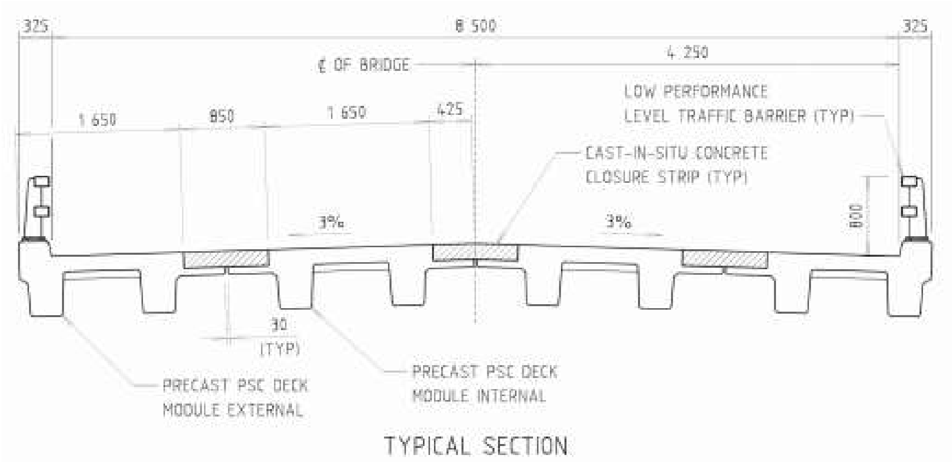

Figure 9: Country Bridge Solution Type 1 Typ. Section *(Roads and Maritime Services, 2016).*

Maintenance Regime

The following maintenance regime provided by RMS has been adopted for this analysis for both alternatives:

- ➢ Level 1 inspections are drive by inspections which would detect clear safety issues of the bridge. The frequency of these inspections would be in accordance with the road maintenance inspection regime set by council which is once every six months (Roads and Maritime Services , 2016).
- ➢ Level 2 inspections are conducted by trained bridge inspections and rate the overall condition of the bridge. These condition assessments inspections are conducted every 2 years (Roads and Maritime Services , 2016). However,

due to the nature of alternative 1, the level 2 inspections will be carried out every year for the duration of the existing structure and extended back out to every two years after the construction of the replacement bridge (after 50 years).

- Level 3 structural engineering inspections are carried out by qualified and experience structural engineers, with an RMS trained bridge inspector. These inspections are more detailed then the previous level 1 and 2 and critically looks at factors affecting the structural capacity. This analysis will assume due to the nature of alternative 1, level 3 inspections will be required on a ten year basis to ensure the longevity of the constructed rehabilitation techniques. Alternative 2 will have level 3 inspections carried out at the 50 year interval.

Comparison of present day lifecycle cost:

The life cycle analysis indicated that the total life cycle cost of the Rehabilitation alternative is significantly lower for the first 50 years. However, the increase maintenance cost for the life time of the rehabilitated structure (first 50 years) and the large jump at 50 years (due to the need to build a new structure), means that the total lifecycle cost of Alternative 1 is significantly higher.

Alternative 1 Present Day Value of life cycle is $1.8 million

Alternative 2 Present Day Value of life cycle is $1.33 Million

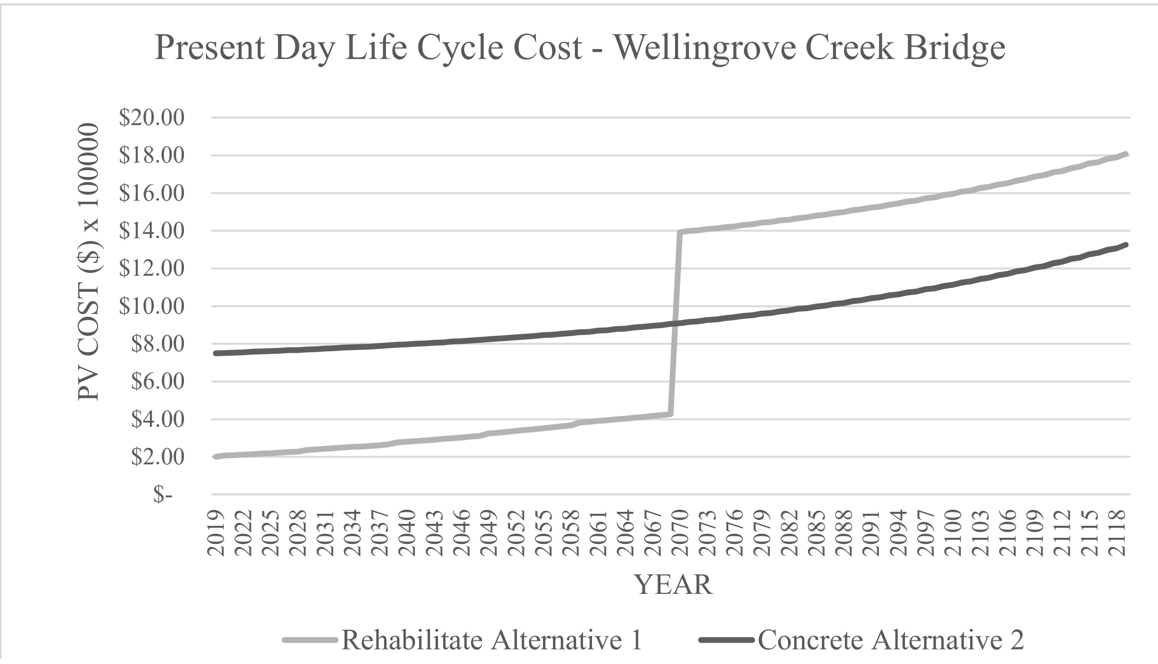

Figure 10: Present day life cycle cost line graph for both alternatives

Comparison of Environmental Factors:

Use of resources: Alternative 1, would have a low impact on the use of resources due to using minimal resources to rehabilitate the structure for 50 years. Once the existing structure is replaced after the 50 years, the proposal is to use a light weigh CLT bridge as a replacement using sustainable resources. Alternative 2, will have a high impact on the use of immediate resources. The high cost of the concrete bridge will cost the council a significant amount of money straight up.

Carbon Emissions: Alternative 1, will have minimal carbon emissions during construction. The benefit of being timber is that it stores up to 50% of its weight in carbon, and hence will act as a carbon sink for the remainder of the design life. Where the replacing CLT structure will also act as a carbon sink and have very minimal – low carbon emissions. Alternative 2, in the deck alone requires $68m^3$ of concrete with an estimated $400kg/m^3$ of Portland cement required for the concrete mix design. As previously discussed, ordinary Portland cement produces 1 tonne of carbon dioxide emissions per 1 tonne of cement. It is expected that $68m^3$ of concrete would produce 27.2 tonnes of carbon dioxide emissions. ($400kg/m^3 \times 68m^3 = 27200kg = 27.2$ tonnes).

Waterway Pollution: Alternative 1, will have very low impact on the water way, for the rehabilitation works, there will be no work conducted within the water way and minimal chance of contaminants entering the water stream. Alternative 2, will have high impact on the water way with large amounts of earth works required for piers and abutments.

Air Pollution: Similarly to Carbon emissions section. Alternative 1, will have minimal impact on air pollution. Alternative 2, will have high impact due to mainly the carbon emissions, but also the dust from earthworks etc.

Impact on Adjacent vegetation/habitat: Alternative 1, will have minimal impact on adjacent land as the rehabilitation works will be undertaken under and within the confines of the bridge. However, once the replacement CLT structure is constructed there might be an impact on the adjacent land, but due to the light weight nature, requiring less footings, it is expected that the impact would be lower than Alternative 2. Alternative 2, will have a high impact on the adjacent land and habitat due to the sheer size and weight of the structure, it's not only the footings that would have an impact but also the need for hard stand areas to crane the bridge decks into place.

Below is a table comparing the environmental factors against the scoring scale as described in section 3.1.3 of this report. It can be seen that the Alternative 1 will have a lower impact on the environment with a score of 7/25 where Alternative 2 have a higher impact on the environment with a score of 19/25.

Table 3: Comparison of environmental factors for Wellingrove Creek Bridge upgrade

	Alternative 1	Alternative 2
Use of resources	2	4
Carbon emissions during construction	1	5
Waterway pollution	1	3
Air Pollution	1	4
Impact on adjacent vegetation/habitat	2	3
Total Score	7/25	19/25

Comparison of Social Factors:

Visual Appearance: Alternative 1, will have a high impact on the visual appearance from a social aspect. When society look at the old timber bridge (appearing to be deteriorated) causing concerns of safety when crossing the bridge. Alternative 2, would see a brand new concrete structure that would be appealing looking safe for motorist to cross.

Perceptions of Council: Alternative 1, will have a high impact on how the relevant society/users of the bridge see council. I.e. the rehabilitation works completed will be invisible to the society eye. So, although the society might feel like the bridge needs upgrading immediately, they won't see any upgrade for 50 years. Alternative 2, however, will have a positive impact on the way society relies on council. It is assumed that they will feel like the council does care about the local road and community as shown by a brand new concrete bridge.

Environmental Justice: Alternative 1, will have a low impact on the way society feels council have solved the issue from an environmental perspective. However, Alternative 2, might see society concerns with damaging the adjacent habitat to provide a new concrete structure.

Economic Justice: This factor could go each way, i.e. the stakeholders might feel that it is the best money spent to provide a new concrete structure as per Alternative 2. However, the rest of the region might feel that because the road has low volumes, and that the immediate money could be better spent elsewhere and hence would favour Alternative 1.

Social Connectivity: Alternative 1, could potential reduce the social connectivity of the community (refer to Visual Appearance above). Whereas, Alternative 2, could increase the community connectivity with larger amounts of traffic being able to use the bridge.

Below is a table comparing the social factors against the scoring scale as described in section 3.1.3 of this report. It can be seen that the Alternative 1 will have a higher impact on the society aspects with a score of 19/25, where Alternative 2 will have a lower impact on the society aspects with a score of 12/25.

Table 4: Comparison of social factors for Wellingrove Creek Bridge upgrade

	Alternative 1	Alternative 2
Visual Appearance	4	2
Perception of council not funding any upgrades for nearby stakeholders	5	1
Social aspect of environmental justice	2	4
Social aspect of economic justice	4	3
Social Connectivity	4	2
Total Score	19/25	12/25

4.1.2 West Wellcamp Airport

Initial Assumptions and model setup:

- Due to the fact that the construction of West Wellcamp Airport saw the first large scale use of geopolymer concrete Australia has ever seen and the lacking Design Standards, meant that the concrete supplies – Wagner's needed to trail and test the Geopolymer concrete product before it could be fully implemented into the project. Along with this testing period and setting up a batch plant for the first time caused the cost to be at a premium rate. However, since the construction of the Airport, Wagners have further developed a Geopolymer Concrete product called Earth Friendly Concrete (EFC) that is available to the consumer. Hence, for the benefit of this analysis, the initial setup and trialling period cost has been ignored, so that the study can look at a unit to unit comparison between the Geopolymer Concrete and the traditional Portland Cement Concrete.
- <u>Alternative 1</u> is the use of Wagners 'EFC' Geopolymer cement for the construction of the 40,000m^3 of pavement.
- <u>Alternative 2</u> is the use of Ordinary Portland Cement for the construction of the 40,000m^3 of pavement.
- Although construction was undertaken in 2014, this study will use 2019 rates.
- The current cost for Wagners EFC Geopolymer Concrete is \$175/m^3 (August, 2019).
- Current cost for Wagners Regular 32MPa cement concrete is \$160/m^3 (August, 2019) which has been assumed to be the closest comparable product available.
- Due to the ability to adopt the AS3600 for the design of Geopolymer Concrete, this analysis assumes that the rigid pavement design provided by ACG engineers as shown in section 2.3.5 of this report is adequate to use for the regular Portland cement material option.
- Australian Airports Association, Airfield Pavement Essential states that the rigid concrete pavement type is to have a design life of minimum 40 years. This analysis assumes that the pavement design for West Wellcamp Airport meets this requirement for regular Portland cement option. With improved durability, superior chemical resistance and high flexural strength of

Geopolymer concrete, it has been assumed that the maintenance requirement will be less, with the adopted maintenance regime explained below.

Maintenance Regime:

The maintenance regime adopted has come directly from the Australian Airports Association, Airfield Pavement Essential, which states the most common concrete maintenance activities include:

- Repairing of concrete spalling by cutting out and replacing with asphalt.
    - Portland Cement Concrete
        - Minor spalling maintenance every 5 years increasing to every 4 years after 20 years and increasing to every 3 years after 30 years.
    - Geopolymer Concrete
        - Due to the chemical resistant nature, it has been assumed that the repairmen of minor spalling would be dragged out to after 7 years, increasing to 5 years after 20 years and increasing to every 4 years after 30 years.
- Severe crack replacement by trenching out crack and refilling with asphalt.
    - Portland Cement Concrete
        - Minor crack maintenance after 20 years and 30 years.
    - Geopolymer Concrete
        - Due to the increased flexural capacity, it has been assumed that crack maintenance could be extended out to after 25 years.
- Partial Slab Replacement by isolated sections being cut out and reconstructed.
    - Portland Cement Concrete
        - Minor replacement after 30 years increasing for the remainder of the pavement life.
    - Geopolymer Concrete
        - Minor replacement after 30 years increasing for the remainder of the pavement life, it is assumed due to the additional durability from Geopolymer Concrete that less pavement will need to be replaced.

Comparison of present day lifecycle cost:

The life cycle analysis indicated that the total life cycle cost of the total life cycle cost of alternative 2 (Geopolymer Concrete) was lower than the Alternative 1 (Portland Cement Concrete). Although the higher initial cost for the outlay of geopolymer concrete, it is expected that the ongoing maintenance costs will be much lower over the course of the design life and hence reducing the overall cost.

Alternative 1 Present Day Value of life cycle is $10.86 million

Alternative 2 Present Day Value of life cycle is $11.13 million

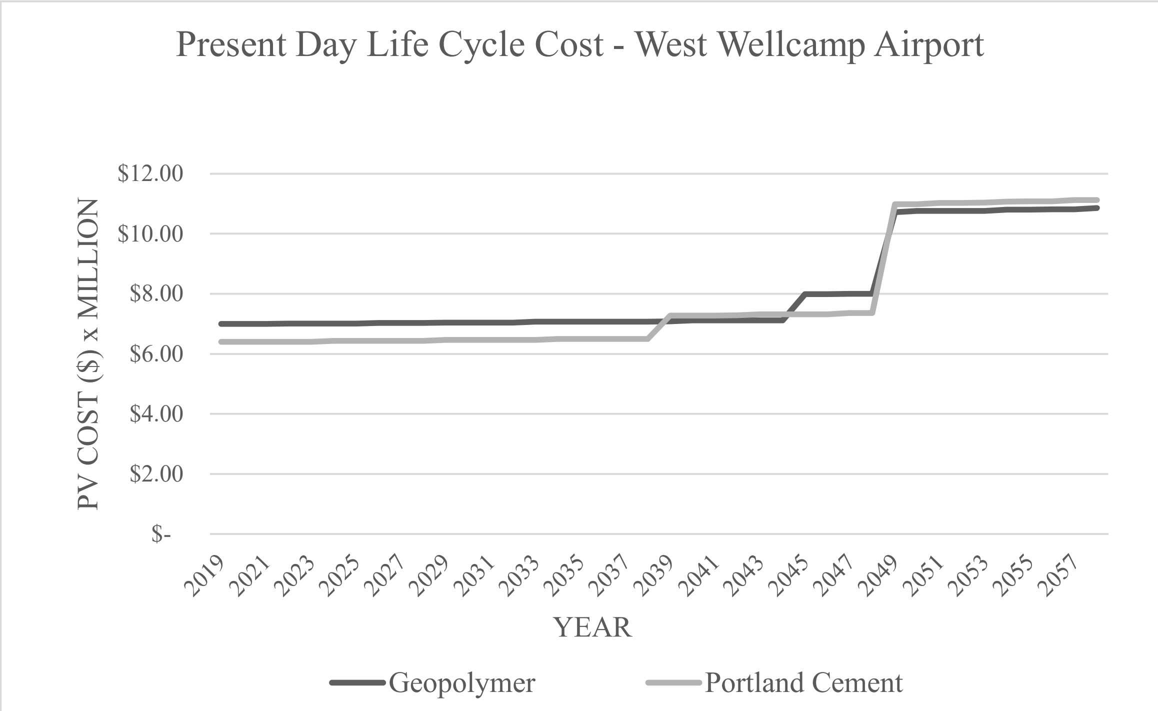

Figure 11: Present day life cycle cost line graph for both alternatives

Comparison of Environmental Factors:

Use of resources: Alternative 1, has a higher cost for initial construction, however, much of the resources required to make Geopolymer concrete comes from a waste product that would normally be sent to landfill. Alternative 2, would see a large amount of cement required, with a high impact on the usage of natural resources.

Carbon Emissions: As previously discussed in section 2.3.5 of this report, it is understood that Alternative 1 would save approximately 5640 tonnes of carbon dioxide emissions.

Below is a table comparing the environmental factors against the scoring scale as described in section 3.1.3 of this report. It can be seen that the Alternative 1 will have a lower impact on the environment with a score of 4/10 where Alternative 2 have a higher impact on the environment with a score of 9/10.

Table 5: Comparison of environmental factors for West Wellcamp Airport

	Alternative 1	Alternative 2
Use of resources	3	4
Carbon emissions during construction	1	5
Total Score	4/10	9/10

Comparison of Social Factors:

Visual Appearance: The visual differences between the two alternatives are negligible.

Environmental Justice: Once society is aware of the greener option, and the reduction of carbon dioxide emissions from alternative 1. Alternative 1 would have a low impact. Whereas, Alterative 2 would have a high impact, with society feeling like the greener option would have been better for the environment.

Economic Justice: Given that the project is privately funded, there would be minimal concern about the economic decisions that are made for the project. However, given that the life cycle analysis shows that the overall cost of the project can be reduced by going the greener option with only a slight increase in initial cost. It is assumed that society would feel Alternative 1 would be the best option in respect to economic justice.

Below is a table comparing the social factors against the scoring scale as described in section 3.1.3 of this report. It can be seen that the Alternative 1 will have a lower impact on the society aspects with a score of 5/15, where Alternative 2 will have a higher impact on the society aspects with a score of 8/15.

Table 6: Comparison of social factors for West Wellcamp Airport

	Alternative 1	Alternative 2
Visual Appearance	1	1
Social aspect of environmental justice	1	4
Social aspect of economic justice	3	3
Total Score	5/15	8/15

4.1.3 Browns Road Bridge

This analysis will compare the construction of Browns Road Bridge crossing Bald Knob Creek as described in section 2.4.5 of this report.

Initial Assumptions and model setup:

- The comparison will be between the cross laminated timber superstructure as built and the Roads Maritime Services (RMS) Type 2 Country Bridge Solution Precast Concrete structure.
- Alternative 1 will consider the construction of a cross laminated timber (CLT) bridge 7.5m long x 4.5m wide. The structure single span structure consists of concrete abutments with CLT headstocks, girders and decking.
- Alternative 2 will consider the construction of a precast concrete bridge designs and prebuilt by Roads and Maritime Services NSW. The single span structure consists of concrete abutments, headstocks, girders and decking. As seen in figure 12 below.
- The total constructed costs for the different options have been provided by Glen Innes Severn Council with $65,000 constructed for the cross laminated timber option and $210,000 for the precast concrete option.
- The design life for the precast concrete standard design is 100 years (Roads and Maritime Services , 2016).
- The design life for the cross laminated timber option is 50 years. Which is half of the design life of the concrete option, hence this analysis will assume a secondary cross laminated timber structure would be built after 50 years.

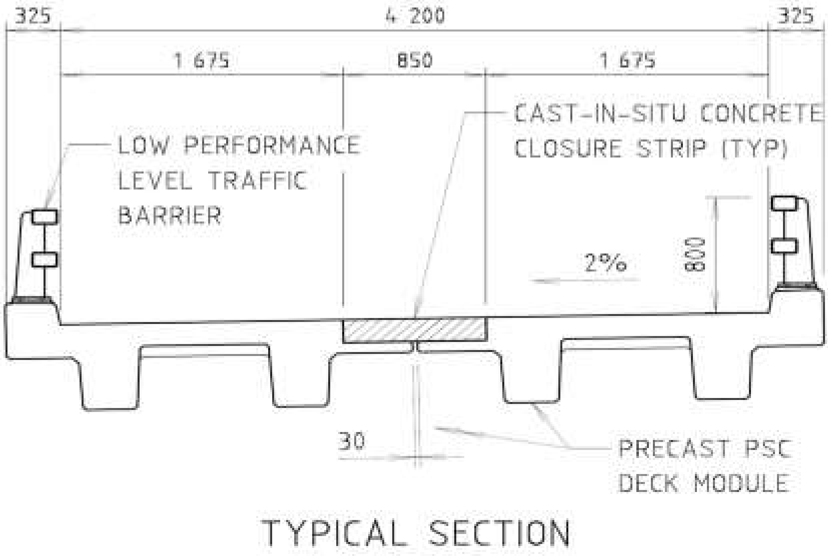

Figure 12: Country Bridge Solution Type 2 Typ. Section *(Roads and Maritime Services, 2016).*

Maintenance Regime:

The following maintenance regime provided by RMS has been adopted for this analysis for both material options (Roads and Maritime Services , 2016):

- Level 1 inspections are drive by inspections which would detect clear safety issues of the bridge. Which would be in accordance with the road maintenance inspection regime set by council which is once every six months.
- Level 2 inspections are conducted by trained bridge inspections and rate the overall condition of the bridge. These condition assessments inspections are conducted every 2 years.
- Due to the bridge being a single span bridge and the water level being relatively low, this study does not make an allowance for level 3 and 4 inspections.

Comparison of present day lifecycle cost:

The life cycle analysis indicated that the total life cycle cost of the Alternative 1 is significantly lower for the first 50 years. However, the need to build a new structure at 50 years because of the reduced design life, means that the total lifecycle cost of Alternative 1 is slightly higher.

Alternative 1 (CLT) Present Day Value of life cycle is $680,000

Alternative 2 (Precast Concrete) Present Day Value of life cycle is $595,000

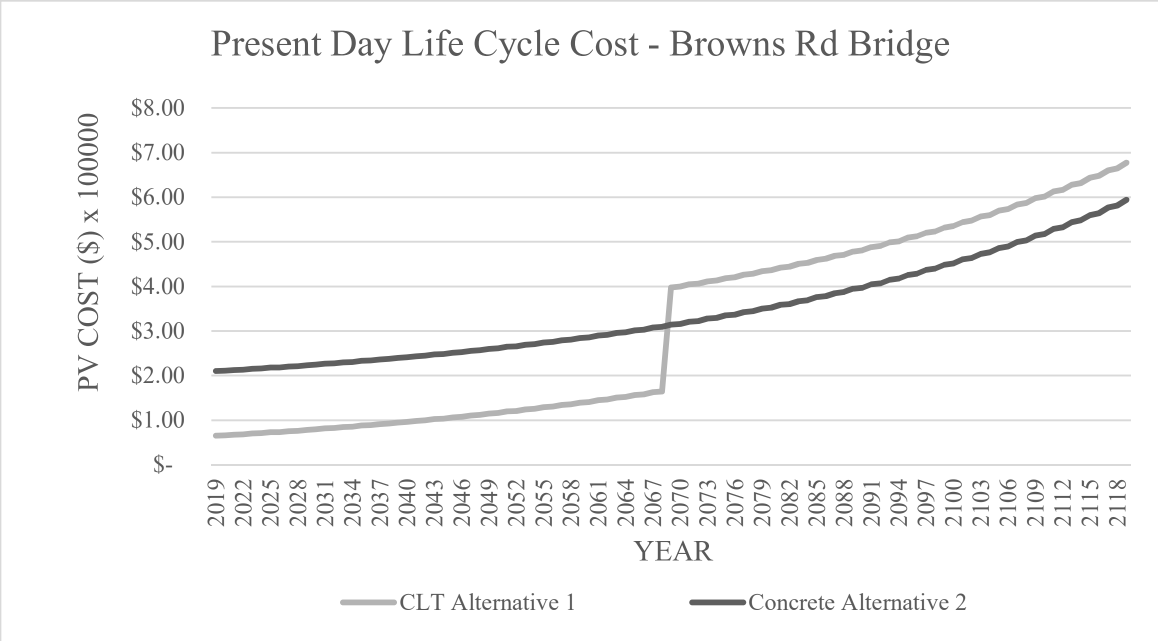

Figure 13: Present day life cycle cost line graph for both alternatives

Comparison of Environmental Factors:

Use of resources: Alternative 1, would have a low impact on the use of resources due to the structure comprising mainly of sustainably sourced CLT. Alternative 2, will have a high impact on the use of immediate resources. The high cost of the concrete bridge will cost the council a significant amount of money straight up, along with using up natural resources to produce cement.

Carbon Emissions: Alternative 1, will have minimal carbon emissions during construction. The benefit of being timber is that it stores up to 50% of its weight in carbon, and hence will act as a carbon sink for the remainder of the design life. Alternative 2, in the deck alone requires $12m^3$ of concrete with an estimated $400kg/m^3$ of Portland cement required for the concrete mix design. As previously discussed, ordinary Portland cement produces 1 tonne of carbon dioxide emissions per 1 tonne of cement. It is expected that $12m^3$ of concrete would produce 4.8 tonnes of carbon dioxide emissions. ($400kg/m^3 \times 12m^3 = 4800kg = 4.8$ tonnes).

Waterway Pollution: Being a single span structure (abutment – abutment) it is expected that the potential waterway pollution would be similar between the two alternatives.

Air Pollution: Similarly to Carbon emissions section. Alternative 1, will have minimal impact on air pollution. Alternative 2, will have high impact due to mainly the carbon emissions.

Impact on Adjacent vegetation/habitat: Alternative 1, will have minimal to low impact on adjacent land. This is mainly due to the light weight nature of the structure requiring no hardstand area for craning etc. Alternative 2, will have a medium impact on the adjacent land and habitat due to the sheer weight of the structure, needing to cater for a hard stand area to crane the bridge deck into place.

Below is a table comparing the environmental factors against the scoring scale as described in section 3.1.3 of this report. It can be seen that the Alternative 1 will have a lower impact on the environment with a score of 9/25 where Alternative 2 have a higher impact on the environment with a score of 17/25.

Table 7: Comparison of environmental factors for Browns Road Bridge

	Alternative 1	Alternative 2
Use of resources	2	4
Carbon emissions during construction	1	5
Waterway pollution	2	2
Air Pollution	2	3
Impact on adjacent vegetation/habitat	2	3
Total Score	9/25	17/25

Comparison of Social Factors:

Visual Appearance: Alternative 1, will have a medium impact on the visual appearance from a social aspect. When society look at the new timber bridge it might raise concerns about strength and durability. Alternative 2, would see a brand new concrete structure that would be appealing looking strong and safe for motorist to cross, hence a low impact. I.e. This ties into the perceptions people have about timber products as discussed further below.

Perceptions of Council: It is expected that the perceptions of the effectiveness of council will be similar between each alternative. Society and stakeholders needed a new bridge for property access, either alternative provides this.

Environmental Justice: Alternative 1, will have a very low impact on the way society feels council have solved the issue from an environmental sustainability perspective. However, Alternative 2, might see society concerns with “more concrete” for the new concrete structure, hence a medium impact.

Economic Justice: This factor could go each way, i.e. the stakeholders might feel that it is the best money spent to provide a new concrete structure as per Alternative 2 because will last longer and potentially require less maintenance. However, the rest of the region might feel that because the road has low volumes, and that the immediate money could be better spent elsewhere and hence would favour Alternative 1.

Social Connectivity: Tt is expected that both alternatives would provide equal social connectivity.

Below is a table comparing the social factors against the scoring scale as described in section 3.1.3 of this report. It can be seen that the Alternative 1 and 2 will have similar impacts on the social aspect.

Table 8: Comparison of social factors for Browns Road Bridge

	Alternative 1	Alternative 2
Visual Appearance	3	2
Perception of council not funding any upgrades for nearby stakeholders	1	1
Social aspect of environmental justice	2	3
Social aspect of economic justice	3	3
Social Connectivity	2	2
Total Score	11/25	11/25

4.1.4 Summary of Cost-Benefit Analysis

The following will summarise the results from the cost benefit analysis and display each alternative on a chart to best display the differences of each alternative. Refer to Appendix E for detailed scoring results.

The figure 14 below shows the cost benefit comparison of the Wellingrove Creek Bridge Upgrade.

It can be seen that the environmental factors for the rehabilitation works are much lower. However the total life cycle cost and the social aspect are higher. Hence, from this information only, it would be better to use the traditional method of demolishing the existing and replacing with a concrete structure. The main reason for this is the ongoing cost of maintaining the existing structure along with replacing the structure mid-way through the analysed period.

It is concluded, that the application of FRP for strengthening and rehabilitation in this project was only viable for the cheap direct access for the windfarm. With the asset already being deteriorated, it becomes very costly to maintain and rehabilitate.

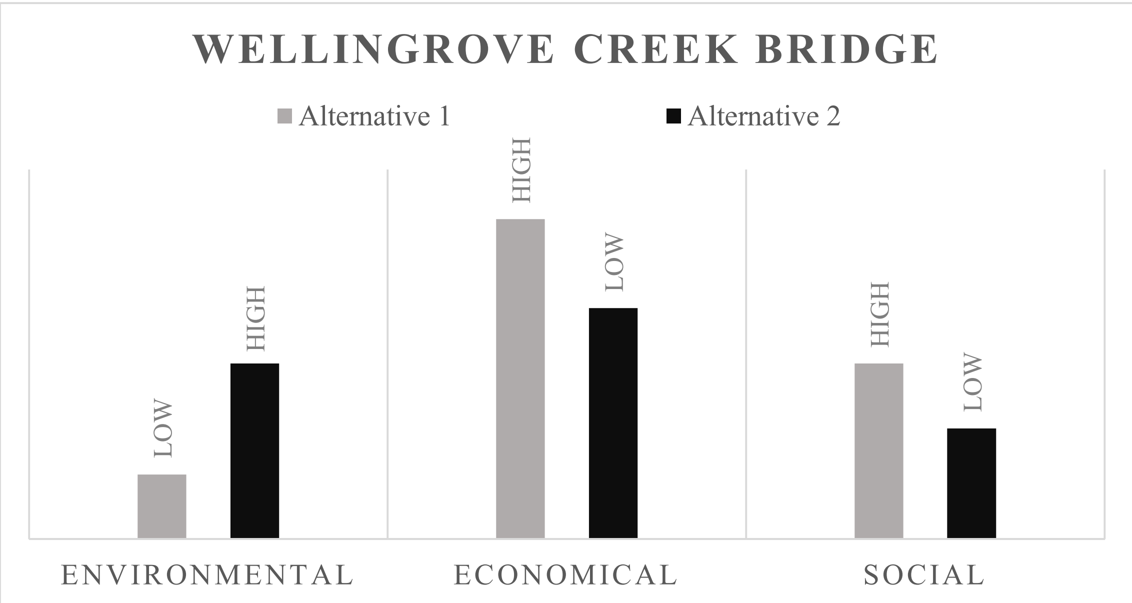

Figure 14: Cost Benefit Comparison - Wellingrove Bridge Upgrade

The figure 15 below Airport pavement shows the cost benefit comparison of the West Wellcamp material.

It can be seen that the environmental, economic and social factors for the geopolymer concrete are lower. This is mainly due to the additional durability properties that the geopolymer pavement offers along with the significant reduction in environmental factors.

It is concluded, that the application of Geopolymer Concrete as a pavement for this project was viable mainly due to the extra initial funding for the trial and testing period, and now that the trial and testing period has completed, Wagners now offer a Geopolymer Concrete. In future construction projects this research hypothesises that further benefits will arise when using Geopolymer Concrete, and hence the initial increased cost might be reduced.

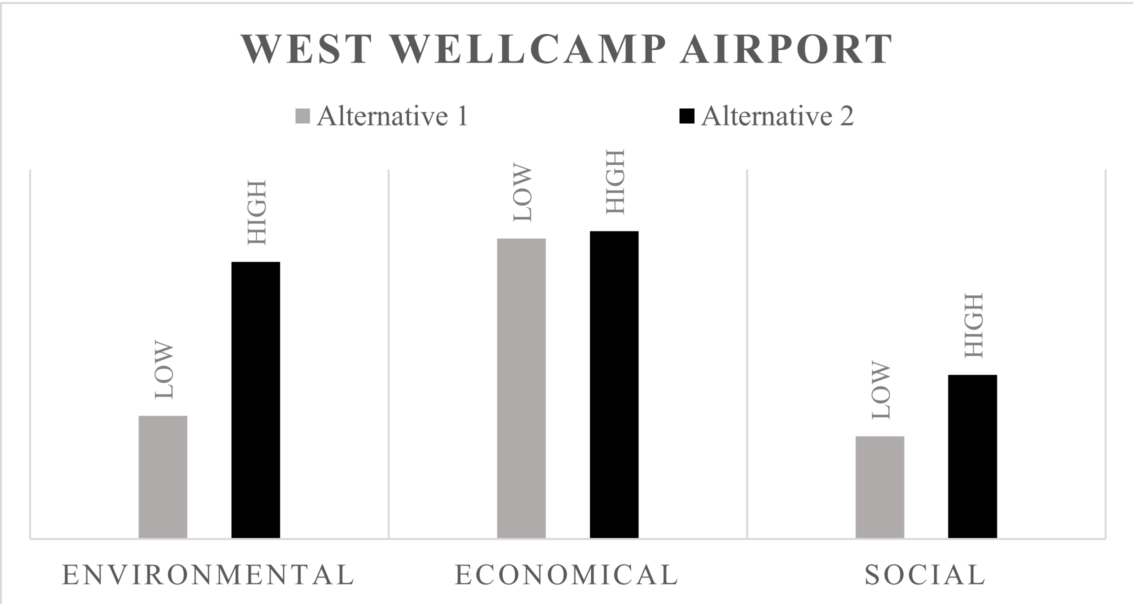

Figure 15: Cost Benefit Comparison - West Wellcamp Airport

The figure 16 below shows the cost benefit comparison of the construction of the Browns Rd bridge upgrade.

It can be seen that the impact on environmental factors lower for alternative 1. The social impacts are similar between the alternatives. However the economic life cycle comparison indicates that the CLT alternative is slightly higher, this is mainly due to the design life of the structure and the need to provide essentially 2 bridges in the same design life of the concrete alternative. However, given that the bridge is on a very low volume road, and is well above the water level, this research expects that the design life of the CLT could be potentially extended out.

With this in mind it is concluded, that the CLT option would be best suited for this option with the initial outlay by council to be a third of the cost for the concrete option. Leaving more room in the early design life to ensure adequate maintenance potentially extending the design life.

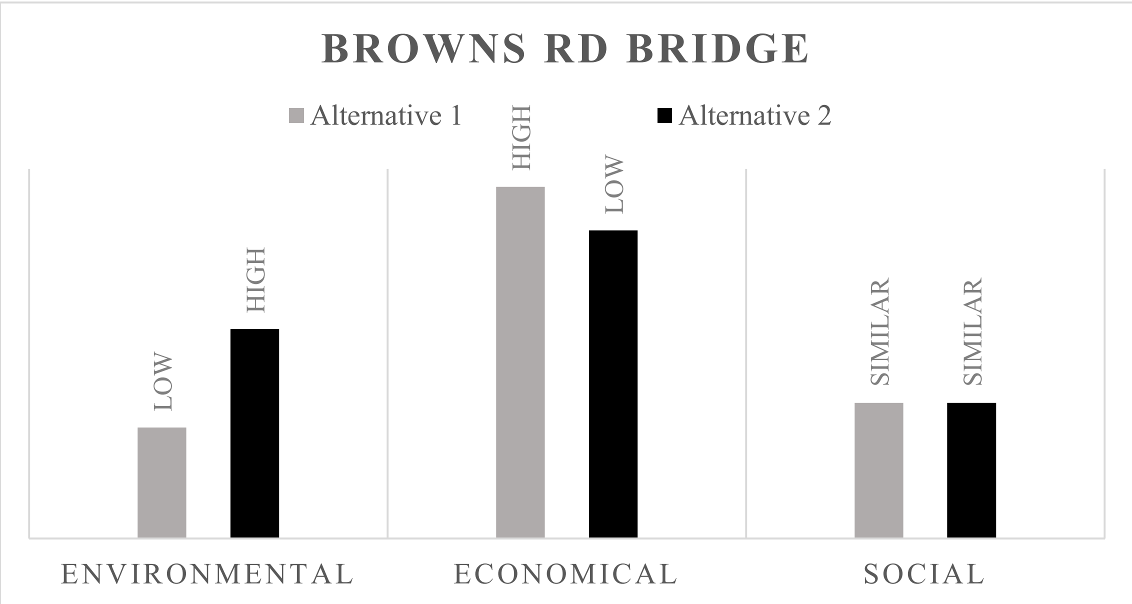

Figure 16: Cost Benefit Comparison - Browns Rd Bridge Upgrade

Chapter 5 – Questionnaire

5.1 Questionnaire Results

The following chapter will display and summarise the results that were obtained from the questionnaire based research that was conducted for this report. Twenty-five questionnaires were sent out to a range of different engineers in the North West NSW area. Of the twenty-five distributed, twenty responded in time to add to this report. The responses are from a good variety and balance of different engineers from the region consisting of the following:

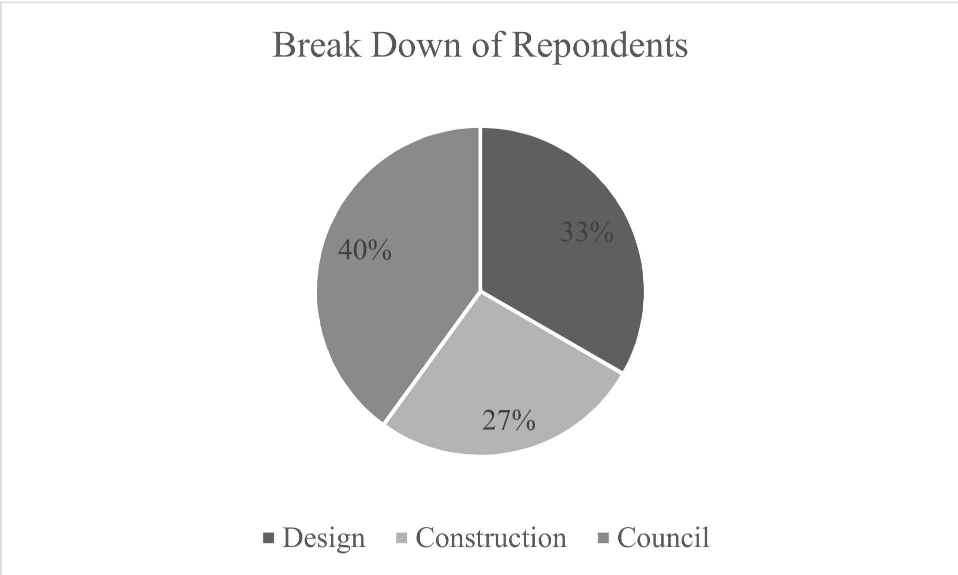

Figure 17: Pie Chart showing distribution of Respondents

The results have been collated to show the percentages of each response to gain an understanding of the critical issues, which will be taken as the issues that have the highest number of responses.

The first five questions are general questions that relate to decisions design and construction engineers make when developing.

Questions 6, 7, 8 and 9 are more material specific and will provide detailed understanding of the critical issues that have hindered the take-up of these advanced engineering materials by industry specifically in the North West NSW region.

Question 1

When designing or constructing, how often would you be more likely to use a traditional method or material rather than trying an innovative alternative?

The results for Question 1 indicated the following:

- 25% of respondents will **always** use a traditional method of construction before considering an innovative alternative.
- 65% of respondents will **often** use a traditional method of construction before considering an innovative alternative.
- 10% of respondents will **rarely** use a traditional method of construction before considering an innovative alternative.
- None of the respondents will always consider an innovative alternative over a traditional method.

These results indicate that the majority of the respondents will be more likely to choose a material or method of construction over a new and innovative material or method of construction. It is generally expected that this is due to today society being so litigious and that choosing new materials will generally incur a higher cost just on insurances and other behind the scene costs.

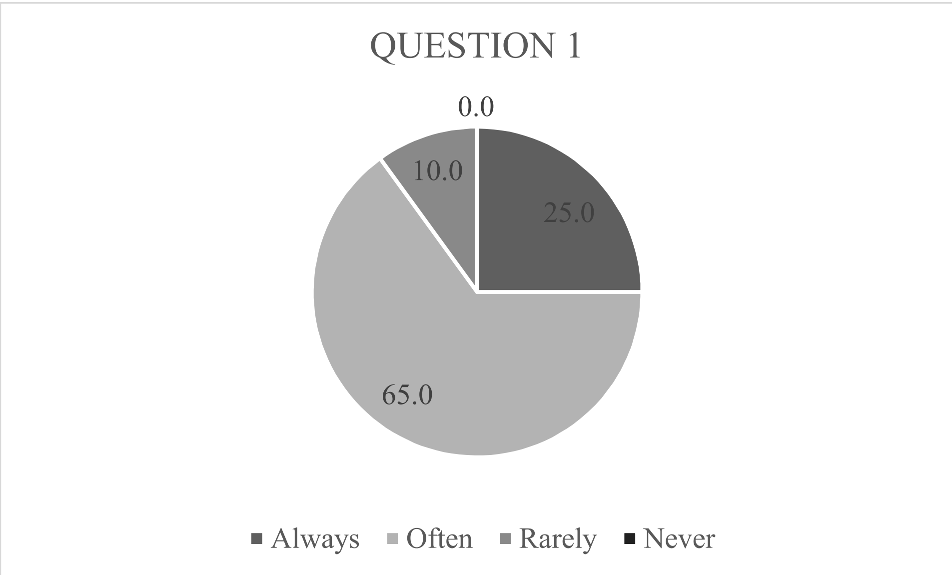

Figure 18: Pie Chart showing distribution of Results for Question 1

Question 2

When designing or constructing, if a new method or material boast superior properties, however, there might be lacking durability results, would you still be open to trying the new method or material?

The results for Question 2 indicated the following:

- 5% of respondents would always consider a new material despite of lacking durability results.
- 15% of respondents would often consider a new material despite of lacking durability results.
- 60% of respondents often consider superior durability results over other superior properties.
- 20% of respondent will never consider a new material if there are lacking durability results.

These results indicate that the majority of the respondents consider durability results to be more important than any other superior property. Similarly to question 4 and 5, these results show that the designer's councils and other stakeholders value the cost of the project over the life time to be more important than any other superior property.

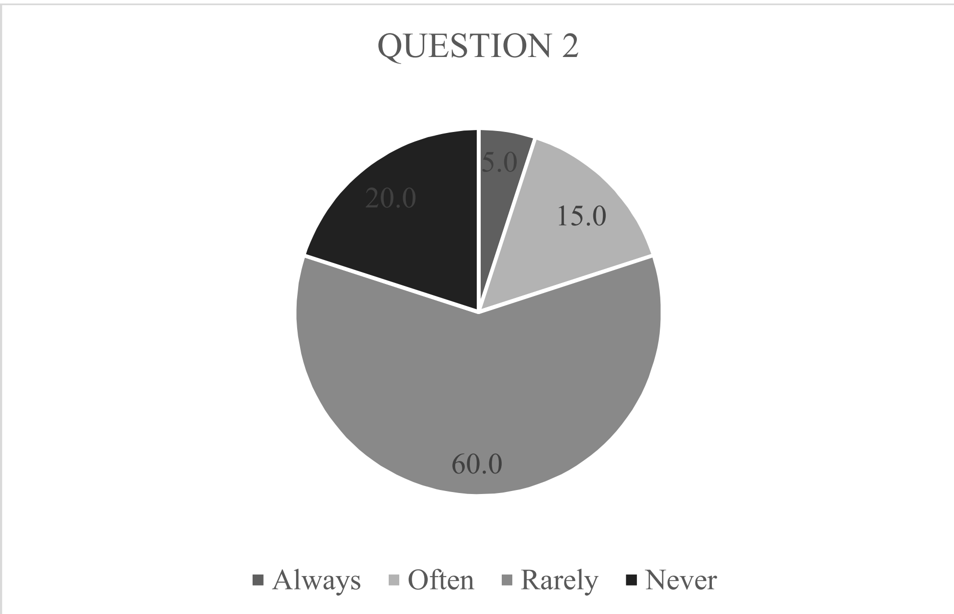

Figure 19: Pie Chart showing distribution of Results for Question 2

Question 3

When designing or constructing, generally how often would the term 'sustainable construction' be used?

The results for question 3 indicated the following:

- 10% of respondents will **always** consider sustainability when design or constructing.
- 35% of respondents will **often** consider sustainability when design or constructing.
- 40% of respondents will **rarely** consider sustainability when design or constructing.
- 15% of respondents will **never** consider sustainability when design or constructing.

These results indicate that the majority of the respondents often or rarely consider sustainability when designing or constructing. It is expected that many of the respondents only ticked the 'rarely' option because of the personal/negative aspect and truth of ticking the 'never' option. It is hypothesised that the above is generally because of the perception that sustainability means an increased cost. It is also hypothesised that the general consensus for the term 'sustainable construction' many believe this to mean only environmental sustainability.

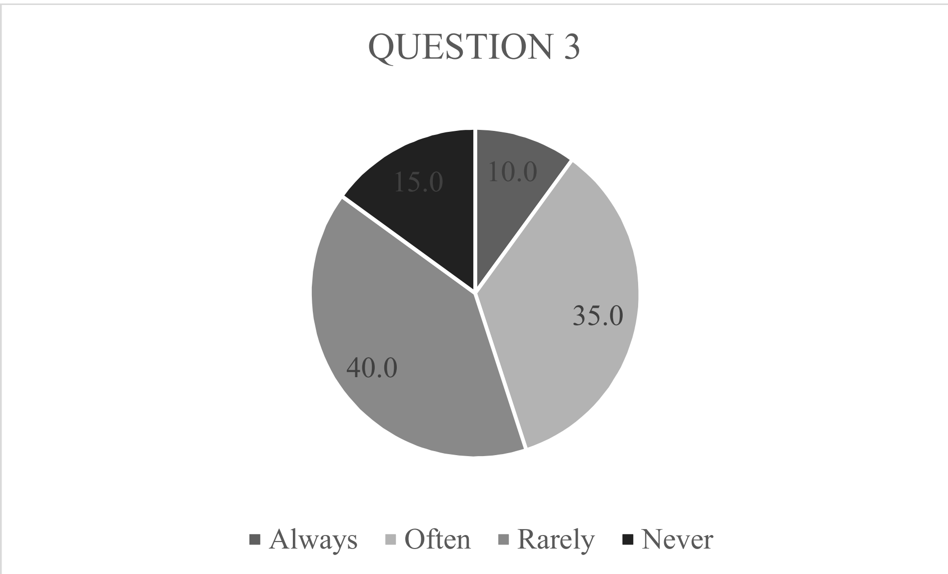

Figure 20: Pie Chart showing distribution of Results for Question 3

Question 4

When designing or constructing, generally how often would ‘cost’ outweigh the importance of ‘sustainable construction’?

The results for question 4 indicated the following:

- 55% of respondents will **always** find that lower cost outweighs the importance of sustainability.
- 45% of respondents will **often** find that lower cost outweighs the importance of sustainability.
- None of the respondents will **rarely** or **never** find that lower cost outweighs the importance of sustainability.

These results indicate that the cost plays a huge role in the decisions engineers make and that the importance of low cost outweighs the importance of sustainable development.

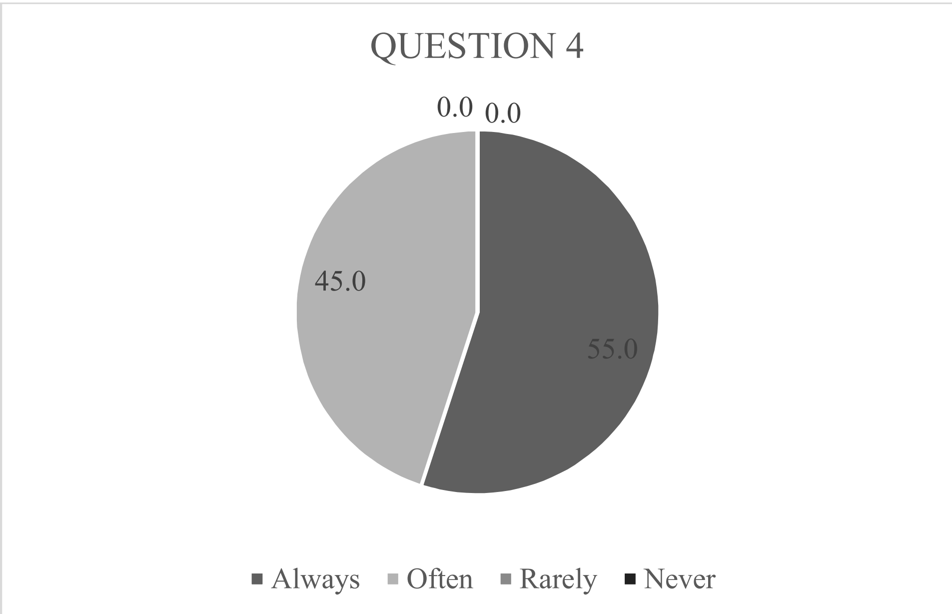

Figure 21: Pie Chart showing distribution of Results for Question 4

Question 5

When designing or constructing, generally how often would 'durability' outweigh the importance of 'sustainable construction'?

The results for question 5 indicated the following:

- 55% of respondents will **always** consider the importance of durability of construction over sustainable construction.
- 40% of respondents will **often** consider the importance of durability of construction over sustainable construction.
- 5% of respondents will **rarely** consider the importance of durability of construction over sustainable construction.
- None of respondents will **never** consider the importance of durability of construction over sustainable construction.

These results indicate that the durability of construction material is a major contributing factor to the decisions engineers make. Even more important than the importance of sustainable construction. This close relates to the responses to question 4 as durability of construction and total project cost over the life time are closely relatable.

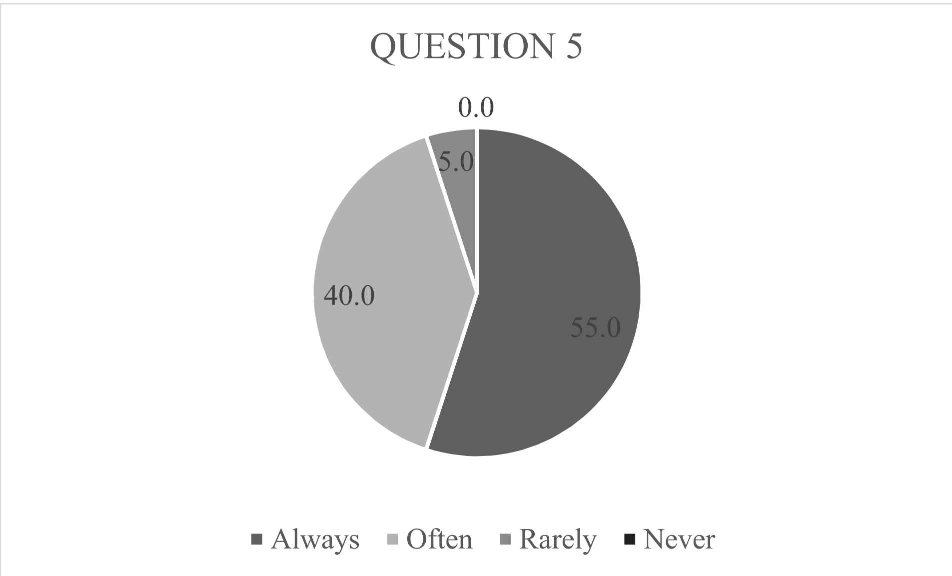

Figure 22: Pie Chart showing distribution of Results for Question 5

Question 6 (a)

Fibre Composite materials (FRP for strengthening existing structures, FRP grating, FRP pipes, FRP reinforcement) boast superior properties including; strength, durability, sustainability, and light weight. What would be the major factor that would stop you from using the fibre composite materials?

The results for question 6a indicated that:

- Lack of design standards is the main factor that impedes and stops design and construction engineers from using fibre composite materials with 10 respondents indicating this as a response.
- Followed closely by a lack of training and lack of material availability with 9 and 8 respondents indicating these as a response respectively.
- Concerns of durability and lack of trust in conducted research also came in as issues, but with not as many respondents indicating this.

Other responses also included:

- Construction engineers not using fibre composite materials because the design engineers have not specified such.
- Unknown life-cycle cost analysis, meaning there are concerns of unknown durability and the cost of maintaining structures that have used fibre composite materials.
- Can be time consuming and hence costly to convince clients of the benefits of using composite materials.

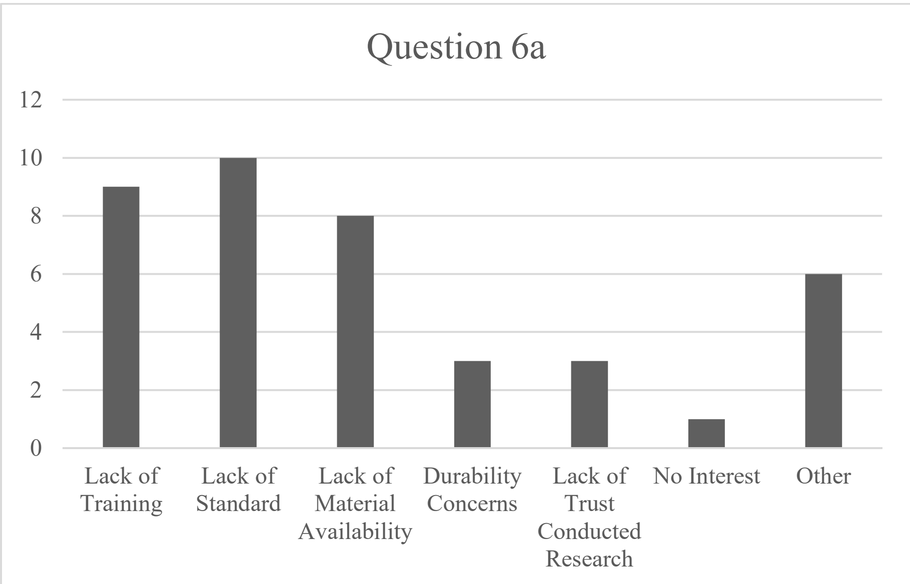

Figure 23: Chart showing distribution of Results for Question 6a

Question 6 (b)

Fibre Reinforced Polymers can be used in a wide range of construction applications. Have you ever used FRPs in construction?

The response for question 6b indicated that 55% of respondents have used fibre composite materials before and 45% have not used them.

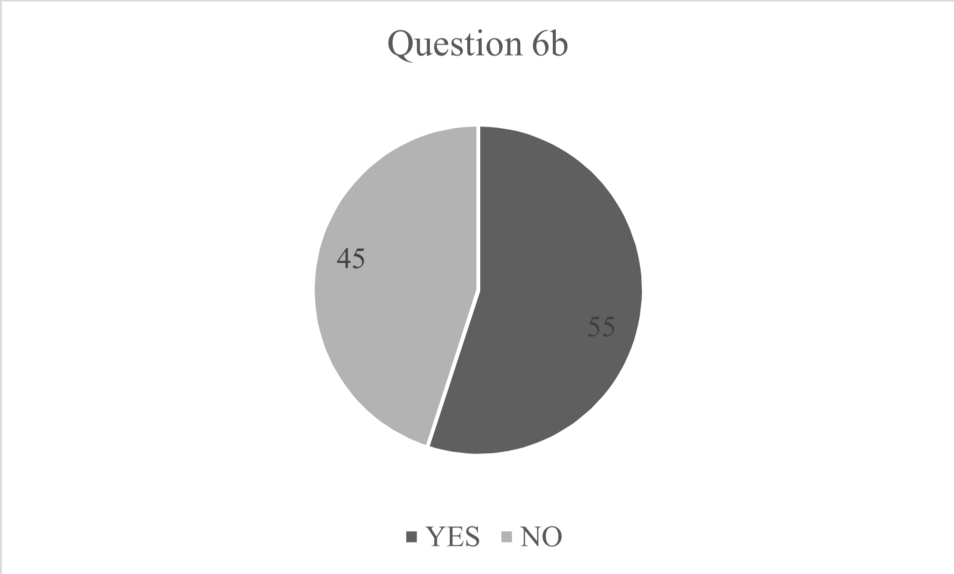

Figure 24: Pie Chart showing distribution of Results for Question 6b

Question 7 (a)

Geopolymers used as opposed to cement in concrete drastically reduces the carbon emissions produced by cement. Having similar strength and cost, what would be the major factor that would stop you from using the geopolymers?

The results for question 7a indicated that:

- Lack of training is the main factor that impedes and stops design and construction engineers from using fibre composite materials with 14 respondents indicating this as a response.
- Followed closely by lack of material availability and lack of design standard with 11 and 9 respondents indicating these as a response respectively.

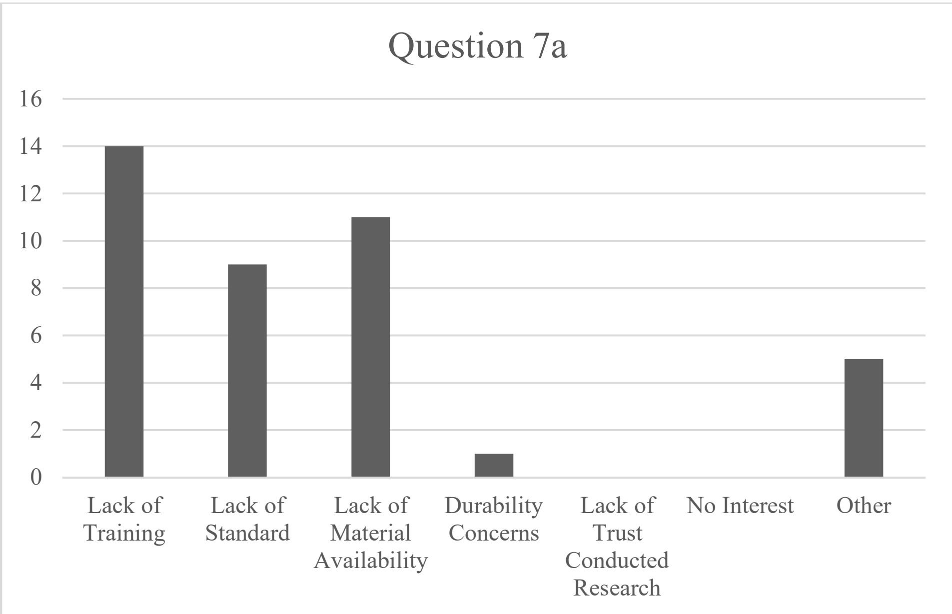

Figure 25: Chart showing distribution of Results for Question 7a

Question 7 (b)

Geopolymers in concrete have many economic and environmental benefits when used as opposed to regular General Purpose cements. Have you ever used Geopolymers in construction?

Interestingly the results of question 7b indicate that only one of the respondents have had the opportunity to use Geopolymers in concrete, this lack of use is mainly due to lack of awareness about the material, along with the issue of not being able to source the Geopolymer material locally in the North West NSW region.

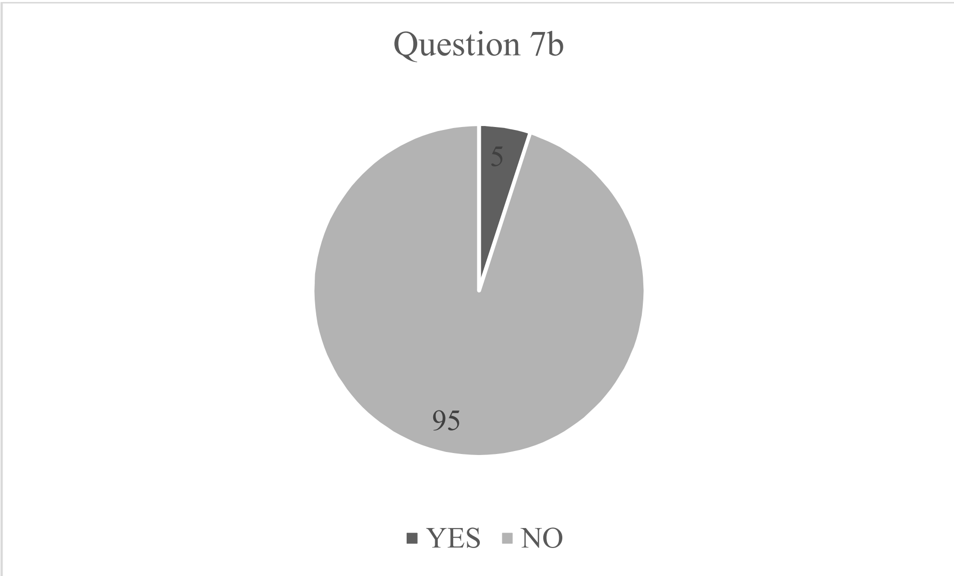

Figure 26: Pie Chart showing distribution of Results for Question 7b

Question 8 (a)

Cross Laminated timbers products boast many economic and environmental properties, including higher strength then regular timber products. What would be the major factor that would stop you from using the fibre composite materials? The results for question 8a indicate that:

- Lack of training is the main factor that impedes and stops design and construction engineers from using cross-laminated timber materials with 9 respondents indicating this as a response.
- Followed closely by Lack of Material Availability or non-standard sizing being a primary concern as 6 respondents indicated.
- Lack of design standards and durability concerns were also an issue. With many of the respondents indicating that there is a perception and concerns about the durability issues in using soft wood materials.

Other responses also included:

- Concerns about a higher cost over regular timber materials.
- Reduced onsite workability with an increase Work Health and Safety risk when cutting or drilling due to the bonding agents.

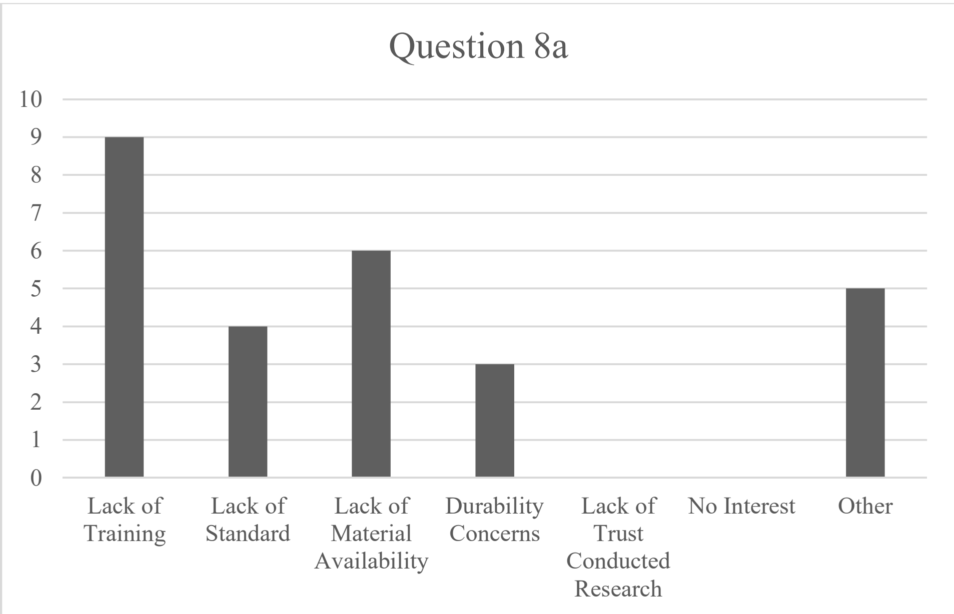

Figure 27: Chart showing distribution of Results for Question 8a

Question 8 (b)

Have you ever used Cross Laminated Timber in Construction?

The response for question 8b indicated that 58% of respondents have used cross laminated timber materials in the past and 42% of respondents have not used this advanced engineering material.

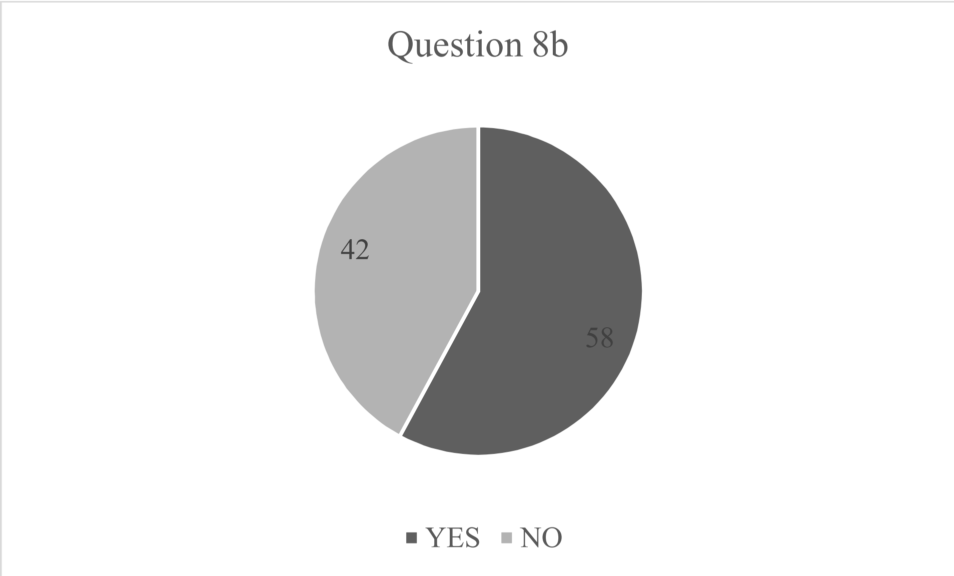

Figure 28: Pie Chart showing distribution of Results for Question 8b

Chapter 6 – Discussion

The following chapter will discuss the issues of using advanced and sustainable engineering materials that have been determined from the review of literature, life cycle analysis, cost benefit comparison and the questionnaire that survey a number of engineers in the field of design, council and construction. At a glance the critical issues that have arisen across the board for all materials researched are sustainable development, relevant training, design standards, material availability, durability and cost.

Sustainable Development:

Institutions like Engineers Australia have practices and policies in play to firstly define and secondly encourage and promote sustainable development. However, from the questionnaire based research, it is clear that many of the engineers in the North West NSW region do not seem to take the term 'sustainable development' as seriously as one might expect. Many respondents believe that cost and durability will always outweigh the importance of sustainable development, where this line of thinking only really encompasses economical sustainability and does not consider environmental and social aspects. This research hypothesises that this way of thinking can be summarised into two direct reasons.

Firstly, there seems to be a perception across the board that sustainable development will always means an increased cost. However results from the cost-benefit analysis and life cycle assessment indicate that this is not always the case and that sometimes the sustainable solution can be cheaper in the long run.

Secondly, although institutions like Engineers Australia have been defining and encouraging sustainable development as part of becoming a Charted Professional Engineer. Which in Queensland and Victoria is a necessity of becoming a registered Engineer. This necessity is not required in New South Wales and hence it is expected that many of the engineers that responded to the questionnaire have not undertaken the process of becoming a Charted Professional Engineer and hence might not be aware of the full importance and meaning of the term sustainable development.

Relevant Training:

Many of the respondents from the questionnaire indicated that 'lack of training' was an issue across all of the Advanced Engineering Materials. Which is also closely linked to 'lack of awareness'. With many of the respondent failing to know what some of these materials were let alone the potential benefits that the materials can offer. Hence, further industry training and awareness meetings would provide the ability for engineers to understand if a different sustainable material is available for use.

Design Standards:

The questionnaire based research found that another issue that has impacted the take up of advanced and sustainable engineering materials in the North West NSW region is the lacking Design Standards. Many design engineers in the region are small consulting engineering firms where and will only design structures to a particular Australian Design Standard. Given that the three advanced engineering materials for this research do not have an equivalent Australian Design and construction standard. It has been hypothesised and taken directly from one of the questionnaire responses that:

> "Advanced Engineering materials are not new, all materials were advanced at one point. Society relies on 'someone else' to trial and prove the products, which is generally an organization that has the financial ability to do so (either self-supported or subsidized).
>
> With today's environment being so litigious, this increases the risk considerably when the product goes to market. Increased risk will always result in an increased cost to the consumer until the product becomes mainstream".

As said above, many of the designers in the North West NSW region come from small consulting companies that do not have the financial ability to take on the additional risk of using a new product or material that does not have relevant Australian Design standards.

Material Availability:

Many of the respondents from the questionnaire indicated that material availability was an issue that has impacted the take up of advanced and sustainable engineering materials in the North West NSW region. With none of these materials being offered by any contractors or companies in the area means that the cost and ability to use such materials is very limited. This is where small and medium sized entrepreneurial companies willing to adopt these materials and hence filling the void of the lacking material availability.

Durability:

From the review of literature, life cycle analysis, cost benefit analysis and the questionnaire it is evident that there are concerns around the durability of these products. Many respondents have persistent perceptions that the longevity of these materials in our harsh environment is a predominant concern. However, it is important to remember that many of these advanced engineering materials will be 'theoretically' more durable then there comparison materials, without the physical proof of the longevity is the limiting factor though.

Most developers want the 'most bang for their buck' and hence are not willing to adopt a new material that does not have the proven longevity.

This will be a difficult issue to overcome for many engineers and developers in the future and might only be overcome with increased proof of durability.

Cost:

Finally the cost of these materials was found to be an issue as a result from life cycle costing analysis and the questionnaire. With the researching suggesting that although the initial upfront cost can be lower for these materials (except geopolymer). However, the ongoing asset management and maintenance for these materials are at a higher rate because of the risk of using a new material. This generally has been the reason for the perception of the additional cost. Which directly relates to the concerns about durability, and when the durability is proven then the cost of the maintenance and asset management might be reduced.

This also reflects the research that was conducted for the literature review, where studies have shown that because of the term 'economies of scale' many of these materials are at a premium rate, and until more small and medium sized entrepreneurial companies begin using these materials more frequently it will likely stay the same.

Chapter 7 – Conclusion

This project had the aim to research why the take-up of Advanced and Sustainable Engineering Materials has not been as rapid as desired particularly in North West NSW and to identify and evaluate factors that might influence the adoption of such. As it had been predetermined that the take up of advanced and sustainable engineering materials in the North West NSW has been quite slow and limited.

The reasons for this research are predominately surrounds by the need to sustain or improve the current conditions we live in for future generations. With the construction industry pertaining to a large portion of the greenhouse gases and environmental issues our current generation is facing. Many current practices for construction use unsustainable materials even though there are many sustainable alternatives available.

This research was been limited to three advanced engineering materials (fibre composites, Geopolymers and Cross-Laminated Timber). However, it has proven that there are similar issues or factors between the three different researched advanced engineering materials. Hence, these issues or factors can be hypothesised to be similar determining factors that have limited the take-up by industry for all advanced engineering materials.

The research methodology included;

- Conducting a succinct and clear review of literature to obtain a clear understanding of the three researched materials.
- Perform a life cycle analysis and cost benefit comparison on each of the materials with a relevant case study, with the case studies being,
    - Wellingrove Creek Bridge upgrade – Fibre Reinforced Polymer comparison.
    - West Wellcamp Airport – Geopolymer comparison
    - Browns Rd Bridge – Cross Laminated Timber comparison
- Design a questionnaire to focus on issues that have impacted the take-off of advanced engineered materials and have it approved by the University of Southern Queensland Human Ethics Review Committee.
- Distribute the questionnaire to relevant engineers in the field of design, construction and council.
- Critically review the research to aid on developing the critical issues.

The critical issues or factors that have arisen across the board from the research that was conducted for all three materials researched include; the lacking premonition for sustainable development, lack of relevant training and awareness, lack of Australian design standards, lacking material availability, durability and cost.

More research is needed to develop mays to mitigate these above mentioned issues in a way to increase the take-up by industry of these advanced engineering materials.

Chapter 8 – Future Work

There are a number of different options that one could do to advance or further the research from this project. Now that the issues of using advanced and sustainable engineering materials have been researched and summarised in this report.

Research and evaluate possible methods of mitigating the risks, issues and wrong perceptions of using advanced and sustainable engineering materials that this report discusses.

This report indicated areas of concern regarding the decisions engineers make early on in the planning and design phase of a project, where currently cost and durability play a more important role ten overall sustainable development. Hence, further research and evaluation of methods that could bring sustainable development higher up on the importance list. Especially with climate change a detrimental problem that our generation will be facing.

Although this report touched on the life-cycle cost analysis, further detailed research into the asset management and ongoing maintenance of structures that have used advanced engineering materials is an area where further research could be conducted.

Furthermore, one could potential begin looking into creating a system, program or method of analysing the best available material for a given project. This could be as simple as a checklist type program that engineers could input some details about the project and have it quickly provide a high level cost benefit analysis on a range of different available materials or methods of construction.

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Appendix A

University of Southern Queensland
Faculty of Engineering and Surveying
Project Specification

For: Jacob Deryck Tan

Title: Evaluation of Issues in Using Advanced and Sustainable Engineering Materials

Major: Civil Engineering

Supervisor: Dr David Thorpe – Associate Professor (Engineering/Technology Management)

Enrolment: ENG4111 – ONL S1, 2019

ENG4112 – ONL S2, 2019

Project Aim: To research why the take-up of Advanced Engineering Materials has not been as rapid as desired particularly in North West NSW and to identify and evaluate factors that might influence the adoption of such.

Programme: Version 3 11/04/2019

1. Undertake a detailed literature review, including identifying different techniques and materials that promise to revolutionise engineering design and construction.
2. Undertake research into and compare economic and environmental costs using these advanced materials as opposed to the traditional methods.
3. Conduct one or more surveys to determine what techniques and materials are currently being used for this process in North West NSW, and what might influence the adoption of advanced materials.
4. Analyse data obtained from survey to determine the current techniques, systems and materials for engineering design and construction, including cost.
5. Identify and evaluate factors that may influence/hinder the adoption of such engineering materials.
6. Develop conclusions and identify where more research is needed
7. Write and submit a dissertation in the required format.

If time permits

8. Further investigate at least one of the factors that have hindered the take-up of alternative engineering materials.

Appendix B

Proof of USQ Ethics Approval

Dear Jacob

I am pleased to confirm your Human Research Ethics (HRE) application has now been reviewed by the University's Expedited Review process. As your research proposal has been deemed to meet the requirements of the National Statement on Ethical Conduct in Human Research (2007), ethical approval is granted as follows:

USQ HREC ID: H19REA216
Project title: Evaluation of Issues in Using Advanced Engineering Materials
Approval date: 30/08/2019
Expiry date: 30/08/2020
USQ HREC status: Approved

The standard conditions of this approval are:

a) responsibly conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal;.

(b) advise the University (email:ResearchIntegrity@usq.edu.au) immediately of any complaint pertaining to the conduct of the research or any other issues in relation to the project which may warrant review of the ethical approval of the project;

(c) promptly report any adverse events or unexpected outcomes to the University (email: ResearchIntegrity@usq.edu.au) and take prompt action to deal with any unexpected risks;

(d) make submission for any amendments to the project and obtain approval prior to implementing such changes;

(e) provide a progress 'milestone report' when requested and at least for every year of approval.

(f) provide a final 'milestone report' when the project is complete;

(g) promptly advise the University if the project has been discontinued, using a final 'milestone report'.

The additional conditionals of approval for this project are:

(a) Nil.

Please note that failure to comply with the conditions of this approval or requirements of the Australian Code for the Responsible Conduct of Research, 2018, and the National Statement on Ethical Conduct in Human Research, 2007 may result in withdrawal of approval for the project.
Congratulations on your ethical approval! Wishing you all the best for success!

If you have any questions or concerns, please don't hesitate to make contact with an Ethics Officer.

Kind regards

Human Research Ethics

University of Southern Queensland
Toowoomba – Queensland – 4350 – Australia
Phone: (07) 4631 2690
Email: human.ethics@usq.edu.au

Appendix C

The Questionnaire

University of Southern Queensland

Participant Information for USQ Research Project Questionnaire

Project Details

Title of Project:	**Evaluation of Issues in Using Advanced Engineering Materials**
Human Research Ethics Approval Number:	H19REA216

Research Team Contact Details

Principal Investigator Details
Mr Jacob Tan
Email: u1097616@umail.usq.edu.au

Mobile: 0487 592 001

Supervisor Details
Associate Professor David Thorpe
Email: David.Thorpe@usq.edu.au
Telephone: (07) 3470 4532
Mobile: 0422 457 749

Description

The following questionnaire is being conducted as part of my University Dissertation on the topic of "Evaluation of Issues in Using Advance and Sustainable Engineering Materials".

The aim of this questionnaire is to aid and provide guidance for research into why the take-up of Advanced Engineering Materials has not been as rapid as desired particularly in North West NSW and to identify and evaluate factors that might influence the adoption of such.

To minimise the scope of the research I have limited the study to the following advanced engineering materials:

- Advanced Fibre Composites
- Geopolymers in Concrete
- Cross Laminated Timber

Participation

Your participation will involve completion of a questionnaire that will take approximately 15 minutes of your time.

Questions will include and revolve around the use of Advanced Engineering Materials in the construction industry.

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 will be unable to withdraw data collected about yourself after the data has been analysed, however, the names of participants is strictly confidential.

Your decision whether you take part, do not take part, or to 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 not directly benefit you. However, it may benefit the future of advance engineering materials and their place in the construction industry.

Risks

In participating in the questionnaire, there are no anticipated risks beyond normal day-to-day living.

Privacy and Confidentiality

All comments and responses will be treated confidentially unless required by law.

The names of individual persons are not required in any of the responses.

Participant's names will not be made available for further research in this field, however, answers and overviews will be available.

The finalized results will be summarized in a short 1-2 page summary report. The report will be issued to directly to all participants.

Any data collected as a part of this project will be stored securely as per University of Southern Queensland's Research Data Management policy.

Consent to Participate

The return of the completed questionnaire is accepted as an indication of your consent to participate in this project. Please return to the principal investigator in person or via email.

Questions or Further Information about the Project

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 Regarding the Conduct of the Project

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 4631 1839 or email researchintegrity@usq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

Thank you for taking the time to help with this research project. Please keep this sheet for your information.

Questionnaire

The following questionnaire is being conducted as part of my University Dissertation on the topic of "Evaluation of Issues in Using Advance and Sustainable Engineering Materials".

The aim of this questionnaire is to aid and provide guidance for research into why the take-up of Advanced Engineering Materials has not been as rapid as desired particularly in North West NSW and to identify and evaluate factors that might influence the adoption of such.

To minimise the scope of the research I have limited the study to the following advanced engineering materials:

- Advanced Fibre Composites
- Geopolymers in Concrete
- Cross Laminated Timber

Question 1

When designing or constructing, how often would you be more likely to use a traditional method or material rather than trying an innovative alternative?

☐ Always ☐ Often ☐ Rarely ☐ Never

Question 2

When designing or constructing, if a new method or material boast superior properties, however, there might be lacking durability results, would you still be open to trying the new method or material?

☐ Always ☐ Often ☐ Rarely ☐ Never

Question 3

When designing or constructing, generally how often would the term 'sustainable construction' be used?

☐ Always ☐ Often ☐ Rarely ☐ Never

Question 4

When designing or constructing, generally how often would 'cost' outweigh the importance of 'sustainable construction'?

☐ Always ☐ Often ☐ Rarely ☐ Never

Question 5

When designing or constructing, generally how often would 'durability' outweigh the importance of 'sustainable construction'?

☐ Always ☐ Often ☐ Rarely ☐ Never

Question 6 (a)

Fibre Composite materials (FRP for strengthening existing structures, FRP grating, FRP pipes, FRP reinforcement) boast superior properties including; strength, durability, sustainability, and light weight. What would be the major factor that would stop you from using the fibre composite materials? (Tick more than one if needed)

☐ Lack of training or experience

☐ Lack of Australian Standard Design/Construction material

☐ Lack of material availability

☐ Lack of material durability results

☐ Lack of trust in conducted research, or different perceptions

☐ No Interest in trying new things

☐ Other, Comment ……………………………………………………………………………………

Question 6 (b)

Fibre Reinforced Polymers can be used in a wide range of construction applications. Have you ever used FRPs in construction?

☐ Yes (explain your experiences)

☐ No (explain the factors that have stopped you)

Question 7 (a)

Geopolymers used as opposed to cement in concrete drastically reduces the carbon emissions produced by cement. Having similar strength and cost, what would be the major factor that would stop you from using the geopolymers? (Tick more than one if needed)

☐ Lack of training or experience

☐ Lack of Australian Standard Design/Construction material

☐ Lack of material availability

☐ Lack of material durability results

☐ Lack of trust in conducted research, or different perceptions

☐ No Interest in trying new things

☐ Other, Comment ....

Question 7 (b)

Geopolymers in concrete have many economic and environmental benefits when used as opposed to regular General Purpose cements. Have you ever used Geopolymers in construction?

☐ Yes (explain your experiences)

☐ No (explain the factors that have stopped you)

Question 8 (a)

Cross Laminated timbers products boast many economic and environmental properties, including higher strength then regular timber products. What would be the major factor that would stop you from using the fibre composite materials? (Tick more than one if needed)

☐ Lack of training or experience

☐ Lack of Australian Standard Design/Construction material

☐ Lack of material availability

☐ Lack of trust in conducted research, or different perceptions

☐ No Interest in trying new things

☐ Other, Comment ……………………………………………………………………………………

Question 8 (b)

Have you ever used Cross Laminated Timber in Construction?

☐ Yes (explain your experiences)

☐ No (explain the factors that have stopped you)

Question 9

Are there any other advance engineering materials that you have had dealings with?

☐ Yes ☐ No

If yes, please comment on the material and any factors would stop you from using them in the future:

....

....

....

Question 10

Do you have any further comments? If so, please list them below:

....

....

....

Name: **(leave blank for anonymity)**	....
Occupation/field of engineering:	....
Date Completed:	....

Appendix D

Typical Questionnaire Response

Questionnaire

The following questionnaire is being conducted as part of my University Dissertation on the topic of "Evaluation of Issues in Using Advance and Sustainable Engineering Materials".

The aim of this questionnaire is to aid and provide guidance for research into why the take-up of Advanced Engineering Materials has not been as rapid as desired particularly in North West NSW and to identify and evaluate factors that might influence the adoption of such.

To minimise the scope of the research I have limited the study to the following advanced engineering materials:

- Advanced Fibre Composites
- Geopolymers in Concrete
- Cross Laminated Timber

Question 1

When designing or constructing, how often would you be more likely to use a traditional method or material rather than trying an innovative alternative?

☐ Always ☑ Often ☐ Rarely ☐ Never

Question 2

When designing or constructing, if a new method or material boast superior properties, however, there might be lacking durability results, would you still be open to trying the new method or material?

☐ Always ☐ Often ☑ Rarely ☐ Never

Question 3

When designing or constructing, generally how often would the term 'sustainable construction' be used?

☐ Always ☐ Often ☐ Rarely ☐ Never

Question 4

When designing or constructing, generally how often would 'cost' outweigh the importance of 'sustainable construction'?

☑ Always ☐ Often ☐ Rarely ☐ Never

Question 5

When designing or constructing, generally how often would 'durability' outweigh the importance of 'sustainable construction'?

☐ Always ☑ Often ☐ Rarely ☐ Never

Question 6 (a)

Fibre Composite materials (FRP for strengthening existing structures, FRP grating, FRP pipes, FRP reinforcement) boast superior properties including; strength, durability, sustainability, and light weight. What would be the major factor that would stop you from using the fibre composite materials? (Tick more than one if needed)

☐ Lack of training or experience

☐ Lack of Australian Standard Design/Construction material

☐ Lack of material availability

☐ Lack of material durability results

☐ Lack of trust in conducted research, or different perceptions

☐ No Interest in trying new things

☑ Other, Comment Cost, and time and effort to convince client of the benefits. Client would have specifically interested or driven by new methodologies…………………………………………….…….

Question 6 (b)

Fibre Reinforced Polymers can be used in a wide range of construction applications. Have you ever used FRPs in construction?

☐ Yes (explain your experiences)

Currently using GFRP 'jackets' for bridge pile strengthening. It is early in the project lifecycle, but the current experience is not positive with an early failure at a critical time. Supplier is having difficulty explaining the issue, which is causing angst.

☐ No (explain the factors that have stopped you)

Question 7 (a)

Geopolymers used as opposed to cement in concrete drastically reduces the carbon emissions produced by cement. Having similar strength and cost, what would be the major factor that would stop you from using the geopolymers? (Tick more than one if needed)

☐ Lack of training or experience

☐ Lack of Australian Standard Design/Construction material

☐ Lack of material availability

☐ Lack of material durability results

☐ Lack of trust in conducted research, or different perceptions

☐ No Interest in trying new things

☑ Other, Comment - I have not heard of this before, and therefore cannot comment either way. The sceptic in me finds it difficult to believe that the cost is similar to cement given the production process has reduced carbon emissions ……………………………………………………………………

Question 7 (b)

Geopolymers in concrete have many economic and environmental benefits when used as opposed to regular General Purpose cements. Have you ever used Geopolymers in construction?

☐ Yes (explain your experiences)

☑ No (explain the factors that have stopped you)

Question 8 (a)

Cross Laminated timbers products boast many economic and environmental properties, including higher strength then regular timber products. What would be the major factor that would stop you from using the fibre composite materials? (Tick more than one if needed)

☐ Lack of training or experience

☐ Lack of Australian Standard Design/Construction material

☐ Lack of material availability

☐ Lack of trust in conducted research, or different perceptions

☐ No Interest in trying new things

☑ Other, Comment - Cost, poor appearance, reduced workability with increase in WHS issues during use from bonding agent (cutting, drilling)……………………………………………………

Question 8 (b)

Have you ever used Cross Laminated Timber in Construction?

☑ Yes (explain your experiences)

Limited use as bridge decking – The product did not perform with any advantage (strength or durability) over traditional (hardwood) timber. Large sections were quick to install in emergency situation, but due to lack of durability were always only a temporary option. --

----

☐ No (explain the factors that have stopped you)

Question 9

Are there any other advance engineering materials that you have had dealings with?

☐ Yes ☐ No

If yes, please comment on the material and any factors would stop you from using them in the future:

....

....

....

Question 10

Do you have any further comments? If so, please list them below:

Advanced Engineering materials are not new, all materials were advanced at one point.

Society relies on 'someone else' to trial and prove the products, which is generally an organization that has the financial ability to do so (either self-supported or subsidized).

With today's environment being so litigious, this increases the risk considerably when the product goes to market. Increased risk will always result in an increased cost to the consumer until the product becomes mainstream.

I should also note that appearance can make a huge difference to people's acceptance of a new material, for example CLT personally is quite unsightly and this alone would be a large obstacle for me to overcome to use the product, despite the practical disadvantages. Shallow, I know......

....

Name:
(leave blank for anonymity) ....
Occupation/field of engineering: Bridge Inspector..

Date Completed: 6/9/19..

Appendix D

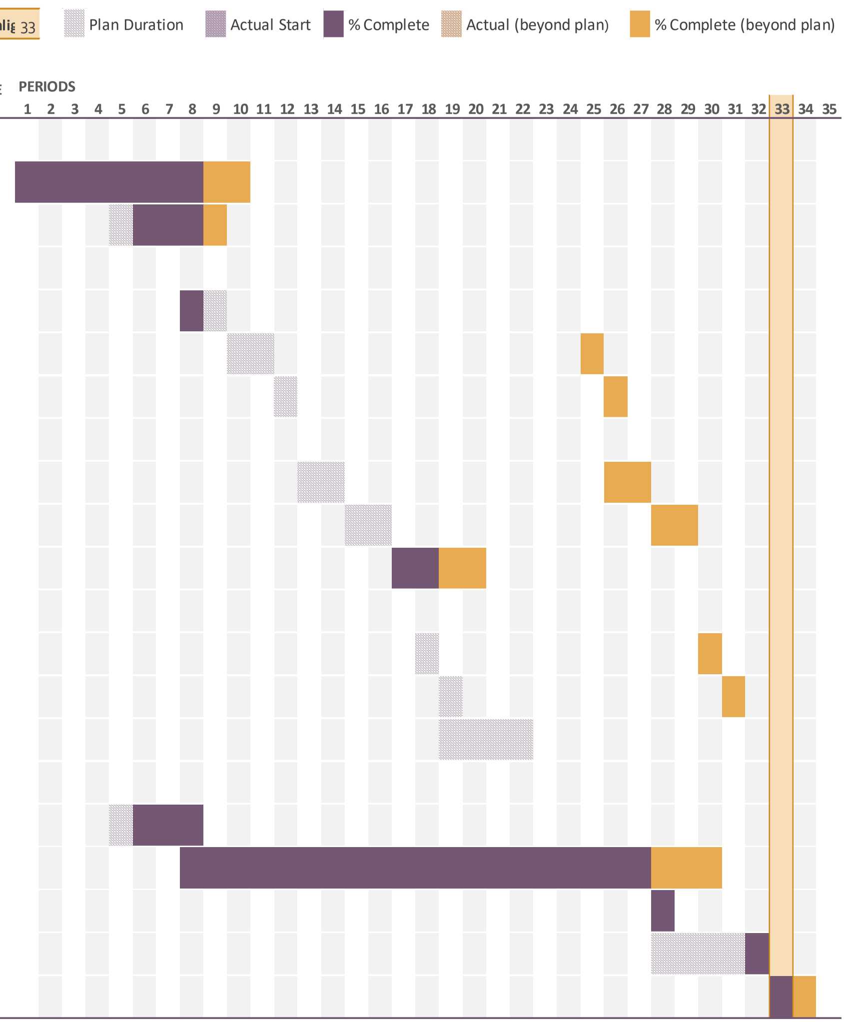
Project Plan

Project Planner

Evaluation of Issues in Using Advanced and Sustainable Engineering Materials. BY JACOB TAN

ONE PERIOD IS EQUAL TO ONE WEEK

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1.0 RESEARCH PHASE					
1.1 Literature Review	1	8	1	10	100%
1.2 Comparison of Methods	5	4	6	4	100%
2.0 DATA COLLECTION PHASE					
2.1 Design relevant survey	8	2	8	1	100%
2.2 Survey Distribution	10	2	25	1	100%
2.3 Collect Survey	12	1	26	1	100%
3.0 DATA ANALYSIS PHASE					
3.1 Analyse and Tabulate Data Collected	13	2	26	2	100%
3.2 Evaluate factors	15	2	28	2	100%
3.3 Cost analysis	17	2	17	4	100%
4.0 CONCLUSIONS and FURTHER RESARCH					
4.1 Write concluding summary to research	18	1	30	1	100%
4.2 Highlight areas of further research	19	1	31	1	100%
4.3 If time permits, further investigate	19	4			
5.0 REPORT PREPERATION					
5.1 Project Planing report (Due 29/05/2019)	5	4	6	3	100%
5.1 Compile data	8	20	8	23	100%
5.2 Submit Draft Dissertation	28	1	28	1	100%
5.3 Revise pending Review	28	5	32	1	100%
5.4 Submit Dissertation	33	1	33	2	100%



Appendix E

Excel Spreadsheets

Life Cycle Costing Analysis

Wellingrove Creek Bridge

Inflation Rate	2%										
Alt 2 - Concrete Bridge											
Design Life	**100**	**Years**									
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Intial Cost of Construction	$ 750,000.00										
Level 1 Maintanence Inspection	$ 600.00	$ 1,224.00	$ 1,248.48	$ 1,273.45	$ 1,298.92	$ 1,324.90	$ 1,351.39	$ 1,378.42	$ 1,405.99	$ 1,434.11	$ 1,462.79
Level 2 Maintanence Inspection	$ 1,200.00		$ 1,248.48		$ 1,298.92		$ 1,351.39		$ 1,405.99		$ 1,462.79
Accumaltive Total	$ 750,000.00	$ 751,224.00	$ 753,720.96	$ 754,994.41	$ 757,592.25	$ 758,917.14	$ 761,619.93	$ 762,998.36	$ 765,810.34	$ 767,244.45	$ 770,170.04
Total PV of Asset Life Cycle	$ 1,325,150.46										
Alt 1 - CFRP Rehab											
Design Life	**50**	**Years**									
Demolition and Rebuild at Year	**2069**										
Cost of Rebuild	$ 350,000.00	**occuring at year 2070**									
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Intial Cost of Construction	$ 200,000.00										
Level 1 Maintanence Inspection	$ 600.00	$ 1,224.00	$ 1,248.48	$ 1,273.45	$ 1,298.92	$ 1,324.90	$ 1,351.39	$ 1,378.42	$ 1,405.99	$ 1,434.11	$ 1,462.79
Level 2 Maintanence Inspection	$ 1,200.00	$ 1,224.00	$ 1,248.48	$ 1,273.45	$ 1,298.92	$ 1,324.90	$ 1,351.39	$ 1,378.42	$ 1,405.99	$ 1,434.11	$ 1,462.79
Level 3 Maintanence Inspection	$ 4,500.00	$ 4,590.00									$ 5,485.47
Accumaltive Total	$ 200,000.00	$ 207,038.00	$ 209,534.96	$ 212,081.86	$ 214,679.70	$ 217,329.49	$ 220,032.28	$ 222,789.13	$ 225,601.11	$ 228,469.33	$ 236,880.39
Total PV of Asset Life Cycle	$ 1,807,496.94										

	A	B	C	D	E	F	G
1							
2							
3	Inflation Rate	0.02					
4							
5	Alt 2 - Concrete Bridge						
6	Design Life	100	Years				
7	Year	2019	=B7+1	=C7+1	=D7+1	=E7+1	=F7+1
8	Intial Cost of Construction	750000					
9	Level 1 Maintanence Inspection	600	=(2*$B$9)*(1+$B$3)^(C7-$B$7)	=(2*$B$9)*(1+$B$3)^(D7-$B$7)	=(2*$B$9)*(1+$B$3)^(E7-$B$7)	=(2*$B$9)*(1+$B$3)^(F7-$B$7)	=(2*$B$9)*(1+$B$3)^(G7-$B$7
10	Level 2 Maintanence Inspection	1200		=$B$10*(1+$B$3)^(D7-$B$7)		=$B$10*(1+$B$3)^(F7-$B$7)	
11	Accumaltive Total	=B8	=B11+SUM(C8:C10)	=C11+SUM(D8:D10)	=D11+SUM(E8:E10)	=E11+SUM(F8:F10)	=F11+SUM(G8:G10)
12	Total PV of Asset Life Cycle	=B8+SUM(C9:CX9)+SUM(C10:CX10)					
13							
14							
15	Alt 1 - CFRP Rehab						
16	Design Life	50	Years				
17	Demolition and Rebuild at Year	2069					
18	Cost of Rebuild	350000	occuring at year 2070				
19	Year	2019	=B19+1	=C19+1	=D19+1	=E19+1	=F19+1
20	Intial Cost of Construction	200000					
21	Level 1 Maintanence Inspection	600	=(2*$B$21)*(1+$B$3)^(C19-$B$7)	=(2*$B$21)*(1+$B$3)^(D19-$B$7)	=(2*$B$21)*(1+$B$3)^(E19-$B$7)	=(2*$B$21)*(1+$B$3)^(F19-$B$7)	=(2*$B$21)*(1+$B$3)^(G19-$E
22	Level 2 Maintanence Inspection	1200	=$B$22*(1+$B$3)^(C19-$B$7)	=$B$22*(1+$B$3)^(D19-$B$7)	=$B$22*(1+$B$3)^(E19-$B$7)	=$B$22*(1+$B$3)^(F19-$B$7)	=$B$22*(1+$B$3)^(G19-$B$7)
23	Level 3 Maintanence Inspection	4500	=$B$23*(1+$B$3)^(C19-$B$19)				
24	Accumaltive Total	=B20	=B24+SUM(C20:C23)	=C24+SUM(D20:D23)	=D24+SUM(E20:E23)	=E24+SUM(F20:F23)	=F24+SUM(G20:G23)
25	Total PV of Asset Life Cycle	=B20+SUM(C20:CX23)					

West Wellcamp Airport

Inflation Rate	2%										
Ordinary Portland Cement Concrete											
Volume of Concrete	**40000**	**m3**									
Design Life	**40**	**Years**									
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Intial Supply Cost	$ 6,400,000.00										
Maintanence Inspection	$ 1,200.00	$ 1,224.00	$ 1,248.48	$ 1,273.45	$ 1,298.92	$ 1,324.90	$ 1,351.39	$ 1,378.42	$ 1,405.99	$ 1,434.11	$ 1,462.79
Repair Spalling	$ 20,000.00					$ 22,081.62					$ 24,379.89
Severe Crack Repair	$ 500,000.00										
Partial Slab Replacement	$ 1,500,000.00										
Accumaltive Total	$ 6,400,000.00	$ 6,401,224.00	$ 6,402,472.48	$ 6,403,745.93	$ 6,405,044.85	$ 6,428,451.36	$ 6,429,802.76	$ 6,431,181.18	$ 6,432,587.17	$ 6,434,021.28	$ 6,459,863.96
Total PV of Asset Life Cycle	$ 11,127,200.87										
Geopolymer Concrete											
Volume of Concrete	**40000**	**m3**									
Design Life	**40**	**Years**									
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Intial Supply Cost	$ 7,000,000.00										
Maintanence Inspection	$ 1,200.00	$ 1,224.00	$ 1,248.48	$ 1,273.45	$ 1,298.92	$ 1,324.90	$ 1,351.39	$ 1,378.42	$ 1,405.99	$ 1,434.11	$ 1,462.79
Repair Spalling	$ 20,000.00							$ 22,973.71			
Severe Crack Repair	$ 250,000.00										
Partial Slab Replacement	$ 1,000,000.00										
Accumaltive Total	$ 7,000,000.00	$ 7,001,224.00	$ 7,002,472.48	$ 7,003,745.93	$ 7,005,044.85	$ 7,006,369.75	$ 7,007,721.14	$ 7,032,073.28	$ 7,033,479.27	$ 7,034,913.38	$ 7,036,376.17
Total PV of Asset Life Cycle	$ 10,858,423.25										

	A	B	C	D	E	F	G
1							
2							
3	**Inflation Rate**	0.02					
4							
5							
6	**Ordinary Portland Cement Concrete**						
7	**Volume of Concrete**	**40000**	**m3**				
8	**Design Life**	**40**	**Years**				
9	**Year**	**2019**	**=B9+1**	=C9+1	=D9+1	=E9+1	=F9+1
10	**Intial Supply Cost**	=160*B7					
11	**Maintanence Inspection**	1200	=$B$11*(1+$B$3)^(C9-$B$9)	=$B$11*(1+$B$3)^(D9-$B$9)	=$B$11*(1+$B$3)^(E9-$B$9)	=$B$11*(1+$B$3)^(F9-$B$9)	=$B$11*(1+$B$3)^(G9-$B$9)
12	**Repair Spalling**	20000					=$B$12*(1+$B$3)^(G9-$B$9)
13	**Severe Crack Repair**	500000					
14	**Partial Slab Replacement**	1500000					
15	**Accumaltive Total**	=B10	=B15+SUM(C10:C14)	=C15+SUM(D10:D14)	=D15+SUM(E10:E14)	=E15+SUM(F10:F14)	=F15+SUM(G10:G14)
16	**Total PV of Asset Life Cycle**	=B10+SUM(C10:AO14)					
17							
18							
19	**Geopolymer Concrete**						
20	**Volume of Concrete**	**40000**	**m3**				
21	**Design Life**	**40**	**Years**				
22	**Year**	**2019**	**=B22+1**	=C22+1	=D22+1	=E22+1	=F22+1
23	**Intial Supply Cost**	=175*B20					
24	**Maintanence Inspection**	1200	=$B$11*(1+$B$3)^(C22-$B$9)	=$B$11*(1+$B$3)^(D22-$B$9)	=$B$11*(1+$B$3)^(E22-$B$9)	=$B$11*(1+$B$3)^(F22-$B$9)	=$B$11*(1+$B$3)^(G22-$B$9)
25	**Repair Spalling**	20000					
26	**Severe Crack Repair**	250000					
27	**Partial Slab Replacement**	1000000					
28	**Accumaltive Total**	=B23	=B28+SUM(C23:C27)	=C28+SUM(D23:D27)	=D28+SUM(E23:E27)	=E28+SUM(F23:F27)	=F28+SUM(G23:G27)
29	**Total PV of Asset Life Cycle**	=B23+SUM(C23:AO27)					

Browns Rd Bridge

Inflation Rate	2%										
Alt 2 - Concrete Bridge											
Design Life	**100**	**Years**									
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Intial Cost of Construction	$210,000.00										
Level 1 Maintanence Inspection	$ 600.00	$ 612.00	$ 624.24	$ 636.72	$ 649.46	$ 662.45	$ 675.70	$ 689.21	$ 703.00	$ 717.06	$ 731.40
Level 2 Maintanence Inspection	$ 1,200.00		$ 1,248.48		$ 1,298.92		$ 1,351.39		$ 1,405.99		$ 1,462.79
Accumaltive Total	$210,000.00	$210,612.00	$212,484.72	$213,121.44	$215,069.82	$215,732.27	$217,759.36	$218,448.57	$220,557.56	$221,274.62	$223,468.81
Total PV of Asset Life Cycle	$594,064.28										
Alt 1 - Cross Laminated Timber											
Design Life	**50**	**Years**									
Demolition and Rebuild at Year	**2069**										
Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Intial Cost of Construction	$ 65,000.00										
Level 1 Maintanence Inspection	$ 600.00	$ 612.00	$ 624.24	$ 636.72	$ 649.46	$ 662.45	$ 675.70	$ 689.21	$ 703.00	$ 717.06	$ 731.40
Level 2 Maintanence Inspection	$ 1,200.00		$ 1,248.48		$ 1,298.92		$ 1,351.39		$ 1,405.99		$ 1,462.79
Accumaltive Total	$ 65,000.00	$ 65,612.00	$ 67,484.72	$ 68,121.44	$ 70,069.82	$ 70,732.27	$ 72,759.36	$ 73,448.57	$ 75,557.56	$ 76,274.62	$ 78,468.81
Total PV of Asset Life Cycle	$677,849.27										

	A	B	C	D	E	F	G
1							
2							
3	**Inflation Rate**	0.02					
4							
5	**Alt 2 - Concrete Bridge**						
6	**Design Life**	**100**	**Years**				
7	**Year**	**2019**	**=B7+1**	**=C7+1**	**=D7+1**	**=E7+1**	**=F7+1**
8	**Intial Cost of Construction**	210000					
9	**Level 1 Maintanence Inspection**	600	=$B$9*(1+$B$3)^(C7-$B$7)	=$B$9*(1+$B$3)^(D7-$B$7)	=$B$9*(1+$B$3)^(E7-$B$7)	=$B$9*(1+$B$3)^(F7-$B$7)	=$B$9*(1+$B$3)^(G7-$B$7)
10	**Level 2 Maintanence Inspection**	1200		=$B$10*(1+$B$3)^(D7-$B$7)		=$B$10*(1+$B$3)^(F7-$B$7)	
11	**Accumaltive Total**	=B8	=B11+SUM(C8:C10)	=C11+SUM(D8:D10)	=D11+SUM(E8:E10)	=E11+SUM(F8:F10)	=F11+SUM(G8:G10)
12	**Total PV of Asset Life Cycle**	=B8+SUM(C9:CX9)+SUM(C10:CX10)					
13							
14							
15	**Alt 1 - Cross Laminated Timber**						
16	**Design Life**	**50**	**Years**				
17	**Demolition and Rebuild at Year**	**2069**					
18	**Year**	**2019**	**=B18+1**	**=C18+1**	**=D18+1**	**=E18+1**	**=F18+1**
19	**Intial Cost of Construction**	65000					
20	**Level 1 Maintanence Inspection**	600	=$B$20*(1+$B$3)^(C18-$B$7	=$B$9*(1+$B$3)^(D18-$B$7)	=$B$9*(1+$B$3)^(E18-$B$7)	=$B$9*(1+$B$3)^(F18-$B$7)	=$B$9*(1+$B$3)^(G18-$B$7)
21	**Level 2 Maintanence Inspection**	1200		=$B$21*(1+$B$3)^(D18-$B$7		=$B$10*(1+$B$3)^(F18-$B$7)	
22	**Accumaltive Total**	=B19	=B22+SUM(C19:C21)	=C22+SUM(D19:D21)	=D22+SUM(E19:E21)	=E22+SUM(F19:F21)	=F22+SUM(G19:G21)
23	**Total PV of Asset Life Cycle**	=B19+SUM(C20:CX20)+SUM(C21:CX21)+AZ19					

Cost Benefit Analysis Score

	Wellingrove		Browns Rd Creek		Wellcamp Airport	
	Alternative 1	Alternative 2	Alternative 1	Alternative 2	Alternative 1	Alternative 2
Environmental	0.28	0.76	0.36	0.68	0.40	0.90
Economical	1.38	1.00	1.14	1.00	0.98	1.00
Social	0.76	0.48	0.44	0.44	0.33	0.53

	Wellingrove		Browns Rd Creek		Wellcamp Airport	
	Alternative 1	Alternative 2	Alternative 1	Alternative 2	Alternative 1	Alternative 2
Environmental	=7/25	=19/25	=9/25	=17/25	=4/10	=9/10
Economical	=1.8/1.3	=1.3/1.3	=678/594	=594/594	=10.86/11.13	=11.13/11.13
Social	=19/25	=12/25	=11/25	=11/25	=5/15	=8/15

Questionnaire Feedback Summary

Question 1						
Always	**Often**	**Rarely**	**Never**			
5.0	13.0	2.0	0.0			
25.0	65.0	10.0	0.0			
Question 2						
Always	**Often**	**Rarely**	**Never**			
1.0	3.0	12.0	4.0			
5.0	15.0	60.0	20.0			
Question 3						
Always	**Often**	**Rarely**	**Never**			
2.0	7.0	8.0	3.0			
10.0	35.0	40.0	15.0			
Question 4						
Always	**Often**	**Rarely**	**Never**			
11.0	9.0	0.0	0.0			
55.0	45.0	0.0	0.0			
Question 5						
Always	**Often**	**Rarely**	**Never**			
11	8	1	0			
55.0	40.0	5.0	0.0			
Question 6a						
Lack of Trai	Lack of Stand	Lack of Mate	Durability Co	Lack of Tru	No Interes	Other
9	10	8	3	3	1	6
Question 6b						
YES	NO					
11	9					
55	45					
Question 7a						
Lack of Trai	Lack of Stand	Lack of Mate	Durability Co	Lack of Tru	No Interes	Other
14	9	11	1	0	0	5
Question 7b						
YES	NO					
1	19					
5	95					
Question 8a						
Lack of Trai	Lack of Stand	Lack of Mate	Durability Co	Lack of Tru	No Interes	Other
9	4	6	3	0	0	5
Question 8b						
YES	NO					
11	8					
57.894737	42.1052632					
Question 9						
YES	NO					
7	10					

Note: Questionnaire feedback soft copies to be kept by Jacob Tan for 5 years.