University of Southern Queensland

University Of Southern Queensland

Faculty of Health, Engineering and Sciences

Evaluation Of Sustainable Engineering Infrastructure

A Dissertation Submitted by

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In fulfilment of the requirement of

ENG4111 AND ENG4112 Research Project

Towards the degree of

Bachelor of Engineering (Honours) Civil

ABSTRACT

The objective of this research project is to evaluate the feasibility of sustainable Engineering Infrastructure through a comprehensive analysis of modern method of practices used in construction industry in Australia. Sustainability plays an important role in creating a better future for present and future generations and is morally supported by all existing philosophies and religious entities. Sustainable Engineering is an essential factor in driving sustainable planet.

This particular research project is primarily based on the road infrastructure and the improvements modern day Engineering has been able to achieve through the use of recycled waste materials as a replacement for aggregates whilst building them. Road Sustainability is significant because it tackles a number of environmental, social, and economic issues. Planning and building sustainable roads envision to form a balance between the need for transportation infrastructure and the needs of the environment, community well-being, and long-term economic sustainability. Sustainable road practices are becoming increasingly important as societies and governments become more aware of these issues.

The research project was initiated with literature reviews on different Engineering Infrastructure built through the sustainability standpoint, materials used and challenges whilst operating and maintaining them as compared to traditional Australian Construction Industry. This evaluation was primarily focused in evaluating the road infrastructure (Being the largest form of land Transportation) located in Queensland. The data and information to assess the selected infrastructure (road) taken through the authentic website through government official page and relevant information are accordingly provided in the methodology section of the report.

With the data and information provided in the methodology section of the report, it seems imperative even though Sustainability plays an important role in maintaining a circular economy and mitigating climate changes, it has been limited to small number of infrastructure expenditures. Whilst government has rigorously implemented waste management and Resource Recovery Strategy to protect natural resources, it still remains an uphill task to endorse sustainability in other parts of the Engineering Infrastructure Expansion. It is believed that the necessity for driving sustainability as a social responsibility for all Engineers remains paramount across different sectors to ensure that the society gets benefits in many ways for present and future generations to live.

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Bipin Adhikari

[redacted]

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Finally, and most importantly, I would like to thank my wonderful family members for all their patience, understanding, support and time over the completion of my studies. I would not have been able to do this without you.

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

In the age of technology and rapid advancement of humanity for last few decades, sustainability has become a paramount for people living around the world to save our natural resources for greater use in the future. Engineering as an important commodity in human development as in whole plays an important role in driving sustainability forward and minimizing the use of non-recyclable goods in infrastructure advancement and development. As rapid globalization across the world have become so prominent and convenient, it is important to understand the concept of sustainability in Engineering and all modern areas of socio economic and environmental activities. As we continue to progress forward with much advancement in Engineering and technologies, it is equally beneficial to incorporate the idea of sustainability into projects and development to better foster the environment for humanity and wellbeing of other living beings too.

1.2 Significance of the study

This project specifically focuses on the impacts of recycled waste materials in modern engineering practices and challenges it brings to Civil Engineering operations and maintenance processes. Sustainability in Engineering has been a hot topic around the world for various reasons. Be it for minimising waste materials for minimizing pollution and saving landfill to preserve natural resources to accelerate the vision of clean environment for the future. Engineering has evolved dramatically in the last few decades, and it is clearly visible in modern day society and has made human life far much better than anyone could have imagined. Many break throughs in the construction industry and designing the road infrastructure has taken off and benefited the environment in myriad ways. However, Sustainability has always become a major challenge for big projects due to the restriction of flexibility it generates for the Engineers to finalise a decision.

Even though Sustainability is feasible in many areas of infrastructure advancement, traditional Engineering has proved to be the best practice for long term retainment of an infrastructure and maintenance purposes. One of the biggest obstacles in practising sustainability in Engineering comes because of excessive world dependency on fossil fuels and non-renewable resources for the gain of profit and political motivation.

1.3 Objectives of the study

The main aim of this dissertation is to provide a brief and comprehensive analysis of how sustainability plays an important role in modern day engineering and its impact on the long-term benefits of the environment and achieving the carbon free vision Australia. For this project, all the data and information were provided from the Governmental bodies in Queensland namely Cairns Regional Council and Department of Transport and Main Roads on building sustainable roads using recycled materials. It is envisaged that the outcome from this dissertation will encourage private as well as government companies to accelerate sustainability across different areas to reducing carbon emission and creating a sustainable future.

To achieve this aim, this dissertation aims to cover few specific objectives as mentioned in the project specifications.

1. The initial objective is to identify the local and state government bodies based in Queensland that are building sustainable roads and accessible to research students.

2. To obtain and study the relevant data and information across the selected infrastructure and their impacts in modern day Civil Engineering practices.

3. To conduct a thorough report on the processes used whilst undertaking recycled materials for constructing roads and challenges occurred during design, operation, and maintenance of the infrastructures.

4. To develop a life cycle-based evaluation and assessment of selected recyclable material properties, benefit and cost assessment based on present value techniques.

5. Upon Completion, this dissertation will provide a comprehensive assessment of sustainable Engineering Road infrastructure and opens doors for other research areas in scaling up sustainability.

All these objectives are primarily focused in making this dissertation as informative and comprehensive as possible to a large audience to foster the importance of sustainability in modern day Engineering. It is equally important to understand that every result and evaluation done throughout the dissertation will be based on the information provided through relevant authorities for meeting these objectives mentioned above.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The key purpose of literature review is to understand and gain the fundamental knowledge around the areas in which sustainability has played an important role in being a part of our functioning infrastructure better for mankind and environment surrounding it. Throughout the entire process of the reviewing of many literatures, journals and papers been done in the field of Engineering and construction management practices throughout the world, it is imperative to the human nature that the only way to preserve and protect the environment is to drive sustainability forward through every means necessary. These research paper has been prepared with an aim to provide an insight on how the Australian government has endorsed sustainability in construction of roads as a part of newly formed waste management and resource recovery strategy. Though this project is primarily focused in addressing the civil construction practices in Australia, it has not limited in addressing the history of road construction around the world and explained how recycled materials used as a substitute for traditional construction materials has helped countries in saving cost, reducing landfills, protecting the environment and most importantly driving circular economy and reducing carbon emission(Zavadskas, Antuchevičienė, & Šaparauskas, 2018).

For making this research more insightful and informative, it is crucial to study all areas of road construction including design, research and environmental impact assessment whilst understanding the challenges recycled materials brings in the process of maintenance and proper functioning of infrastructures. The challenges occurred during the use of recycled materials in the development of an infrastructure have a significant impact on various aspects of the construction phases. It's crucial to keep in mind, too, that not all types of roads or all geographical areas may be suitable for employing recycled plastic in road construction. The usefulness is influenced by variables like the local climate, traffic volume, and the availability of recycled plastic materials(Shaikh, Khan, Shah, Kale, & Shukla, 2017). Profound in-depth engineering and testing are required to guarantee the performance and safety of such road construction techniques. In order to enhance the methods and address any potential long-term environmental issues connected with employing recycled plastics in infrastructure projects, continual research and development is also necessary. A figure listed below provides an overview of how the road life cycle plays an important role in different aspects of road construction.

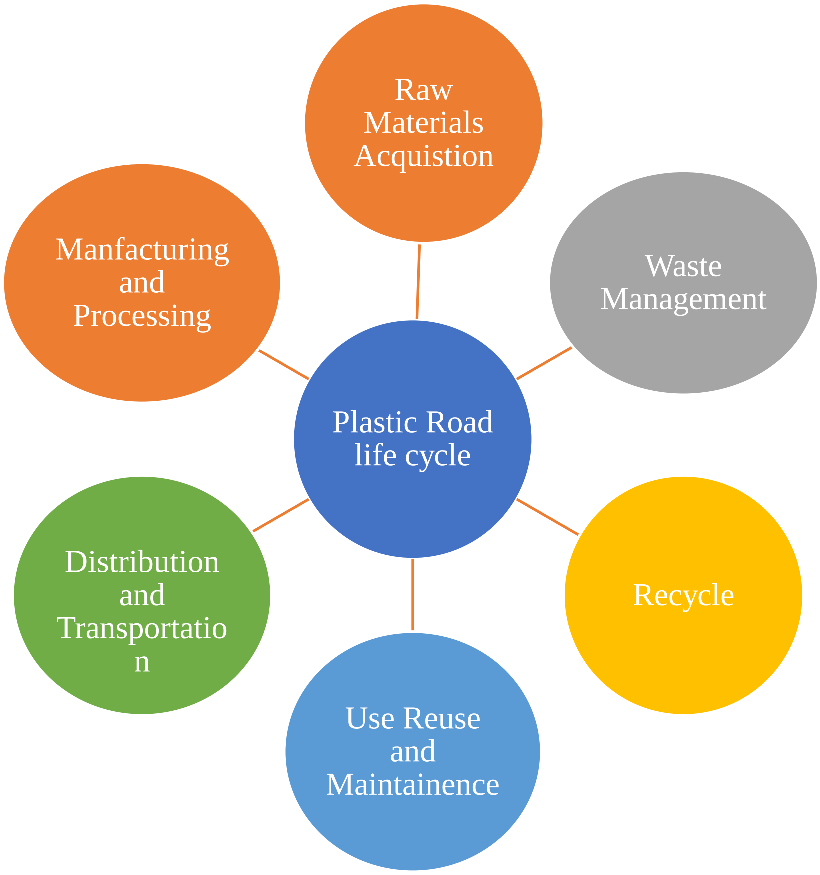

Fig 1: Plastic Road Life Cycle in Modern Day Engineering

2.1.1 Introduction

The substance that is currently used the most is plastic. It is affordable, flexible, moisture-resistant, and light in weight. These characteristics make plastic more appealing to us, increasing its prevalence. Today, plastic is employed in every important sector of the economy, from construction to agriculture to the automotive and technological industries and civil construction industry. It has radically altered every aspect of existence. To understand the magnitude of input of plastics to the natural environment and the world's oceans, we must understand various elements of the plastic production, distribution, and waste management chain. This is crucial, not only in understanding the scale of the problem but in implementing the most effective interventions for reduction. However, this plastic eventually ends up in the trash. Both in urban and rural locations, it is typical to find plastic debris lying around on the highways. It makes up the lion's share of all municipal solid wastes (MSW). Every year, tons of plastic garbage, such as polyethene, cups, bags, etc., are thrown out, polluting the land, rivers, seas, and oceans(Gawande, 2013). Plastic is a substance that cannot biodegrade and can remain on earth for about 4500 years without any signs of Degradation(Shaikh et al., 2017). Inappropriate disposal of it can endanger humans' health seriously. Considering how plastics are currently used, a complete ban on them is not feasible. With Proper justification, hence we must look for alternatives to recycling plastic.

The graph represents the rise in annual global plastic output, expressed in tonnes, beginning in year 1950 till 2019 around the globe. As indicative from the graph, only 2 million Tonnes were manufactured globally year in 1950. Since then, yearly production has been than 440 times grown, reaching up to record 8 billion tonnes in 2019(Ritchie & Roser, 2018).
The 2008 global financial crisis primarily caused the brief decline in yearly production in 2009 and 2010; a comparable impact is visible across numerous indicators of resource production and consumption, including energy(Ritchie & Roser, 2018).

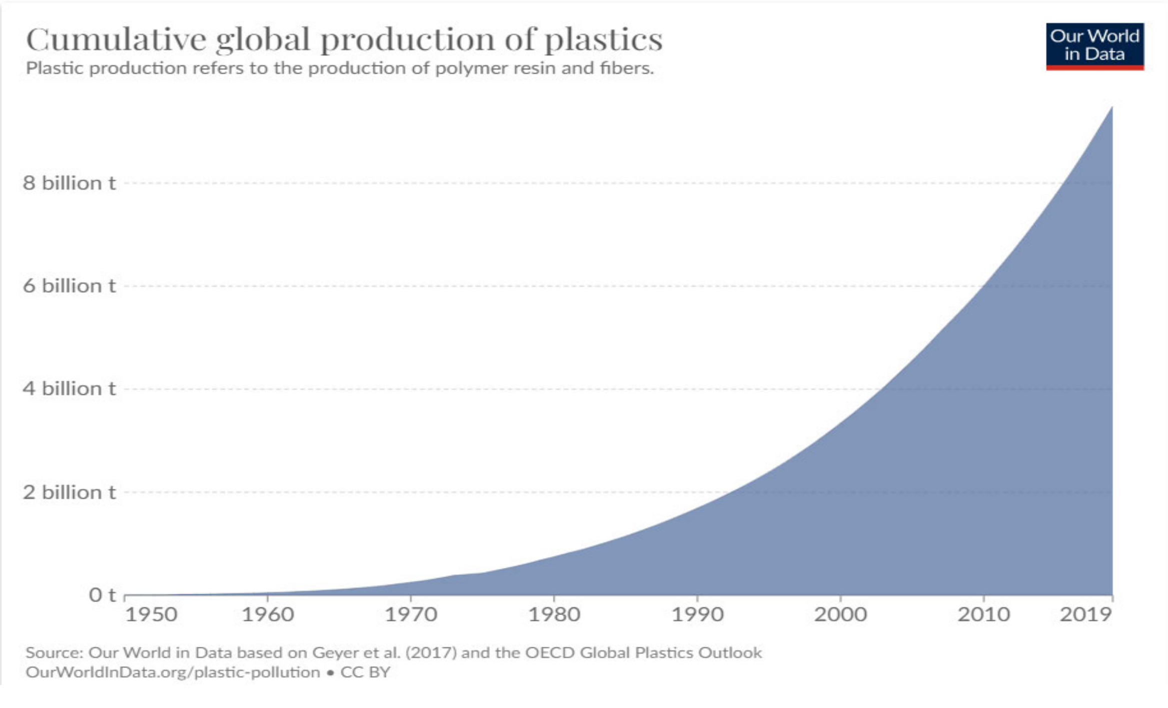

Fig 2: Global Cumulative Production of plastics

(World In data, 2018)

The above graph shows that the latest cumulative production of plastic is close to 9 billion and it is consistent with an upward trajectory in coming years in global production throughout the world. As a rough estimation, it is more than one tonne of plastic for each person alive in the world to be precise.

2.1.2 Manufacturing and Production

Plastic waste must be collected from the site of production or disposal, sorted, compressed, crushed, and pelletized before being used as raw materials in the recycling process(Shen & Worrell, 2014). Thermal, chemical, or mechanical processing is done after these steps to create the finished product. Because of this, recycling plastic waste is difficult and less desirable than recycling other materials including paper, glass, ceramics, and aluminium. The automated sorting of plastic wastes using methods including spectroscopy, infrared, fluorescence, flotation, and electrostatics is the first step in their chemical, thermal, or mechanical recycling(Kamaruddin, Abdullah, Zawawi, & Zainol, 2017). Plastic wastes are degraded during mechanical recycling through shredding and grinding. However, if the waste mixture is complex, the process is not chosen; in this case, incineration is preferred. Plastic is recycled chemically where they are converted into monomers or smaller chains and chemically modified to turn them into new raw materials. Waste plastic is melted at a high temperature during heat treatment, then its shape is used to recycle it into new products (Nyika & Dinka, 2022).

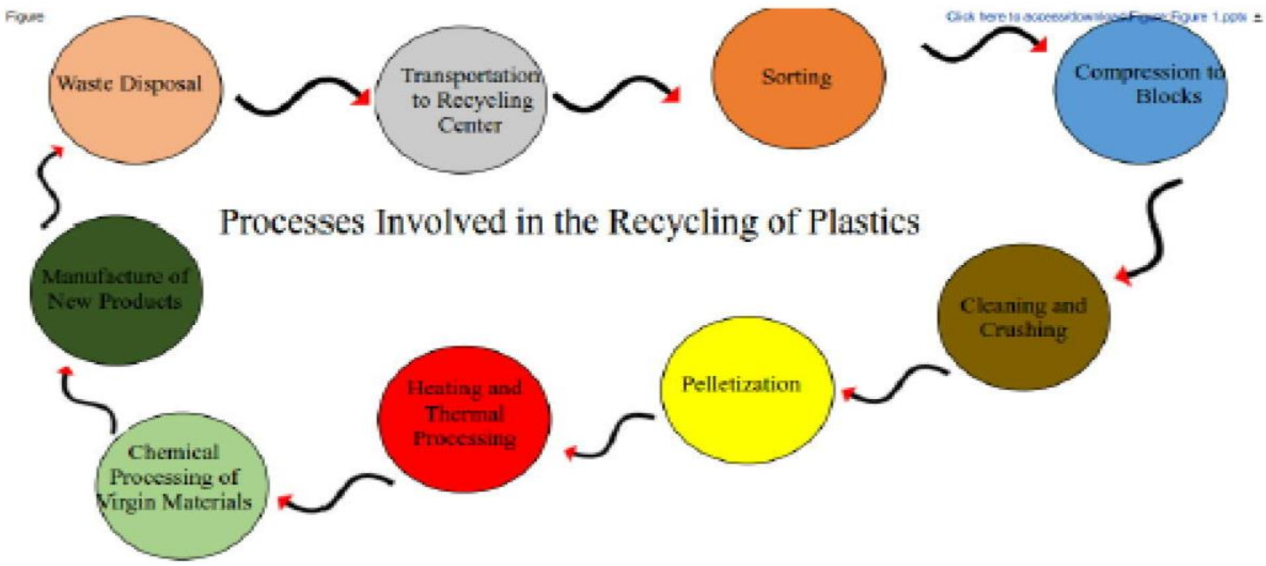

Fig 3 : Process involved in Recycling (Nyika & Dinka, 2022).

2.1.3 Use Of plastic Wastes for road Construction

Concrete can be made from a variety of plastic wastes that can either completely or partially replace aggregate in road construction. They are likewise utilized in making fillers, black-top, and adjusted bitumen. In the subbase and base construction of pavements, where such wastes improve their bearing capacity, stiffness, and shear, this use of plastic waste is more prevalent(Shafiq & Hamid, 2016). It displays these plastic wastes, their function in road construction, and the proportions in the mixtures. Albeit the plastic waste produces OK execution during street developments in their versatile modulus, solidness, and bearing limit, their actual attributes, for example, smooth surface brings this limit contrasted down with traditional street development materials(Patel, Popli, & Bhatt, 2014). During road construction, plastic wastes have improved the volumetric and mechanical characteristics of the resulting mixtures, as well as improved road surface quality and service life(Dyer, 2014). The manufacturing of the plastic is different with the demand and requirements assigned for their respective uses. In this particular research, majority of data from the record and literature review showed different types of plastic used in the market and their respective uses. The following table gives the description about different types of plastic used in the market and their contribution in the road construction with their respective uses and characteristics.

Plastic Waste	Description
Polyethylene Terephthalate (PET)	A plastic polymer commonly used for manufacturing of various products and strong, lightweight and 100% recyclable.
High Density Polyethylene (HDPE)	A thermos plastic polymer made from petroleum products and is considered most environmentally stable of all plastics.
Polypropylene Plastic (PP)	A thermoplastic commonly used for manufacturing and packaging purposes.
Low Density Polyethylene (LDPE)	A thermoplastic made from monomer ethylene and is soft, lightweight, and used for making grocery and bin bags.
Polyethylene (PE)	It is most commonly used plastic in the world. It has a flexible, durable and tear- resistant properties and commonly used for making containers for liquids.
Thermoset Plastic	It is made from polymers which can be neither decomposed nor reprocessed due to their chemical properties. Currently, this waste is typically burnt or buried.
Electronic Plastic waste	It appears from electrical and electronic equipment waste. Because of the dynamics used in these wastes, it is hard to recycle them from an economic standpoint.

Plastic Waste	Role of the Plastic Waste	Plastic Content (%)
PET	Replacement of sand	1–10%
	Fine aggregate	0–50%
HDPE	Aggregate	0–10%
Shredded plastic bags		0–5%
PP	Coarse aggregate	0–2%
Fine plastic waste	Partial substitute for aggregate	0–12.5%
Recycled plastic aggregate	Substitute	25, 50, 77 and 100%
LDPE	Partial substitute to sand	0–50%
Thermoset plastic waste	Modifier	–
Electronic plastic waste	Aggregate	0–30%
PE	Binder	5–11%
PET, HDPE, LDPE	Component of asphalt	–
HDPE	Component of subbase and base	–

Fig 4: Plastic waste and their respective role (Nyika & Dinka, 2022)

2.1.4 Cost Benefit and durability of plastic waste for Road construction

Due to the materials capacity to replace natural ones, reduce manufacturing, and ultimately protect the environment from pollution, the utilization of plastic waste in the building and construction industry has been praised. Benefits subsidiary with plastic properties like lightweight, waterproof, high strength, and simplicity of trim make it a reasonable and tough material for building and development materials. However, when compared to conventional materials, adding plastic waste to various building and construction products is associated with some property changes. When compared to regular asphalt, the fracture resistance of PET asphalt was found to be higher(Nyika & Dinka, 2022). The addition of plastic wastes enhanced the base, subbase, and mortar's mechanical properties, thereby enhancing durability. Plastics likewise further develop the solidness parts of building and development materials, for example, elasticity holding limit and hairlike ascent obstruction contrasted with normal materials. In certain examinations, the plastics are contaminations that diminish the warm conductivity and compressive strength of resultant composites bringing about decreased sturdiness and bad quality items(Mohammadinia et al., 2015). Consequently, the discoveries on plastic properties in building and development materials as to strength present blended results. The existence cycle evaluation of plastic properties contrasted with traditional structure materials shows that the previous enjoys the benefit of cost-viability. This idea could be that recycling plastic waste is cheaper than using regular materials because it saves money on transportation, energy, landfill disposal, and the production of new materials. The elaborate cycles in reusing the materials ought to be assessed for a money saving advantage examination contrasted with handling or customary structure and development materials. Such life cycle costing could lessen costs subsidiary with assortment and arranging of plastic materials that make the reusing system costly.

A recent case study done in cost and benefit analysis of producing natural and recycled concrete aggregates in south Africa by (Ohemeng & Ekolu, 2020) provides a total cost estimation suing a comparison pie chart that is provided below.

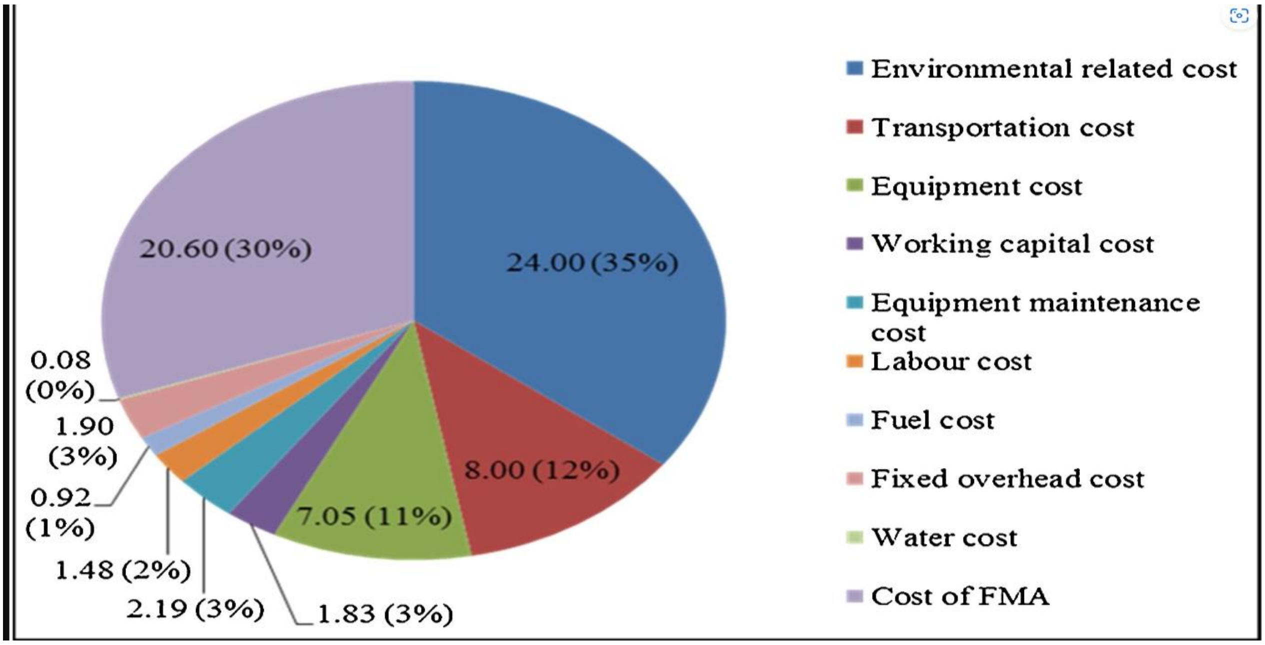

Fig 5: Cost associated with production of natural Concrete.

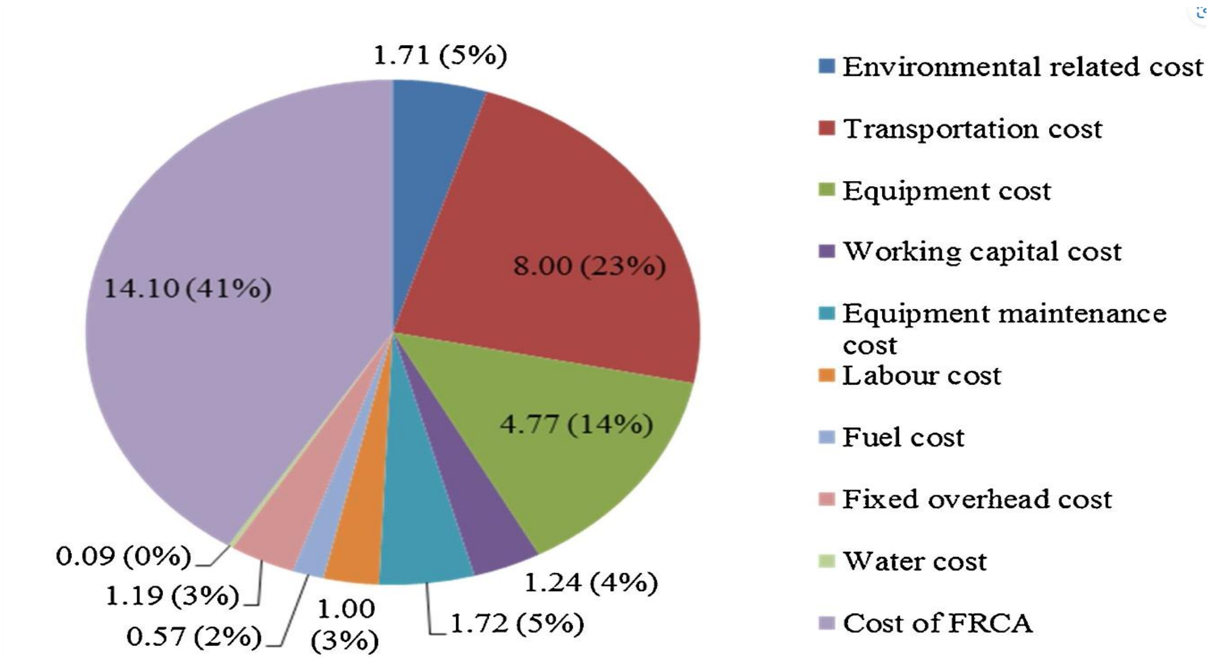

Fig 6: Cost associated with production of recycled Concrete.

The above two chart describes the cost associated with the entire production of natural concrete with respect to recycled concrete in whole. From the graph, it is understandable that the analysing the costs and benefits of using recycled concrete in construction projects is essential. Several aspects are considered when recycled concrete usage is being thought about. When compared to natural concrete production, employing recycled concrete frequently results in lower material acquisition costs and lower landfill disposal costs. The environmental advantages of recycling concrete, including decreased energy use and carbon emissions, can also result in long-term cost savings and increased sustainability. However, it's crucial to take into account the recycled concrete's quality, prospective processing and transportation costs, and any modifications to construction methods that will be required. These variables will be carefully considered against the financial, environmental, and social benefits of using recycled concrete. This will in turn allow decision-makers to make well-informed decisions that can lead to reducing carbon footprint in the atmosphere.

2.2 Sustainability and its Importance in Engineering

Sustainability has been a strong topic around the world more than ever as the world faces many problems regarding climate crisis, ozone layer depletion, melting of glaciers and extinction of much wildlife through the emission of carbon dioxide and other greenhouse gases. Even though countries around try to explain sustainability whilst referencing the activities that has impacted the environment in certain ways but there is not a single way to define Sustainability. As one or the earliest definition that was endorsed by the world Commission on Environment and Development in Early 1987, Sustainability can be defined as an economic development activity "that meets the need of the present without compromising the ability of Future generations to meet their own needs" (Portney, 2015).

The inclusion of sustainability in modern day Engineering reflects one of the fundamental human milestones to preserve the resources for the future generations whilst maintaining the functioning ecosystem in today's day and time. The conservation of environment and natural resources to have a civilized and balanced society has become so necessary that the countries around the world have pledged for aiming net zero carbon emission within the span of upcoming 25 to 35 years. So, how is Sustainability is related with modern day Engineering? The inclusion of word "Sustainability" in Engineering has been around for long time now and institute around the world use different methodologies to integrate Sustainability in day-to-day Engineering Education. Modern day breakthroughs and innovative ideas emerging around the world in the field of Engineering makes the headline day in day out. News is bombarded through all the social media platform to announce many incredible milestones. But yet Sustainability gets ignored whilst forming several policies and procedures for the betterment of the environment and non-renewable natural resources.

Fig 7: Conceptual Chart of Sustainability and Engineering Infrastructure

2.3 Recycled Concrete in road Construction

The most widely used material in the world and one of those with the greatest environmental impact is concrete. However, in the context of the developing world, there is no anticipated substitute for this content. As a result, there is an urgent need to encourage the increase the sustainability of concrete, while simultaneously ensuring that its technological and financial advantages, remain valid. One option to accomplish this goal is to substitute recycled materials or various waste/by products from various industries, including the construction industry, for all or a portion of the natural aggregates. The extremely active research on this topic has established many of the effects on the technical, economic, and environmental performance of recycled aggregate concrete. Nevertheless, In the quest for sustainable recycled aggregate concrete, there is a gap between research and actual applications in industry, as well as a number of topics that still need to be investigated(de Brito, Poon, & Zhan, 2019).

Roads among all the other infrastructure around the world normally use more concrete as it provides better service life and durable through a long course of time. Modern day transportation and ideal heavy barrage of traffic loads causes roads to deteriorate quicker and affects the durability of the road infrastructure(Abu-Saleem et al., 2021). Be it for the durability of the infrastructure or sustaining less maintenance, the use of concrete plays an important role in maintaining the infrastructure functioning for a long period of time. Ideally it is safe to say the use of recycled concrete in the road construction industry greatly benefits the environment to maintain sustainability and reducing carbon emission(Su & Chen, 2002).

2.3.1 Issues with Recycled concrete in Construction

Australia's concrete and road paving industries have always placed a significant emphasis on the usage of available natural aggregates. Construction and engineering standards, an apparently endless supply of waste disposal sites, and the availability of high quality natural fine and coarse aggregates have all contributed to this trend. Whilst the overuse of non-recyclable natural aggregates in modern day construction has become an alarming issue around the world because of its carbon footprint and global warming causes, recycled concrete is not always suitable for modern day construction. First and foremost, one of the important implications of concrete in modern construction it its strength, durability, versatility, and resilience to Environmental factors. All the materials used in concrete plays an important role in achieving those properties and has proven to be the most effective aspect of building infrastructures due to its proven track record(Ibrahim, Katman, Karim, Koting, & Mashaan, 2013). Using recycled glasses as a substitute for sand aggregate affects majority of its properties and brings numerous challenges in the field at the time of use. Few of the most common challenges and drawbacks using the recycled concrete are listed as follows.

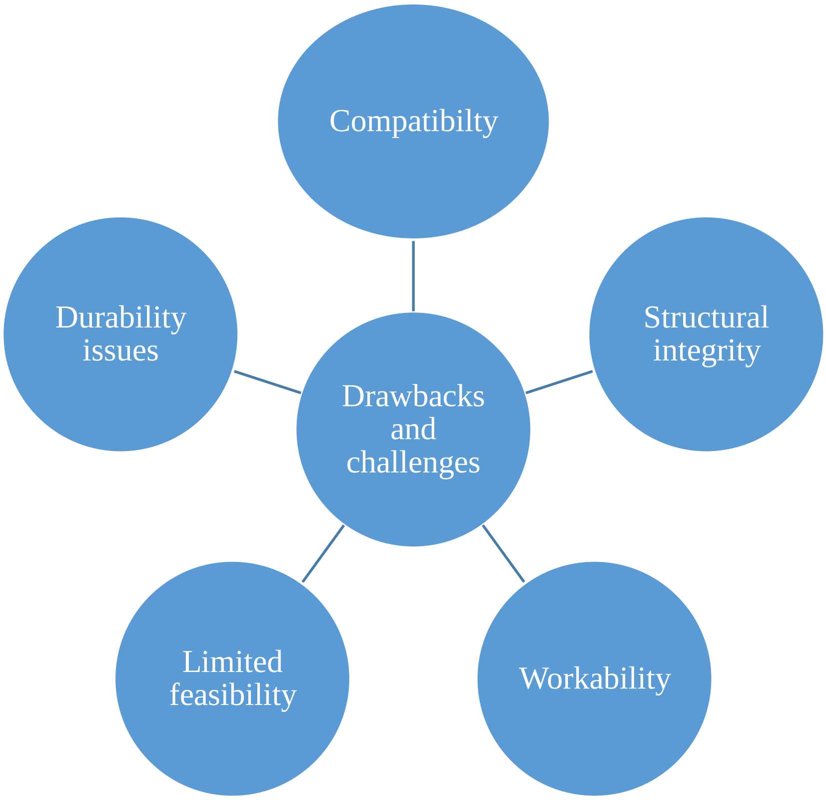

Fig 8: Recycled concrete challenges and drawbacks Chart.

Adding recycled plastic glasses to concrete presents a number of noticeable difficulties. Making sure the plastic material is compatible with the concrete mix is one of the main challenges because concrete's workability, strength, and long-term durability can all be negatively impacted by the various sizes and types of plastic particles. Another challenge is keeping recycled plastic material uniform, which might affect the quality of the concrete. Furthermore, there are also questions about how well recycled plastic would hold up over time in concrete structures, raising concerns about possible degradation. Quality assurance is made more difficult by the absence of generally acknowledged industry standards and regulations, and project budgets may be affected by the increased expenses associated with processing, testing, and sorting recycled plastics. The goal of current research and development is to make recycled plastic in concrete a reality despite these obstacles.

2.4 Recycled Glasses as Sand Replacement

Recycled glass is a mixture of variously coloured glass fragments and frequently contains a variety of waste materials, primarily paper, plastic, soil, metals, and food scraps. The main challenges to employing recycled glass in the industries that make bottles are the existence of various coloured glass particles and various sorts of debris. The majority of recycled glass particles are angular in shape; however some are flat and elongated. The quality of the material, particularly the amount of debris in the combination, is thought to be controlled by the waste stream from which the glass particles have been created (Landris, 2007). Additionally, the production method and crushing technique have a significant impact on the maximum particle size, debris level, and flakiness index of recycled glass, all of which have an impact on geotechnical characteristics.

In this investigation, three different sample types of recycled glass from Victoria's recycling businesses were examined. Based on their maximum particle sizes, which are 4.75, 9.5, and 19 mm, respectively, the three forms of recycled glass were designated as Fine Recycled Glass (FRG), Medium Recycled Glass (MRG), and Coarse Recycled Glass (CRG). Their gradation curve, which affects other geotechnical qualities, is the primary variation between these three samples. To close the information gap on the geotechnical properties of recycled glass in general and specifically that produced in Australia, a complete set of laboratory tests were performed on samples of recycled glass. The environmental and chemical tests were also conducted to measure the pH value, the number of debris, the amount of organic material, and to evaluate the Total contamination of recycled glass samples(Disfani, Arulrajah, Bo, & Hankour, 2011).

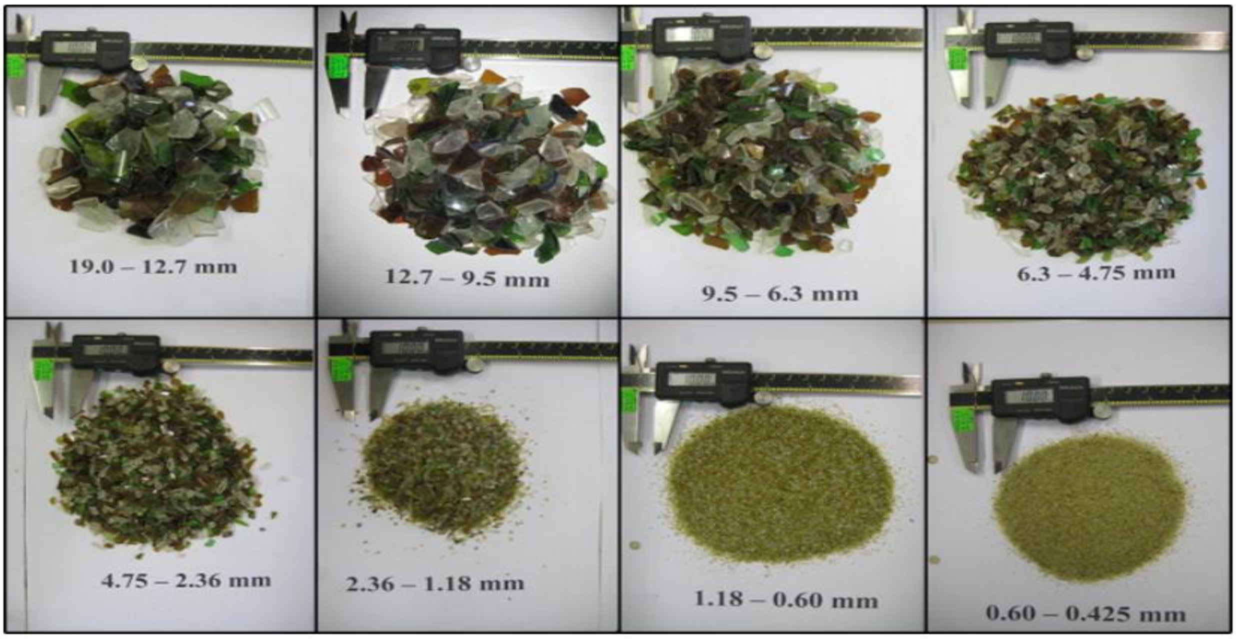

Fig 9: Glass particle classification for different aggregate Samples

The rapid growth of population and massive globalization around the world has made recycling an increasing issue in recent times. 54 million tonnes of plastic were produced in Australia in 2018. That is almost 2.2 tonnes per person every year, and this number is rising yearly. Nearly one-third of the recyclable debris that is collected in Australia is made up of glass. Typically, 40% of the waste glass that is collected is recycled, while the remaining 60% is crushed and dumped. When used as a partial replacement for fine aggregate and cement in concrete, waste glass performs as well as glass that is used in huge volumes. Its physical and pozzolanic qualities, as well as its economic and environmental advantages, have all been assessed.

The study's findings finally demonstrated that replacing fine aggregate in concrete with recycled glass was advantageous because it produced strength which was equal to or greater than a control mix, and also enhanced a range of other durability indicators. Replacement levels up to 60% replacement of natural sand were considered feasible with an optimal replacement level of 40%(Disfani et al., 2011).

Reclaimed Asphalt Pavement

A completely recyclable material for construction is asphalt concrete that has been taken out of an existing road pavement. It can be reused in new asphalt mixtures, decreasing the demand for aggregates and bitumen, or as recycled aggregates to produce unbound layers of pavements because it is made up of valuable non-renewable resources, such as 95% weight of aggregates and 5% weight of aged bituminous binder (Razak et al., 2023). The latter alternative, however, does not fully utilize the material as the former does since it fails to consider the worn-out bituminous binder that covers the recovered aggregates. Reusing discarded asphalt concrete in the same technical applications at the top of the recycling hierarchy rather than downcycling it into simple aggregates maximizes its value.(Tarsi, Tataranni, & Sangiorgi, 2020).

After multiple re-uses and recycling procedures, it may eventually be desirable to downgrade the removed bituminous mixture into a lesser value product (i.e., aggregates for unbound layer). In fact, some studies have shown the potential for multiple recycling of the removed asphalt concrete, i.e., the material's ability to undergo many recycling operations without losing its quality and carry out some valorisation actions when necessary. One example of sustainable development in the infrastructure industry is the recycling and/or reusing of removed bituminous mixture. The promotion of its use reflects the global trend to address the current environmental problems by attempting to boost resource efficiency and decrease carbon emissions. However, the usage of scrap asphalt and concrete must be cost effective and provide a significance in decreasing the bituminous product. (Hoppe, Lane, Fitch, & Shetty, 2015). Reduction of construction waste, preservation of non-renewable natural resources, and lower energy costs are the main driving forces for recycling activities. Typically, the performance requirements of pavement design balance the financial savings and environmental advantages of using recycled materials. It is widely accepted that using recycled materials in construction as much as possible should be done in the overall framework of maintaining a financially viable, high-quality, high-performing, and ecologically responsible pavement infrastructure (Emersleben & Meyer, 2014). The following picture provides a descriptive process of production of RAP aggregates.

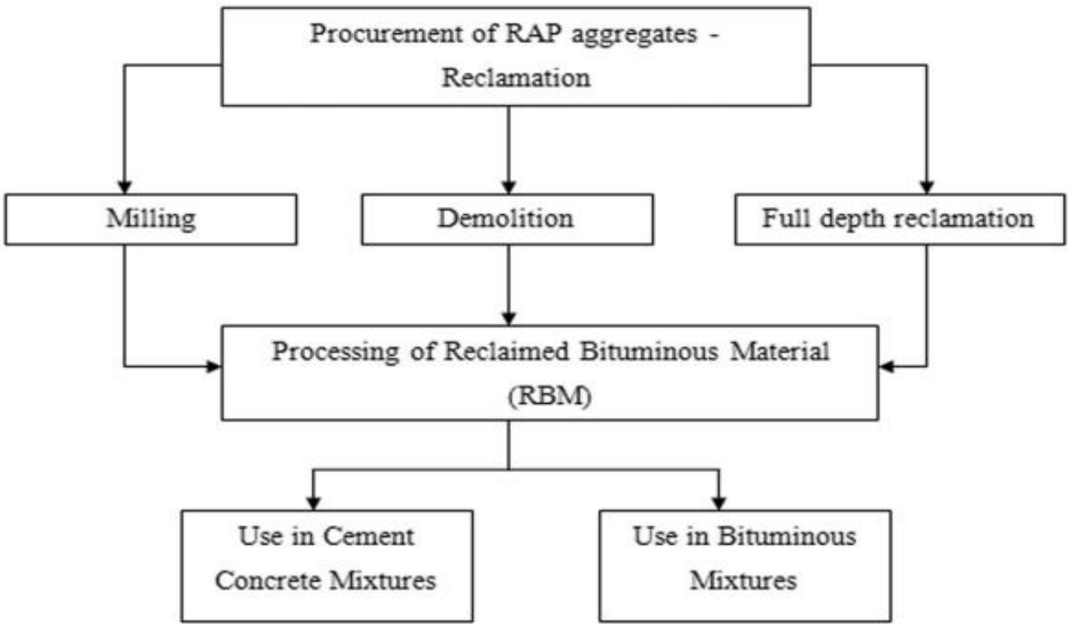

Fig 10: RAP Production Flowchart

Reclaimed Asphalt Pavement (RAP) material is primarily made up of asphalt concretes that have been recovered from existing infrastructures, with some leftover or rejected mix materials from the manufacturing process. Because it is made up of two valuable non-renewable resources, bituminous binder and aggregates, its careful application can guarantee the long-term viability of asphalt pavement construction and reducing the addition of non-recyclable materials in the infrastructure.

Crumb Rubber Modified Bitumen

Crumb rubber modified bitumen (CRMB) is a specialty asphalt binder that improves the functionality of asphalt pavements by combining recycled rubber from old tires with regular bitumen. This environmentally friendly method increases road durability and safety in addition to recycling waste materials. It is especially beneficial for road surfaces in areas with extreme weather since it has various advantages, including higher elasticity, increased elasticity against cracking, and increased resilience to temperature changes. The use of this bitumen in building and maintaining road infrastructure has grown in popularity as an economical and environmentally beneficial alternative, resulting in more robust and long-lasting transportation networks(Presti, 2013).

“Waste tire treatment is a worldwide problem that requires increased attention to the recycling process and resultant reuse of materials. The main factors in comprehensive utilization of waste tires include derivative fuels, renovation of waste tires, production of recycled rubber, thermal decomposition, production of vulcanized crumb rubber (CR), and civil engineering materials. Until recently, the main treatment of waste tires involved direct landfilling and burning, which has led to severe soil and air pollution. Waste tires for tire-derived fuel in the United States accounted for 54.1% of its annual production of waste tires in 2007; this amount was decreased slightly to 43% in 2017. In Brazil, waste tires are used chiefly to produce fuel, the emissions of which contain large amounts of toxic substances”(Wang, Wang, Tseng, Huang, & Li, 2020).

i. A case study in China by (China Industry Information Network,2018)

The largest tire manufacturer in the world, China is a tire production powerhouse. The size of the nation's tire business, which yearly produces millions of tires for both home and foreign markets, is what makes it so distinctive. From passenger car tires to commercial and specialized tires, Chinese tire manufacturers provide a wide selection of tire kinds. China has become a popular global destination for tire consumers looking for affordable solutions due to their competitive pricing. Numerous Chinese tire businesses have responded to criticism of the industry's quality and environmental practices by investing in research, innovation, and sustainability practices to improve product quality and lessen environmental effect. In general, China's tire industry dominates the worldwide market and offers consumers a variety of tire options. A figure and comprehensive analysis done by China Industry Information Network below provides a complete data on waste tire recycling archives since 2011.

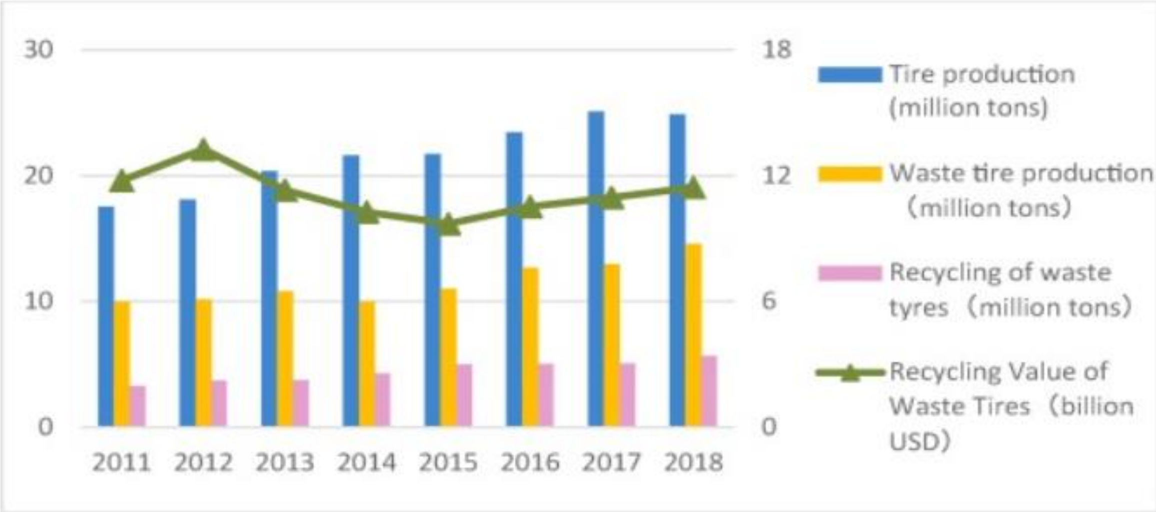

Fig 11: Tire production and recycling in 2011-2018

(China Industry Information Network,2018)

A total of 172.82 million tons of weight were manufactured between 2011 and 2018, of which 4.493 billion were new tires and 96.41 million tons were garbage tires. However, only 35.87 million tons, or 37.2%, of the waste tires were recovered, which resulted in waste tire accumulation and serious environmental problems. Annual waste tire output has grown, yet recycling of these tires has lagged far behind. Therefore, it is essential for environmental protection that more sophisticated methods of recycling these used tires be developed.

ii. Recycling methods used in China.

In order to remove valuable elements and lessen the impact on the environment, mechanical and thermal processes are typically used in China's tire recycling techniques. Mechanical shredding is a popular strategy that reduces used tires into smaller pieces for subsequent processing. To recover steel, textile fibres, and rubber fragments, these shred materials are subsequently separated and treated. Rubber tiles and matting can be made from the rubber scraps after further processing. China has been researching thermal technologies like pyrolysis, which may turn waste tires into valuable resources like oil, carbon black, and steel, in addition to mechanical techniques(Singh, Kumar, Gupta, Chauhan, & Chauhan, 2013). These tire recycling techniques in China support the sustainable use of resources and lessen the environmental impact of tire disposal, in line with the nation's emphasis on environmental conservation and resource efficiency. A figure and comprehensive analysis done by China

Industry Information Network below provides a complete data on utilization of waste tires through different methods.

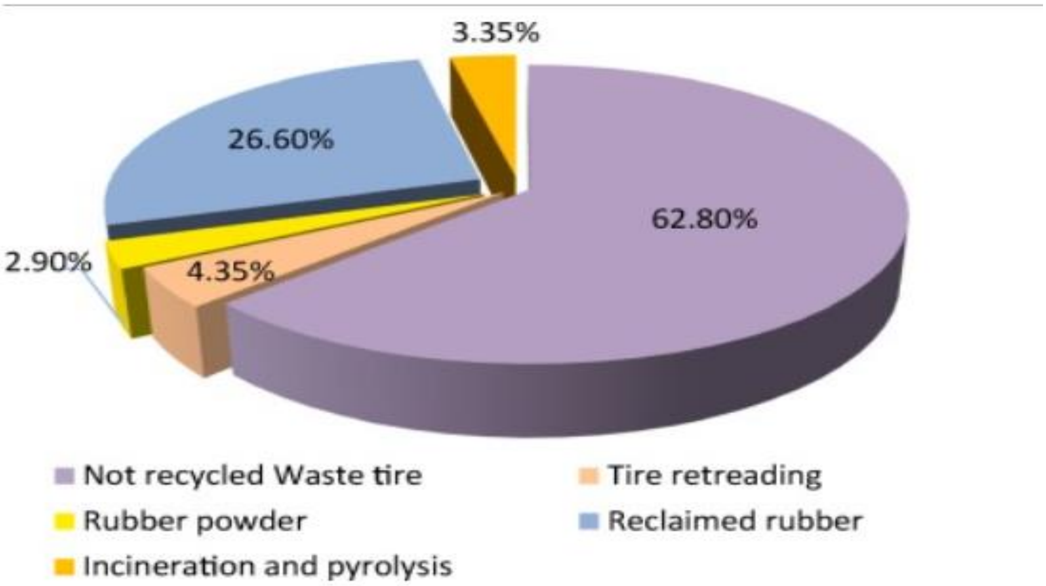

Fig 12: Utilization of Waste tires

(China Industry Information Network,2018)

The figure demonstrates that waste tire recovery is mostly utilized for tire retreading and to create rubber powder and reclaimed rubber. The utilization rate of rubber powder, the method with no secondary contamination, is now 2.9% due to the low practical performance of recycled and reused products. Furthermore, the recycling rate for used tires peaked in 2015 at roughly 45.9%. Only 150,000 tons of modified asphalt were created out of the 350,000 tons of rubber powder produced, making up 42.86% of CR's total output. The government and industry need to place a strong emphasis on reusing scrap tires in order to handle the massive recycling problem.

2.5 Conclusion

The literature review provides a brief understanding of sustainability in modern day Engineering and its importance in fostering carbon free environment for all the living beings. The section starts by establishing the definition of sustainability along with the expectation of how it affects the Environment in general. The section highlights the process involved in manufacturing and production of recycled plastic in modern day operation. The cost implications of recycled plastic as supported by many research papers signifies the process a really expensive procedure and insist on finding alternative regarding its use and management. Along the literature review of research materials regarding sustainability and recycled plastics, it plays an important role in road construction industry. Different Studies done through the years around the world on use of recycled plastics in road construction has become apparent and has contributed enormously to the reduction of use of non-recyclable materials in road infrastructure in general and sand replacement for concrete. A snapshot of different plastic waste and their respective contribution as a substitute in the construction industry for infrastructure development and maintenance has been included to cement a better understanding of their progress in modern day Engineering. Following the use of recycled plastic in road infrastructure, a cost benefit and durability analysis study is included for the comprehensive understanding of its importance in modern day evaluation of progress made in construction industry in Australia regarding waste management and low carbon emission.

2.6 Research Questions

Based on the findings from the extensive literature review and addressing the key objective of the thesis, this research aims to answer the urgent inquiry: "How can sustainable engineering principles be effectively integrated into the use of recycled materials in building infrastructure to reduce environmental impacts while improving efficiency and accessibility?" as the need for sustainable practices in engineering continues to gain prominence. To address the growing issues of urbanization, environmental deterioration, and energy consumption, this study question is crucial to limit the consequences of using excessive carbon emission to the environment. The development of environmentally sound, energy-efficient, and socially inclusive construction practices is possible with the help of sustainable engineering. This study intends to offer insights into creative approaches for reinventing Australian constructing industry to incorporating recycled materials for building infrastructure and challenging conventional route of using non-recyclable materials, ultimately resulting in more resilient, cleaner, and accessible cities by examining the delicate relationship between sustainable engineering techniques. Before the methodology process for this particular research were established, a series of research question were articulated primarily for studying the structure and key findings of the project.

Research Element	Hypothesis	Research Question	Analysis
Analysis of Recycled materials	The use of recycled materials in Modern day construction is vital for sustainable Environment.	What benefits does recycled materials has on building infrastructure?	Quantitaive: Literature reviews and study of previous results.
Recycle plastic and Glasses	It requires urgent attention and incorporating them into construction practices reduces carbon footprint and reduce landfill.	Which infrastructures are best suited for using recycled materials with minimum effect to their performance?	Tabulation and bar graph.
Benefits of using recycle materials.	As long as the use of recycling materials meet the standards, it should be endorsed.	What are the challenges that occurs during the use of recycling materials in a project?	Quantitaive: Literature reviews and study of previous results.
Benefits of using recycle materials.	It is important to invest as much as possible in recycling to avoid climate catastrophe.	What are the long-term cost implications for maintain and operating recycled infrastructure?	Tabulation and bar graph.
Benefits of using recycle materials.	Every infrastructure around the world may incorporate recycle materials to minimize carbon emission.	What potential risk are associated with using recycled materials for high load bearing infrastructures?	Quantitaive: Literature reviews and study of previous results.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

This section of this thesis specifies the methods used to collect and analyse the data that is specific and relevant to this particular research project. In order to successfully obtain desired information, the methodology was developed in the consultation of my supervisor, Dr David Thorpe. The key aim for this project remains to evaluate the sustainable Engineering Infrastructures existing within Australia. The first step in this research project was studying the existing construction practices in Australia through multiple literature reviews and deciding on a specific area that accelerates Sustainability among Engineering Infrastructure. With multiple meetings and consultations with my project Supervisor, this project was done to evaluate the impacts of recycled materials on the use of construction and maintenance of roads and other major works. All the data and information used through the course of this project were provided from Transport and Main Roads Queensland (TMR) and Cairns Regional Council (CRC).

3.2 Ethical Statement

Due to time and Travel Constraints, obtaining the permission of the UniSQ Ethics Committee for Human Ethics Clearance to actively approach and involve relevant delegates in this research project was not feasible. All the primary data and information were obtained through the means of credibility letter from the university as a part of the research project and contacting the respective authorities in the department. To meet the research objectives and fulfilling the set standard for the comprehensive work for the project, multiple data and information were used for analysing the effectiveness of recycled materials in building road infrastructure and driving sustainable Engineering forward.

3.2.1 Introduction

As an Engineering student, it is important to understand every project one wish to undertake or work on requires credibility to create Engineering Solutions for a sustainable future. Different codes are introduced by Engineers Australia to ensure that proper requirements are set for any professionals to understand and must abide by these Standards to establish proficiency and professionalism at all levels. As a guide to code of ethics set by Engineering

Australia regarding Engineering Practices, one should abide by the following disciplinaries regulations to seek and disclose information under proper supervision.

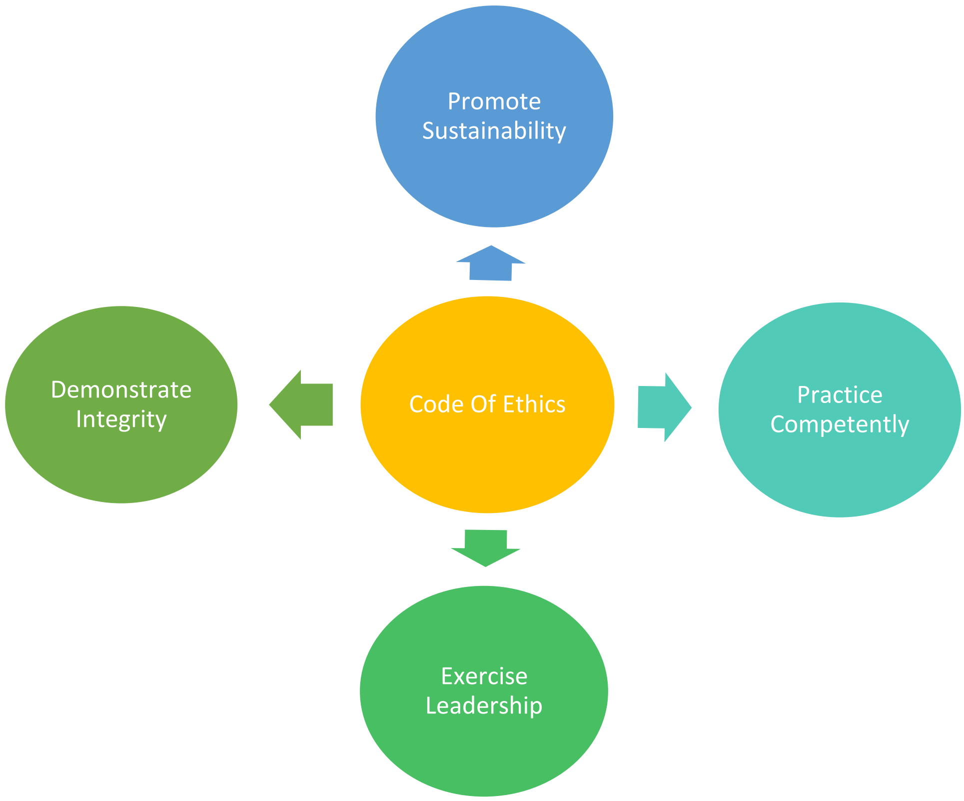

Fig 13: Engineers Australia Code of Ethics Flowchart

This flowchart is established to provide a framework for conducting professional practices for all members of Engineers Australia. While these guidelines are not limited to an exclusive framework for all Engineering situations, it is necessary to work within the jurisdictions of these ethics to adhere with disciplinary regulations.

3.2.2 United Nations Sustainable Development Goals

The Sustainable Development Goals, commonly referred to as the Global Goals, are often described as an international call to action to eradicate poverty, preserve the environment, and guarantee prosperity for all people by the year 2030. They were included in the 2030 Agenda for Sustainable Development, which was endorsed by all of the UN's member states in 2015. The Sustainable Development Goals are a collection of 17 ambitious, interconnected goals that address 169 different social, economic, and environmental challenges. These objectives are interconnected and acknowledge the need for policies that address climate change, reduce inequality, promote economic growth, enhance health and education, eliminate poverty and other forms of deprivation, and safeguard the environment. It is a global framework for solving some of the most important issues facing the globe, with a focus on the idea that no one should be left behind. Collaboration and action are needed at all levels, from businesses and governments to civil society and individuals, to achieve these sustainable goals. The goals cover majority of problems that exists in the modern world and therefore requires immediate attention to ensure necessary steps are taken.

Fig 14: (United Nations Sustainable Development Goals, 2016)

Engineering is closely connected to the Sustainable Development Goals in a number of ways. Even though some of the development goals objectives are met by the collective effort from all the relevant authorities and policies but majority of the goals can be addressed through sustainable engineering practices. In order to address the most critical sustainability concerns facing the globe, engineers must use their technical knowledge, creativity, and problem-solving abilities to find sustainable solutions for modern problems. Fundamentally, engineering is crucial in tackling many of the issues mentioned in the United Nations, from increasing access to clean energy and water to creating robust and sustainable infrastructure. In order to help achieve these global sustainability goals and build a more just and sustainable future, engineers have a special opportunity and obligation to achieve the milestones.

3.2.3 Sustainable Engineering Ethics

Engineering research in Sustainability requires involvement of human participants and any project with the involvement of participants excluding UNISQ stakeholders must obtain approval from the Human Research Ethics Committee. As set by the project guidelines and Ethics Board from the University, no research can take place without Ethics Clearance. For this particular research and obtaining relevant information regarding the completion of the project, a brief discussion with the project supervisor, it was concluded that the relevant information was to be collected through a request to use a data from record with necessary details to disclose relevant data. On doing so, the relevant data and information were provided from the respective government entities. This exchange of information through email made it possible to avoid human participants and made data readily available for use. However all the data being used and that will be used in the future will strictly be conducted under the Code of Ethics.

3.3 Detailed Approach

To achieve the aims and objectives of this thesis project, the following steps shall be taken to foster the comprehensiveness of the work involved in this project.

1. Identify the sustainable road infrastructure within the local and state level government premises to ensure the data and information are readily available for use. This will include communication with the support staff and relevant authorities to assist with further processes. With the help of project supervisor and aim of the research program, determine whether there is any necessity for the technical knowledge to assist with the due process forward.

2. Once the data and information are obtained, proper analysis through screening and consultation the supervisor will be conducted to ensure that it meets the project objectives. It is important to understand that this infrastructure is required to both deliver service and meet environmental, economic, and social requirements at all life cycle stages.

3. Once the primary data and information are divided into different categories and subcategories for life cycle evaluation, a thorough assessment will be conducted on the material properties, benefit, and cost effectiveness to highlight how the selected infrastructure meets the environmental and social requirements.

4. After obtaining all the information from the assessment above, a general life cycle evaluation model approach will be developed to review and evaluate the challenges and reward for a selected type of infrastructure from a sustainability perspective.

5. Conducting research in various types of life cycle evaluation model will be conducted and compared to distinguish different attributes required for the selected infrastructure. It is

paramount to understand a clear and comprehensive model provide profound understanding of the outcomes and will assist with the room for constructive feedback from the shareholders.

6. The development of the model helps to navigate the outcomes and open room for future research areas by providing a comprehensive and well thought knowledge regarding the selected infrastructure and its benefits.

3.4 Methodology Design

3.4.1 Research Materials

This research project is based on evaluation of sustainable Engineering Infrastructure and its importance in modern day Engineering. It clearly outlines the sustainable engineering infrastructure that are built using recycled materials and their impact on traditional Australian construction practices. Traditional Construction Practices in Australia has been deeply dependent on non-renewable resources and contributed vastly to carbon emission. Many governments as well as the private companies involved in construction and infrastructure development has not fully aligned with the idea of sustainability till today's date and it has become an alarming issue regarding global warming and carbon Emission. To provide an important insight to the reform and change sustainability can bring in modern day Engineering, it was important and necessary to identify the areas around which is contributing and provide valuable insights to make it even better. Subsequently with the help of Local Council and Transport and Main Roads, this project is heavily focused on the use of recycled materials like plastic, recycled bottles, and Recycled asphalt for building the road infrastructure and the process involved for their maintenance and life cycle evaluation.

3.4.2 Data collection

Before choosing the topic "Evaluation of Sustainability Engineering Infrastructure", a brief discussion with my supervisor about requirements and feasibility of the project, it was argued that it would be best to focus on the infrastructure in the country where the information is readily available for research purposes. Doing personal research and continuous guidance from the supervisor, it was decided that this project would focus on road infrastructure built using sustainability materials used as a substitute for traditional construction practices. So, in order to maximize the chances to collect as much as information for better understanding the project objectives, local Council and Department of Transport and Main roads were the best available entity with the best suited attributes. The proposed data and information required to meet the requirements of the project criteria were gained through respective delegates within the company through email communication and a personal request to use the data from record with necessary protocols.

3.4.2.1 Recycled Glass Primary data

The reuse of recycled glasses in construction of road infrastructure has proven to be one of the most profound findings to help reduce production of non-renewable waste materials. Civil construction companies nowadays use recycled glasses for several applications such as Asphalt, pavement, Non-structural Concrete, and drainage in general. It has well met all the criteria set by the Austroads and is well supported by Department of Transport and Main Roads. These data are readily available through the website of local council and Department of Transport and Main Roads. In this particular dissertation, methodology involved to classify the data collection and evaluation has been obtained from the government website. As this dissertation is exclusively based on evaluation of sustainable Engineering Infrastructure, it will highlight the evaluation of material properties used in construction industries and their life cycle analysis. The primary data collection obtained through the Cairns Regional Council provides an understanding of how recycle glassed played an important role in driving sustainability forward into Engineering.

In the construction of roads, recycled materials can be utilized to replace conventional (sometimes non-renewable) materials or to enhance the qualities of conventional materials (for instance, fly ash used as a partial cement replacement in concrete or pavement stabilization). There are many different types and suppliers of recycled materials, all of varied quality and consistency. Not all recycled materials can be used to build roads. Frequently, recycled materials are garbage. With some materials requiring substantial processing to assure their compatibility with other operations. Properties can be recycled or used again as roads. Transport and Main Roads specifies the requirements for recycled materials and their use. technical requirements. These specifications are meant to guarantee that recycled materials work to the same as or better whilst meeting the standard of AS/NZS. The following picture provides the different size distribution of recycled glass aggregate that the Cairns Council has produced between 2021 and 2022.

Fig 15: Particle Size Distribution along Sieve Aperture

(Cairns Regional Council, 2022)

Throughout the whole manufacturing process, the manufacture of recycled glass aggregate is under constant observation. To ensure quality, this procedure includes testing the material using a sieve for consistency in the product and daily visual checks for impurities, sharpness, and other defects. The recycled aggregates are sampled from time and again into the testing laboratory to ensure that the specified requirements are met before deploying them to the site. All requirements are tailored in according to the chemical composition and specification set by Transport and Main roads. The following table provides an understanding of how the with the specifications. material properties are set by their properties in accordance with the specification set by the TMR.

	Result (5 most recent*)		MRTS36 Specification
Property Tested	**CRS Glass**	**MRF Glass**	**Maximum Average** (5 most recent)
Electrical Conductivity (µS/cm)	520	488	1000
Arsenic (As)	0.1	1.4	10
Cadmium (Cd)	0.1	0.3	0.5
Chromium (Cr)	3.0	4.2	20
Copper (Cu)	1.5	8.4	40
Nickel (Ni)	1.6	3.2	10
Lead (Pb)	0.6	20.1	50
Zinc (Zn)	38.2	24.2	100
Molybdenum (Mo)	0.0	0.0	5
Mercury	0.0	0.0	0.5
Total Organic Carbon	0.10%	0.52%	1%

*Test results to January 2022. -mg/kg 'dry weight' unless otherwise specified.

Fig 16: Recycled plastic components along with TMR specifications.

(Cairns Regional Council, 2022)

A sample of quality control of material report is provided below to justify the requirements set by the clients and government regulations are met by the materials used in the construction process.

GEOTECHNICAL

23 Knight Street
Cairns Qld 4870

Quality of Materials Report

Client:	Cairns Regional Council	Report Number:	GT19-004- CS43590 Q
Client Address:	PO Box 359, Cairns QLD 4870		
Job Number:	GT19-004	Report Date:	25/08/2021
Project:	Various Job Projects	Test Request No:	-
Location	Cairns Region		
Lab No:	CS43590	Sample Location:	Sample 1 Recylced Concrete & Glass
Date Sampled:	Rec19/08/2021		
Date Tested:	24/08/2021		
Sampled By:	Client		
Sample Method:	As Received		
Material Source:	As Supplied	Spec Description:	-
For Use As:	-	Lot Number:	-
Remarks:	Sample tested as received, this report does not endorse sampling.	Spec Number:	-

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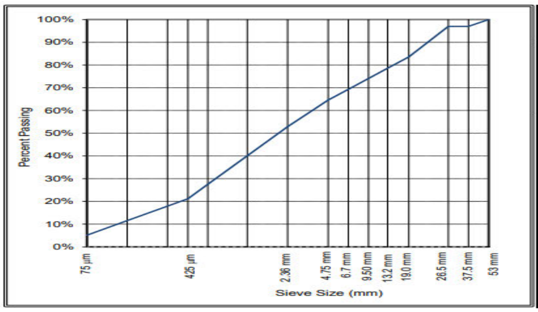

Particle Size Distribution
Test Method Q103A

A.S.	Specification -		Result
Sieve Size	Specification Minimum	Result % Passing	Specification Maximum
53mm	-	100	-
37.5mm	-	97	-
26.5mm	-	97	-
19.0mm	-	84	-
13.2mm	-	78	-
9.5mm	-	74	-
6.7mm	-	68	-
4.75mm	-	65	-
2.36mm	-	53	-
0.425mm	-	21	-
0.075mm	-	5.1	-

Fig 17: Geotechnical Report of the different Sieve aggregates

(Cairns Regional Council, 2022)

i. Safety Issues

There are several potential concerns associated with employing crushed recycled glass on site from an OH&S perspective. The handling of glass particles and breathing in glass dust are prone to pose these dangers. Glass dust is an inert nuisance dust that has no substantial biological effects, but it may interfere with personal comfort. Contractors working on the trial site noted that it produced less dust than other materials typically used, although it is nevertheless advised to hose down stockpiles and demand that it be provided damp to reduce dust generation. Additionally, handling crushed glass fines has the same risk of skin wounds as handling regular crushed building stones. But because of its abrasive nature, shattered glass can cause more skin irritation and eyes related problems. The same protective precautions that apply to naturally crushed aggregates and are typically specified in the Material Safety Data Sheets for all supplied materials can be used to reduce the OH&S risks associated with handling crushed glass and handling airborne glass dust.

3.4.2.2 Crumbed Rubber

A specialized asphalt binder used in paving and road construction is called crumb rubber-modified (CRM) binder. It is created by mixing regular bitumen (asphalt) with finely crushed tire-recycled crumb rubber. Crumb rubber is added to bitumen to improve its qualities, making it more resilient to aging and cracking, flexible, and durable. It's also known as rubberized asphalt**.**

FIG 18: Crumb Rubber in CRM Binder

(Department of Trasport and Main roads, 2020)

The end-of-life tyre rubbers has been used in pavement construction for an extensive time in Australia and proved to be viable with its properties that helps in strengthening the durability of the road. Due to the potential it gives to enhance the performance of asphaltic mixes and the potential solution it offers to reduce waste tires in landfills, usage has recently increased(Presti, 2013). Rubber crumbs can be added to the asphaltic mix as aggregates (dry process) or blended with bitumen at a particular temperature to act as a binder modifier (wet process). It has been demonstrated that adding crumb rubber through the wet process can enhance the resilience modulus, fatigue cracking resistance, and rutting resistance of asphaltic mixtures(Ibrahim et al., 2013). This is because the bituminous binder's properties, such as its viscosity, softening point, and loss modulus, have changed. The process by which rubber particles swelled after interacting with bitumen controls the improvement. Due to the bitumen's maltene component being absorbed, rubber fragments have been known to grow up to three to five times their original size. As a result, the amount of asphaltenes in the binder increased, which raised its viscosity. The properties of crumb rubber-modified binder are extremely sensitive and heavily influenced by the mixing process, which depends on both internal and external variables, including the bitumen type, the amount of crumb rubber, the size of the particles, and the type(Jamal & Giustozzi, 2020). The secret to good production is accurate processing variable selection.

Specification		Application
MRTS11	*Sprayed Bituminous Treatments (Excluding Emulsion)*	Sprayed sealing
MRTS18	*Polymer Modified Binder (including Crumb Rubber)*	Binder manufacture and supply
PSTS112	*Crumb Rubber Modified Asphalt*	Gap graded and open graded asphalt

FIG 19: Crumb rubber specifications.

(Department of Trasport and Main roads, 2020)

i. Key Benefits

Particularly in regions with considerable temperature fluctuations, high traffic volumes, or where sustainability and environmental considerations are crucial, the use of crumb rubber Modified binder has grown in popularity in road construction and maintenance. It offers an economical and environmentally responsible way to increase the functionality and lifespan of road surfaces. To ensure the effective application of Crumbed Rubber in road projects, it is crucial to adhere to industry standards and quality control procedures set by Queensland Transport and Main Roads**.** Some of the key benefits can be explained by using a chart below.

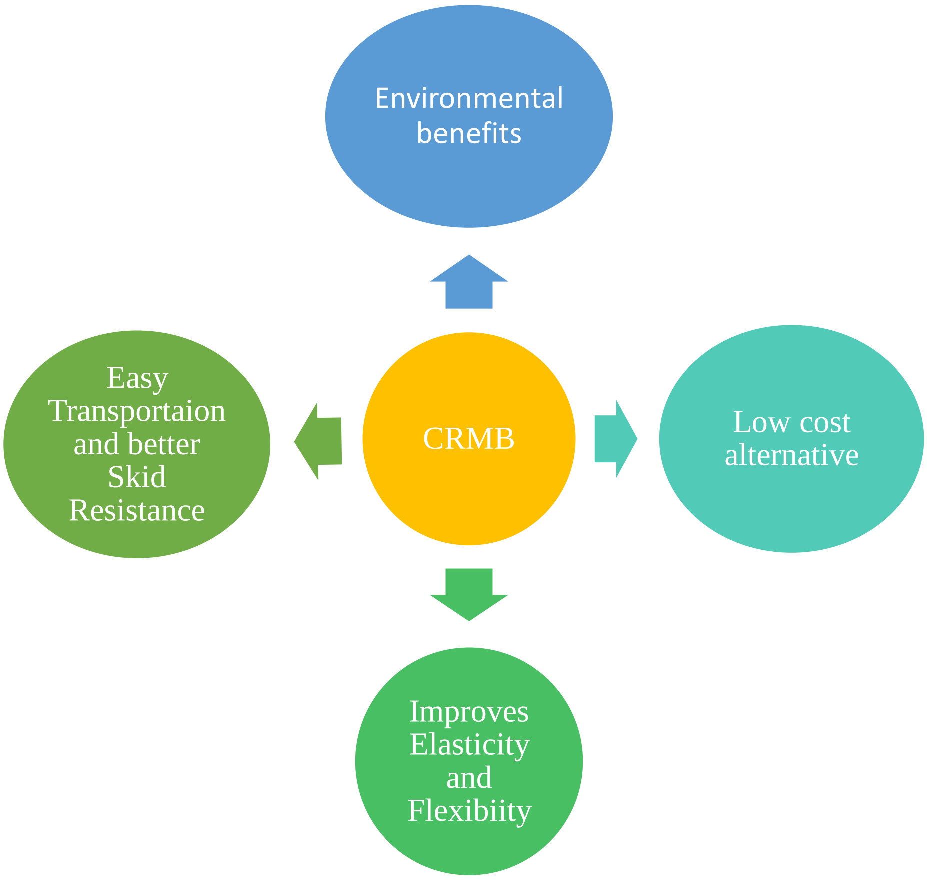

Fig 20: Crumb Rubber Modified Bitumen Chart

A number of important advantages are provided by crumb rubber modified bitumen (CRMB) in the construction and maintenance of roads. It improves the toughness and functionality of road surfaces by mixing recycled tire rubber into the bitumen. The rubber particles make the material more elastic and resilient, which increases its resistance to rutting, weather-related damage, and cracking, extending the lifespan of the road. It also lessens noise pollution and skid resistance, making roads safer and quieter. Additionally, by keeping these materials out of landfills and lowering the demand for non-recyclable bitumen, the use of used rubber tires in road construction helps environmental sustainability by lowering resource consumption and carbon emissions. In general, CRMB corresponds with eco-friendly techniques and enhances road quality and longevity, making a sustainable choice for building infrastructures.

3.4.2.3 Reclaimed Asphalt Pavement (RAV)

Fig 21: Reclaimed Asphalt from a Construction Site

(Department of Trasport and Main roads, 2020)

Reclaimed Asphalt Pavement (RAP) is a recycling strategy applied to road building and maintenance that involves reusing and repurposing old asphalt components for a long period of time as a part of Waste Management plan in Queensland, Australia. It is a sustainable and economical method that raises the efficiency and durability of asphalt pavements while reducing waste and conserving natural resources(Ibrahim et al., 2013). The following picture provides a list of specifications for the use of reclaimed Asphalt Pavement in accordance with Austroads and Transport and Main Roads.

Specification		Application
MRTS05	*Unbound Pavements*	Unbound pavement materials
MRTS07B	*Insitu Stabilised Pavements using Cement or Cementitious Blends*	Stabilised pavements Note – these specifications refer to MRTS05 *Unbound Pavements* for recycled material requirements
MRTS07C	*Insitu Stabilised Pavements using Foamed Bitumen*	
MRTS08	*Plant-Mixed Heavily Bound (Cemented) Pavements*	
MRTS09	*Plant-Mixed Pavement Layers Stabilised Using Foamed Bitumen*	
MRTS10	*Plant-Mixed Lightly Bound Pavements*	
MRTS30	*Asphalt Pavements*	Asphalt
MRTS32	*High Modulus Asphalt (EME2)*	
MRTS102	*Reclaimed Asphalt Pavement Material*	

Fig 22: Reclaimed Asphalt Specification Table

(Department of Trasport and Main roads, 2020)

i. Key Benefits

The key objective of the recycled materials used in the construction industry is to find an alternative to non-recyclable materials and to manage the harm that traditional aggregates bring to the environment in the long run. Several benefits brought with the use of recycled waste materials has taken new heights into the world of engineering and sustainability is imagined possible to some extent. Few of the benefits that can be obtained using the recycled Asphalt Pavement can be understood by using the chart below.

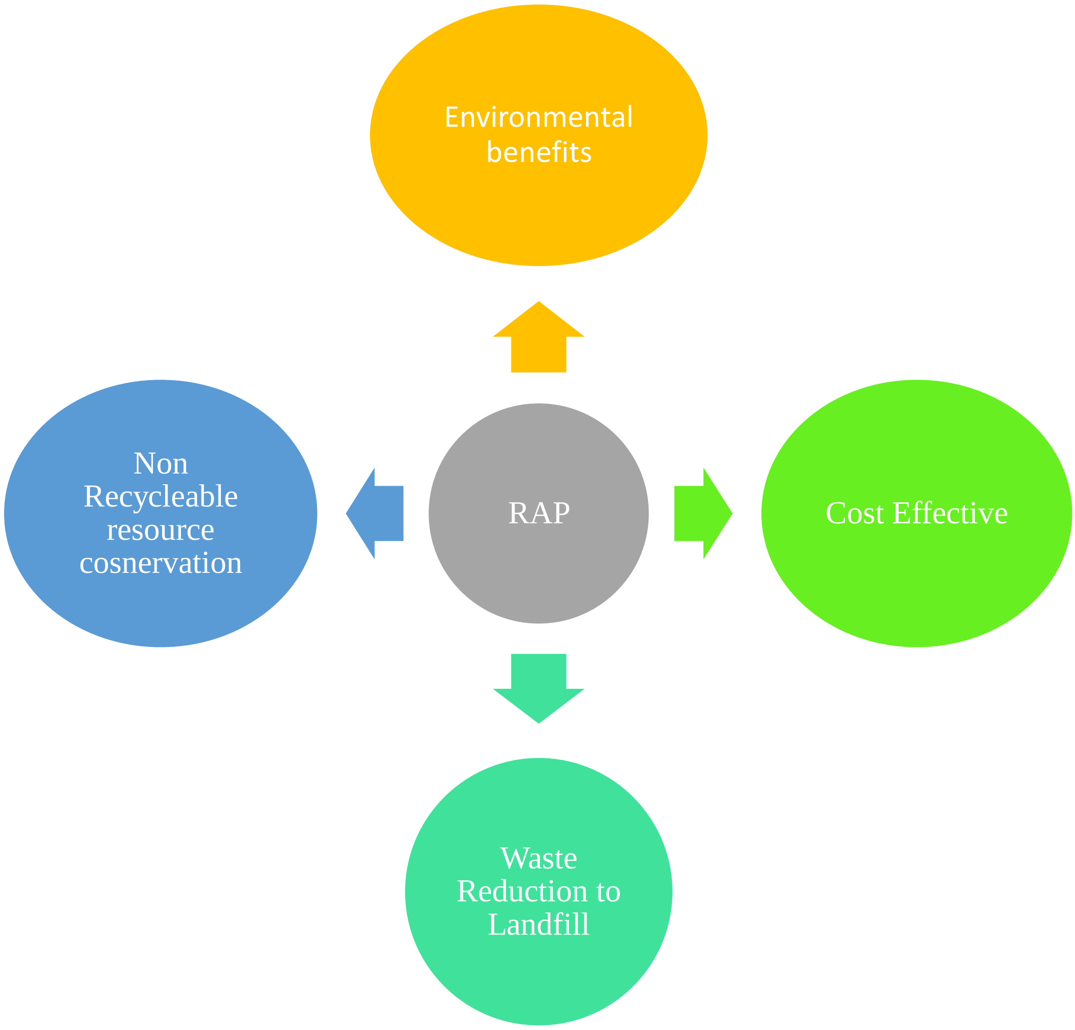

Fig 23: RAP Benefits Chart

The use of the reclaimed Asphalt Pavement (RAP) in modern day Engineering has taken new heights in the area of road construction in Australia. Government's initiative to promote sustainability and reduce carbon emissions in the environment accelerates the use of recyclable materials in building infrastructures such as road. The chart above describes the key areas in which reclaimed asphalt Pavement plays an important role from maintaining eco-friendly environment to reducing waste in the landfill. It has a number of numerous advantages for building and maintaining roads. In order to reduce the demand for new raw materials and waste, RAP recycles and reuses asphalt components from old pavements that requires replacement or reconstruction(Emersleben & Meyer, 2014).

This method is both environmentally friendly and cost effective as well. This ultimately helps to reduce the carbon impact of road developments and preserves non-recyclable natural resources in the long term for future generations. Apart from this, it also aids in enhancing the quality and endurance of roads because it frequently includes well-aged asphalt that can boost the effectiveness of fresh mixes. Over time, its use may result in smoother roads and lower maintenance expenses. Additionally, the addition of RAP to asphalt mixtures can reduce costs significantly, making it a financially sound option for the construction of sustainable road infrastructure. These benefits as described above clearly aligns with the idea of obtaining sustainable goals for the benefit of the environment. It requires extensive effort to meet the objectives of achieving net zero carbon emissions and using recyclable materials in the field of Engineering infrastructures lays out a solid foundation for making a change in modern day construction.

3.4.3 Conclusion

The methodology section of this part of the report makes a comprehensive analysis on the summary and reflection of different methods used for introducing and analysing data and their benefits in a coherent manner. As described in the methodology above, majority of data are obtained from the government official website with formal consent from the respective delegates and information are then categorised accordingly. The key purpose of this dissertation is to conduct a thorough investigation of how sustainable infrastructure plays an important role in Engineering and challenges that occurs whilst replacing traditional non-recyclable materials with the recyclable materials. As described in the section above, different recycled materials used in road construction industry have different roles to play. Before undertaking any project, the rigorous assessment and validity of the project are researched well to establish the faith that the material used in the process are meeting the specifications and brings the necessary benefits to it. The methodology used in this project brings justification in many ways for the authenticity of the evaluation of the infrastructure regarding sustainability. Firstly, the data and information obtained reflects validity, relevance and easily available through the official website of the relevant government officials. This guarantees that the data and information used for different methodology analysis are totally aligned with the objectives mentioned in the project specifications and respective expectations are met.

3.4.4 Ethical requirements and Limitations

It is important to understand that the project is well based on the ethical requirements set by the University of Southern Queensland for any attainment of data and information required for the completion of the project. Whilst obtaining the data, it was ensured that all the information strictly mentioned and disclosed in the process are well presented in a matter to ensure the agreed confidentiality are well covered. Apart from this, the methodology also adheres with the ethical requirements set be the Engineers Australia to ensure that the project reflects competency, integrity, leadership, and sustainability as in whole to educate the importance of sustainability in Engineering.

The methodology used in the section covers majority of the information required for the evaluation of sustainable engineering infrastructure but is limited to certain extent critically. Research transparency and Credibility has been fully achieved in all aspects of the recycled materials used in the process but were restricted to certain sample sizes and data collection methods. It is imperative to say that the method used in obtaining the results used in the methodology section will not be viable for all soil types and road infrastructure expansion in different parts of the country. This is merely due to the geographical arrangement, population density, weather condition and traffic intensity in the respective areas. All these factors play a critical role in determining the nature of the road from designing, construction and maintaining the infrastructure in the long run. Several restrictions should be acknowledged despite the careful methods used in this process through Queensland government to drive sustainability forward. Although measures were made to guarantee feasibility and promote sustainability engineering, we are aware of the possibility of the potential drawbacks achieved respectively. Future studies might consider using several methods approaches to provide a more extensive exploration of the matter. Despite these restrictions, the study's findings offer insightful knowledge about the evaluation of sustainable Engineering infrastructure and open doors for further research in the future.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

After careful consideration of literature review along with constant guidance and comments from supervisor, this project was intended to provide a comprehensive understanding of how Sustainability plays an important role in driving our focus in Net zero Emissions through every possible way. It is important that Engineers as a whole should think about bounding with the code of ethics set by Engineers Australia to find solution to problems that benefits society more than in one way. The report above clearly demonstrates that the use of recycled glass as a substitute for road construction and concrete has been done in a government funded sectors. To achieve the ultimate short term and long-term goal, every sector needs to heavily invest in using alternative resources for infrastructure expansion and innovation. Whilst doing so, recycled crushed glass used in construction has brought many benefits from Environmental stewardship to conservation of natural resources for the future generation. Be it mitigation against climate change or regulatory compliance, it is important to understand that considerable about of thought needs to be put into making human civilization easy and reducing environmental impact and improving efficiency. Local and state level government taking an important role in investing heavily in road construction using recycled plastic and other non-recyclable provides a strong testament in bringing exclusively more private companies and investors in promoting sustainable infrastructure in other areas of Engineering.

Stage 1: Recycled plastic and Glasses as aggregate Substitutes

Recycled glass and plastic alternatives are essential for tackling urgent societal and environmental problems around the world in a comprehensive way. They help to minimize the depletion of natural resources, the energy and carbon gas emissions produced during production, and the pollution brought on by conventional construction techniques that exist in Australia and around the world. These eco-friendly options encourage a more responsible and circular approach to materials by diverting waste from landfills and seas, which helps to create a cleaner, healthier environment and meeting sustainable goals. Further highlighting their importance in promoting environmental resilience and economic prosperity are the financial gains and employment creation linked to recycling and sustainable materials. Ultimately, we move meaningfully closer to a more sustainable and environmentally sound future by using recycled glasses and investing on plastic alternatives for sustainable future. From the methodology and project objectives, a decision matrix is adopted to understand the feasibility of recycled infrastructure as compared to conventional one.

(With 1 to 5, 5 being the best)

Items	Environmental impact	Cost Effectiveness	Econmoic Viability	Social Equity	Workability and Feasibility	Total Score (%)
Traditional aggregates	1	4	3	3	5	64 %
Recycled aggregates	5	4	4	5	3	92%

Traditional Aggregates = ((1+4+3+3+5)/25) *100% = 64 %

Recycled Aggregates = ((5+4+4+5+3)/25) * 100% = 92 %

A decision matrix can be used to compare and assess various possibilities in relation to a set of criteria. It is a useful tool in sustainable engineering for assessing and choosing eco-friendly solutions and procedures. It enables engineers to methodically assess multiple sustainability criteria, including environmental effect, resource efficiency, social acceptability, and economic viability. Decision matrices help in choosing the best sustainable alternative by scoring and weighting these criteria. Decision matrices assist in ensuring that engineering decisions are made in accordance with the sustainability principles, promoting environmentally responsible and socially beneficial outcomes while minimizing unfavourable environmental and societal impacts. This is true whether choosing renewable energy sources, eco-efficient materials, or sustainable construction techniques. Engineers can make well-informed decisions that help create a more sustainable future with the help of this methodical methodology. In the table above, it is clear that the use of recycled materials in building sustainable engineering infrastructure is far more beneficial as compared to traditional method as it clearly demonstrates the benefits society receives in the long run of the project.it is important to understand that even though the idea of sustainable infrastructure may not be viable across different areas of the construction but incorporation of its policy does make a difference in making profound decision based on several factors.

Stage 2: Reclaimed Asphalt Pavement

A sustainable alternative, recycled asphalt pavement (RAP) has contributed to encouraging outcomes in the fields of building road in recent studies and proven data mentioned on this dissertation. It lowers the environmental impact of conventional road construction and maintenance by recycling and treating used asphalt materials. This conserves vital natural resources. Recent research and practical implementations have shown that it can perform as well as freshly made asphalt while using less energy and less money during production. More durable and environmentally friendly road infrastructure is one of the outcomes of its use, and this has the potential to advance sustainable engineering concepts in the construction industry. Additionally, the expanding scope of research on RAP keeps advancing technology and best practices, boosting the efficiency and durability of reclaimed asphalt in constructing infrastructures(Coventry, Woolveridge, & Hillier, 1999). From the methodology and project objectives, a decision matrix is adopted to understand the feasibility of recycled infrastructure as compared to conventional one.

(With 1 to 5, 5 being the best)

Items	Environmental impact	Cost Effectiveness	Econmoic Viability	Social Equity	Workability and Feasibility	Total Score (%)
Fresh Asphalt Pavement	1	2	3	3	5	56%
Reclaimed Asphalt pavement	5	4	4	5	4	88%

A decision matrix is extremely helpful in the context of using reclaimed asphalt pavement (RAP) to create roads in order to be environmentally friendly. Due to the fact that RAP entails recycling and reusing previously used asphalt, it is a resource-efficient material. Project planners and engineers can use the decision matrix to compare various use strategies, like recycling rates, production processes, and mixing ratios, against elements like cost-effectiveness, environmental impact, durability, and performance. Decision matrices allow the selection of the most effective and sustainable strategy by giving these criteria ratings and weights. At the end of the day, this methodical evaluation guarantees that RAP is appropriately included into road building projects, accomplishing the double objectives of financial savings, and decreased environmental imprint. This clearly demonstrates that sustainable engineering infrastructure plays vital role in maintaining circular economy by meeting the social, economic, and environmental benefits profoundly as compared to normally built infrastructure.

Stage 3: Crumb Rubber Modified Bitumen

The development of crumb rubber modified bitumen (CRMB), a fundamental advancement in asphalt technology, has led to notable improvements in the durability and performance of roads. Various asphalt qualities have improved as a result of bitumen including recycled crumb rubber made from used tires. The resilience of asphalt is improved by CRMB, making it more resistant to fatigue cracking, rutting, and heat cracking, according to research findings and real-world applications(Presti, 2013). Additionally, by reusing waste materials, the addition of crumb rubber to bitumen not only increases the lifespan of road surfaces but also helps preserve the environment.

The findings show that CRMB not only matches but frequently outperforms the performance of conventional bitumen, demonstrating its potential to completely transform the road construction industry in Australia. Providing long-lasting, high-performing pavements while also addressing environmental issues connected to tire waste will benefit the road construction sector. The success of its applications is likely to further solidify it as a viable and practical option for creating robust and environmentally friendly road infrastructure as this field of study develops(Jamal, Lanotte, & Giustozzi, 2022). From the methodology and project objectives, a decision matrix is adopted to understand the feasibility of recycled infrastructure as compared to conventional one. All these elements of factors used in the matrix are based on the information used from the existing data used for the fulfilment of this thesis and hence few other requirements can be added as required in the future.

(With 1 to 5, 5 being the best)

Items	Environmental impact	Road longevity	Econmoic Viability	Social Equity	Workability and Feasibility	Total Score (%)
Fresh Bitumen	3	5	4	3	5	80%
Crumb Rubber Modified Bitumen	5	3	4	5	4	84%

When using crumb rubber modified bitumen (CRMB) in road building, a decision matrix is an essential tool for maximizing the development of sustainable infrastructure. To reduce waste and enhance the performance and durability of road surfaces, it recycles rubber from tires. A decision matrix helps engineers compare various implementation strategies, such as mixing ratios, temperature tolerances, and effectiveness, with key criteria like environmental impact, route longevity, skid resistance, and overall effectiveness in this situation. Decision matrices help in choosing the optimum bitumen formulations and application techniques, ensuring the longevity of roads, improving safety, and reducing environmental impact. It can be altered to represent the particular requirements and choices pertinent to the choice at hand. You can maintain a disciplined, data-driven approach to decision-making and consistently align project choices with your goals and objectives by employing decision matrices at various points throughout a project. Recycled Materials is essential to modern infrastructure and environmental stewardship because it supports sustainability goals, provides long-term cost savings by prolonging road life, and adds to safer, smoother, and more environmentally friendly road networks.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

From the brief discussion and analysing the data throughout the report for this particular dissertation, a conclusion can be drawn that Sustainability is an important aspect of modern-day engineering to solve problems that lies ahead which is beyond building tall buildings and expanding infrastructure. In essence, sustainability in engineering is not simply a strong idea but it is a critical requirement for the survival of our world and saving the natural resources for better uses in the future. Solutions that maintain a balance between societal well-being, economic prosperity, and environmental stewardship must be developed by engineers by establishing policies and procedures through research and development in the field of Engineering. It is more important than ever to promote sustainability in the face of climate change, resource shortages, and environmental degradation. Sustainable Engineering makes a substantial contribution to creating a more resilient, fair, and environmentally sustainable future for everybody by embracing sustainability concepts and incorporating them into their work.

Sustainability demands individual disciplines and industries and most importantly a team effort from institutions like governments, corporations, local communities, and people themselves. It requires us to find a balance between meeting the needs of the present and ensuring that future generations will be able to do the same. It covers a broad range of opportunities and problems, from preserving finite resources and reducing climate change to promoting social fairness and safeguarding biodiversity. Particularly engineers have an important role to play in establishing a sustainable society through creative ideas and ethical behaviour to ensure that the society is greatly benefited not just from latest advancement in the technologies and infrastructure but also socially and environmentally friendly atmosphere.

During the research and data analysis, some of the key results and discussions where we have uncovered significant discoveries and insights throughout this study that highlight the critical necessity of integrating sustainability concepts into the creation of road infrastructure by using recyclable materials. This research with the necessary data and information confirms the need of lowering resource use, utilized renewable energy sources, and limiting the environmental impact of infrastructure projects through sustainable solution to modern day engineering problems. The negative effects of infrastructure and carbon emission on our world might be greatly reduced with the use of eco-friendly materials, revised and innovative construction methods to mitigate the immediate problems we collectively face today around the world.

Furthermore, the use of recycled glasses as an aggregate in the construction industry and building infrastructure plays an important role in maintaining the circular economy and meeting key objectives set by the United Nations. Reclaimed Asphalt Pavement (RAP) and Crumb rubber used in the construction of the roads enables us to minimize the use of non-recyclable materials whilst reducing waste in the landfill and hence proving to be cost beneficial overall. Few of our findings suggest that the incorporation of recyclable materials in the industry has raised few concerns such as affecting the strength of the materials and not being viable for areas with high traffic volumes. Meaning even though sustainability being an important aspect of modern-day engineering will not be fully incorporated in every aspect of the building infrastructure. The choice of materials, their manufacturing process and limitation within the specifications set by the government will greatly define the extent of advantages of using them in the construction industry. Sustainability is an evolving and broad topic, it has a wide range of possibilities and research scope in the future as we move forward with the progress that is already made in different parts of the world. Few other factors such as Quality Variability, durability, weather implications and required availability can be explored to have a comprehensive understanding of how these can impact the project and their Effectiveness.

The following areas could be looked at for further research purposes:

a. Analyse the infrastructures compressive strength using different plastic materials.
b. Study the effect of weather in recycled infrastructure in the long run.
c. Study the comprehensive performance assessment on efficiency and carbon footprint of recycled infrastructure.

To conclude, it is important to understand the importance of sustainability in modern day engineering and construction industry and the benefits it brings to the society in whole. However, the use of recycled materials in building infrastructures should be carefully monitored through relevant standards and regulations to ensure that the parameters set for the projects are made. Many of these issues associated with the use of recycled materials are being addressed by ongoing research and innovation in the field of environmentally friendly building materials, which will make it more practical and advantageous to endorse recycled plastics in construction industries. Before integrating recycled plastics in concrete projects, it's crucial to carefully analyse the requirements and applications.

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Appendix A Project Specifications

ENG4111/4112 Research project Specification

For: **Bipin Adhikari**

Title: **Evaluation of Sustainable Engineering Infrastructure**

Major: Civil Engineering (Honours)

Supervisors: Dr. David Thorpe

Enrollment: ENG4111 – ONC S1, 2023

ENG4112 – ONC S2, 2023

Project Aim: This project aims to investigate the importance of sustainability in modern Engineering construction methods. It will determine if the use of sustainable products as a substitute for construction materials will meet the required specifications from an Engineering perspective.

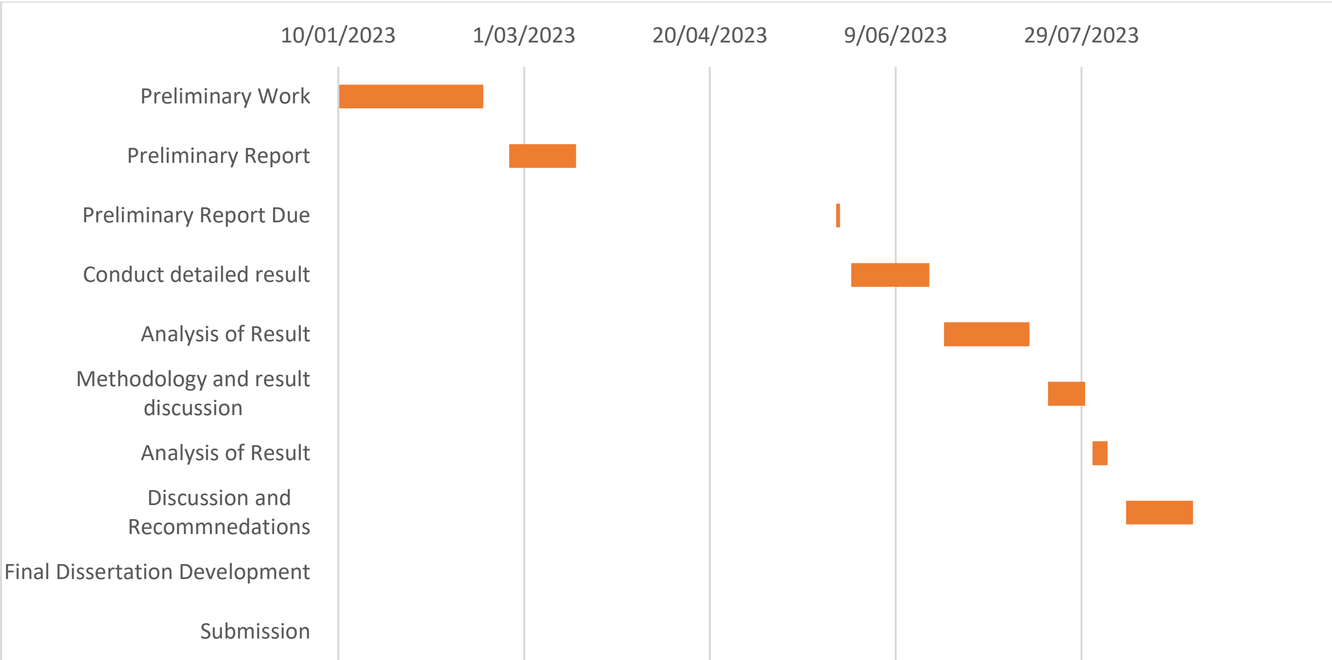
Programme: Version 1, 15th March 2023

1. Conduct an extensive literature review to understand the factors affecting the infrastructure from a sustainability perspective and find any research gap.
2. Review and analyze the important aspects of sustainable engineering and challenges that construction management practices face at different levels regarding sustainability and define them.
3. Research different areas for best selection of sustainable Engineering infrastructure and perform thorough assessment.
4. Evaluate the significant readings and conduct detailed results.
5. Outline the analysis of result through methodology and discussion.
6. Submit an overview of benefit, cost, feasibility, and durability of the selected infrastructure.
7. Report the dissertation in sound and cohesive format.

If time and resource permit:

1. Physically visit construction plants in different locations to obtain practical Engineering Experience regarding Sustainability.

Project Gantt Chart for ENG4111/ENG4112 2023



Resources Required for project completion.

1. University of Southern Queensland Student Liability insurance for possible Site visit.

2. University of Southern Queensland Human Ethics Approval.

Based on the nature of the dissertation and personal research, no other resources can be allocated for the completion of this project at this very moment however there will be clear description of any resources if being used throughout the course of the course.

Appendix 2 Risk Assessment

Likelihood	**Consequences**				
	Insignificant	Minor	Significant	Major	Severe
Almost Certain			2		
Likely			1		
Moderate					
Unlikely					
Rare					

Risk Legend

Low	
Medium	
High	
Catastrophic	

Task Number	Activity	Hazard	Rectifications
1	Working on computer for long hours.	Eyesight and back problems.	Having scheduled breaks and maintaining proper postures whilst sitting on a chair.
2	Writing the project.	Stress and high workload.	Limiting the amount of hour consuming nutritious food and doing Physical exercises and Sports.