THE FEASIBILITY OF A NETWORK MATERIALS UTILIZATION PLAN, WITH AN EMPHASIS ON UPCYCLING OF MATERIAL

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DECLARATION

Supervisor:

As the candidate’s Supervisor I agree/ do not agree to the submission of this dissertation.

Signed …[redacted] (Prof M Mostafa) Date……02 December 2022…

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ABSTRACT

In most countries, the road network is under the jurisdiction of an agency that is state-owned. Road agencies have the responsibility for the management, maintenance and development of the network through careful management of resources taking into consideration the financial obligation to manage public funds. Kasim et al. (2005) quantify that the cost to manage materials can range from 30-80% of the total construction costs. Because these costs are so high, they can determine the winning bidder. This gives rise to the need for the agency to reuse materials to their full potential and ensures the optimal salvage value of each material. The fall back design approach is to down cycle materials by recycling the existing pavement layers into lower-value layers. This design approach becomes questionable when the road agencies have a responsibility to optimally reuse the agency's current assets. Due consideration of the financial obligation to manage public funds underpins the need to upcycle.

Materials from the existing layer and materials required from external sources are managed in the Materials Utilisation Plan. The aim of the research is to investigate the opportunities of upcycling in a Materials Utilisation Plan. The objective of the research is to determine the factors influencing the specification of upcycling in the design of a Materials Utilisation Plan, to assess the effect of the identified factors and to produce a set of recommendations when implementing upcycling in a road upgrade project/program.

Competitive tendering is the procurement process followed by potential design consultants, whereby the consultants, bid against each other to win a tender. The efficiency of the tendered resource becomes a major influential factor when competitive tendering is adopted. The consequence of such an environment is reduced rates and reduced hours with no additional capacity for any additional design improvements as described by Messner et al. (2018).

The design for upcycling is the process of applying engineering judgment to assess the existing materials and determine its function in the new pavement. The use of engineering judgement is pinned on relevant design experience, the lack of adequate design experience to facilitate upcycling was a recurring theme throughout the research. The reliance on the catalogue design for pavements was emphasized as a major disbenefit to upcycling.

Planning is the process of forethought into the project requirements. At the planning stage, key decisions are made. The design philosophy and design strategy is developed to meet the objective of the clients. The type of contract implementation is influenced by the decisions made at the planning stage.

Technology advancement is the application of new, more accurate or more efficient use of scientific methods or equipment to improve on previous methods. The use of nanomaterial and nanotechnology in pavement design is gaining momentum. Design engineers are still to respond to the advancement in technology so that the industry can progress in the various methods of upcycling.

There is a fundamental mismatch between the knowledge learned at tertiary level and what is being implemented in the industry. The data collected indicated a gap in knowledge relating to upcycling of materials, stemming from tertiary level education. The gap in knowledge was based on the undergraduate syllabus not including current industry practices. Upcycling is a fundamental concept and must be engrained at the tertiary level so that graduates can rely on the knowledge gained to enhance and improve on methods of upcycling. Exposure at tertiary levels promotes further research in the field.

Key words

Downcycling, upcycling, materials utilisation plan, competitive tendering, pavement

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ACRONYMS

ANOVA	Analysis of Variance
CED	Cumulative Energy Demand
EPR	Extended Producer Responsibility
GWP	Global Warming Potential
OMC	Optimum Moisture Content
RAP	Reclaimed Asphalt Pavement
SANRAL	South African National Roads Agency
SAPEM	South African Pavement Engineering Manual
TVET	Technical Vocational Educational and Training
UCS	Unconfined Compressive Strength

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Transportation infrastructure is a valued asset in every country's economy (Liu et al., 2019). The road network of a country's transport system constitutes the foundation of economic activity facilitating mobility, accessibility and the transportation of goods and services (Boisjoly & El-Geneidy, 2017). The success and progress of human society depends on physical infrastructure for distributing resources and essential services to the public (Uddin et al., 2013).

In South Africa, majority of the national road network is under the jurisdiction of an agency that is state owned. The South African National Roads Agency (SANRAL) has a responsibility for the management, maintenance and development of the network through careful management of resources, taking into consideration the financial obligation to manage public funds (Ross & Townshend, 2019).

The road network's pavement is a structure consisting of layers of processed materials which is constructed above the natural soil subgrade. The general design of a flexible road pavement comprises of the surface layer, base course, subbase, selected layers and roadbed on the natural subgrade. The main function of the pavement layers is to distribute the load of the vehicle to the natural soil subgrade. Ultimately, the pavement ensures that the transmitted load from the wheel is reduced so that the load does not exceed the bearing capacity of the subgrade. The pavement structure must be designed for a surface of acceptable riding quality, skid resistance and low noise pollution. The cost and quality of the materials required, decreases from the surfacing layer to the roadbed. Therefore, the pavement structure is an asset that must be preserved and maintained throughout its expected life (South African Pavement Engineering Manual SAPEM, 2019).

1.2 Background to the problem

According to the Engineering Council of South Africa (ECSA), engineering codes of conduct require that engineers apply their knowledge and skill in the interest of the public and environment. Materials required for the project are generated from embankment cuttings, borrow pits or quarries (SAPEM, 2009). The existing pavement structure also becomes a source of material that can be reused (Epps et al., 1980). The management of the materials is detailed in the materials utilisation plan.

The location of commercial quarries is fixed, and the project must absorb the cost of transport to obtain the required roadbuilding stone for the project. The location of stockpiled material from previous projects is also fixed and the project must absorb this cost. Transport costs influences the viability of the construction projects and hence, is a key consideration during the planning stages (Rasch, 2018).

When projects are required to reuse the existing materials, there is the risk of using these materials in a lower layer thereby underutilising the full potential of the material (Rasch, 2018). Some materials also require further processing to achieve the desirable constructability of that material. Thus, this process poses an additional cost to the contractor, therefore, sometimes it is considered more feasible to stockpile for further use or spoil the material rather than to process and reuse the material. Because the transport costs in a project are so high, it can determine the winning bidder. This gives rise to the need for the agency to plan the need to reuse materials to be included in the design phase. The cost to manage materials can range between 30-80% of the total construction costs (Kasim et al., 2005).

The concepts of upcycling and downcycling in terms of the reuse of materials is discussed by Gnatiuk, Novik and Melnyk (2022). The process of upcycling increases the value of the original material and the process of downcycling lowers the value of the original materials. The design approach to reuse and recycle the existing pavement in a lower layer, minimise spoil, and stockpiling excess material for future use becomes questionable when the road agencies have a responsibility to optimally reuse the agency's current asset with due consideration given to the financial obligation to manage public funds.

1.3 Problem statement

Project limits give the start and end location of the project to be constructed. Within the project limits, materials utilisation is optimised for the design requirements of that project. This approach is acceptable when a project is implemented in isolation. Sometimes projects are adjacent to one another or grouped to form a network as indicated graphically in Figure 1.1, where Km represents the project kilometre as a chainage reference, and X_1, X_2, X_3, indicate the linear start and end chainages in a road construction project.

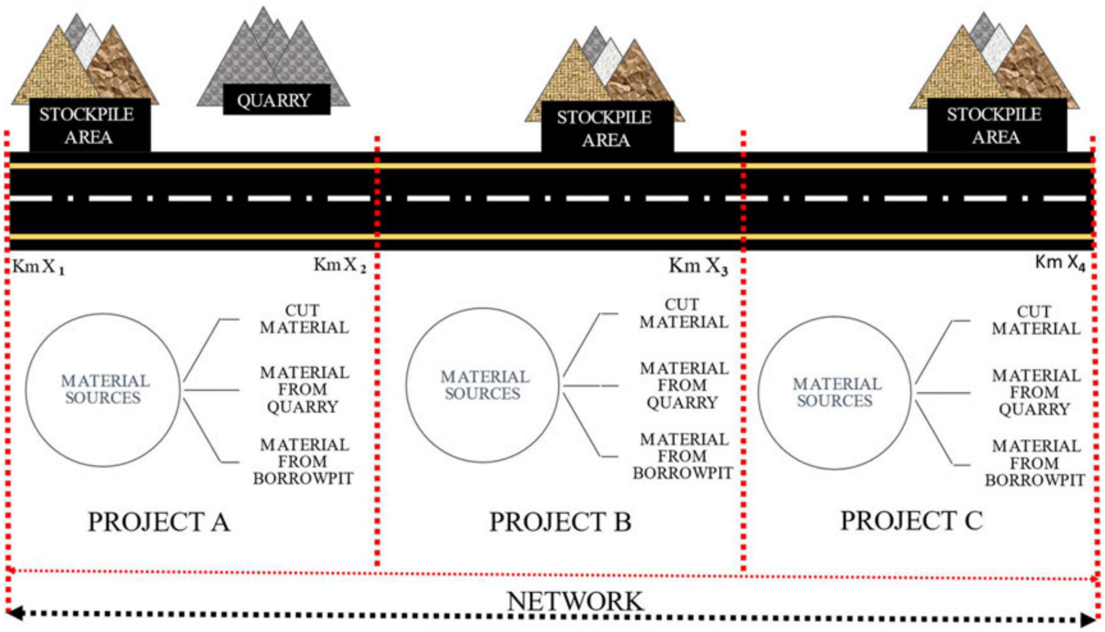

Figure 1.1 Graphical representation of the projects in silos

The adjacent project can become a source of materials. Due to the proximity of the adjacent project, the flow of materials between projects would reduce transport costs. This would be because of the shorter haul distance from commercial quarries or borrow pit areas.

However, this strategy to facilitate the flow of materials between construction projects is often overlooked. Client bodies do not have a formal approach to determine the feasibility of implementing a network materials utilisation model. Consequently, this research study intends to investigate the feasibility of the optimisation of materials for network compared to the optimisation of materials for a project.

1.4 Aim of the study

The aim of this research study is to investigate the opportunities of upcycling in a Materials Utilisation Plan.

1.5 Objectives of the study

The objectives of this research study are to:

- determine what are the factors influencing the specifications of upcycling in the design of the Materials Utilisation Plan
- determine what the effect is of the identified factors influencing the specification of upcycling in the design of the Materials Utilisation Plan
- make recommendations to the client body for consideration of upcycling in the planning and design phase when implementing a road upgrade project/program.

1.6 Research questions

The following research questions were developed for this study:

- What are the perceptions in the industry regarding upcycling in a Materiasl Utilisation Plan?
- What are the factors influencing the specifications of upcycling in the design of the Materials Utilisation Plan?
- What is the effect of the identified factors influencing the specification of upcycling in the design of the Materials Utilisation Plan?
- What recommendations can be made to the client body for consideration of upcycling in the planning and design phase when implementing a road upgrade project/program?

1.7 Research methodology

This study adopted a mixed methods research approach and analysed both qualitative and quantitative data in order to answer the research questions optimally to achieve the objectives of this study. A dialectical approach was used regarding the paradigms. A positivist paradigm framed the quantitative components of this study and the qualitative components were couched within the interpretivist paradigm. The dialectical approach to mixed methods research endeavours to capture the rich dialogue and interaction between the findings and perspectives that come from each paradigm.

Quantitative data was collected from the currently contracted personnel working on the upgrade of the National Route 3 and comprised of Project Managers, Pavement Design Engineers, Contract Engineers, Resident Engineers, Materials Technicians, Contract Directors and Contracts Managers. The respondents had to complete an an online survey questionnaire.

The questionnaire used the Likert scale of references, and the results were analysed through statistical software analysis.

In addition to the Quantitative data, Qualitative data was collected through interviews with various key stakeholders. The qualitative data was then analysed using thematic analysis.
The data from both the qualitative and quantitative analysis were then consolidated, analysed and used to present the findings of the study.

1.8 Limitations of the study

The limitations of this study emanated firstly from the process of road pavement building. There are two ways of building road pavements, the first being with asphalt which is flexible and secondly with concrete which is rigid. However, this research study focused only on the flexible pavements because the different material layers are totally reusable and recyclable. This is regarded as a limitation because it would have been more feasible to focus on both the flexible and rigid pavements but it was not possible within the confines of the requirements of this qualification.

The other limitation arose from the sample size. The upgrade of the National Route 3 comprises 13 projects, ten in design and three in construction and each project had a designer and a project manager. Unfortunately, only three of the 13 projects are in construction and the sample was drawn from the three active projects. This is considered as a limitation as the results of this study would be hindered from being extrapolated because the sample size was limited.

If all 13 projects were in construction, then the sample would expand to include the relevant construction personnel, namely the Contracts Directors and / or Contracts Managers, from all 13 projects. Since all the projects are not in the construction phase, the sample included relevant site personnel, namely the Contract Engineers, Resident Engineers and Materials Technicians, and represents the construction phase of the project.

1.9 Structure of the dissertation

Chapter One: Introduction

Chapter One sets out the background and emphasises the need for this research study as well as outlining the research problem and research objectives.

Chapter Two: Literature Review

Chapter Two expands on the key definitions for the research study to facilitate the correct interpretation of this study. Previous literature reviewed is categorised into the overarching macroscopic level, referred to as the network level; and the microscopic level referred to as the project level.

Chapter Three: Research Methodology

Chapter Three outlines the research methodology and design used in this study to respond to the research objectives.

Chapter Four: Findings, Discussion and Interpretation

Chapter Four highlights the findings and interpretation of the findings of the qualitative data collected.

Chapter Five: Results, Discussion and Interpretation

Chapter Five delineates the results of and interpretation of the results of the quantitative data collected followed by a consolidated report of the findings.

Chapter Six: Conclusions and Recommendations

Chapter Six sets out the conclusion based on the research results in line with the research objectives. Recommendations are provided to initiate industry change.

1.10 Summary

This chapter brings this research study to a close by linking the discussion with what was discussed in the first chapter which included the background to the problem statement and where the research objectives and research questions were set out. The next chapter will explain the key concepts used in this research study and a review of the available literature related to this research study will also be provided.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter introduces the conceptual framework for the research. The clarification of concepts pertinent to the research is also given. A review of the literature in the industry is presented from a macroscopic (network level) and microscopic (project level). The literature review reveals the gaps in the research relevant to the research objectives.

2.2 Conceptual model

The conceptual model of the study is presented in Figure 2.1.

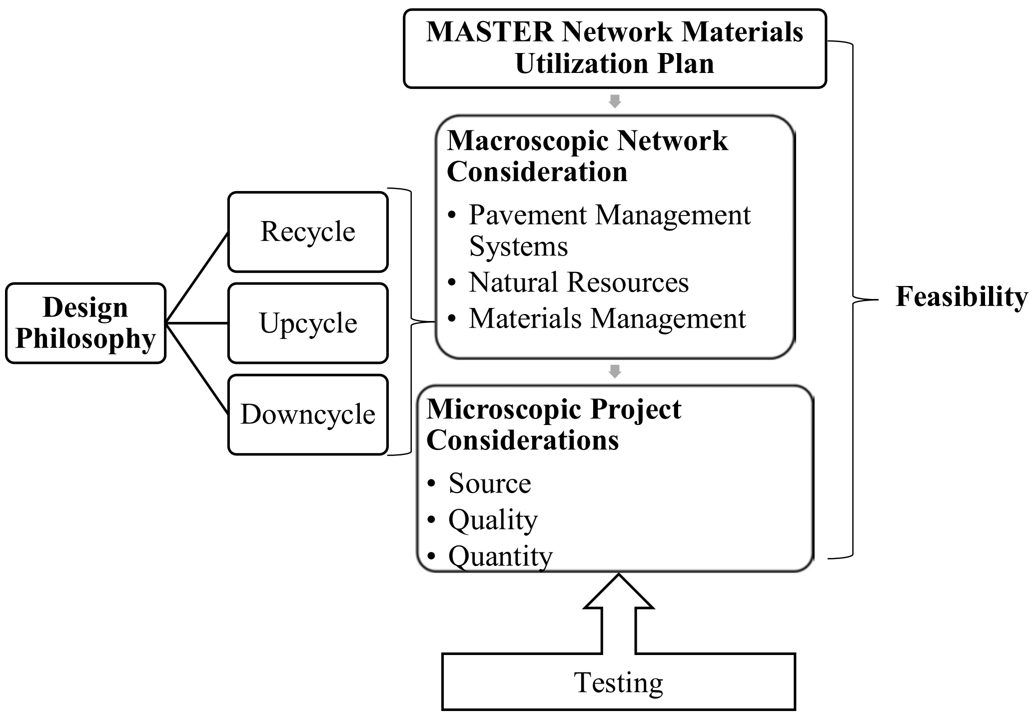

Figure 2.1 Conceptual model of the study

The elements of this research model will be presented next. Key concepts are presented in Appendix A.

2.3 Macroscopic Network Level

The literature reviewed has been categorised into the macroscopic level which highlights the network level and the microscopic level, which highlights the project level.

2.3.1 Pavement Management Systems

The success of a country's economy is directly related to the management of road infrastructure because it forms a significant portion of the country's assets. Existing infrastructure needs are maintained in a cost-effective manner to safeguard public funds. Material and human resources must be optimised on project and network levels (Uddin et al., 2013, pp. 26-31). In the context of road pavement infrastructure, the need to preserve the road asset has led to the formulation of a Pavement Management System (PMS) as a decision support system (Ismail et al., 2009). The main purpose of a PMS is to make the correct choice in terms of the available options for the preservation of the pavement asset and to have a consistent approach within an agency (Hudson et al., 1992).

There are several Pavement Management Systems available to road authorities to aid in the decision making in maintaining the pavement structure as an asset. In most cases, the road network is identified in sections. During the stages of planning, design and construction, these sections form the project limits (Ismail et al., 2009). These limits are informed by historic data and previous asset preservation interventions. The systematic approach to the maintenance and rehabilitation of pavements that is implemented by many road agencies through the Pavement Management System (PMS) (Shahin, 2005).

In the early days of road building, especially when budgets were readily available, maintenance initiatives were performed as and when the condition of the road deteriorated. The type of maintenance intervention was temporary in nature with little regard for the preservation of the road asset. Given the current limitation on available funds for maintenance and rehabilitation and the rapid decline in the pavement condition, the PMS allows for the roads agency to prioritise the required strategy according to available funds, using economical methods of analysis. The PMS is a tool to assist in the forecasting of the pavement condition over a certain period. It is crucial to identify the pavement condition and rate of deterioration early in the lifecycle of the pavement so that the corrective repair strategy can be performed. This can result in savings up to 80%.

An overall framework for pavement asset management mainly, has three tiers. The highest tier is the Program/Network/System-wide level which is driven by financial models, budgets and the agency's policies. The middle tier is the Project/Section level which is driven by standards and specifications, budget limits and environmental constraints. The final tier output is monitoring and evaluation of the project or section level (Uddin at al., 2013, p. 30).

2.3.2 The need for sustainability

There is a need for roads agencies to include the concepts of sustainable development into infrastructure projects which can be achieved through the use of sustainable rating systems (Maher et al., 2015). The concept of sustainable development originated in 1987 and is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Cassen, 1987).

The analysis of pavement strategies based purely on cost and benefit is limited when the user considers the impact on the environment. Presently, there are numerous roads agencies that are implementing sustainability measures in their pavement strategy. The principle of sustainability is to include economic, environmental and social aspects into the strategic process of pavement maintenance and rehabilitation. The concept of sustainability has been used previously, albeit in a casual manner. Efforts have been made to enable the user to assess sustainability measures in a structured and methodical manner (FWA, 2014).

The issues of the sustainable element of road construction in addition to the traditional economic analysis has been researched by Gschösser et al. (2012). The research was developed as a result of the agreement between Switzerland and the European Union to reduce the carbon footprint by 8%. To convert the traditional economic analysis into a sustainability analysis, the user must consider the environmental and social influences on the project.

The UN had developed sustainable development goals and in particular goal 9 is to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. Included in the target is to ensure the development of sustainable infrastructure. The emphasis is to use resources efficiently and adopt environmentally beneficial strategies (United Nations, 2015).

2.3.3 Pavement Lifecycle Assessment

There has been much focus on a Pavement Lifecycle Assessment framework by Harvey et al. (2016). Their research acknowledges that there are more road authorities that are including concepts of sustainability into their policies and procedures. There are broadly four types of tolls to help measure sustainability, namely:

- *Performance Assessment:* This requires that the pavement be evaluated according to its intended purpose and measured against the expected service life. Conditional assessments generally form part of performance assessments.
- *Life Cycle Cost Analysis (LCCA):* These are economic evaluations as discussed by Uddin et al. (2013).
- *Sustainable Rating Systems:* This includes a comprehensive inventory of activities that contribute towards sustainability. These contributing factors are measured using a common unit of measurement.
- *Life Cycle Assessment (LCA):* This includes a methodology for calculating and measuring environmental effects of a material, system or process. The methodology includes the evaluation of the entire lifecycle of the material including all the inputs and outputs to achieve the material's desired use.

Details related to the pavement lifecycle and the material from cradle to grave is discussed by Harvey et al. (2016) and includes all aspects inclusive of:

- *Material Fabrication:* This is the origin of the material from its source which could be mined or extracted which is then processed to form pavement materials. All aspects of the fabrication process is modelled and evaluated.
- *Design:* This refers to the intended purpose of the material in the pavement.
- *Construction:* This is when the material is processed using various machinery to achieve its intended purpose. This stage includes transportation, equipment and energy.
- *Service Phase:* In this phase, the material is in its service life and is being traversed with traffic and exposed to all environmental conditions.
- *Maintenance/Preservation:* During this phase, the pavement is maintained through different interventions to get the maximum service life from the material. All efforts to maintain the pavement is included in this modelling phase.
- *End of Life:* In this stage, the materials have reached their terminal stage and can no longer be utilised in the pavement as per its original intended purpose. The activities and sub-activities of either disposal or recycling is included in this phase.

The framework by Harvey et al. (2016), includes each phase of a material during the different elements of a project encompassing the material from production to end of life. The framework includes inventory tools to track the parameters of the material during all phases. There are possible application of Life Cycle Assessment (LCA) within roads agencies which supplements the Life Cycle Cost Analysis (LCCA) process, such as:

- The selection of suitable materials to be used in the pavement that can be recycled or reused for future service life requirements
- Used in comparing alternate pavement designs and the environmental impacts which include the rehabilitation and maintenance interventions for that project
- Used in the analysis of a network where different strategies are compared for the route

Although the use of LCA by road authorities is still limited, there is benefit being derived by its use in conjunction with the conventional LCCA (Harvey et al., 2016).

The Life Cycle Assessment (LCA) technique is documented in the ISO 14040 Standard which details the benefits of the LCA technique such as the guidance to make a knowledgeable choice for roads agencies. LCA focuses on the product life-cycle and methods to increase the viability of the product during every phase of the life cycle. LCA provides a strategy to agencies to best use the product and assist in the reuse of that product in another stage of the product's life-cycle and allows the user to test against key performance indicators of the product (Finkbeiner et al., 2006).

A reference document geared towards how sustainable pavement systems considers the sustainability of pavement materials at all stages in the pavement life-cycle was developed. A methodology for reducing cost and minimising environmental and social impact was produced for the design phase of a project. The parameters of the methodology are set within the physical limits of a project and does not extend to the route or section of a route. In many similar studies, it has been concluded that the materials required for pavements dominates the analysis especially when traffic volumes are eliminated from the study. This dominance is applicable to both asphalt and concrete pavements. The aggregates required for the pavement is the most significant contributor to LCA studies which then directly links to haulage costs for both virgin materials and the process of recycling and reuse. Previous studies have also focused on the durability of a pavement which increases with reduced environmental effects. It has been stressed that the LCA is a tool that must be developed specifically for the goals of the agency or the project (Van Dam et al., 2015).

Over the past few decades, there has been a tremendous growth in interest across the globe in employing recycled materials in flexible pavements as an alternative to virgin materials. Recycling has therefore been used in operations for maintaining and repairing pavement. Three different kinds of in-place recycling techniques have been developed: full-depth reclamation, cold in-place recycling, and hot in-place recycling. They have changed as a result of the usage of new machinery, mix design guidelines, and additives (e.g., engineered emulsion, lime, and cement). Utilising these innovative approaches has several benefits, such as preserving virgin materials, reducing energy use and environmental consequences, reducing construction time and delays to traffic flow, reducing the number of carrying trucks, and improving pavement quality. The development of a framework and an easy-to-use LCA tool that evaluates the environmental effects of a variety of pavement treatments, including in-place recycling, traditional techniques, and surface treatments, is the study's ultimate goal. The pavement life cycle assessment tool makes use of data, simulation, and models for all in-place recycling stages, including material selection, construction, maintenance and rehabilitation, use, and end-of-life. The created application offers agencies, consultants, and professionals in the pavement industry the chance to quantify the environmental implications of their projects in addition to their economic and social impact analysis. The tool also lists the key elements that affect the energy used and created emissions at each step of the pavement life cycle as a result of pavement treatment. (Al-Qadi,2020).

The Life Cycle Assessment was used by Gschösser et al. (2013) to analyse the environmental impact of the materials manufacturing processes, resource consumption and emission from the cradle to gate endpoint. The environmental measure for the study is Global Warming Potential (GWP) which measures the materials impact on climate change, Cumulative Energy Demand (CED) which measures the use of energy throughout the lifecycle of the material and Ecological Scarcity which measures the effect of the material's toxins. The analysis is performed on the typical pavement layers, namely asphalt, concrete, subbase and its components. A sensitivity and Monte Carlo Simulation is modelled for the different material production processes. The study indicates that recycling material has positive environmental impact on GWP, CED and Geological Scarcity. The study has limited results for the bitumen manufacturing process.

2.3.4 Economic evaluation

The economic analysis of PMS is dependent on cost and benefit factors. Costs are categorised into Agency costs and non-Agency costs. Agency costs are primary costs incurred by the agency and is budgeted from the agency's financial plan. These are also known as direct costs to the agency. The non-Agency costs are further categorised into user costs, nonuser costs and societal costs. User costs are the time spent on the roads, delays experienced on the road network either because of accidents or maintenance requirements and vehicle operating costs such as tyre wear and tear amongst others. Nonuser costs are peripheral costs such as the disruption to the surrounding areas because of accidents, the reduction in property market value as a result of the increasing road networks, noise pollution from the surrounding road network, health implications as a result of the air emissions or related factors. Societal costs are costs resulting from environmental pollution caused by contamination of the soil, disruption of the ecosystem, deforestation and water pollution. Benefits accumulate from the reduction of costs and can be both direct and indirect. The reduction in operating costs, minimising of delays (accident or maintenance), minimising of air emission, reduction in congestion and the resultant minimising of fuel costs are some examples of the benefits.

Many methods for Economic Analysis are presented below:

- Equivalent Uniform Annual Cost Method that summates the original monetary outlay with ongoing scheduled maintenance costs into equal annual payments for the full analysis period. This is the least complex method and allows the agency to compare strategies that have differing analysis periods. This method is limited in its ability to determine economic viability since its does not consider the benefits of the strategy.
- Present-Worth Method is versatile and seeks to analyse the cost or benefits or the combination of the costs and benefits. All future costs are discounted to current values by the use of an adjustment factor commonly referred to as a discount rate.
- Net Present Value method is a derivation of the PWC cost method and is the simple subtraction of the net present worth cost from the net present worth of benefits. A positive value indicates that the strategy has greater benefits than costs and is considered to be economically justifiable.

- In the Internal Rate of Return (IRR) method, the discount factor used, is derived from equating the costs and benefits. The costs and benefits calculated can be extracted from equivalent annual costs/benefits or the net present worth cost/benefits. The IRR can be calculated and compared for the various strategies.
- Benefit Cost Ratio is the proportion of benefits to costs using either the equivalent annual costs/benefits or the net present worth cost/benefits. The higher the ratio, the more lucrative the strategy. A big disadvantage of this method is the allocation of the maintenance cost reduction to either being a benefit or a cost, which then affects the proportion and gives undesired results.
  Uddin et al. (2013, pp. 342-345).

The use of economic evaluation techniques such as Cost Effectiveness Analysis, Replacement Analysis, and Break-Even Analysis these are techniques based on year-to-year decisions. These decisions are dependent on the pavement condition.

- Cost Effectiveness is an add on the benefit-cost ratio as detailed by Uddin et al. (2013, pp. 342-345). This method becomes suitable when the benefits are the same as the competing alternatives.

- Replacement Analysis is used to determine the optimum time to implement a construction strategy on road pavement. This method uses the annual cost of the construction, together with the maintenance costs and repair costs over time a period to determine the economic life of the pavement. The optimal time to implement a strategy is when the total annual costs are minimal.

- Break-Even Analysis determines the value at which the spending on maintenance breaks even with the annual cost savings. This would be applicable to an extended asset preservation strategy,
  Luhr and Rydholm (2015)

2.3.5 Financial environment of South Africa

The financial environment in South Africa and the need to provide transportation infrastructure to achieve economic growth is an important factor to consider. For the country to be developing in both the micro and macro economy, the relevant cost of transportation and influencing production and delivery costs needs to be reduced. This is crucial to the competitive and strained economy (Jordaan & Kilian, 2016). As described by Uddin et al. (2013, pp. 342-345), this includes the agency costs such the upgrading, rehabilitation and maintenance of the existing road, in terms of preservation of the existing infrastructures. The same authors elaborate on the role of the design engineers and the responsibility they have in reducing the agency costs. This can be achieved by advancing in the design and optimally using technology. The testing process becomes critical to analyse and investigate the potential of the existing materials. The buy in for the client authorities is also key to achieving the desired outcome of optimising the existing materials.

2.3.6 Technology

South Africa is behind in terms of using the available technology that has been introduced over the past 10 years for testing the strength characteristics of the material. The road pavement fraternity in South Arica is over cautious and very conservative. This can be attributed to the significant financial challenges and competitive tendering environment. It then becomes the responsibility of the client body to promote the investigation of new practices and advanced technology. The consequence of keeping to the traditional methods of designing and construction is a huge financial premium to the country (Jordaan & Kilian, 2016).

Design engineers need to be able to design more cost-effective roads by providing road infrastructure using a lesser budget. This can be achieved through a mind-shift change and promoting the use of technology thus enabling the use of existing materials. In many designs, the existing material does not meet the minimum standard of the required layer. This often results in the conventional design methodology of importing crushed, natural aggregate to supplement the design. This method of design is expensive and not cost-effective (Jordaan & Kilian, 2016).

2.3.7 Chemistry and Conventional Indicator Tests

The improvement of the load-bearing capacity of materials is the ultimate aim to reuse and improve the potential of existing materials. The current testing regime is to analyse the material based on empirically formulated testing procedures. This method of testing excludes the testing of the mineral composition as a result of the geology of the materials. The mineral composition of the material gives an indication of the compatibility of the material with various polymers that can influence the potential of the material. A typical test for the mineral composition is the X-Ray Diffraction (XRD). The equipment to perform this test is readily available in South Africa. However, this type of testing is not yet considered standard practice and is lacking in the knowledge base in the pavement design process (Jordon & Killian, 2016).

2.4 Microscopic Network Level

This section focusses on the microscopic project level.

2.4.1 Sources, materials optimisation and reduction in waste

The need for aggregates in road construction which includes road embankments, asphalt and concrete mixes for pavements, concrete mixes in structures and road-base courses as elaborated on by Sobotka et al. (2012). The source, destination, quality and quantity of the aggregates all influence the cost of the aggregate materials. Road contractors pay either per hour or per kilometre of haulage. The identification of the number of suppliers, transportation economics, stockpile areas, haulage from stockpile areas to the road section under construction as key variables in the road construction process that contributes towards an efficient supply of aggregate for the project is further elaborated on by Jaskowski et al. (2014). Many of these factors are further influenced by the required volume of materials versus the available volume of materials, the location of stockpile areas closest to the construction work zone which is always variable due to the close proximity of the work zone.

The bulk of road building stone are sourced from natural rock, sand and gravel sources, all of which are limited sources and are the primary resources for construction. There are a number of benefits to using alternate materials instead of natural rock, sand and gravel which include:

- Reduced mining of natural rock, sand and gravel
- Reduced landfill sites
- Increase in the reuse of materials
- Increase in the recycling of materials

In some countries, there is a tax on the use of landfill sites and a further levy imposed on the use of natural rock, sand and gravel. In conjunction with these taxes and levies, it increases the cost for the use of natural resources and therefore encourages recycling initiatives. Alternate materials characterisation, particle size, compaction ability and binder treatments are recognised by Hill et al. (2001) in his study. This study concludes that the use of alternate materials possess mechanical properties that can be used in road construction.

There have been discussions about a concept called system of systems. This stems from the construction sector which is amongst the biggest worldwide industries. Construction adversely attracts major environmental effects contributing to 5-10% of greenhouse gas pollution in road construction alone. The study uses road construction as an example and recognises that there are several stakeholders involved in a decision pyramid required to construct a road. At the top level of the decision pyramid is the road agency who determines the specification to be used in the road construction. The overall specification is largely determined by the total cost, timelines and quality. The main attributes to total costs includes aggregates and fuel (Axelsson et al. (2018). The same author defines waste as a factor in road construction and divides waste into the following subcategories:

- *Overproduction:* There is no benefit in producing materials in larger quantities than what is required. The supply and demand models underpins overproduction of materials, especially in the case of blasting and crushing aggregates.
- *Waiting:* When a plant is dormant and waiting for upstream events to occur, this contributes to an inefficient program. This is prevalent when loaders are waiting to haul material and tippers are not available.
- *Transportation:* Transportation can be considered waste when duplicate trips are made and the movement of material is double-handled. The poor location of stockpile sites and haul roads contributes to transportation wastage.
- *Over-processing:* This occurs when the material is overworked beyond the required specification. Unclear specifications and construction techniques contribute to this wastage.
- *Unnecessary inventory:* This is when material is stockpiled unnecessarily taking up space and changing the materials characteristics. This occurs when aggregates are crushed prior to construction, up to a point when the stockpile segregates cause fraction of the particle sizes.
- *Unnecessary Motion:* When the movement of plant and people are not optimised as a result of the site layout.

- *Defects:* Any defect that requires reworking is considered wastage as it requires more materials and effort.

These contributing waste factors can be effectively managed with the system of system model that is based on the reduction of waste by improving communication, specification and synchronisation. This is achieved using the Internet of Things Technology to combine all information into a single interconnected system. The system is live and functional between the various vendors on a project. In the problem analysed by Axelsson et al. (2018), using a system called Building Information Management (BIM), the overall productivity is increased by 25%. Waste is reduced by 30% due to the synchronisation of people and machinery.

2.4.2 Materials management

The issue of the management of materials in a construction project is expanded on by Kasim et al. (2005) who claims that the management of materials has a direct influence on the productivity and costs which includes aspects such as planning and materials distribution. The cost to manage materials on site can range between 30-80% of the total construction costs. This massive contribution to project costs underpins the need to efficiently manage materials on site. Various research studies such as Smith et al. (2007), Hechler et al. (2012) and Kasim et al. (2005) conclude that the factors contributing to the mismanagement of materials includes transportation, lack of work plans and the management of excess materials. The planning of materials on site, haul routes and access points contribute significantly to a successful strategy for the management of materials. Apart from the planning, the handling of materials is equally important to a successfully implemented project. Some of the components of a materials handling strategy includes: the sequence, amount, time, position, place, method, condition and cost of movement of the materials.

Asphalt is made up of different binder properties which continue to age in the lifecycle process. When one mills off the asphalt pavement to stockpile, the binder still continues to age in stockpile. There are two ways to remove the asphalt layer: one is to mill off the layer using a milling machine which produces fine-sized Reclaimed Asphalt Pavement (RAP) aggregates and the next method is to rip the asphalt pavement into slab and crush it in a crushing machine which produces larger sized aggregate particles (De Lira et al., 2015). The same authors go on to explain the effect of ageing on the milled RAP vs the crushed RAP. Their study focused on oxidation being the main attribute to the ageing of binder from cradle to grave. The management of stockpile does influence the ageing of binder however it was found that the smaller sized particles exhibit higher oxidation properties as a result of the higher binder content. This has a direct effect on the binder life of reclaimed asphalt in stockpiles. The larger particle sizes will have a slower ageing process compared to smaller reclaimed asphalt particle sizes.

The findings from the study above does contribute to the materials management process from a network perspective in that the road agency will want the best value from the RAP asset and the deconstruction method of the asphalt layer will influence the quality of the asset and the utilisation in other projects which is now time dependant.

The manufacturing process of cement yields one of the most significant contributions to air emissions and harmful effects on the environment (Detterborn & Korkiala-Tanttu, 2017). Their study also focusses on the reduction in the haulage distance to dispose of concrete at a landfill site as compared to the use of a concrete crusher on site. A contributing factor to the high transport costs is the weight of concrete which makes it more expensive to transport. Their study concluded that crushed concrete is more advantageous than virgin aggregate material. Similar to oxidation being the main ageing process in asphalt, carbonation is the main ageing process in concrete. They also drew comparisons that the smaller-sized crushed concrete aggregate is more susceptible to carbonation than the larger-sized crushed concrete aggregate.

The previous research focused on the haulage of materials and reducing overall haulage costs only (Ji et al., 2019). The research also concentrated on the use of mathematical modelling to optimise earthworks on a network level. The model is set up to determine cut and fill sections along a route. The location of the borrow pit as a materials source and the location of a dump site as a materials spoil site is included in the linear model. The model is then implemented to balance earthworks in smaller unbundled sections of the route. This concept is applicable to major roads projects in which the unbundled sections are then tendered for construction as individual projects. The research is on a macroscopic level and is modelled in the planning and design stage which is then executed in the construction phase.

2.4.3 Barriers to deconstruction

Gschösser and Wallbaum (2013) went further to analyse the environmental impacts on new pavements and reconstructed pavements for asphalt, concrete and composite pavements. The process for a new pavement includes the materials production, transportation and construction. In addition to these, for the reconstructed pavement, one would need to include the deconstruction of the existing pavement layers, transportation of the existing material to stockpile, and the reworking of the material in the recycling process. The analysis considers the plant and equipment needed for the different activities and its contribution to Global Warming Potential (GWP), Cumulative Energy Demand (CED) and Ecological Scarcity. The results of the test data show that concrete and composite pavements have a higher negative impact on the environmental measures compared to asphalt pavements. The same relationship exists with the comparison of new pavements and reconstructed pavements for the identified pavement type.

The Working Commission 115 Construction Materials Stewardship of the International Council for Research and Innovation in Building Construction (CIB) researched the opposite of the need for deconstruction, but rather focused on the barriers to deconstruction (Smith, 2017). The intention was to find methods to help optimise the sustainability (financial, economic, social and environmental) of non-renewable resources. Consideration was given to the lack of demand for reusable material coupled with the segregation costs of materials for re-use which makes it a non-viable option for contractors to save non-renewable resources. To overcome this challenge, landfill sites are placing hefty fees and taxes on the use of landfill sites for the spoiling of material. Some of the key findings of this study includes the need to design for deconstruction and not leave it to the next user to identify the methods to maximise the reuse of existing materials. One way to achieve this is by implementing the Extended Producer Responsibility (EPR) program which places the responsibility of reuse on the supplier of the material. In this matter, there is a constant cycle of reusing material. When considering the reuse of concrete, the challenges that come into consideration are the high transport costs to load and remove concrete material, the complexity of removing the steel from concrete without deforming the steel and the lack of knowledge on the reuse of concrete in design. There are still opportunities for crushing plants to crush steel and the use of crushed steel in the industry.

Unlike Smith et al, (2007), Hechler et al. (2012) details the barriers and benefits of deconstruction. Their study focused on the environmental, economic, social, health and legislative benefits in the design for deconstruction as part of the life cycle assessment. The study sets out principles for the selection of materials to be included in construction according to its recycling ability and durability.

2.4.4 Materials flow analysis

The various barriers to a better materials management were investigated by Rasch (2018) and the results conclusively reveal that agencies and materials suppliers are in favour of reuse and recycling of materials to promote the reduction of the depletion of natural resources thereby emphasising the commitment to maintaining a sustainable environment. Recycling also assists to reduce agency and ultimately road-user costs. As much as the concept in theory is justifiable, it is difficult to attain this in construction. There are certain impediments which hinder the process of sustainability. Stakeholders need to focus on incentives for the reuse, recycling and the management thereof. Timely utilisation and stockpile areas of materials, transport costs, regulations and the layout of the construction sites and programming contribute to a better position to achieve the requirements for sustainability.

- *Incentives for the reuse, recycling and the management thereof*-there is no incentive for contractors to reuse and recycle materials on site. The process of recycling has cost implications and in many cases. the contractors opt to spoil materials as opposed to use and recycle materials. This is especially the case on the smaller construction sites where spoil sites are close and available. One of the ways to counter this action is to introduce a charge on construction spoil material from an environmental management perspective. This further assists in preventing the filling up of landfill sites.
- *Limited awareness and teamwork*-the movement of material between projects requires further investigation. The concept is limited in knowledge and requires extensive collaboration to determine the utilisation strategy of each project and how the user-requirements can be accommodated during the construction. This process is limited in terms of tools to assist in the process. Ownership of the process needs to be taken by the roads agencies on a network level as opposed to project level.
- *Timing of material requirements and stockpile areas*-timing is one of the aspects that needs to be understood and comprehensively coordinated between projects. Apart from the required quality and grade of materials, the time aspect is of utmost importance. In

conventional construction projects, all excess material is removed from the site with very little consideration to the life cycle of the excess materials and the uses to other industries. The constraint of space, limits many sites from storing materials for use on other projects. This creates additional contractual risk between projects as a result of the dependency for materials between sites. It then becomes critical for the roads agency to take the lead during the design phase and conduct in-depth pre-investigations into the materials plan for the construction.

- *Transport costs*-this contributes to the viability of the construction projects and hence is a key consideration during the planning stages. As much as there is an intent to reuse the existing materials, there is a risk of using these materials in a lower layer thereby under-utilising the full potential of that material. Some materials also require further processing to achieve the desirable constructability of that material. This process is an additional cost to the contractor and it can be considered more feasible to spoil rather than to process and reuse the material. Because the transport costs in a project are so high, it can determine the winning bidder. This gives rise to the need for the agency to plan the need to reuse materials to be included in the design phase.
- *They physical arrangement of the construction site*-this also has an influence on the reuse and recycling of materials. Space for the sorting and mixing of the various excavated materials can become limited and must be considered in the planning phase. Generally, sites closer to urban areas have limited space and have further need to determine the environmental regulations due to the dense population and the resultant noise and dust.

2.4.5 Laboratory testing

The purpose of laboratory testing in the design phase of the project is to exclude and prevent the use of substandard materials as part of the quality control process. Quality control considers the material's properties and behaviour, both beneficial and detrimental. The significant element of quality control is the interpretation of the test results on the final product and the effect of that result on the final product to be achieved in construction. It is crucial for the design engineer to fundamentally understand the materials' behaviour, and not be limited and compare test results with specifications to make a decision on the utilisation of the materials tested. The isolated use of specifications to confirm the existing material potential in the design phase, will not achieve economic value for the reuse of the current materials. The use of modification for marginal materials can offer better economic options and this can only be achieved through the understanding of the material by the design engineer. The experience of the design engineers must not be limited to book knowledge. The design engineer must be competent in field experience as well (Kisunge, 2021).

2.5 Summary

Chapter Two provided an in-depth review of the literature applicable to the conceptual model of the research. Gaps were identified in the macroscopic and microscopic levels of materials utilisation. There is a need to further explore the basic understanding of upcycling of materials and the influencing factors. The next chapter will outline and explain the methodology used in responding to the research questions.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

The previous chapter focused on the elements of a materials utilisation plan and the literature reviewed in relation to those elements. This chapter details the research design and associated methodology in response to the research questions. Bilaua et al. (2017) emphasises that the methodology is the philosophical framework of the research. The research methodology is a structure that relates to the research paradigm (Oshagbemi, 2017). The research methodology must be appropriate to satisfy the research objects (Sudheesh et al., 2016). The research methodology is determined by the type of data required, the type of data to be collected and the selected data analysis strategies.

Likewise, there are several variables that need to be considered as inputs into the Network Materials Utilisation Plan. The emphasis on upcycling of materials is dynamic in nature and requires a dynamic research approach founded on both quantitative and qualitative epistemology. Hence, a mixed methods research approach will be the right choice for this research process because quantitative or qualitative data alone will not sufficiently answer the research question (George, 2021). The mixed methods approach allows for the detailed theories underpinning the research to be discussed, while achieving objectivity in the research (Ivankova & Creswell, 2009). Furthermore, the results from the qualitative data type can be used to support, expand, improve, or supplement the quantitative data (Schoonenboom & Johnson, 2017).

3.2 Research design

A research design can be described as the master plan that is required to investigate the research objectives or the overall strategy that is chosen to integrate the different components of the study in a coherent and logical way, thereby, ensuring that the research problem will be addressed adequately. The research design plans the data collection process and methods of analysing the obtained data to be able to effectively answer the research questions (Creswell & Creswell, 2018). There are three main types of research designs.

3.2.1 Descriptive research design

The objective of a descriptive research design is to investigate the results of an event without too much consideration of the reason for the event (Berndt, 2020). Descriptive research studies describe the characteristics of an individual or of a group of people, a situation or a phenomenon precisely and methodically (McCombes, 2022). This approach uses a variety of data collection instruments with some of the more common methods being surveys, interviews, observations, case studies, and portfolios. The data collected through these methods can be either quantitative or qualitative (McCombes, 2022).

3.2.2 Exploratory research design

Exploratory research is the process of investigating a problem that has not been studied or thoroughly investigated in the past (Lelissa, 2018). The exploratory research design can be considered as the initial phase of the research. It is intended to acquire knowledge on a matter of interest. At this starting point of the research, one can articulate the matter of interest into a problem which then requires exploring. Normally, this type of research design stems from knowledge gaps in the industry and the research initiates the closure of these knowledge gaps in the industry (Akhtar, 2016).

3.2.3 Explanatory research design

Explanatory research design explains the research problem in the form of a causal relationship. (Rahi, 2017). This type of research is helpful in obtaining a different perspective that will assist to develop or elaborate on a theory or a test. The objective of explanatory research is to be able to recognise variables and key issues associated with the research problem.

3.3 Research approach

The research approach is the plan that encompasses the elementary assumptions for detailed data collection, analysis and ultimately, the interpretation of the research findings. The research approach is heavily reliant on the research problem and questions that the research wants to address. There are three main approaches, which are the qualitative research approach, quantitative research approach and mixed-methods research approach.

3.3.1 Qualitative research approach

The qualitative research approach uses the participants' opinions as data. Data is collected from participants comprising predominantly of words. The data is then decoded, and various themes emerge from the data. These themes are used to gain an understanding of differing views in response to the research questions (Pandey & Pandey, 2015). The results of the qualitative research approach are based on the direct experiences, opinions and behaviours of human beings as meaning-making agents in their everyday lives. It is important to determine the reason for the event leading to the research questions (Aspers & Corte, 2019).

3.3.2 Quantitative research approach

Quantitative research is a well-known research methodology that solicits quantifiable data from participants and uses statistical methods of analysis to analyse the data gathered. The analysis is objective and unequivocal (Creswell & Creswell, 2018). The quantitative research techniques are unbiased. The unbiasedness is achieved by the randomly selecting participants from the study population, the use of standardised questionnaires and the use of statistical methods to test hypotheses and inferential statistics to determine the relationship between groups or variables.

3.3.3 Mixed Methods research approach

The evolution of research has necessitated the need for improved research approaches (Dawadi et al., 2021). More flexible methods of research are required to fully investigate research problems. The combination of the conventional qualitative and quantitative research methods, termed mixed methods research, can be used to enhance the research investigation. This alleviates the limitations of a single method approach (Ivankova & Creswell, 2009).

The philosophical foundation of practicality and rationality, makes it possible to use a combination of approaches to respond to research questions (Doyle et al., 2009). This type of research explores the collections of data as well as the blending and integration of the qualitative and quantitative data in the research. The underlying reasoning of mixing both qualitative and quantitative data, is to provide sufficient methods to investigate the intricacies and trends in responding to the research questions (Creswell et al., 2004). Johnson and Onwuegbuzie (2004) concur with Creswell et al. (2004), that mixed methods research uses induction which refers to pattern discovery, deduction which refers to hypothesis and theory testing and abduction which relates to the discovery and reliance of the interpretation of the results.

There are four themes that constitute the rationale of mixed methods research, namely: participant enrichment, instrument fidelity, treatment integrity and significance enhancement (Onwuegbuzie et al., 2010). Participant enrichment is the optimisation of the sample by the addition of more appropriate participants (Burch & Heinrich, 2015). This type of research calls for the laboratory testing to be included in the in-depth interviews conducted, to give richness and complexity to the impact of the testing on the Materials Utilisation Plan.

The instrument fidelity theme refers to the instruments used to obtain data and the appropriateness of those instruments (Onwuegbuzie et al., 2010). In this research study, questionnaires and in-depth interviews were used. The questionnaires were used to determine the existing current practices of materials utilisation and to determine the industry keenness for upcycling of materials. The in-depth interviews were used to gain a better understanding of the industry challenges and benefits of upcycling in the Materials Utilisation Plan.

The theme of treatment integrity refers to the combination of quantitative and qualitative methods to determine the reliability of the interventions and treatment of programs. The theme of significance enhancements refers to the maximisation of the interpretation of the data (Onwuegbuzie et al., 2010).

3.4 Research philosophy

A research philosophy is the starting point of the research. The research philosophy assumptions guide the entire research process and includes assumptions about the research methods which influences the research outcomes (Hakansson, 2013). There are core paradigms related to the research philosophy. A paradigm is a world view that people have based on their ideals, values and beliefs. The most widely used paradigms are Positivism and Interpretivism. Positivists prefer scientific quantitative methods, while interpretivists prefer humanistic qualitative methods.

3.4.1 Positivism

Positive research strategy is founded on principles of independence and objectivity. Theories are tested in a deductive manner to promote understanding of the research. This type of strategy is used in research that requires experimentation or testing. This research uses inferences about a population by testing hypotheses (Hakansson, 2013).

3.4.2 Interpretivism

Interpretivism is a strategy inclined towards the participants' understanding as opposed to principles of independence and objectivity. The participants' responses influence the data collection, analysis and results of the research. Research that requires an interpretivist strategy typically desires to highlight perceptions, understanding and experiences to determine themes that can be further analysed. (o'Gorman & Macintosh, 2015).

3.4.3 Research paradigm for this study

This research study considered a combination of positivism and interpretivism. The qualitative research allowed for interpretation and explanations and the quantitative aspects allowed for the positivist research philosophy.

3.5 Sampling strategy

A sample is a subset of the population related to the research study. The sampling strategy is the plan used to ensure that the sample selected represents the population for the research study.

3.5.1 Target population

In qualitative research, the intention is to describe the research problem to a group. Various questions are asked to the participants from a script and the responses will be recorded. The open-ended type of questions allows for more flexibility. Typically, three to ten participants are interviewed for qualitative research (Zikmund, 2000).

Quantitative research allows for statistically significant inferences about a population (Creswell, 2003). This is achieved by studying a representative sample from the population. The population refers to the entire group being examined, and it takes into consideration whether the population group is narrow or broad. The sample population must include every individual that will represent the population group examined.

The idea of a representative sample is practical because it is not possible to include everyone from the total population in the sample population. If represented correctly, the sample population will be statistically identical to the population. This will allow for statistical inferences to the population (Zikmund, 2000).

- **Qualitative study target population:**
  In this study, the target population referred to the total number of personnel working on the National Route 3 upgrade. The analytical unit of population for this research is number. The target population consisted of Project Managers, Consulting Engineers and Laboratory Technicians contracted to the upgrade of the National Route 3 summating to 39.
- **Quantitative study target population:**
  In the present study, the quantitative target population referred to the total number of personnel working on the National Route 3 upgrade. The analytical unit of population for this research is number. The target population comprised Project Managers, Pavement Design Engineers, Contract Engineers, Resident Engineers, Materials Technicians, Contract Directors and Contracts Mangers currently contracted to the upgrade of the National Route 3 summating to 41.

3.5.2 Sampling techniques

Sampling refers to the selection of individuals from the population. The selection is performed in a manner so that each individual has the same chance of being considered in the sample. (Pandey & Pandey, 2015).

3.5.2.1 Probability sampling

With probability sampling, each individual has the same and equal chance of being included in the sample population (Nikolopoulou, 2022). Probability sampling has two main properties; each individual in the sample has a known non-zero chance of sampling; and the process of sampling involves the random selection of participants (Etikan & Bala, 2017). Simple random, stratified, and cluster random sampling are among the most common probability sampling techniques.

- **Simple random sampling:** Simple random sampling techniques allows all individuals the same and equal opportunity of being selected to participate as part of the sample (Etikan & Bala, 2017).

- **Stratified sampling:** Stratified sampling techniques allows for the categorisation of the population into groups referred to as strata. Thereafter, simple random techniques are used to select the sample (Taherdoost, 2016).

- **Clusters random sampling:** Clusters random sampling allows for the categorisation of the population into sub-groups. Thereafter, simple random techniques are used to select the sub-groups for the sample population (Etikan & Bala, 2017).

3.5.2.2 Non-Probability sampling

Non-probability sampling selection is performed in a manner that each individual does not have the same chance of being considered in the sample. Quota sampling, purposive sampling, convenience sampling and snowball sampling are some types of non-probability techniques (Etikan, 2016).

- **Purposive sampling:** Purposive sampling is also referred to as judgmental or a subjective sampling method. Samples are identified, based on understanding and knowledge of the participant, who can respond to the objective. This type of sampling is best suited for qualitative research where experts in the research topic are selected (Etikan, 2016).

- **Quota sampling:** Quota sampling is similar to the non-probability version of stratified sampling. The population is categorised into groups and a selection is made based on the characteristics of the groups (Etikan, 2016).

- **Convenience sampling:** Convenience sampling allows participants to be chosen, based on convenience factors. Some of these factors include ease of access to participants, physical proximity of participants and willingness of participants to take part in the study (Young, 2016).

- **Snowball sampling:** Snowball sampling allows for the selection of a small group of individuals who have the knowledge to respond to the research questions. Thereafter, additional participants to be included in the research, from the initial group selected (Young, 2016).

For the present study, the participants were selected as follows:

Qualitative study sample: For the qualitative aspect of this study, nine participants were selected from the target population using non-probability purposive sampling

Quantitative study sample: For the quantitative part of this study, 32 participants were selected from the target population using non-probability convenience sampling.

3.6 Research instruments

There are numerous instruments for collecting data. The primary instruments used in mixed methods research can include classroom observations, interviews, open-ended questionnaires and closed-ended questionnaires. The mixed methods of collecting data support each other thereby enhancing the validity and dependability of the data (Zohrabi, 2013).

3.6.1 Interviews for Qualitative data collection

There are three main types of interviews used in the collection of data for qualitative analysis, namely: structured interviews, semi-structured interviews and unstructured interviews. (Guest et al., 2013).

3.6.1.1 Structured interviews

Structured interviews use a standardised and predetermined question set to collect data from the participant. These questions are predetermined prior to the interview. As part of the interview process, the predetermined questions are asked to the respondent and the respondents' answers will be recorded. To ensure that there is no bias, interviews will be conducted in the same manner, tone of voice and use the exact same predetermined question-set. This type of interview is also referred to as qualitative research interviews (Saunders et al., 2016).

3.6.1.2 Semi-structured interviews

Semi-structured interviews are different to structured interviews because they do not make use of the standardised and predetermined question-sets. Rather, the research uses themes and key thoughts which are not ordered in any way. There is flexibility to add to the key thoughts or even remove the key thoughts, depending on the respondents' contribution to the interview. The respondents' responses are recorded. (Saunders et al. 2016)

3.6.1.3 Unstructured interviews

According to Klenke (2008), unstructured interviews are aimed at prompting the respondents' rendition of their experiences. Unstructured interviews allow for further exploration and solicitation of data based on the respondents' experiences and learnings. The unstructured interview can be initiated with a single question and thereafter continue the discussion in real time, without following a predetermined question set (Barrett, & Twycross, 2018).

3.6.1.4 The interview design

A Semi structured interview was used in this research (see annexure D).
The interview schedule was developed and comprised of four parts. Part A included demographic related questions which collected data on age, gender, education, experience and position occupied in the current industry. Part A also included questions relating to the understanding of the Materials Utilisation Plan and the various options to upcycle materials. Part B, in addition to Part A, was applicable to the Laboratory testers and sought to determine the factors affecting the testing of materials. Part C, in addition to Part A was applicable to Pavement Design Engineers and sought to understand the challenges with designing for upcycling. Part D, in conjunction with Part A was applicable to all participants and sought to understand the factors required to approve a Network plan for Materials Utilisation.

3.6.1.5 Transcribing interviews for data analysis purposes

Most interviews are recorded and needs transcribing before analysing. This can be extremely time-consuming (Barrett & Twycross, 2018). There are various software applications available for the function of recording. Microsoft Teams is an application that has the function to record and transcribe and was used for the research interviews conducted. Permission was requested from the respondents prior to the start of the interview for recording and transcribing the interviews and this feature was then activated (Saarijärvi & Bratt, 2021).

3.6.2 Questionnaires for Quantitative data collection

Questionnaires are convenient and accessible instruments to collect data from a smaller number of individuals and compare this data to data collected from a larger number of individuals. To be able to achieve the optimum potential of the questionnaire, the questions must be concise, clear and coherent for all the respondents (Mathers et al., 2009).

3.6.2.1 Closed and Open-Ended Questionnaires

Closed-ended questions offers the respondents a choice of responses from a fixed selection of available responses. Once the respondent selects a response, they are not permitted to expand on that response. Open-ended questions allows the respondent to respond to the question without being limited to a fixed selection of responses (Young, 2016). Closed-ended questions are considered easier to numerically code and is thus used in producing quantitative data and to use statistical methods of analysis to draw findings (Young, 2016).

3.6.2.2 Questionnaire design

Questionnaires are one of the main avenues in the collection of data for any research. It is an instrument for receiving responses to questions by making use of a form that the respondent completes at their own convenience. It a set of questions, sent to the sample of the population from which information is required. The questionnaires can be categorised into three types namely, structured (closed-end questions), unstructured (open-ended questions) or a mixture of both, structured and unstructured questions. (Farrell, 2016).

For this research, a structured questionnaire was used to collect quantitative data. The research questionnaire comprises of two parts. Part A of the survey questionnaire consists of socio-demographical questions which were questions relating to the usage patterns of the existing materials from the existing pavement in terms of recycling, upcycling and downcycling. Part B of the survey questionnaire is based on a scenario and the respondents are requested to respond based on the scenario presented. There were 43 questions in total.

The questionnaire was structured using a Likert Scale with responses rating from one extreme to the other namely, from ‘Strongly Disagree’ to ‘Strongly Agree’, ensuring an all-inclusive response reflecting the respondents’ levels of agreement. The detailed Likert scale used was the 5-point Likert scale represents statements as follows: 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree and 5=Strongly Agree (Mathers et al., 2009).

3.7 Data collection

In this section, the collection of the qualitative data and quantitative data will be presented.

3.7.1 Collection of Qualitative data

The collection of the qualitative data followed a five-step process. The steps included: (a) development of the interview schedule; (b) piloting of the semi-structured interviews; (c) scheduling of the face-to-face interviews with participants; (d) performing the face-to-face interviews and (e) transcribing interviews for the data analysis intentions.

3.7.1.1 Developing the interview schedule

Semi-structured interviews are flexible and allows the respondents the opportunity to more information when compared to the other types of interviews (Zohrabi, 2013). More information results in more data being collected from the respondents. An interview schedule is developed after a comprehensive review of all available literature associated with the research topic (Barrett & Twycross. 2018).

Most importantly is the type of questions being asked to the respondents. Questions are prepared in accordance with the research objectives. (Zohrabi, 2013).

3.7.1.2 Piloting the semi-structured interviews

Before the data collection process commences, the interview schedule is often piloted to experts in the industry. The pilot interview is a review to confirm that all key subjects have been included (Barrett & Twycross, 2018). The pilot interviews gives an indication if the interview schedule is clear, unambiguous, understandable and concise to answer the research questions. For this research, the first interview was used as the pilot interview and there were no changes to the schedule thereafter.

3.7.1.3 Scheduling face-to-face interviews with participants

The Covid-19 pandemic has transformed our methods of interaction and communication. Face-to-face meetings are now less common. Qualitative researchers and their potential respondents can now conduct their work activities using virtual platforms without the need to travel. These changes allow qualitative researchers the capability to use virtual platforms to conduct "face to face" interviews (De Villiers et al., 2021).

The researcher can partially see and observe the respondents through the camera function available on the virtual platform. This is dependent on how the respondent is positioned in front of the camera. Body language, non-verbal signals and facial expressions can be interpreted to a limited extent. Reliable technology, stable internet connection, high quality cameras and microphones are essential for a successful interview (Saarijärvi & Bratt, 2021).

For this research, Microsoft Teams was used to conduct the interviews.

3.7.1.4 Conducting face-to-face interviews

In general, semi-structured interviews can take a considerable amount of time. The interview can become involved and intense. It is important to ensure that the interview will not be disrupted. It is also essential to create a comfortable engaging environment and to allow the respondent to be at ease. The researcher's main aim in a semi-structured interview is to guide and facilitate the discussion, without being dictatorial and rigid. (Smith & Fieldsend, 2021).

It is important to explain the reason for the interview, the format of the interview and the nature of the interview. It is important to highlight that there is no right or wrong answer and that the objective of the interview is to understand the respondents' experiences (Doody & Noonan, 2013). With regard to the present study, nine interviews were conducted and steps provided in the discussion above were followed in the interview.

3.7.2 Collection of Quantitative data

This research is a mixed method research and as such, includes the collection of quantitative data. Similar to the piloting of the interview schedule for the qualitative data, the similar approach was used for the quantitative data collection.

3.7.2.1 Pilot testing of the questionnaire

According to Young (2016), once the questionnaire has been designed, it should be piloted by experts before being administered. During the pilot phase, the contents of the questionnaire should be carefully considered to ensure that the questionnaire has no ambiguity, has the correct terminology and is worded correctly.

The pilot questionnaire was sent to experts in the industry to test the clarity of the wording used in the statements, the time taken to complete the questionnaire and any other concerns that could negate the potential of the survey questionnaire. The survey questionnaire was divided into parts with Part A responding to the current materials utilisation patterns. This was further drilled down to the various pavement layers. Questions relating to the current specialisations, costs and parameters were also considered. The pilot study revealed the need to consider the terminology of the questions so that there was no ambiguity. Certain principles were already listed as limitations and was not be repeated in the other survey questions. Part B of the survey, included scenario-type question. The pilot study revealed that t more details introducing the scenarios was needed.

The comments from the pilot survey were considered and the questionnaire was amended.

3.7.2.2 Field survey

For this study, the use of the online questionnaire was chosen, due to several advantages namely: it facilitates a quicker response rate for the collection of data; it allows a more flexible creation of the question set; it is cost effective and it is easier to manage the process (Nayak & Narayan, 2019). The online survey platform used was Google Forms.

3.7.2.3 Editing of the data

On the last day of circulating the survey questionnaire, the online link was closed and deleted. This ensured there was no further participation in the survey questionnaire. The data was automatically saved to Google Drive and presented in Microsoft Excel format. This allowed for further processing using statistical software analysis.

3.8 Storage and security of data

The Microsoft Excel spreadsheet was saved using Google Drive which is cloud- based hence ensuring the safe storage of the data. The Microsoft Excel spreadsheet was password protected to guarantee that only the researcher had access to the data collected from the survey questionnaires.

3.9 Data analysis

In this section, the data analysis of the qualitative data and quantitative data will be presented.

3.9.1 Data analysis of Qualitative data

According to Braun and Clarke (2012), thematic Analysis is a technique for methodically identifying, categorising and presenting understanding into patterns of meaning also referred to as themes that are present in a data set.

3.9.1.1 Thematic analysis: a six-step process

There are six steps that were developed, to analyse the data collected from the interviews:

- **Step 1: Familiarisation of the data-** This step involves the transcribing of responses collected from the interviews. This is a continuous process of listening to the recording and writing down the key understandings of the respondents. For this research, Microsoft Teams automatically transcribed the interview, however the correct transcription had to be verified by listening to the recording and verifying the transcription.
- **Step 2: Generating of the initial codes-** While reviewing the transcript, initial codes are identified.. The coding of the data included the comments that are considered to be meaningful in context of the research.
- **Step 3: Searching for themes-**Once the data collected is coded, , the next step allowed for the searching of themes. The codes are interpreted from the interviews and then categorised into themes and subthemes.. A thematic map was created that demonstrated the relationship between the themes and the codes that were pertinent to the research.
- **Step 4: Reviewing of the identified themes-**Upon completion of the initial search for themes, the themes are then scrutinized for coherency and appropriateness. There were two levels of review. The themes were reviewed within the theme category and then for the overall data collected.
- **Step 5: Defining and naming themes-**After the identification of the themes, an iterative process of refining and defining was followed. The themes were analysed in detail and improved on to correctly describe the essence of the themes for the development towards the overall story.
- **Step 6: Producing the report-**The themes are then converted into responses for the research questions. The final report must be merited and valid. The final report was not limited to the description of the themes, but also included for the analysis which was supported by literature and responded to the research questions (Braun & Clarke, 2006)

3.9.2 Trustworthiness

Research projects provide knowledge to key stakeholders and through the insight gained from the research, this knowledge can be put into practice. For this to be achieved, research must be legitimate and understood by the industry especially policy makers, practitioners and the public (Nowell et al., 2017).

Trustworthiness is a key element to convince the readers that the results and recommendation reported in the research are valuable for further action in the industry. Trustworthiness can be enriched by the research adhering to criteria such as credibility, transferability, dependability and confirmability in addition to the conventional quantitative assessment criteria of reliability and validity (Lincoln & Guba, 1985).

3.9.2.1 Credibility

Credibility is an indication of confidence in the findings and accuracy of the research (Tobin & Begley, 2004). There are a number of techniques to address credibility such as prolonged engagement, persistent observation, data collection triangulation and peer debriefings. These allow for reviews on the research process, which enhances credibility (Lincoln & Guba, 1985).

3.9.2.2 Transferability

Transferability allows the research findings to be aligned to other applicable contexts (Tobin & Begley, 2004). The researcher has the task to provide thick descriptions to indicate how the research findings can be transferred to other areas of context (Lincoln & Guba, 1985).

3.9.2.3 Dependability

In order to achieve dependability, researchers must ensure the research process is clearly documented, logical and clearly traceable (Tobin & Begley, 2004). This allows for readers to be able to scrutinise the research process and put the reader in a better position to evaluate the dependability of the research (Lincoln & Guba, 1985).

3.9.2.4 Confirmability

Confirmability ensures that the interpretation of the research results are clearly founded on the data collected and not based on the researchers imagination (Tobin & Begley, 2004). Research studies emphasise that confirmability of qualitative research is achieved by means of an audit trail, reflexive journals and triangulation which are some of the methods to ensure that confirmability is achieved in the research. An audit trail is helpful for qualitative studies, since it illustrates using visual evidence that the researcher did not pre-empt the findings of the research (Bowen, 2009).

Since this research is a mixed-method study, confirmability was achieved by using both qualitative and quantitative approaches to collect and analyse data.

3.9.3 Data analysis of Quantitative data

The data collected from the questionnaire was analysed using a statistical analysis software program namely SPSS Version 27. The data collected was analysed and described using descriptive statistics and inferential statistical methods.

3.9.3.1 Descriptive statistics

Descriptive statistics refers to the methods used to explain the cases in a compilation of qualitative data. This is achieved by illustrating patterns in those data sets. The patterns identify the data distributions. Researchers use descriptive statistics to analyse the data collected through online questionnaires and surveys. Graphs, charts and tables can be used to present the data (Vogt et al., 2015).

The methods used in the descriptive data analysis was the median and standard deviation to give an indication of the distribution of the data.

- *Mean:* This is the arithmetic average of the data set. It is the sum of all the values in data set divided by number of observations within the data set. Due to the fact that a interval Likert scale was used in the study, (each number refers to a measurable something and distances can be calculated) the mean was not calculated as a measure of central tendency because, according to Sullivan and Artino (2013), it makes no sense for example to find out what is the mean of "agree".
- *Median (M):* The median is the middle number in a sorted list of numbers. In some cases, it can be more descriptive of that data set than the mean (Pallant, 2020).
- *Standard deviation (SD):* This is a measure to show how far the data is spread around the mean. A low SD is an indication the data is clustered around the mean, and a high SD shows that the data is spread out away from the mean (Pallant, 2020).

3.9.3.2 Inferential statistics

Inferential statistics includes procedures such as point estimates, interval estimates and hypothesis tests—all based on the idea of probability. Inferential statistics are approaches used to generalise the populations from which the samples were obtained using the findings (Kok & Meyer, 2018). The following test methods were used:

- **Factor analysis:** Factor analysis allows for the anlysis to reduce many individual items into a fewer number of variables.
- **Reliability Analysis:** According to (Pallant, 2020), the Cronbach Alpha score, as indicator of internal consistency reliability of scale should have a value of 0 .7 or higher.
- **Normality testing:** The Kolmogorov-Smirnova Normality gives an indication whether the parametrical or non-parametrical tests needs to be conducted (Pallant, 2020).
- **Relationship testing:** Spearman rank correlations, a non-parametric measure, was used to assess the measure of strength of association between two variables, which can be described using a monotonic function (Pallant, 2020). A positive correlation means that the movement of both variables will be in the same direction while for a negative correlation, the movement of variable will be in the opposite direction.
- **Variable Mean Score Comparisons:** The non-parametric Mann-Whitney U Test (two variables) and Kruskal–Wallis Test, (more than two variables) were conducted to determine if there were are any significant differences in the mean scores of the categorical independent variables (for example experience) on the dependent variables (design for upcycling) (Pallant, 2020).

3.9.3.3 Validity

Validity in quantitative research ensures that the survey questionnaire is measuring what it intended to measure (Saunders et al., 2009). To test the criteria of validity of the questionnaire, confirmatory or exploratory factor analysis methods are used. The purpose of the factor analysis calculation is to analyse the degree to which respondents answered the same questions in the same manner. The instrument is valid, if the degree is high (Field, 2018).

3.9.3.4 Reliability

Reliability in quantitative research, refers to stability of the measurements used as well as the consistency of the results achieved (Ghauri & Gronhaug, 2010). To test the criteria of reliability of the questionnaire, Cronbach's Alpha tests can be applied. The Cronbach's Alpha measures internal consistency, in order words, how closely do the individual questions relate to each other, when grouped together (Field, 2018).

3.10 Limitations of the study

- The population of the service providers and project managers currently responsible for the National Route 3 upgrade project proved to be a limitation of the study. Despite the fact that the National Route 3 project comprises of 13 projects, only three projects are active. The research population was summated at 41 participants; however only draw 32 respondents from the three active projects participatedin the study. As a result, the statistical analysis was performed a smaller sample size than initially anticipated.

- The lack of previous research on the upcycling of a network in a road network presented a drawback steering the research in the direction of assessing the industry understanding and shortcomings because the lack of research on this topic made it difficult to rely on previous studies on which to compare conclusions and findings.

3.11 Delimitations of the study

- The research is limited to flexible pavements and the upgrading of a national road network
- The research is limited to upcycling of the existing layers for reuse in the new pavement and does not consider the reclaimed material being used in other forms as part of the lifecycle of that material.

- The research is limited to the South African industry.

3.12 Elimination of bias

This research study was objective. No assumptions were founded on experience, education, age, gender and race. Language that reinforces stereotypes from the process of data collection, data analysis and the explanation of the research results, was excluded.

3.13 Ethical considerations

Ethical considerations are essential during the development of the evaluation strategy therefore ethical clearance was applied for and received from the UKZN Ethical Clearance Committee. (See Appendix B). In addition to this, following research ethical requirements were ensured for this study:

3.13.1 Ensuring informed consent has been obtained from participants

For this research study, the participants and respondents were well-informed about the study, the background into the study and the objectives of the study. Informed consent was sought from the participant and respondents to establish if they were comfortable to participate in this research study. The objectives of the study was explained to the participants and respondents. . The participant and respondents were given the option not to participate in the interviews or complete the survey questionnaire if they wished not to do so even after they had initially consented to participate. They received and signed the consent form before participating in the interview or responding to the survey questionnaire.

It was also highlighted in the consent form that consent may be withdrawn at any stage of the study and that participation was completely voluntary.

3.13.2 Ensuring no harm comes to participants

Harm can be considered either as physical, psychological or emotional harm. Harm can manifest in many different forms such as anxiety, tension, discomfort or low self-esteem amongst others. It is crucial to not cause harm, either intentionally or unintentionally as a result of participating in this research study. The participants were protected from harm, both physically and emotionally as well as psychologically, by creating a safe environment and allowing the participants to answer only those questions that they were comfortable with.

3.13.3 Respect for confidentiality and anonymity

Confidentiality was protected by ensuring that only the researcher had access to the information collected for the research. Confidentiality was also ensured by the exclusion of the participants' personal information from any reports or public papers. Anonymity is another form of privacy and more stringent than confidentiality. The participants' identity and personal details are unknown to those involved in the research. The names of the participants in the study was protected.

3.13.4 Ensuring that proper gatekeeper consent was obtained

For this study, the researcher was granted permission by the relevant authority to conduct the research with the participants identified for this study and report on the findings.

3.14 Summary

The methodology is a significant part of the research and provides details of the research design and strategies used to respond to the research objectives. This chapter provided guidelines on the methodology followed for this research study.

The next chapter will highlight the findings of this study, then engage in a discussion about the findings followed by the interpretation and analysis of the findings.

CHAPTER FOUR
FINDINGS, DISCUSSION AND INTERPRETATION OF FINDINGS

4.1 Introduction

In Chapter Three, the methodology used to conduct the research study was presented. In this chapter, the qualitative data and analysis of the data using thematic analysis will be provided. The discussion and interpretation of findings in the form of main themes and sub-themes will also be outlined.

4.2 Presentation of Qualitative data findings

When selecting participants to take part in the interviews, a purposive sampling technique was used by identifying participants from the 13 National Route 3 projects who possessed the experience, knowledge and insight into the phenomenon being researched in this study. However, only nine participants responded as only three of the 13 projects were in construction.

4.2.1 Demographic characteristics of the participants

The demographic profile of the participants is to give the reader an understanding of the characteristics of the participants. The demographic characteristics of the participants are presented in Table 4.1

Table 4.1 Demographic characteristics of the participants

Participant	Age in Years	Education	Gender	Job Position – Industry	Work Experience in years
1	41-50	BTechCivil	Male	Pavement and Materials Design Engineer - Consultant	22
2	60+	PHDCivil	Male	Pavement and Materials Design Engineer - Consultant	44
3	41-50	Matric	Male	Pavement Laboratory - Laboratory	15
4	60+	BScEngCivil	Male	Pavement and Materials Design Engineer - Consultant	40
5	51-60	NDIPCivil	Male	Project Manager specializing in Laboratory Testing – Client	29
6	31-40	BTechCivil	Female	Project Manager specializing in Laboratory Testing – Client	24
7	41-50	BScEngCivil	Male	Project Manager - Client	20
8	31-40	BTechCivil	Male	Pavement Laboratory – Laboratory	4
9	51-60	MengCivil	Male	Pavement and Materials Design Engineer - Consultant	35

As presented in Table 4.1, the participants are in the age group of 31 to 60+ years of age. This makes it an experienced and established work force. One of the participants is female and the rest are male. Their years of experience range from 4 years up to 44 years. The participants are all well-educated and two participants have higher education qualifications. Based on this information, it is clear that the participants will provide valuable information that will enable the objectives of this study to be achieved.

4.3 Findings of the Study

The aim of the research study is to investigate how the different project-based Materials Utilisation Plans can be integrated into one Network Materials Utilisation Plan. A qualitative research approach was adopted to collect data from experienced participants using semi-structured interviews that were subjected to thematic analysis with the aim to achieve the following research objectives:

> **Research Objective 1:** To determine what the factors influencing the specifications of upcycling in the design of the Materials Utilisation Plan are.

Research Objective 2: To determine what is the effect of the identified factors influencing the specification of upcycling in the design of the Materials Utilisation Plan.

The six-step thematic analysis process to analyse the data with intent to find relationships or patterns within the data was used (Clarke et al., 2015). The thematic framework in Figure 4.1 below was developed as the framework to present the findings from the qualitative research study. For the purposes of this chapter, the factors will be identified and the impact will be discussed in the same model.

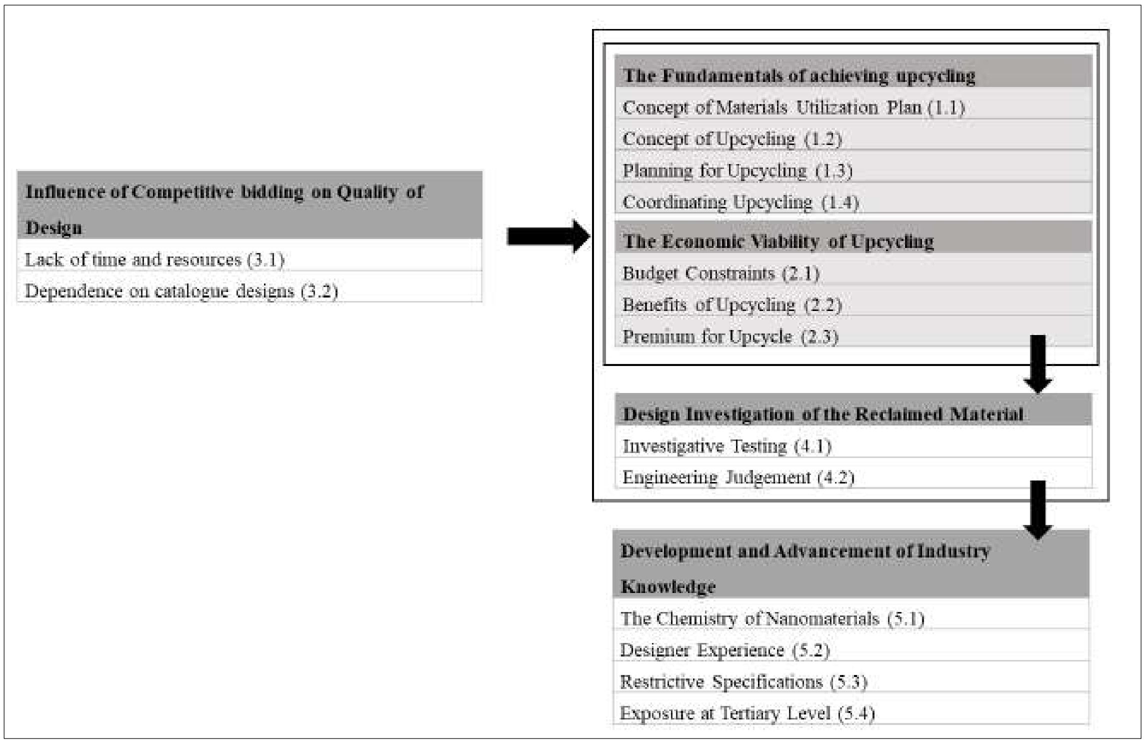

Figure 4.1 Thematic Framework for the factors influencing materials utilisation

The understanding of fundamental concepts will influence an array of factors that will, in turn, influence the upcycling in a material utilisation plan for a network as discussed next.

4.3.1 Development of the Themes

The data collected from the semi-structured interviews was analysed the data using the six-step thematic analysis process as proposed by Braun and Clarke (2006).

Familiarisation with the data was achieved by listening to the recording and confirming the transcriptions automated by the Microsoft Teams application. The next step involved the coding of data manually by reading each line of the transcript and developing codes for each sentence. The codes were then sorted into categories that yielded 46 codes spread over six categories. The categories and their sub-codes were then grouped into main themes and sub-themes relative to the research objectives of the study. The thematic structure in Figure 4.1 above, provides an overview of the main and sub-themes identified.

4.3.2 Main Theme 1: Fundamentals of achieving upcycling

According to Rasch (2018), the movement of materials between projects, requires further investigation. The concept is limited in knowledge and requires extensive collaboration to determine the utilisation strategy of each project and how the users' requirements can be accommodated during construction. Ownership of the process needs to be taken by the road's agencies on a network level as opposed to project level. Table 4.2 shows the emerging theme of understanding of the fundamental concepts of achieving upcycling.

Table 4.2 The Fundamentals of Achieving Upcycling

Fundamental Concepts	Emerging Theme
1.1 Concept for materials utilisation	1: The fundamentals of upcycling in a materials utilisation plan
1.2 Concept of upcycling	
1.3 Planning for upcycling	
1.4 Coordinating upcycling	

The network materials utilisation plan is dependent on the understanding of fundamental concepts influencing the ability to implement effective methods of upcycling. All the sub-themes were derived from the thematic analysis of the qualitative data.

4.3.2.1 Sub-theme 1: Concept of the Materials Utilisation Plan

The following responses were received from the respondents related to the definition of the material utilisation plan:

> *Participant 5: The Materials Utilisation Plan is taking something that you have and deciding how best you can reuse it and to come up with a strategy.*

Participant 6: To me, is a plan that gives a full description of how and where we going to place materials on a construction site.

Participant 7: Materials utilisation is how you utilise materials on layer work, it's reusing or recycling material.

The materials utilisation plan is a strategy for the reuse of the existing materials. The plan gives details of the handling of each existing layer in the construction process. The material utilisation plan includes plans for reuse and recycling of materials.

Many of the participants focused on the reuse of materials as part of the materials utilisation plan. The study completed by Kasim et al. (2005) identifies some of the components of a materials handling strategy, which includes: the sequence, amount, time, position, place, method, condition and cost of the movement of the materials.

4.3.2.2 Sub-theme 2: Concept of Upcycling

Upcycling is the process of using the reclaimed road layer as a layer of higher value in the upgraded road. For example, the upcycling of the base course is using the reclaimed base layer as the new surface layer while upcycling the sub-base is using the reclaimed sub-base layer as a new base course or new surface layer. Upcycling of selected layers is using the reclaimed selected layer as the new surface layer, new base course or new sub-base layer.

Participants' understanding of the concept of upcycling is revealed by the following statements:

Participant 5: I think it's a complete mind-set that we have to start introducing upcycling and I think as a client and being one of the biggest client bodies in the country is something that they can enforce.

Participant 6: When you can increase or you can mechanically or chemically modify, upgrade the material to a different material class.

Participant 7: When we are reusing the material but for a higher quality layer work or material usage.

> *Participant 8: Upcycling in essence, is improving the material to a higher standard to some extent or at least combining through another product to provide some degree of improvement in terms of structural use.*

Based on these comments from the participants, upcycling is the process of improving the existing materials so that it can be reused as higher quality material. Although the understanding is evident, there seems to be a reluctance in driving the process of upcycling as noted by the following statement:

> Participant 5: *I think the problem is everybody wants the easy way out. The moment you talk upcycling, they start always scratching their heads.*

Based on the statement above, upcycling can be considered difficult or challenging to achieve. The Dictionary of Sustainable Management (2009) defines upcycling as "The process of converting an industrial nutrient (material) into something of similar or greater value in its second life." The study by (Sung et al., 2014) revealed that the determining factor influencing upcycling includes the perceived benefits and materials competency. Emotions, social factors and habits also contribute to the process of upcycling.

4.3.2.3 Sub-theme 3: Planning for Upcycling

The process of planning allows the project owner to develop and defines the objectives of the project. During this stage, the project owner chooses the best design and construction methodology to execute the project and achieve the objectives of the project. Planning is critical, especially if the project or any component of it, is new or has not been tested and is piloted.

The following statements from the participants relating to the planning of upcycling are presented:

> *Participant 1: It's not just a design stage, it's a planning stage, it all starts in the beginning especially if you are looking at it from a network level. The same philosophies that you implemented for a network project you need to apply that same philosophy in your design.*

Participant 3: You need to know at the design stage to be able to design the best solution.

Participant 9: Allows for planning during design and specification stage.

The participants' responses indicated that upcycling must be planned for at the design stage. However, as indicated by participant 1, the planning starts at the planning stage of the project and not the design stage. This is fundamental especially for a network. This philosophy of planning is supported by the study of (Zwikael, 2009) which concludes that the planning phase of the project life cycle is critical to decision-making during the project and for achieving a higher quality end product.

4.3.2.4 Sub-theme 1.4: Coordinating Upcycling

Network collaboration is when the individual project's key personnel and all stakeholders, with varying skills and experience, work together towards achieving the goal of the individual project and network objective. All the key personnel and stakeholders are included in the decision-making process, and all have access to the information needed for the projects. The following responses were received regarding the coordination of upcycling:

Participant 4: Coordination is right up front in terms of principles that the client wants and wants to achieve. The engineers need to be on the same wavelength. Then you've got to have coordination of the demand and supply of materials. I think it's a coordination that's going to be very important in all of this. You must investigate the options for cross-usage of materials.

Participant 5: Each consultant goes about it their own way how to analyse and do stuff then we may not achieve the end result that we looking for.

Participant 9: This will require meticulous co-ordination of location and timing of supply and construction. The turnaround time will impact the overall programme.

Lavikka et al. (2015) suggests that to resolve the issues of lack of coordination, the project can define process flows at the onset. This includes process flows for organisational design and processes for working towards the project's shared objectives. The aspects that also needs consideration is the contract type, timing and extent of procedural coordination. This is coordination that is needed at the onset of the project, before the implementation of the design phase.

4.3.2.5 Main Theme 1: Summary

The materials utilisation plan gives the contractor the design methodology of handling of each existing layer. The reuse and recycling of materials are included in the material utilisation plan. The plan must also incorporate the sequence of movement of the materials, the amount of material to be stockpiled or reused, timing of the materials allocated activity, position of end use, and the cost of movement of the materials. (Kasim et al., 2005).

Upcycling is the process of improving the reclaimed material to be reused as higher quality material. The process of upcycling requires the understanding of fundamental concepts which contribute to the design of the various methods of upcycling. The methods to improve the materials' strength includes processes of mechanical and, or chemical modification of the reclaimed material.

The participants' responses indicate upcycling must be planned for, at the design stage. This is aligned to the study of Kasim et al. (2005), which suggests that an integrated material handling process from the design stage to the usage of materials, is needed to make materials management on-site more effective.

4.3.3 Main Theme 2: The economic viability of upcycling

Existing infrastructure needs to be maintained in a cost-effective method to safeguard public funds. Materials and human resources must be optimised on the project and network levels. (Uddin et al., 2013). Table 4.3 shows the emerging theme of economic viability of upcycling.

Table 4.3: The Economic Viability of Upcycling

Economic Related factors	Emerging Theme
2.1 Budget constraints	2. The economic viability of upcycling
2.2 Benefits of upcycling	
2.3 Premium to upcycle	

Design engineers need to be able to design more cost-effective roads, through the provision of road infrastructure using a lesser budget. This can be achieved through a mind shift change and promoting the use of technology. In many designs, the existing material does not meet the minimum standard of the required layer. This often results in the conventional design methodology to import crushed, natural aggregate. This method of design is expensive and not cost effective (Jordaan & Kilian, 2016).

4.3.3.1 Subtheme 2.1 Budget Constraints

Budget constraints refers to the limited funding available to build, manage and maintain road infrastructure. Design engineers need to be able to design more cost-effective roads (Jordaan & Kilian, 2016).

These statements were received from respondents regarding budget constraints:

> *Participant 1: Biggest hindrance to that is budget availability, never going to have enough money to do everything you want.*
>
> *Participant 3: So now we don't have money inside Africa. I think we all know that we're trying to do things as economically as possible so if we've got an opportunity to try and make things work.*
>
> *Participant 7: Providing that cost because you know you're going to save in the long run is all the help those guys be able to make these decisions.*

The budget availability has a significant influence on the project outcomes. Road agencies make use of public funds to build, manage and maintain road infrastructure (Uddin et al., 2013, pp. 26-31). Knowing that there are insufficient funds, the research recommends that the need for cost-effective designs are crucial to ensuring continuance in building, managing and maintaining road infrastructure.

4.3.3.2 Subtheme 2.2: Benefits of Upcycling

The benefit of upcycling is the positive outcome of reclaiming the existing material and reusing it as a higher value in the new pavement. These responses relate to the benefits of upcycling:

> *Participant 3: There's obviously the cost-benefit of trying to avoid the extra cost by transport and purchasing extra materials and then also the CO2 admissions. It is a good environment-friendly way, and also a cost-effective way of managing the materials in the long term, it'll be a huge cost saving for us if we don't have to worry about spoiling materials or stockpiling.*
>
> *Participant 5: I think for clients ultimately, it'll be a big cost saving for us.*
>
> *Participant 7: Long-terms factors it is environmental, but initially, it's just going to be saving.*

The highlighted benefit of upcycling is focused on cost savings. Long-terms benefits include environmental savings such the reduction in CO_2 emissions and factors contributing to activities of spoiling and stockpiling of materials. The study by Sung (2015) aligns with the responses received, in that the economic benefits and environmental benefits are among the most evident in terms of upcycling. Economic benefits are viewed as cost savings in terms of the reduced process in the production of new material.

4.3.3.3 Subtheme 2.3: Premium for Upcycling

The premium to upcycle is the additional costs associated with reclaiming the existing material and reusing it as a higher value in the new pavement because of various contributing factors. The responses below were received related to the premium of upcycle:

> *Participant 1: You need to look at this type of material utilisation, not just from an environmental point of view, but also from cost-effectiveness. What should happen is the engineer should provide the client with an estimated budget of how much, let's say a pavement investigation would cost. That does increase the cost of your testing because now obviously you need to have a proper backfilling of that material that you've taken out.*
>
> *Participant 4: You need to go back down to the economies of doing that, you know is it, is it worth your while economically, to do that and what premium are you*

prepared to pay economically for the more efficient use of scarce natural resources?

Participant 5: I think on the outset there will be a premium attached to the whole operation. I think the cost that we invest at the design stage in terms of the initial investigations will be well, well worth spent. The thing is testing is such a small cost relative to the cost of the material and the construction.

Participant 9: Cost of upcycling vs. in-situ recycling.

The above statements received gives an indication that the participants are aware of the additional testing and design required for the process of upcycling in a network and the optimal usage of the reclaimed material. Kasim et al. (2005) goes into details on the management of materials in a construction project, which includes processes of upcycling. The management of materials has a direct influence on the productivity and costs and includes aspects such as planning and materials distribution. The cost to manage materials on-site can range from 30-80% of the total construction costs. This massive contribution to project costs underpins the need to efficiently manage materials on-site.

4.3.3.4 Main Theme 2 Summary

The budget available for rehabilitation and a new road is becoming increasingly constrained. Road agencies are responsible for using public funds to develop and improve road infrastructure (Uddin et al., 2013, pp. 26-31). In response, the design engineers need to design more cost-effective roads.

The participants acknowledged the need for upcycling. The benefits of upcycling are two-fold: the initial benefits would be costs savings while the long term-benefits are centred around environmental benefits. With upcycling, there is more focus on the economic analysis associated with the strategy to upcycle. The investment at the design stage and increase in costs to investigate the existing pavement, will prove to be invaluable to the decision of upcycling for the project and network.

4.3.4 Main Theme 3: Influence of competitive tendering on the quality of design

Elfving et al. (2005) explains that competitive bidding which is the procurement vehicle to appoint the service providers such as the design engineer, is used in an attempt to cut costs. However, the value of the design remains questionable. Table 4.4 shows the emerging theme of the Competitive Tendering on the Quality of Design.

Table 4.4: Competitive Tendering on Quality of the Design

Design factors	Emerging Theme
3.1 Lack of time and resources	3. Competitive tendering on quality of design
3.2 Dependence on catalogue designs	

The development of the theme of competitive tendering includes the subtheme of lack of time and resources as a result of the competitive tendering process. The dependence on the catalogue design is linked to the lack of resources, hence the reliance on theoretical knowledge.

4.3.4.1 Subtheme 3.1: Lack of Time and Resources

Time and resources are the basis of competitive tendering. Design engineers tender on hours and key personnel rates. The challenge with competitive tendering is insufficient provision of hours to be able to complete the design effectively.

The statement below was received regarding time and resources:

> *Participant 4: In general, you're not going to go volunteer a lot of extra time to do all the investigation work and then still only get paid the small amount that you tendered. No real incentive to go and look at something different. Hence why you continue with the good old tried and tested path and do that.*

Due to the reduced rates used in competitive tendering, the least amount of time and resources are used to get the design completed and approved. The study by Messner et al. (2018) confirms that the competitive bidding procurement yields the lowest performance attributed to the lack of experience with the project delivery system, poor communication and understaffing.

4.3.4.2 Subtheme 3.2: Dependence on Catalogue Designs

The catalogue design refers to the theoretical design procedure followed in the design process with limited input in terms of innovation or upcycling.

The following responses were received regarding the use of the catalogue design:

> *Participant 3: Many follow the catalogue design.*
>
> *Participant 5: Obviously based on theoretical.*
>
> *Participant 6: So there the current designers at the moment rely on the catalogue design.*
>
> *Participant 7: They just basically put something on the catalogue.*

The dependence on the catalogue design becomes a key restrictor when needing to design for upcycling. Meghana et al. (2016) succinctly points out that the appointment of a designer has the ability to influence the project's success. The client will set standards and design criteria which allows for the design of the project using the applicable codes and other requirements. The standards and design criteria govern the project budget. The quality of the design, the time taken to complete the design, preparation of contract specification documents, and supervision of the construction work is very important for the success of the project. The major problems evident in the design phase that affect the quality of construction includes design quality, design changes, lack of information and lack of coordination.

4.3.4.3 Main Theme 3 Summary

Meghana et al. (2016) strongly suggests that the designer engineer has the ability to influence the project's success. Many of the participants from the interviews highlighted the heavy reliance of the engineer on the catalogue design of pavements. One of the reasons for such dependency, is the reduced rates associated with competitive bidding. Franz and Roberts (2018) emphasised that the procurement method of the competitive bidding procurement produces the lowest performance because of the lack of experience with the project delivery requirements and understaffing. The lack of adequate resources and the substantial dependence on the catalogue design impacts the opportunities for upcycling.

4.3.5 Main Theme 4: Design investigation of the reclaimed material

The purpose of laboratory testing in the design phase of the project is to block out and prevent the use of substandard materials as part of the quality control process. Quality control considers the materials' properties and behaviour, both beneficial and detrimental. The significant element of quality control is the interpretation of the tests result on the final product and the effect of those results on the final product to be achieved in construction. The isolated use of specifications to confirm the existing material potential in the design phase, will not achieve economic value for the reuse of the current materials. The use of modification for marginal materials can offer better economic options and this can only be achieved through the understanding of the materials by the design engineer. The experience of the design engineers must not be limited to textbook education. The design engineer must also be competent in field experience (Kisunge, 2021). Table 4.5 shows the emerging theme of the Design Investigation of the reclaimed material.

Table 4.5 Design Investigation of the Reclaimed Material

Laboratory Related Factors	Emerging Theme
4.1 Investigative Testing	4. Design investigation of the reclaimed material
4.2 Engineering Judgement	

The investigation during the design stage of the project informs the quality of the materials. The quality of the existing materials determines the design strategy. The testing as well as engineering judgement drive the process of the design.

4.3.5.1 Subtheme 4.1: Investigative Testing

During the design phase of the project, the design engineer is required to investigate the existing pavement material. The design engineer is responsible for procuring the services of a laboratory to extract samples of the existing road pavement and test the materials. The testing is conducted according to the testing plan that the engineer submits to the laboratory providing details of the test required.

The following responses were received with respect to the testing conducted for the process of upcycling of the existing materials.

Participant 1: Is it important to have a good understanding of how to sample the material, but we have found that it is quite beneficial for them to also understand why they sampling the material.

Participant 3: There's a lot of extra stuff that can be done and that's where the engineers sort of block out this bit.

Participant 4: Obviously you need to know what is in the properties' characters of your proposed materials sources. Also, I think that anytime you run into problems with roads jobs is when you didn't do enough testing up front. I think we as an industry probably do not do enough initial testing. It's important we need to really look at that material properly and those test results.

Participant 5: Sample size can greatly influence and then you may not get the required design that you need. So I think with upcycling you got to actually do them even if it means every kilometre or few hundred meters because we have to be certain that we're not missing any links.

Participant 6: Obviously it will take time, but the tests are out there, and he can inquire, even ask laboratories. But the point is the lab then can outsource these special tests. if the designer is aware of them.

Participant 7: The consultants will be more conservative with what they're testing because of the really limited nature of the testing that they do.

Participant 8: You need to obviously evaluate risk in terms of the amount of data is going to get out from this investigation process.

The above responses indicate a gap in the potential of information that the laboratory can supply and the information being requested. Apart from the existing materials, the as-built records are meant to give the design engineer information on the road pavement that was constructed. According to the statement below, the engineer needs to be mindful of the shortcoming of the as-built records.

Participant 2: As-builts are very dangerous. You will never find a consultant that will produce you and as-builts showing anything that does not conform to the *specifications. But you will never get somebody that will produce as built that contains anything that was not built according to the specifications.*

Unreliable as-built records influence the importance of the laboratory testing plan and impacts the level of confidence of the existing materials. The traditional tests requested are every limited as presented by Arnold and Stubbs (2015), in the design of pavement rehabilitation. The laboratory tests conducted are generally the traditional tests such as particle size distributions, fines quality tests and Unconfined Compressive Strength (UCS). These tests are limited and does not analyse the pavement structure as a composite. The traditional tests require engineering judgement to determine the suitability of the recommended rehabilitation strategy.

4.3.5.2 Subtheme 4.2: Engineering Judgement

Kisunge (2021) further highlights the influence of the design engineers experience on the interpretation of results. It is crucial for the design engineer to fundamentally understand the materials' behaviour and not be limited and compare test results with specifications to decide on the utilisation of the materials tested.

The following statements are the responses received in relation to the interpretation of key results:

Participant 1: Testing and the interpretation of those tests, that's very critical. And also, a very high level of confidence in the existing properties. The level of confidence drops, and that means that you need a different action for that section of road.

Participant 2: It's not about layers in the pavement, it's about a pavement structure. So that is the essence of understanding your pavement structure as a whole and doing it scientifically.

Participant 3: The engineers have to make the engineering judgment.

Participant 6: The laboratory only acts on the instruction of the engineer. So, the designer is responsible. He or she needs to give instructions to the laboratory as to what he wants tested. The design engineer must create scenarios for testing. Is that you create the scenarios in terms of your outside the number and tell the *laboratory to test, especially test the optimal. You create an OMC too high, too low and then optimal. You test the sensitivity.*

The interpretation of test results is key to the design process. Apart from interpretation, the designer must request the correct tests and request a sensitivity analysis for the various scenarios that could become reality in the construction. Informed engineering judgment impacts the design and the resultant construction strategy.

Jordaan and Steyn (2021) emphasises that materials characterisation tests, lack a scientific basis and gives minimal indication on the potential bearing capacity. The absence of sound engineering concepts needed for the characterisation of materials and the resultant specifications used in the construction, is a limiting factor in the conventional laboratory tests, such as indicator tests.

Arnold and Stubbs (2015) provide a solution to the limited traditional design approach and testing which is to implement performance-based design. Performance-based design will allow for a higher level of confidence in the design and will ensure no early failure of the pavement. By nature of the performance-based approach, it will yield a higher level of scientific support for the recommended pavement design.

4.3.5.3 Main Theme 4 Summary

The laboratory is not being used to its full potential. The design engineer is only requesting the traditional tests. The traditional tests are very limiting as described in the study by Arnold and Stubbs (2015). This indicates that the engineer is not obtaining all the possible information that pertains to the existing pavement layer. This is further compounded by the unreliable as-built data which can have significant consequences on the design and construction and further reduce the level of confidence in the existing pavement.

Jordaan and Steyn (2021) continually emphasises that traditional materials tests lack a scientific basis and gives minimal indication on the potential bearing capacity. The laboratory provides the results of the tests received and the design engineer is responsible for interpreting the laboratory test results. The interpretation of test results is paramount to the design process

since it indicates the potential of the existing pavement. The design engineer uses design experience and informed engineering judgment to determine the use of the existing material. The engineer's interpretation influences the design and the resultant construction strategy.
The limited tests requested by the engineer from the laboratories and the lack of scientific methods to analyse test results reduces the information yielded to maximise the existing material potential. The use of engineering judgement, which is influenced by the competitive tendering further impacts on upcycling in a materials utilisation plan.

4.3.6 Main Theme 5: Development and advancement of industry knowledge

Bayard et al. (2014) states that knowledge is perishable and has a "best before" date. The reason he gives for this is that it is necessary to continually be updated and aware of the latest findings and advancement in the industry. Universities and other education institutions can be helpful in promoting the continuous learning.

The development and advancement of the industry knowledge theme is developed and is influential across the fields of the developers in technology, design engineers, client bodies and tertiary institutions. Table 4.6 shows the emerging theme of the Development and Advancement of Industry Knowledge

Table 4.6: Development and Advancement of Industry Knowledge

Knowledge Source Factors	Emerging Theme
5.1 The Chemistry of Nanomaterials	5. Development and Advancement of Industry Knowledge
5.2 Designer Experience	
5.3 Restrictive Specifications	
5.4 Exposure at Tertiary Level	

The development of new technology in the last decade has become a "game-changer" in the search for cost-effective solutions in the provision of road infrastructure (Jordaan et al., 2017). The presence of water is the main contributing factor in the chemical weathering of pavement layers. If water can be largely prevented from contact with the material particles, the material layer can be saved from further weathering and the strength properties of the material improves.

The most efficient method to prevent contact with water is to alter the polarity of the materials. This alteration is achieved by the addition of another compatible material.

4.3.6.1 Subtheme 5.1: The Chemistry of Nanomaterials

Nano refers to one-billionth. All materials have special properties at a nanoscale and at a macro scale. The properties differ for both spectrums of the scale. Nanotechnology refers to the adaptation of the nanoscale properties of materials. Nanotechnology can be used in the modification of the material's properties at macro scale by combining nanoparticles of other materials into it. Chemistry is the analysis of the materials' properties and composition when being modified by another product, namely nanotechnology (Jordaan & Steyn, 2021).

The following statements were received regarding chemistry and nanotechnology:

> *Participant 2: They use indicator tests that are empirically derived that date back 20 or more years and are not appropriate for the pavement engineer in our field, where we are dealing with science.*
>
> *Participant 2: With new technologies, we can neutralize any negative effect of secondary materials that are present in materials. I can upcycle G8 materials or G7 materials with G6 materials. And that is because I understand the chemistry involved in changing the material properties and neutralizing any negative effect of certain minerals that may be present. I determine the strength to look at engineering properties and not other properties. You have to look at the chemistry involved in this, and you have to go to a scientific way of designing material tests to learn something about chemistry and the interaction with minerals and the bond strengths that can be achieved with minerals to understand these things and what you will find when you talk about mineralogy and chemistry. I knew it would work because I made sure I understood the chemistry between the materials I'm using to stabilize it.*
>
> *Participant 2: How can you compare that scientific knowledge with a test that is empirically derived. Every mining operation throughout the world got XRD equipment. You need a scientific test to determine and understand what is happening with the materials and the minerals, you understand mineralogy and need to have more interaction with that. People didn't even know what Nano*

meant. When I speak about nanotechnology, they asked me, what's the effect of that, especially with new technology, we can now introduce scientific ways of design.

Participant 3: It's the technology you know, we, we've got the equipment. We've got technology. This is a new market, and people fear it. There's a new technology and people need to give you the opportunity because what we've done is so much up to date. We've had great success with most of the projects that we've been into so it's just that people need to get over that hurdle or fearing recycling.

Participant 5: I'm still very sceptical with nanotechnology. Personally, for me test results are just test results – need to try it and see it for ourselves. I'm not putting nanotechnology down, but I personally have not seen it, but I'm very sceptical.

Participant 6: Well, this is what we need. How would you know the chemistry behind the nanotech, the chemistry of our materials, how it will interact? We need a workshop for what people think is nanotech, but from first principles.

Participant 7:Promoting researchers promoting initiatives or out-of-the-box thinking. I have no experience in nano technology. I think there's not much local published data on it we are going to use nanotechnology it shouldn't just be on the BSM materials and should be on everything.

From the statements received, the use of empirical tests to determine the potential of the reclaimed materials is superseded by the introduction of new technology and nanomaterials. The use of nanomaterials requires scientific methods of analysis so that the full potential of the reclaimed material can be understood, analysed and designed. The industry is hesitant on nanomaterial and the chemistry supporting the use of it. The comments received indicate a need to increase the awareness and research in nanomaterials, nanotechnology and chemistry. As a result of the lack of buy-in, the industry is losing the opportunity to upcycle materials.

The possibilities of nanomaterials are studied by Ugwu (2013) who investigates the use of nanomaterials to enhance the geotechnical properties of soils for road pavement. The primary contributing effect to road damage is water ingress into pavement layers which can be mitigated using nanomaterials. The inclusion of nanomaterials allows for hydrophobic behaviours which creates a waterproof layer thus surfacing the road. The introduction of nanomaterials revealed the potential to use available marginal materials for pavement layers. Crucial to the use of nanomaterials is the understanding of the materials' microstructure, science and chemistry underpinning the behavioural reaction of the materials. The study promotes innovation in road construction and education of advanced methods in developing construction materials. The impact of using available materials reduces the need for importing aggregate and yields an array of advantages, contributing to sustainable road infrastructure.

The comments received, reveal that the industry is at risk. This message is supported by Maynard (2006) who describes nanotechnology as being the next industrial revolution and warns the industry of the difficult lessons learned from advances in technology being ignored.

4.3.6.2. Subtheme 5.2: Designer Experience

Complex design experience is a key component of a competent design engineer. Experienced designers should have a combination of site and theoretical knowledge.

These statements below were received regarding designer experience:

> *Participant 1: The importance of experience for the design, for the designer, is to understand that the lab gives you test results. It should be your responsibility or someone that has got knowledge of materials. They usually give it to junior people in the organization that might not have that experience or that exposure to certain critical things. There is limited experience and have book or theory knowledge about what to do. I've made it a point to question assumptions. We are not going to be working on pure facts the whole time because there are a lot of unknowns that we need to take into account to understand these things and what you will find when you talk about mineralogy and chemistry.*

> *Participant 2: Engineering is to be derived from ingenuity, and it's the right from science and what we have done in pavement engineering and materials engineering. So you need to understand this concept. People never know where to identify where they should be doing their test pits, for example. And it's so easy if you understand a few statistics.*

> *Participant 3: Not everyone has the same experience. And there is all new to them, so they're very scared of making decisions so that's why they just referred*

to the documents instead of making their own decisions. And it's impossible to convince them to look at the new ones. It does come with experience.

Participant 4: It's important we need to really look at that material properly that those test results.

Participant 5: There are new consultants on the block. I don't know whether the age of a design is important to experience that they would have, because I think you also got to have a bit of think out the box kind of concept. It does mean that the design experience is directly related to the interpretation of the actual test results for upcycling.

Participant 7: We're going to start seeing that the savings will be increasing but I think initially with the lack of knowledge, it will be difficult

The key concepts in upcycling relate to mineralogy and chemistry. Without adequate on-site materials knowledge, the design engineers' fall-back design is the theoretical catalogue design. This is the simplistic method of design and does not allow for the reclaimed materials to be used optimally.

The overall comments above concur with results of the study conducted by Aziz and Abdel-Hakam (2016) which summates that delays are a common occurrence in construction projects. In the study, the contractors identified the lack of design as a major cause for delay on projects. Causes included design rework due to changes of design, design errors made by the designers and wrong or improper design.

4.3.6.3 Sub-theme 5.3: Restrictive Specifications

Included in tender specifications are a list of applicable standards and manuals to be used in either the design or the construction. The clients specify the works, the quality criteria and the standards. Any design completed that does not align to the specifications are considered as contrary to the contract specification.

The response below was received regarding the clients' specifications:

Participant 6: As a client body, we have to loosen the reins. We should explore things like performance-based systems and leave that up to the consultant to *decide. The engineer must use our technical guidelines because we enforce our documentation and that restricts them into, you know, exploring outside, exploring new innovations, and so on. Only a few key people in the industry have this knowledge for nanotechnology. And there is a lack of appetite to explore innovation. They have an appetite to explore, but they are limited due to what we have put in place.*

The clients' specifications are restrictive and do not promote innovation or upcycling. Performance-based systems will allow for more innovative practices in the industry. Rose and Manley (2012) support the increase in performance-based specifications, which will provide more flexibility to investigate new innovative practices and products. The focus of the study was to provide solutions to incorporate innovation in road construction.

The advances in technology and knowledge influences the industry standards. This change can only be effective if it is developed during the initial learnings at tertiary level.

4.3.6.4 Subtheme 5.4: Exposure at Tertiary Level

Tertiary level education refers to the third level of education generally received at universities or Technical and Vocational Education and Training (TVET) colleges. It is at this tertiary level, that students learn about pavement design and the fundamental concepts underpinning road infrastructure.

The following statements regarding tertiary level education was received:

Participant 2: There is a big problem in the training of pavement engineers, inferring that the syllabus on the very beginning stages of pavement design at the tertiary level needs to be re-looked at. They've kept the same sort of syllabus from over the last 40 years, I strongly feel that engineers should study statistics from year one to year 4, even in postgraduate courses, so that they understand what they are designing.

Participant 3: I mean, people don't walk out at universities and think of upcycling you know, they just want to do what they've been taught so it would be great to get that into universities.

Participant 5: There's a lot of new generation engineers coming in and I think some content in the syllabus at a level of university or Technikons needs to be integrated at that level. I think then they will understand and obviously when they are studying and starting to do research or masters, they can all start looking into this. So, I would recommend that if the powers may be, we need to start introducing this at a very young early age when people enter university and included in the syllabus in university.

Participant 6: So the new designers that are coming out of the universities are better equipped to do upcycling. These guys understand the science behind it. So bottom line, the universities need to include these.

Participant 8: You should be at grassroots level because I mean, specific content at a university syllabus level and I think that the way things are heading nowadays would sort of reuse and repurposing of materials, we bound to encounter this. It makes sense to introduce it to universities to prepare students for what's going to happen in industry.

There is a need to introduce the fundamental concepts of upcycling at tertiary level. The learning at this level will support the understanding of future graduates and promote further research to support the industry.

Tertiary education needs to align to advancements in the industry. Nanotechnology propositions a new paradigm of ground-breaking advancement in material by manipulating and controlling the fundamental building blocks of matter on the nanoscale. The growth in nanotechnology has evolved conventional design practices. The uniqueness of nanotechnology has made education in the field of nanotechnology increasingly important for the students and industry. This specific technology requires that education bodies collaborate to adequately prepare competent graduate engineers (Balakrishnan & Visvanathan, 2013).

4.3.6.5 Main Theme 5 Summary

Maynard (2007) describes nanotechnology as being the next industrial revolution and warns the industry of the difficult lessons learned from advances in technology being ignored. The chemical weathering of pavement layers as a result of water is the main failure mechanism of road infrastructure. This can be eliminated using nanomaterial. However, with the introduction of nanomaterials and nanotechnology, the design engineer will be required to understand and analyse the materials using chemistry. Herein lies the challenge, in that the majority of the industry is unfamiliar with chemistry. Chemistry requires scientific methods of analysis which is different to the traditional empirical methods.

Without the required knowledge and understanding on nanotechnology, the opportunity for upcycling is reduced. This limits the maximum use of the existing materials. Design experience must also include experience in the latest industry developments and knowledge so that alternate methods of optimisation can be explored.

The interviews also highlighted the restrictions of the client's specification which is instructive on the standards to be used in the design. This instructive client specifications adversely influences upcycling in the materials utilisation plan. One of the ways to ensure the continuous development of industry is to ensure that graduates are exposed to the latest developments. This will allow for growth and progress from the beginning of work experience. The exposure at tertiary level can also be used to promote further research in the field for development.

4.4 Summary

This chapter presented the findings from the qualitative data analysis. The thematic analysis identified the relevant themes of the study. The thematic analysis findings will be consolidated with the results from the quantitative analysis. The following chapter will detail the results from the quantitative study.

CHAPTER FIVE

RESULTS, DISCUSSION AND INTERPRETATION OF RESULTS

5.1 Introduction

In Chapter Four, the qualitative findings were presented. In Chapter Five, the results of the statistical analysis conducted on the quantitative data collected from the research questionnaire will be presented. The survey questionnaire consists of two parts. The questions included in Part A are relevant to the current status quo. The questions in Part B present a scenario.

Firstly, the participation details are presented followed by the demographical profile of the respondents and then the results of a descriptive statistical analysis of the items in the research questionnaire. Lastly, the findings of the inferential statistical analysis of qualitative data are presented.

5.2 Details of the participation

To undertake the qualitative study, 32 participants were selected based on non-probability convenience sampling. The researcher uses the understanding and knowledge of the participants as inclusive criteria in selecting the sample to take part in the survey questionnaire.

5.3 Demographical data of respondents

In this section, the field of practice and the number of years employed by the organisation are presented.

5.3.1 Field of practice

The Field of Practice of the respondents is presented in Table 5.1.

Table 5.1: Field of Practice of the respondents n = 32

Field of Practice	Frequency	Percentage
Construction Manager	2	6.3%
Contracts Director	1	3.1%
Contracts Engineer	1	3.1%
Materials Technician	3	9.4%
Other	1	3.1%
Pavement and Materials Engineer	9	28.1%
Project Manager	12	37.5%
Resident Engineer	3	9.4%
Grand Total	**32**	**100.0%**
Field of Practice Roll-up	**Frequency**	**Percentage**
Contracts Engineer	13	40.6%
Project Manager		
Pavement and Material Engineer	9	28.1%
Construction Manager	10	31.3%
Contracts Director		
Materials Technician		
Other		
Resident Engineer		
Grand Total	**32**	**100.0%**

As presented in Table 5.1, the majority of 37.5% of the respondents are Project Managers and 28.1% are Pavement and Material Engineers. As some of the inferential statistical calculations conducted in the study required group categories with at least five and more members, a role - up of the Field of Practice was conducted. The Contracts Engineer was grouped with the Project Managers to give a 40.6% representation. The Construction Managers, Contracts Director, Materials Technicians, Resident Engineers and the other fields of practice was group together to give a 31.3% representation followed by the 28.1% that are Pavement and Material Engineers.

5.3.2 Work experience in years

The Work Experience in years of the respondents is presented in Figure 5.1

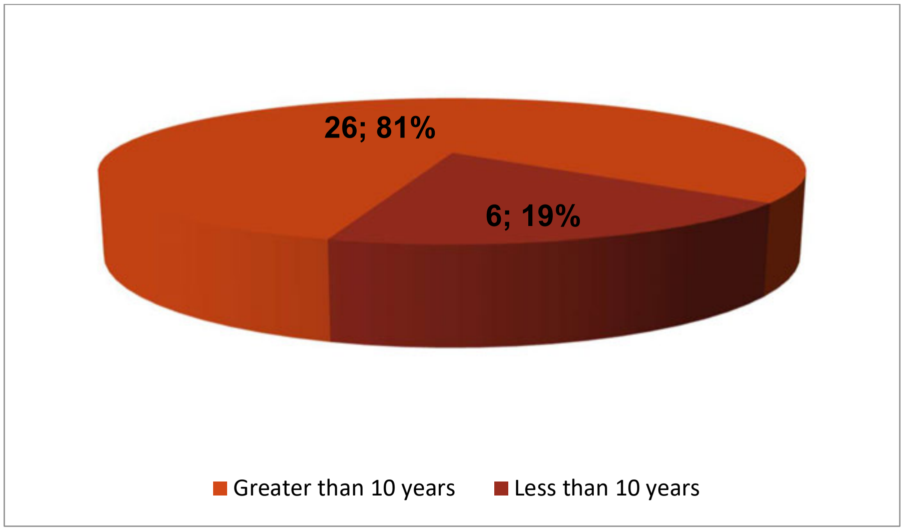

Figure 5.1: Work experience of the respondents in years (*n* = 32)

As reflected in Figure 5.1, a total of 81% of the respondents have 10 years or more work experience while 19% have less than 10 years of work experience. Based on this information, it is clear that the respondents have the work experience to provide valuable information for this study. In the next section, the results of the descriptive statistical analysis, conducted on the items of the research instrument, will be presented.

5.4 Descriptive statistical analysis of Quantitative data

By means of an online survey questionnaire, quantitative data was collected from 32 employees that are part of the South Africa National Route 3 upgrade between Durban and Pietermaritzburg. The respondents were asked to indicate their level of agreement with a set of statements given to them on a five-point Likert scale where (1) Strongly disagree, (2) Disagree, (3) Neutral, (4) Agree, and (5) Strongly agree (See Appendix C: Survey Questionnaire). The distribution statistical methods, namely the mean and standard deviation was used to describe the distribution of the scale items.

The **median** (*M*) is the middle value of the set of the numerical values. For this study, the median score will follow the same values as that of the Likert scale. The **standard deviation** (*SD*) gives an indication of how far a set of numbers are scattered away from the mean. A high standard deviation score is an indication of a wide data spread from the mean and a low standard deviation score is an indication that the data are scattered closely around the mean (Pallant, 2020).

5.4.1 Project parameters

The question set of measuring project parameters of materials utilization in a flexible pavement project are presented in Table 5.2

Table 5.2: Measuring project parameters of materials utilization (*n* = 32)

Focus	Questions	1	2	3	4	5	Total	Median	SD
Influence of Project Limits	P1: The utilisation of reclaimed materials within a project, is restricted to the project limits	9	8	2	8	5	32	2.0	1.50
		28%	25%	6%	25%	16%	100%		
	P2: The utilisation of materials between adjacent projects are limited to surplus reclaimed material	4	7	2	10	9	32	4.0	1.43
		13%	22%	6%	31%	28%	100%		
	P3: The movement of reclaimed materials between projects imposes a contractual risk	1	8	6	10	7	32	4.0	1.19
		3%	25%	19%	31%	22%	100%		
Viability of client-owned quarry	P4: It is economically viable to utilise a quarry owned by the client in close proximity to the project	0	0	5	11	16	32	4.5	.75
		0%	0%	16%	34%	50%	100%		
Viability of client-owned stockpile site	P5: It is economically viable to utilise a stockpile site owned by the client in close proximity to the project	0	0	1	15	16	32	4.5	.57
		0%	0%	3%	47%	50%	100%		

The majority of the respondents disagreed that the utilisation of reclaimed materials within a project, is restricted to the project limits as indicated by $M = 2.0$ and $SD = 1.50$. This response inversely aligns to the statement that the utilisation of materials between adjacent projects are limited to surplus reclaimed material ($M = 4.0$; $SD = 1.43$), indicating that materials can be sourced from outside the project limits. During the design stage, the utilisation of materials is conventionally limited to the project limits, and this is coherent with the mean and standard deviation in response to the question that the movement of reclaimed materials between projects, imposes a contractual risk ($M = 4.0$; $SD = 1.19$). Since the cost of materials contribute to 80% of the project costs, many of the respondents agreed that it is economically viable to utilise a quarry owned by the client in close proximity to the project as indicated by the median

$M = 4.5$ and $SD = 0.75$. It is economically viable to utilise a stockpile site owned by the client in close proximity to the project ($M = 4.5$; $SD = 0.57$).

5.4.2 Current utilisation patterns of natural resources

The question set that measures the current utilisation patterns of natural resources in a pavement project is presented in Table 5.3.

Table 5.3: Current utilisation patterns (*n* = 32)

Focus	Questions	1	2	3	4	5	Total	Median	SD
Avoidance of the depletion of natural resources									
P6: The reclaimed aggregates from the existing surface layer, is a source of materials for the project		0	1	5	5	21	32	5.0	.88
		0%	3%	16%	16%	66%	100%		
P7: The reclaimed base layer is a source of material for the new pavement layer		0	1	5	11	15	32	4.0	.84
		0%	3%	16%	34%	47%	100%		
P8: The reclaimed subbase layer is a source of material for the new pavement layer		0	1	8	10	13	32	4.0	.89
		0%	3%	25%	31%	41%	100%		
P9: The reclaimed selected layers are a source of materials for the new pavement layers		3	3	8	9	9	32	4.0	1.27
		9%	9%	25%	28%	28%	100%		
Surface layer									
Equivalent value of the reclaimed layer	P10: The reclaimed surface layer can be recycled and utilised in the surface layer of the new pavement	0	7	4	8	13	32	4.0	1.19
		0%	22%	13%	25%	41%	100%		
Reduced value of the reclaimed layer	P11: The reclaimed surface layer can be downcycled and utilised in the new pavement	0	2	7	11	12	32	4.0	.93
		0%	6%	22%	34%	38%	100%		
Little or no value of the reclaimed layer	P12: The reclaimed surface layer can be downcycled and utilised as fill for the project	7	6	6	7	6	32	3.0	1.45
		22%	19%	19%	22%	19%	100%		
Base layer									
Increased value of the reclaimed layer	P13: The reclaimed base layer can be upcycled and utilised in the surface layer of the new pavement	10	8	8	4	2	32	2.0	1.24
		31%	25%	25%	13%	6%	100%		
Equivalent value of the reclaimed layer	P14: The reclaimed base layer can be recycled and utilised in the base layer of the new pavement	2	3	12	7	8	32	3.0	1.16
		6%	9%	38%	22%	25%	100%		
		0	1	5	13	13	32	4.0	.82

Focus	Questions	1	2	3	4	5	Total	Median	SD
Reduced value of the reclaimed layer	P15: The reclaimed base layer can be downcycled and utilised in the new pavement	0%	3%	16%	41%	41%	100%		
Little or no value of the reclaimed layer	P16: The reclaimed base layer can be downcycled and utilised as fill for the project	5	4	9	6	8	32	3.0	1.39
		16%	13%	28%	19%	25%	100%		
Subbase Layer									
Increased value of the reclaimed layer	P17: The reclaimed subbase layer can be upcycled and utilised in the new pavement	9	2	14	3	4	32	3.0	1.33
		28%	6%	44%	9%	13%	100%		
Equivalent value of the reclaimed layer	P18: The reclaimed subbase layer can recycle and utilised in the subbase layer of the new pavement	3	3	11	6	9	32	3.0	1.27
		9%	9%	34%	19%	28%	100%		
Reduced value of the reclaimed layer	P19: The reclaimed subbase layer can be downcycled and utilised in the new pavement	1	4	6	10	11	32	4.0	1.15
		3%	13%	19%	31%	34%	100%		
Little or no value of the reclaimed layer	P20: The reclaimed subbase layer can be downcycled and utilised as fill for the project	2	6	7	7	10	32	4.0	1.29
		6%	19%	22%	22%	31%	100%		
Selected Layer									
Increased value of the reclaimed layer	P21: The reclaimed selected layers layer can be upcycled and utilised in the new pavement	10	6	11	1	4	32	2.5	1.32
		31%	19%	34%	3%	13%	100%		
Equivalent value of the reclaimed layer	P22: The reclaimed selected layers layer can be recycled and utilized in the selected layers of the new pavement	1	2	8	11	10	32	4.0	1.05
		3%	6%	25%	34%	31%	100%		
Little or no value of the reclaimed layer	P23: The reclaimed selected layers layer can be downcycled and utilised as fill for the project	3	1	4	12	12	32	4.0	1.23
		9%	3%	13%	38%	38%	100%		

5.4.2.1 Avoidance of the depletion of natural resources

As presented in Table 5.3 above, the respondents agreed that the existing layers are a source of materials for the new pavement as supported by the statements that the reclaimed aggregates from the existing surface layer, must be a source of materials for the project (M = 5.0; SD = 0.88), the reclaimed base layer is a source of material for the new pavement layer (M = 4.0; SD = 0.84), the reclaimed subbase layer is a source of material for the new pavement layer (M = 4.0; SD = 0.89) and the reclaimed selected layers are a source of materials for the new pavement layers (M = 4.0; SD = 1.27).

5.4.2.2 Surface layer

Since the surface layer is already the top layer, it cannot be upcycled and hence the respondents supported the statement that the reclaimed surface layer can be recycled and utilised in the surface layer of the new pavement (*M* = 4.0; *SD* = 1.19). The respondents are further in agreement that the reclaimed layers can be downcycled and this is supported with the statements that the reclaimed surface layer can be downcycled and utilised in the new pavement (*M* = 4.0; *SD* = 0.93). Downcycling of the existing surface layer as fill material is neither agreed nor disagreed on as is evident by the responses to the statement that the reclaimed surface layer can be downcycled and utilised as fill for the project (*M* = 3.0; *SD* = 1.45).

5.4.2.3 Base layer

The limitations to upcycling are further highlighted by the responses disagreeing to upcycle the individual layers and shown by the responses disagreeing with the statements that the reclaimed base layer can be upcycled and utilised in the surface layer of the new pavement (*M* = 2.0; *SD* = 1.24). There is no consensus in the responses to the statements that the reclaimed base layer can be recycled and utilised in the base layer of the new pavement as indicated by *M* = 3.0; *SD* = 1.16. The base layer can be downcycled and utilised in the new pavement (*M* = 4.0; *SD* = 0.82). There is no consensus in the remaining responses to downcycling the existing materials as fill materials The reclaimed base layer can be downcycled and utilised as fill for the project (*M* = 3.0; *SD* = 1.39).

5.4.2.4 Subbase Layer

The need for the engineer's responsibility manifests in the response to the statement that the reclaimed subbase layer can be upcycled and utilised in the new pavement (*M* = 3.0; *SD* = 1.33), with no consensus being reached. Upcycling of the subbase is neither agreed on nor disagreed on, as indicated by the responses to the statements that the reclaimed subbase layer can recycled and utilised in the subbase layer of the new pavement (*M* = 3.0; *SD* = 1.27).

The reclaimed subbase layer can be downcycled and utilised in the new pavement (*M* = 4.0; *SD* = 1.15) and the reclaimed subbase layer can be downcycled and utilised as fill for the project (*M* = 4.0; *SD* = 1.29).

5.4.2.5 Selected Layer

The reclaimed selected layers cannot be upcycled and utilised in the new pavement (*M* = 2.5; *SD* = 1.32) however the reclaimed selected layers can be recycled and utilised in the selected layers of the new pavement (*M* = 4.0; *SD* = 1.05). The reclaimed selected layers can be downcycled and utilised as fill for the project (*M* = 4.0; *SD* = 1.23).

5.4.3 Specifications

The question set measuring the specification influencing materials utilization in a flexible pavement project are presented in Table 5.4.

Table 5.4: The specifications influencing materials utilization (*n* = 32)

Questions	1	2	3	4	5	Total	Median	SD
P24: The clients' specifications are a barrier for the recycling of materials	5	5	5	10	7	32	4.0	1.40
	16%	16%	16%	31%	22%	100%		
P25: It is the responsibility of the client to specify minimum % of reclaimable material to be used in each layer of the new pavement	5	5	5	10	7	32	4.0	1.39
	16%	16%	16%	31%	22%	100%		
P26: There is limited awareness for the need for upcycling of the existing pavement layers	0	2	1	16	13	32	4.0	0.80
	0%	6%	3%	50%	41%	100%		
P27: The engineer is responsible for designing the upcycling of the existing pavement layers	0	3	6	9	14	32	4.0	1.01
	0%	9%	19%	28%	44%	100%		
P28: The current testing regime during the design phase is insufficient to inform the upcycling of the existing pavement layers	2	2	9	14	5	32	4.0	1.05
	6%	6%	28%	44%	16%	100%		

Many of the respondents agree that the clients' specifications are a barrier for the recycling of materials as indicated by *M*=4.0, *SD*=1.40. This response aligns with the need for the client to provide more information and the respondents agree when asked if, it is the responsibility of the client to specify the minimum percentage of reclaimable material to be used in each layer of the new pavement (*M* =4.0, *SD*=1.39). In addition to the clients' specifications, many of the respondents agree that the engineer is responsible for designing the upcycling of the existing pavement layers, as indicated by *M* =4.0, *SD*=1.01.

Some of the challenges faced with upcycling included the lack of awareness as evidently agreed on by many of the respondents when asked if there is limited awareness of the need for upcycling of the existing pavement layers (*M* =4.0, *SD*=0.80). Another challenge agreed on by the respondents is the fact that the current testing regime during the design phase is insufficient to inform the upcycling of the existing pavement layers, as evident by (*M* =4.0, *SD*=1.05).

5.4.4 Costs

The question set that measures the costs in a flexible pavement project is presented in Table 5.5

Table 5.5: Cost of natural resources in a flexible pavement project (*n* = 32)

Questions	1	2	3	4	5	Total	Median	SD
P29: The process of recycling has cost implications and it is easier to spoil materials	11	7	9	3	2	32	2.0	1.23
	34%	22%	28%	9%	6%	100%		
P30: The process of upcycling has cost implications and it is easier to downcycle materials	4	3	11	7	7	32	3.0	1.28
	13%	9%	34%	22%	22%	100%		
P31: Contractors need to be incentivized to reclaim and upcycle the existing pavement layers	1	3	7	12	9	32	4.0	1.07
	3%	9%	22%	38%	28%	100%		
P32: The introduction of a surcharge when spoiling material at a landfill site, will increase efficient utilization of existing pavement layers in the new pavement	3	1	8	10	10	32	4.0	1.22
	9%	3%	25%	31%	31%	100%		

Many of the respondents disagreed when asked if the process of recycling has cost implications and it is easier to spoil materials as indicated by *M* =2.0, *SD*=1.23. There was no consensus reached when asked if, the process of upcycling has cost implications and it is easier to downcycle materials, as evident by (*M* =3.0, *SD*=1.28). The respondents agreed when asked if the contractors need to be incentivised to reclaim and upcycle the existing pavement layers, as indicated by *M* =4.0, *SD*=1.07. It was interesting that the inverse of incentives being a punitive measure was also met with agreement when asked if the introduction of a surcharge when spoiling material at a landfill site, will increase efficient utilisation of existing pavement layers in the new pavement as shown by (*M* =4.0, *SD*=1.22).

5.5 Factor analysis of questionnaire

With the aim of reducing the number of variables into a smaller number of variables, Principal Components Analysis (PCA) was conducted. Eight factors that explained about 70% of the variance in the factor space were postulated according to Kaiser's (1970) criteria and extracted by means of Principal Components Analysis (PCA). The eight values of the unreduced item inter-correlation matrix is given in Table E. 1 and Table E. 2 (See Appendix: E). This was followed by the Kolmogorov-Smirnova normality test to determine the type of inferential statistical calculations, either parametrical or non-parametrical that should be conducted.

5.5.1 Reliability analysis of the extracted factors

Reliability analysis was conducted on the sub-scales as presented in the Risk Management questionnaire (Appendix F: Iterative Reliability Analysis Results). According to Nawi et al. (2020. p. 24), an Alpha Coefficient Range of 0.6 to <.70 strength of association can be regarded as moderate, 0.7 to < .8 as good and > as 0.8 as very good. Cronbach's Alpha findings by study variables is presented in Table 5.6.

Table 5.6: Cronbach's Alpha findings by study variables

Study Variables	Cronbach's Alpha	N of Items
Factor 1 – Reusing the existing reclaimed materials	.88	7
Factor 2 – Downcycling material to fill	.86	4
Factor 3 – Limited design for upcycling	.77	5
Factor 4 – Optimising costs	.79	5
Factor 5 – Client's responsibilities	.81	5
Factor 6 – Reluctance to upcycle	.64	4
Factor 7	.59	3
Factor 8 – Economic viability of materials utilization	.66	3

As the majority of the variables yielded Cronbach's Alpha values greater than .60. the scales demonstrate satisfactory reliability and can be used in the inferential statistical analysis of quantitative data for this study. The variable Factor 7 will be excluded from further analysis.

5.5.2 Kolmogorov-Smirnova Normality Tests

As certain statistical tests for example the two-way ANOVA requires that the survey data is drawn from a normally distributed population, normality tests need to be conducted (Pallant, 2016, p. 224). The Kolmogorov-Smirnova Normality test will indicate if parametrical or non-parametrical tests needs to be conducted (Pallant, 2016, p. 80). In Table 5.7, the Factor Scales tests of normality is presented.

Table 5.7: Factor Scales Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Factor 1 – Reusing the existing reclaimed materials	,132	32	,166	,923	32	,026
Factor 2 – Downcycling material to fill	,121	32	.200*	,947	32	,121
Factor 3 – Limited design for upcycling	,109	32	.200*	,962	32	,304
Factor 4 – Optimising costs	,127	32	.200*	,946	32	,112
Factor 5 – Client's responsibilities	,146	32	,080	,930	32	,039
Factor 6 – Reluctance to upcycle	,145	32	,085	,954	32	,193
Factor 8 – Economic viability of materials utilization	,161	32	,034	,885	32	,003

**. This is a lower bound of the true significance.*

a. Lilliefors Significance Correction

The Kolmogorov-Smirnova test finding (*Sig.* > 0.05) for the majority of the sub-scales does not suggest a violation of the assumption of normality. This finding means that to conduct the inferential data analysis of this study, parametrical inferential statistical methods needs to be used (Pallant, 2016, p. 81).

5.6 Inferential Statistical analysis of Quantitative data

The purpose of inferential statistics is to make predictions or generalisations based on the received data by making estimates about populations. This is followed by testing the hypotheses to draw conclusions about populations (Bhandari, 2020).

5.6.1 Pearson's Correlation Calculation

The relationship between two variables is determined by correlation calculations. If one variable changes in value, the other variable tends to change in a specific direction, either positive or negative. The value of the effect size of Pearson's (r) correlation varies between -1 (a perfect negative correlation) to +1 (a perfect positive correlation) (Pallant, 2016). The relationship between variables can be used for prediction purposes. Pearson's inter-correlations were calculated to determine the strength and nature of the relationships between the selected factors as presented in Table 5.8.

Table 5.8: Inter-correlations matrix (Pearson Correlations) of the different factors

	Factor 1 Reusing the existing reclaimed materials	**Factor 2** Down-cycling material to fill	**Factor 3** Limited design for up-cycling	**Factor 4** Optimising costs	**Factor 5** Client's responsibilities	**Factor 6** Reluctance to upcycle	**Factor 8** Economic viability of materials utilization
Factor 1 – Reusing the existing reclaimed materials	1						
Factor 2 – Downcycling material to fill	-,198	1					
Factor 3 – Limited design for upcycling	,302	-,221	1				
Factor 4 – Optimising costs	,330	-,117	,142	1			
Factor 5 – Client's responsibilities	,209	-,146	-,064	-,007	1		
Factor 6 – Reluctance to upcycle	,030	-,048	,296	,136	-,042	1	
Factor 8 – Economic viability of materials utilisation	**.353***	**-.400***	,209	,193	,174	,108	1

**. Correlation is significant at the 0.05 level (2-tailed).*

Correlations ranging between	$0.10 \leq r \leq 0.29$ Small effect	$0.30 \leq r \leq 0.49$ Medium effect	$0.50 \leq r \leq 1.00$ Large effect

As presented in Table 5.8 representing the Pearson product-moment correlation (*r*) calculations, the following statistically significant relationships can be derived by:

a significant positive relationship exists between Factor 1 (Reusing the existing reclaimed materials) and Factor 8 (Economic viability of materials utilisation) (r (df = 31; p < 05) = 0.353) and a significant negative relationship exists between Factor 2 (Downcycling material to fill) and Factor 8 (Economic viability of materials utilisation) (r (df = 31; p < 05) = -0.400).

5.6.2 Predicting Factor 1

Hierarchical multi-regression was used to determine the ability of the selected predictors Factor 2 (downcycling material to fill), Factor 3 (Limited design for upcycling), Factor 4 (Optimising costs), Factor 5 (Client's responsibilities), Factor 6 (Reluctance to upcycle) and Factor 8 (Economic viability of materials utilisation) to predict Factor 1 (Reusing the existing reclaimed materials) , after controlling for the possible effect of Field of Practice and Years of Experience (see Table 5.9 below). Factor 7 was omitted as it did not yield an acceptably Cronbach Alpha.

Table 5.9: Regression of Factor 2 to Factor 8 can predict on Factor 1

Models		Unstandardized Coefficients		Standardized Coefficients	*t*	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.281	.573		3.982	.000
	Code Select the field in which you practice	.060	.143	.069	.420	.678
	Code Number of years' experience	.915	.308	.489	2.975	.006
2	(Constant)	-.876	1.426		-.615	.545
	Code Select the field in which you practice	.076	.138	.088	.552	.586
	Code Number of years' experience	.831	.286	.444	2.906	**.008**
	Factor 2 – Downcycling material to fill	.012	.132	.014	.088	.931
	Factor 3 – Limited design for upcycling	.227	.145	.256	1.569	.130
	Factor 4 – Optimising costs	.218	.137	.242	1.586	.126
	Factor 5 – Client's responsibilities	.205	.192	.164	1.070	.296
	Factor 6 – Reluctance to upcycle	-.094	.135	-.108	-.693	.495
	Factor 8 – Economic viability of materials utilization	.238	.184	.217	1.299	.207

Dependent Variable: Factor 1

Hierarchical multi-regression was used to determine the ability of the selected factors to predict Factor 1 (Reusing the existing reclaimed materials) after controlling for the possible effect of Field of Practice and Years of Experience. Preliminary analyses were conducted to ensure no violation of the assumptions of linearity, normality, homoscedasticity and multi-collinearity. The demographical variables Field of Practice and Years of Experience were entered in step one explaining 26% of the variance in Factor 1 (reusing the existing reclaimed materials). After entry of the predictor variables at step two, the total variance explained by the model was 50.2%, F (8, 23) = 2.897, $p < .022$. The variable control measures explain an additional 24.3% of the variance in Factor 1 after controlling for Field of Practice and Years of Experience. R squared change = .24, F change (6, 23) = 1.868, p = .130. In the final model, one control measure was statistically significant, with Years of Experience recording a higher beta value (beta = 0.444, $p < .008$).

Based on the results above and the small sample, it is accepted that the selected factors cannot predict Factor 1 (reusing the existing reclaimed materials) as the model is statistically insignificant (p = 0.130) for this study.

5.7 Summary of the survey questionnaire

Part A of the survey questionnaire presented, allowed for responses to the project parameters, current utilization patterns, specifications, and costs. The case study presented below is in response to a scenario presented in Part B.

5.8 The Case Study

In the survey questionnaire, Part B presented a scenario for the respondents. The scenario was as follows:

> All layers of a flexible pavement layers from the individual projects are excavated and stockpiled at a Central Processing Site. The central processing site is operated independently from the individual projects and is in close proximity to a quarry and the individual projects. The central processing site contractor then has the responsibility to blend the stockpiled materials with virgin material to produce the individual projects desired materials quality.

The respondents were asked to indicate how strongly they agreed or disagreed with each statement presented, based on the scenario where the 5-point Likert scale was used. Table 5.10 presents the results of the case study.

Table 5.10: Results of the Case Study (n = 32)

Focus	Questions	1	2	3	4	5	Total	Median	Std.
				Design Standards					
Uniform Pavement	P35: Based on the scenario; The use of a central processing site will ensure a uniform pavement for the network	0	1	6	13	12	32	4.0	.83
		0%	3%	19%	41%	38%	100%		
Variability in design	P36: Based on the scenario; The use of a central processing site will limit the approval of sources for materials	2	7	8	10	5	32	3.0	1.17
		6%	22%	25%	31%	16%	100%		
Investigation detail	P41: Based on the scenario; The client must lead during the design phase and conduct in depth pre-investigation into the materials plan for the construction.	0	1	4	7	20	32	5.0	.84
		0%	3%	13%	22%	63%	100%		
				Costs					
Haulage	P37: Based on the scenario; The use of a central processing site will reduce the number of trips made by the project to obtain materials from various sources	1	6	6	11	8	32	4.0	1.16
		3%	19%	19%	34%	25%	100%		
Transport costs	P38: Based on the scenario; The use of a central processing site will reduce the overall transport cost of the individual projects to obtain materials from various sources	2	6	6	10	8	32	4.0	1.24
		6%	19%	19%	31%	25%	100%		
Material costs	P39: Based on the scenario; The use of a central processing site will reduce the individual project materials costs.	1	4	10	10	7	32	4.0	1.08
		3%	13%	31%	31%	22%	100%		
				Increase in upcycling opportunities					
	P33: Based on the scenario; The implementation of central processing site will improve the opportunities for upcycling of the material.	0	0	4	16	12	32	4.0	.67
		0%	0%	13%	50%	38%	100%		
				Client Responsibility					
	P34: Based on the scenario; The central processing site will work best if it is managed by the client	2	4	10	10	6	32	3.5	1.13
		6%	13%	31%	31%	19%	100%		
				Coordination					
	P40: Based on the scenario; Timing is the most important aspect that needs to be understood and comprehensively coordinated between projects.	0	0	2	10	20	32	5.0	.62
		0%	0%	6%	31%	63%	100%		

5.8.1 Design standards

By nature of the activities, the respondents strongly agreed that the use of a central processing site will ensure a uniform pavement network (*M* = 4.0; *SD* = 0.83). The respondents are neutral about the fact that the use of a central processing site will limit the approval of sources for materials (*M* = 3.0; *SD* = 1.17), for the scenario presented in the questionnaire, and addressing the selection of the source of materials for use. Further to the coordination, the respondents identified that the client must lead during the design phase and conduct in-depth pre-investigations into the materials plan for the construction as indicated by the *M* = 5.0 and *SD* = 0.84.

5.8.2 Cost

In addition to the use of a client-owned quarry, many of the respondents agreed with the scenario-based statement that the use of a central processing site will reduce the number of trips made by the project to obtain materials from various sources with (*M* = 4.0 and *SD* = 1.16). This agreement is further supported as evident by the respondents' statements that the use of a central processing site will reduce the overall transport costs of the individual projects to obtain materials from various sources (*M* = 4.0; *SD* = 1.24) and the use of a central processing site will reduce the individual project materials costs. (*M* = 4.0; *SD* = 1.08).

5.8.3 Increase in upcycling opportunities

Apart from the selection of the source of the materials, the emphasis on upcycling is to promote the use of reclaimed material in a better and more valuable manner. Efforts can be made to upcycle materials as supported by the scenario presented in the questionnaire in that the implementation of a central processing site will improve the opportunities for upcycling of the material as indicated by the median and standard deviation of *M* = 4.0 and *SD* = 0.67 respectively.

5.8.4 Client responsibility

In every aspect of the project, the client is responsible to ensure a value is added in terms of the product being delivered. The clients' responsibilities measure the perception of the clients' responsibilities in the management of materials.

With the scenario presented to the respondents, there was consistency about the client's responsibility as shown by the response to the statement that the central processing site will work best if it is managed by the client (M = 3.5; SD = 1.13).

5.8.5 Coordination

The coordination of activities at a central processing site is key to ensure efficient and consistent delivery of materials to the various sites which is supported by the responses to the statement that timing is the most important aspect that needs to be understood and comprehensively coordinated between projects. (M = 5.0; SD = 0.62).

5.8.6 Summary of case study

The case study presented allowed for responses to a specific method of upcycling, namely the use of the central processing site. There are several determining factors influencing upcycling, which is aligned to Part A of the questionnaire.

5.9 Consolidation of the Quantitative and Qualitative findings

In this section, the findings of the quantitative and qualitative studies are consolidated (Creswell, 2009). From the quantitative analysis, the respondents tended to strongly agree that the reclaimed materials can be reused in the new pavement structure (M range = 4 to 5; SD range = 0.84-1.27). In the development of the main theme 1, the participants confirmed that the materials utilisation plan is intended to give the details of the management of each reclaimed layer. When interviewed on the upcycling of materials, the participants understood the concepts, however there was a level of reluctance to upcycle. The quantitative survey yielded a strong tendency to agree on the reclaimed surface layer being recycled (M=4, SD=1.19), however the responses to upcycling the remaining layers tended to disagree (M range = 2 to 3; SD range = 1.24 to 1.33). The participants in the interviews emphasised the need for planning upcycling at the beginning of the decision-making process. This would be the planning phase of a network. The responses to the case study tended to strongly agree with the need for coordination (M=5, SD=0.62). The understanding of concepts, planning and coordination are fundamentals of upcycling in a materials utilisation plan.

For the research, the economic viability of upcycling is underpinned by budget constraints, the benefits to upcycling and the premium to upcycling. When the respondents were asked if the process of upcycling has cost implications and it is easier to downcycle materials, the respondents tended to disagree (M=2, SD=1.23). However, when the respondents were asked if the process of upcycling has cost implications and it is easier to downcycle materials, the response received was neutral, with widespread responses received (M=3, SD=1.28). The qualitative interview data indicated that there are cost factors associated with upcycling. There were indications of benefits to upcycling, however there was a premium to upcycling which needs to be considered. Interestingly, there was a strong tendency to agree when asked if the contractors need to be incentivised to reclaim and upcycle the existing pavement layers (M=4, SD=1.07). Contrarily, there was a strong tendency to agree when asked if the introduction of a surcharge when spoiling materials at a landfill site, will increase efficient utilisation of existing pavement layers in the new pavement (M=4, SD=1.22). This indicates that either incentives for or implementing punitive measure for the process of upcycling can be considered.

The case study produced a strong tendency to agree when asked if the use of a central processing site will reduce the overall transport costs of the individual projects to obtain materials from various sources (M=4, SD=1.24). Similarly, there was a strong tendency to agree when asked if the use of a central processing site will reduce the overall transport costs of the individual projects to obtain materials from various sources (M=4, SD=1.08). The information for the assessment of the existing pavements and resulting economic analysis, is included in the premium to upcycle as identified in the qualitative interviews.

The quantitative survey respondents tended to strongly agree that the engineer is responsible for designing of the upcycling of the existing pavement layers (M=4, SD=1.01). However, the qualitative interviews drew attention to major challenges with the competitive tendering procurement method for design engineering consultants. The participants associated the lack of upcycling design initiatives as a result of the lack of time and resources due to the tender strategy. The limited hours to complete the design was highlighted as a factor that does not allow for the effort to be spent on a different design. The general feeling was to depend on the tried and tested catalogue design.

In the case study presented, the quantitative survey results indicated a strong agreement when asked if the client must lead during the design phase and conduct in-depth pre-investigation into the materials plan for the construction (M=5, SD=0.84). In terms of the current testing regime, when asked, if the design phase is insufficient to inform the upcycling of the existing pavement layers, there was a strong tendency to agree (M=4, D=1.05). This aligns with the qualitative interviews in that the laboratory is not being used to its full potential because the design engineer is only requesting the traditional tests. The traditional tests are very limiting in any design for upcycling.

The study by Jordaan et al. (2017) spotlights that the development of new technology in the last decade has become a “game-changer” facilitating cost-effective solutions of road infrastructure. Empirical test methods used to examine the potential of the existing pavement as reclaimed materials, is superseded by the introduction of nanomaterials. Nanomaterials require scientific methods of analysis and chemistry to understand the material behaviour. The challenge is that there is limited awareness and education of nanomaterials, nanotechnology and chemistry. There was agreement and a high level of consensus in the survey questionnaire responses when asked if there is limited awareness of the need for upcycling of the existing pavement layers (M=4, SD=0.80).

The qualitative interviews highlighted that the awareness of industry developments is needed at tertiary level. This will enable graduates to become knowledgeable with new industry developments. The tertiary level learning will also promote the drive and enthusiasm to consider alternate methods for upcycling in the materials utilisation plan as well as industry research in the field.

In addition to the challenges in promoting upcycling methods, the interviews describe the restrictions with the client’s specification which is aligned to the agreed responses when asked if the clients’ specifications are a barrier for the recycling of materials (M=4, SD=1.40).

5.10 Summary

This chapter presented the findings from the quantitative data analysis. The findings from the qualitative data analysis in Chapter Five, was consolidated with the results of the quantitative data analysis and presented. A discussion of the results, measures and recommendations that can be adopted, are presented in the following chapter.

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Introduction

Chapter Five presented the consolidated research findings and results. In this chapter concludes the research and give recommendations, in response to the following research questions:

What are the factors influencing the specifications of upcycling in the design of the Materials Utilisation Plan?

What is the effect of the identified factors influencing the specification of upcycling in the design of the Materials Utilisation Plan?

What recommendations can be made to the client body for consideration of upcycling in the planning and design phase when implementing a road upgrade project/program?

6.2. What are the factors influencing the specifications of upcycling in the design of the Materials Utilisation Plan?

Based on the findings of the primary research, it can be concluded that the following factors influence the specifications of upcycling in design of the Materials Utilisation Plan:

6.2.1 Competitive tendering

The first factor was Competitive tendering. Competitive tendering is the procurement process followed by potential design consultants. Design consultants bid against each other to win a tender. Typically, in South Africa, the standard procurement strategy is functionality, preference and price. This type of procurement strategy promotes a highly competitive tendering environment. The consequence of such an environment is reduced rates and reduced hours with no additional capacity for any additional design improvement.

From the interviews conducted, it was highlighted that design consultants allocate the bare minimum in terms of time and resources to a project. The designs are based on previous design methodologies that have been accepted for similar works. The repeated methodologies allow for the minimum engineering input with no resolution for any improvement. This is evident from the survey where respondents indicated a tendency to reuse and downcycle the surface layer. The respondents indicated a tendency to downcycle the remaining base layer and subbase layers. The responses do not indicate any tendency to upcycle any of the layers. The value of the design becomes questionable especially when competitive bidding is applied. Competitive bidding is the procurement vehicle to appoint the service providers such as the design engineer. It is used as an attempt to cut costs (Elfving et al., 2005).

6.2.2 Economic viability

The next factor is the economic viability. The economic viability is the financial feasibility of upcycling materials. Budget constraints have established the need for cost-effective design. The implementation of cost-effective designs is crucial to ensuring continuance in building, managing, and maintaining road infrastructure.

The interviews concluded that the budget availability influences the design of the project. The survey questionnaires highlighted the fact that the economic viability of a project is dependent on the proximity of the project to either a quarry source or a stockpile source. Design engineers need to be able to design more cost-effective roads, through the provision of road infrastructure using lesser budgets. This can be achieved through a mind shift change and the promoting of the use of technology. In many designs, the existing material does not meet the minimum standard of the required layer. This often results in the conventional design methodology to import crushed, natural aggregate. This method of design is expensive and not cost effective. (Jordaan & Kilian, 2016).

6.2.3 Design for upcycling

Another factor is the need to design for upcycling. The design for upcycling is the process of applying engineering judgement to assess the existing materials and determine its function in the new pavement. The design would include the methodology of processing and management of the reclaimed materials to ensure its final function in the new pavement.

The interviews yielded significant feedback on the design engineers engineering judgement in the process of the design for upcycling in the materials utilisation plan. The design engineer controls the plan for the testing of the existing materials. The test results present the quality of the existing materials and it is the design engineers’ responsibility to interpret the test results.

This aligns with the quantitative results where many of the respondents agree that, the engineer is responsible to design for the upcycling of the existing pavement layers.

The appointment of a designer has the ability to influence the project's success (Meghana et al., 2016). The client will set standards and design criteria which allows for the design of the project using the applicable codes and other requirements. The standards and design criteria govern the project budget. The quality of the design, the time taken to complete the design, preparation of contract specification documents and supervision of the construction work is very important for the success of the project.

6.2.4 Planning and coordination

Another contributing factor is the planning and coordination for upcycling. Planning is the process of forethought into the project requirements. Coordination is the organisation of systems to achieve the project requirements. Planning and coordinating is undertaken by the client and indicates the high-level scope, objectives, and stakeholders in the project. Key decisions are informed at this stage.

The interviews revealed that upcycling is only achievable if performed at the planning stage of the project. The design philosophy to include upcycling, either at a project or network level, influences the entire design. Upcycling cannot be an additional add-on towards the end of the design. The research indicated that there are many opportunities to promote upcycling at a network level. This process must be driven by the client body, which is best suited as an enabler for the process of upcycling as indicated by the response to the survey questionnaire. Upcycling for a network would require intense coordination from the planning stages of the program. At the planning stage, key decisions are made. The design philosophy and design strategy are developed to meet the objective of the clients. The type of contract implementation is influenced by the decisions made at the planning stage.

Upcycling begins at the planning stage and the philosophy of planning is supported by the study of Zwikael (2009) which concludes that in the planning phase of the project life cycle, it is critical to decision making during the project and achieving a higher quality end product.

6.2.5 Technology advancement

Technology advancement is the application of new, more accurate or more efficient use of scientific methods or equipment to improve on previous methods. Upcycling of material can be accomplished through the process of chemical modification, mechanical modification and through the use of nanomaterials. The use of nanomaterial and nanotechnology in pavement design is gaining momentum. The chemical weathering of pavement layers because of water is the main reason for the failure of road infrastructure. Nanomaterials can be blended with the existing layer to reduce chemical weathering. For this process to be successful, it is important to understand and analyse the structure of the materials. Chemistry is being used to analyse the material.

From the interviews, it was concluded that the use of empirical test methods to determine the quality of the reclaimed materials is superseded by the introduction of new technology and nanomaterials. Nanotechnology is described as being the next industrial revolution and warns the industry of the difficult lessons learned from advances in technology being ignored (Maynard, 2007).

6.2.6 Skills gaps

There is a fundamental mismatch between the knowledge learned at tertiary level and what is being implemented in the industry. This is the gap in knowledge relating to upcycling of materials. The interviews concluded that continuous development of industry and exposure to the latest developments are crucial to the industry development. The exposure at tertiary level can also be used to promote further research in the field for development. This will allow for growth and progress from the beginning of work experience.

Education and training contribute to the increase in knowledge and manpower. The upskilling allows for the increase in productive capacity referred to as human capital. Education is the process of the formation of skills. The major gap in the industry is the insufficient skill set of the workforce. There is a mismatch between the tertiary level output and industry needs (Padmini, 2012).

6.3 What is the effect of the identified factors influencing the specification of upcycling in the design of the Materials Utilisation Plan?

It was found that the identified factors influence the specifications of upcycling in the design of the Materials Utilisation Plan, in the following way:

6.3.1 Effect of competitive bidding

The efficiency of the tendered resource becomes a major influential factor when competitive tendering is adopted. The award is based on the tendered rate and hours which are inevitably reduced rates and reduced hours, just to win the tender. There is no additional capacity to explore various method of design. This is restrictive to the client, especially when upcycling requires the investigation and optioneering for the use of the existing pavement. The competitive bidding procurement yields the lowest performance attributed to lack of experience with the project delivery system, poor communication and understaffing (Franz & Roberts, 2018).

6.3.2 Effect of economic viability

The benefit of upcycling is the positive outcome of reclaiming the existing material and reusing it to a higher value in the new pavement. The interviews highlighted the benefit of upcycling which is focussed on cost savings. There are also long terms benefits which include the need for environmental savings such the reduction in CO_2 emissions and factors contributing to activities of spoiling and stockpiling of materials.

The study by Sung (2015) aligns to the responses received in that the economic benefits and environmental benefits are among the most evident in term of upcycling. Economic benefits are viewed as cost savings in terms of the reduced process in the production for new material. The budget availability has a significant influence on the project outcome. Road agencies make use of public funds to build, manage and maintain road infrastructure (Uddin et al., 2013, pp. 26-31).

6.3.3 Effect of the design for upcycling

The use of engineering judgement is pinned on relevant design experience, The lack of adequate design experience to facilitate upcycling was a recurring theme throughout the research. The response from the interviews concludes that the reliance on the catalogue design for pavements was a major disbenefit to upcycling. South Africa is faced with a major challenge to build cost-efficient roads and the designers need to respond with an appropriate design strategy to this need. At present, the focus is still on downcycling marginal materials and importing natural gravel. This conventional design is leading to expensive road infrastructure. The experience of the design engineer is influential in this process and majority of the respondents tend to agree that the engineer is responsible to design for the upcycling of the existing pavement layers.

The quality of the design, the time taken to complete the design, preparation of contract specification documents, and supervision of the construction work is very important for the success of the project. The major problems evident in the design phase that affect the quality of construction includes design quality, design changes, lack of information and lack of coordination (Meghana et al., 2016),

In addition, the study conducted by Aziz and Abdel-Hakam (2016) summates that delays are a common occurrence in construction projects. In the study, the contractors rated the lack of design as a major cause for delay on projects. Causes included design rework due to changes of design, design errors made by the designers and wrong or improper design.

6.3.4 Effect of planning and coordination

The coordination of activities at a central processing site is key to ensure efficient and consistent delivery of materials to the various sites which is supported by the response to the statement that timing is the most important aspect that needs to be understood and comprehensively coordinated between projects. Majority of the respondents tend to agree that there is a need for the client to provide more information and that it is the responsibility of the client to specify details of materials to be reclaimed and reused.

To resolve the issues of lack of coordination, the project can define process flows at the onset (Lavikka, 2015). This includes process flows for organisational design and processes for working towards the shared project objectives. The aspects that also needs consideration is the contract type, timing and extent of procedural coordination. This is coordination that is needed at the onset of the project before the implementation of the design phase.

Aligning with the need for project coordination, Kasim, et al., (2005) emphasises the need for management of materials in a construction project, which includes the processes of upcycling. The management of materials has a direct influence on the productivity and costs and includes aspects such as planning and materials distribution. The cost to manage materials on site can range from 30-80% of the total construction costs. This massive contribution to project costs underpins the need to efficiently manage materials on site.

6.3.5 Effect of technology advancement

The use of nanomaterials requires scientific method of analysis so that the full potential of the reclaimed material can be understood, analysed and designed. Some of the challenges faced with upcycling included the lack of awareness as evidently agreed to by many of the respondents. Another challenge agreed on by the respondents is that the current testing regime during the design phase is insufficient to inform the upcycling of the existing pavement layers.

The industry is hesitant on nanomaterial and the chemistry supporting the use of it. The comments received indicate a need to increase the awareness and research in nanomaterials, nanotechnology and chemistry. As a result of lack of buy-in, the industry is losing the opportunity to upcycle materials. Design engineers are still to respond to the advancement in technology so that the industry can progress in the various methods of upcycling.

The industry needs to advance by emphasising that materials characterisation tests, lack a scientific basis and gives minimal indication of the potential bearing capacity. The absence of sound engineering concepts needed for the characterisation of materials and the resultant specifications used in the construction, is a limiting factor in the conventional laboratory tests, such as indicator tests (Jordaan & Steyn, 2021).

The introduction of nanomaterials is supported by Ugwu (2013) as well as the revealed potential to use available marginal materials for pavement layers. Crucial to the use of nanomaterials is the understanding of the material's microstructure, science and chemistry underpinning the behavioural reaction for the materials. The impact of using available materials reduces the need for importing aggregate and yields an array of advantages, contributing to sustainable road infrastructure.

6.3.6 Effect of skills gaps

The research revealed there is a need to promote the concepts of material utilisation and upcycling at the tertiary level of education. The industry is evolving towards better practices and more efficient methods of design and construction. Upcycling is the enabling factor in this evolution. These fundamental concepts must be engrained at the tertiary level so that graduates can rely on the knowledge gained to enhance and improve on methods of upcycling. Exposure at tertiary levels promotes further research in the field. The questionnaire survey highlighted that the challenge faced with upcycling was the lack of awareness in the industry.

The uniqueness of nanotechnology has made education in the field of nanotechnology increasingly important for the students and industry. This specific technology requires that education bodies collaborate to adequately prepare competent graduate engineers (Balakrishnan & Visvanathan, 2013).

Knowledge is perishable and has a "best before" date. For this reason, one has to be continually updated and be aware of the latest findings and advancement in the industry. Universities and other education institutions can be helpful to promote the continuous learning (Bayard et al., 2014).

6.4 Recommendations

The following recommendation are based on the research objectives:

6.4.1 Planning and specifying the design of upcycling

It was found that the competitive tendering procurement method restricts the design to what is conventional and is least costly to design. The fallback onto the catalogue design is accepted. The inclusion of specific pay items and associated specification in the consultant design tender for upcycling, testing of upcycling, design for upcycling can be included in the tender documentation. This will draw focus and attention to the clients' requirement. In so doing, the tender is requested to price for upcycling to be included in the design. This still aligns to the client procurement policy and it's the simplest change that can be used to promote industry awareness and the optimum use of materials.

6.4.2 Promoting awareness of upcycling

The promotion of awareness of upcycling can be achieved through the facilitation of technical workshops. South Africa has various voluntary technical associations within the civil engineering fields. These associations can be approached to facilitate industry workshops specific to the optimal use of materials and the various upcycling methodologies.

6.4.3 Promoting nanotechnology and chemistry

The research found that nanotechnology and the use of chemistry is at present, a niche market. The industry needs knowledge on these specific fields of development. The succession of knowledge will allow for the progress of the latest development in the field. Continuous education in the field of nanotechnology and chemistry can be enabled through widespread industry workshops. The client bodies can promote the use of technology through pilot projects to gain the full knowledge of the opportunities that exist.

6.4.4 Closing the skills gap

There is a need for effective engagement between the industry and tertiary institutions, specifically, engagement between the workforce and students. The content of these engagements can be focused on identifying the challenges, shortfalls and needs in the design process. These challenges can then become focus areas of research. The focus areas of research then attracts students to continue with postgraduate studies. The exposure of the postgraduate research becomes industry knowledge which must be marketed further to reduce the knowledge gaps.

6.5 Area for further research

It was found that the planning phase for upcycling is the driving force from the clients to implement upcycling. Further research can focus on the planning tools for the client to use in the implementation of upcycling.

Further research in the field of nanotechnology to upcycling material is required to promote industry awareness and exposure to the advancement in technology.

Flexible pavement layers were the focus of this study and further research can be done to include the upcycling opportunities for concrete pavements. This will give a holistic indication of the upcycling opportunities for the road design and construction industry.

The study included for the three construction projects and was limited to a small sample. The sample size can be increased to include the remaining nine projects to be constructed thereby addressing the limitation of this study.

6.6 Conclusion

The findings of the study indicates that the factors influencing upcycling in a Materials Utilisation Plan is widely spread across several industries. These industries include the Client Body, Design Consultants, Contractors and Tertiary Institutions. The recommendations provided in the study gives a holistic approach to further upcycling opportunities and if adopted, it will significantly optimise the use of existing materials in future construction, forging innovation and sustainability.

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Appendix A: Concept Clarification

In this section the concepts use in this study will be clarified with the use of graphics.

Upgrading Of Current Road Layers

The upgrading of current road layers is illustrated in Figure A.1 below

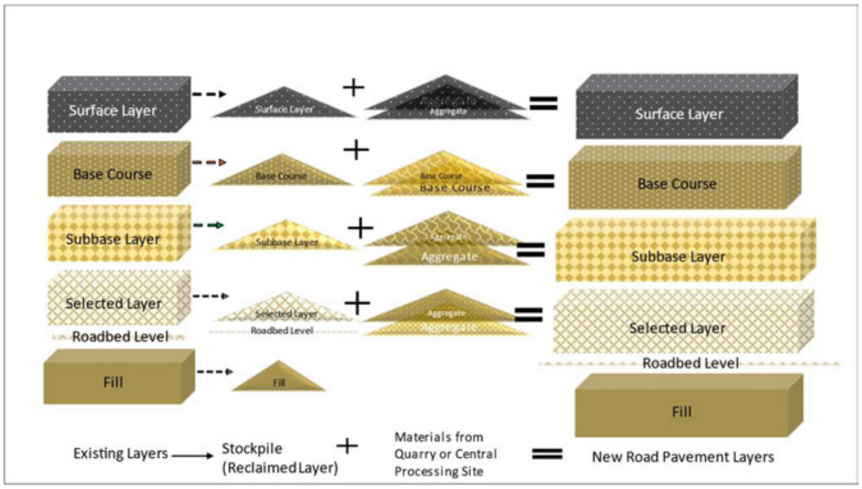


Figure A.1: Upgrading of a current road pavement layer

Source: Researcher

Reuse of current paving

The reuse of current road layers is illustrated in Figure A.2. below

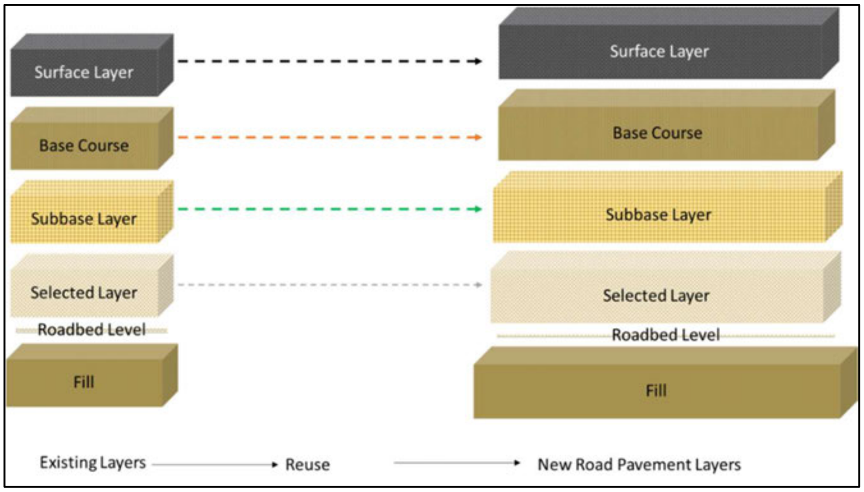


Figure A.2: Reuse of a current road pavement layers
Source: Researcher

Reuse of Surface Layer course: Reclaiming and reusing the existing surface layer in the new surface layer.

Reuse Base course: Reclaiming and reusing the existing surface base layer in the new base layer.

Reuse of Subbase: Reclaiming and reusing the existing surface subbase layer in the new subbase layer.

Reuse of Selected Layers: Reclaiming and reusing the existing surface selected layer in the new selected layer.

Upcycling

The upcycling of current road layers into higher road layers are illustrated in Figure A.3 below

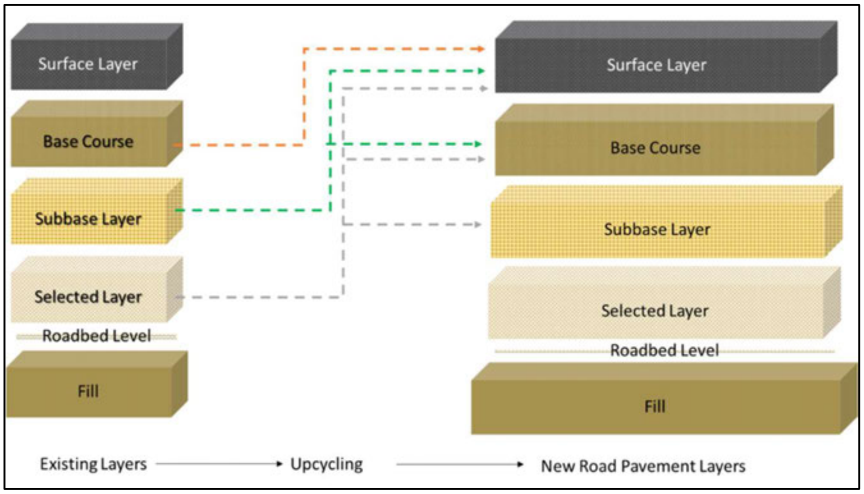


Figure A.3: Upcycling of existing layers into higher road pavement layers
Source: Researcher

Upcycling of base course: Reclaimed base layer to new surface layer

Upcycling Subbase: Reclaimed sub-base layer to new base course or new surface layer

Upcycling of Selected layers: Reclaimed selected layer to new surface layer, new base course or new sub-base layer

Downcycling

The downcycling of current road layers into lower road layers are illustrated in Figure A.4 below

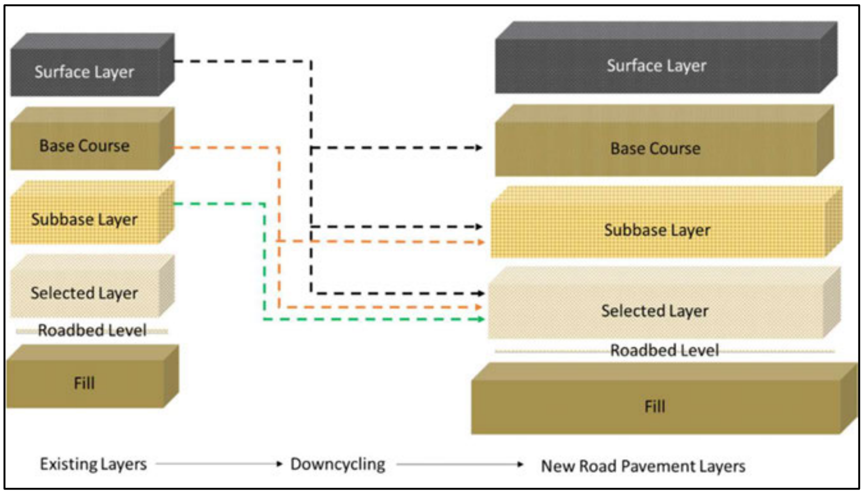


Figure A.4: Downcycling of existing layers into lower road pavement layers
Source: Researcher

Downcycling surface layer: Reclaimed surface layer to new base course, sub-base or selected layers

Downcycling Base Course: Reclaimed base course in new sub-base or selected layer

Downcycling Sub-base: Reclaimed sub-base to new selected layer

Downcycling to fill

The downcycling of current road layers into the fill layer of the new road pavement are illustrated in Figure A.5 below

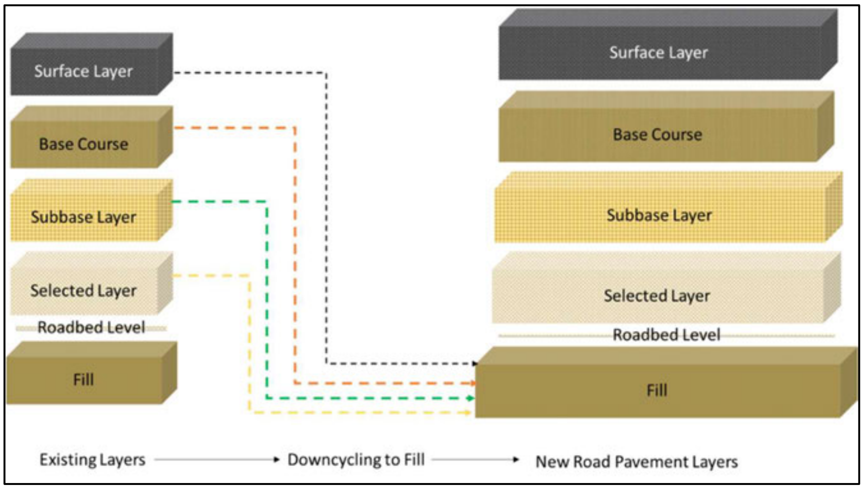


Figure A.5: Downcycling of existing layers into the fill layer of the new road pavement

Source: Researcher

Summary of value implications

		To New Pavement Layer				
		Surface Layer	Base Course	Subbase Layer	Selected Layer	Fill
From existing pavement	Surface Layer	Reuse	Downcycle	Downcycle	Downcycle	Downcycle
	Base Course	Upcycle	Reuse	Downcycle	Downcycle	Downcycle
	Subbase Layer	Upcycle	Upcycle	Reuse	Downcycle	Downcycle
	Selected Layer	Upcycle	Upcycle	Upcycle	Reuse	Downcycle

Increase in value	Same Value	Decrease in value	Minimal Value

Appendix B: Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL ™
INYUVESI YAKWAZULU-NATALI

14 October 2021

Salome Naicker (202514376)
School Of Engineering
Howard College

Dear S Naicker,

Protocol reference number: HSSREC/00003378/2021
Project title: THE FEASIBILITY OF A NETWORK MATERIAL UTILIZATION PLAN, WITH AN EMPHASIS ON UPCYCLING OF MATERIALS
Degree: MSc

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 14 September 2021 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

This approval is valid until 14 October 2022.
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

All research conducted during the COVID-19 period must adhere to the national and UKZN guidelines.

HSSREC is registered with the South African National Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

Professor Dipane Hlalele (Chair)

/dd

Humanities and Social Sciences Research Ethics Committee
Postal Address: Private Bag X54001, Durban, 4000, South Africa
Telephone: +27 (0)31 260 8350/4557/3587 **Email:** hssrec@ukzn.ac.za **Website:** http://research.ukzn.ac.za/Research-Ethics

07 October 2022

Salome Naicker (202514376)
School Of Engineering
Howard College

Dear S Naicker,

Protocol reference number: HSSREC/00003378/2021
Project title: The feasibility of a network material utilization plan, with an emphasis on upcycling of materials
Degree: MSc

Approval Notification – Amendment Application

This letter serves to notify you that your application and request for an amendment received on 06 October 2022 has now been approved as follows:

- Change in research instrument

Any alterations to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form; Title of the Project, Location of the Study must be reviewed and approved through an amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

Best wishes for the successful completion of your research protocol.

Yours faithfully

[redacted]

....

Professor Dipane Hlalele (Chair)

/dd

Humanities & Social Sciences Research Ethics Committee
UKZN Research Ethics Office Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Tel: +27 31 260 8350 / 4557 / 3587
Website: http://research.ukzn.ac.za/Research-Ethics/

Appendix C: Semi-Structured Interviews

THE FEASIBILITY OF A NETWORK MATERIALS UTILISATION PLAN, WITH AN EMPHASIS ON UPCYCLING OF MATERIAL

Interview number_______________

Before the interview

- Thank participants for agreeing to participate in the study.
- Explain the purpose of the study, what it seeks to achieve and conditions for participation in the study.
- Deal with issues of informed consent and explain options to participant's e.g., voluntary nature of participation and options to opt out.
- No names will be linked to any data
- Distribute consent forms for signature before interviews start and get permission in writing to record.

Process: Explain the process of the interview

- How long it will take and how many questions (Number of questions and will take not more than 45 minutes).
- Find out if participants are able to sit for interviews at that time.
- Indicate that the <u>interviews will be recorded</u> and why it is important, explain issues of confidentiality and this information will be used and stored.

PART A – Applicable to all

Explain reason for demographical data collection

Type of Participant

1. Pavement Laboratory Testers □; Pavement Designers □;Clients □;
2. Gender of participant: Male □; or Female □;
3. Which age bracket do you fit into: 20-30 □; 31-40 □; 41-50 □; 51-60 □; 60+□
4. What is your highest qualification?
5. What is your position in the organisation?
6. How many years' experiences do you in your field?
7. Please tell me about your current job responsibilities
8. What is your understanding of a Materials Utilisation Plan?
9. What is your understanding of Upcycling of Materials?
10. What factors do you consider influences upcycling in a Materials Utilisation Plan?
11. What is the impact of those factors in a Materials Utilisation Plan?

12. What factors do you consider influences a central processing site to upcycle materials
13. What is the impact of those factors?
14. What do you think about the proposal to establish a central processing site to upcycle materials?
15. What are the advantages of using a central processing site to upcycle materials?
16. What are the disadvantages of using a central processing site to upcycle materials?

PART B – Applicable to Pavement Laboratory Testers only

17. What factors influences the variability in test results
18. What is the impact of these factors?

PART C – Applicable to Pavement Designers Only

14. What factors influences the design of upcycling
15. What is the impact of these factors?
16. What factors should be considered when integrating a Materials Utilisation Plan to a Network Utilisation Plan
17. What would be the advantages of a Network Utilisation Plan?
18. What type of industry training would be relevant to achieve a better standard of upcycling of materials?

PART D – Applicable to Clients only

14. What factors influences the acceptance of a Network Utilisation Plan
15. What is the impact of those factors?

Thank you

At end of interview

- Thank participants again for agreeing to participate in the study
- Summarise again the reason for the study
- Make sure you have the consent form
- Share information about the next steps with your project

END

Appendix D: Survey Questionnaire

INTRODUCTION:

I am Salome Naicker, currently employed as a Project Manager at SANRAL Eastern Region. I am registered for a Master's Degree in Civil Engineering at the University of KwaZulu – Natal (UKZN). This correspondence contains information relating to the research which I am pursuing as part of the degree. My research topic, "FEASIBILITY OF A NETWORK MATERIAL UTILIZATION PLAN, WITH AN EMPHASIS ON UPCYCLING OF MATERIALS" requires your input.
The aim of the research is to analyze the current design strategies for a materials utilization plan and to develop a model for a network materials utilization plan for a program, based on the optimal use of the existing pavement layer. This study will assist policymakers such as SANRAL in formulating appropriate planning strategies that will address materials utilization and the efficient use of the existing pavement asset.

The research questionnaire assesses the perception of clients (SANRAL Project Managers), consultants and contractors' perception of the existing pavement asset, current design strategies, appetite for upcycling of materials and addresses barriers to upcycling. The questionnaire should take 10 minutes and is divided into 2 parts. Part A indicated the existing use of materials and Part B applies a scenario to the utilization of materials.

The questionnaire and consent form will be sent to SANRAL Project Managers, their Consultants and Contractors currently contracted to the N3 Upgrade Project. The N3 upgrade project forms the case study used in the research.

This research does not pose any known risk and is for the submission to the Department of Civil Engineering for the fulfilment of the requirement for the award of the MSc in Civil Engineering at UKZN under the supervision of Professor Mostafa. Participant's confidentiality and anonymity will be maintained throughout the study. Any data and information received will be exclusively used of research only.

PART A	**SURVEY**
Question 1	Select the field in which you practice. Chose from: Project Manager, Pavement Design Engineer, RE, SMT, GF, Construction Manager, Contracts director
Question 2	Please indicate the number of years experience. <10 years, >10 years

	Below is a list of statements relating to the utilization of materials. Please indicate how strongly you agree or disagree with each statement. Rating scale 1-5 (1 - strongly disagree, 5 - Strongly agree)
Question 3	The utilization of reclaimed materials within a project, is restricted to the project limits
Question 4	The utilization of materials between adjacent projects are limited to surplus reclaimed material
Question 5	The movement of reclaimed materials between projects imposes a contractual risk
Question 6	It is economically viable to utilize a quarry owned by the client in close proximity to the project
Question 7	It is economically viable to utilize a stockpile site owned by the client in close proximity to the project
Question 8	The reclaimed aggregates from the existing surface layer, is a source of materials for the project
Question 9	The reclaimed base layer is a source of material for the new pavement layer
Question 10	The reclaimed subbase layer is a source of material for the new pavement layer
Question 11	The reclaimed selected layers are a source of materials for the new pavement layers
Question 12	The reclaimed surface layer can be recycled and utilized in the surface layer of the new pavement
Question 13	The reclaimed surface layer can be downcycled and utilized in the new pavement
Question 14	The reclaimed surface layer can be downcycled and utilized as fill for the project
Question 15	The reclaimed base layer can be upcycled and utilized in the surface layer of the new pavement
Question 16	The reclaimed base layer can be recycled and utilized in the base layer of the new pavement
Question 17	The reclaimed base layer can be downcycled and utilized in the new pavement
Question 18	The reclaimed base layer can be can be downcycled and utilized as fill for the project

Question 19	The reclaimed subbase layer can be upcycled and utilized in the new pavement
Question 20	The reclaimed subbase layer can recycled and utilized in the subbase layer of the new pavement
Question 21	The reclaimed subbase layer can be downcycled and utilized in the new pavement
Question 22	The reclaimed subbase layer can be downcycled and utilized as fill for the project
Question 23	The reclaimed selected layers layer can be upcycled and utilized in the new pavement
Question 24	The reclaimed selected layers layer can be recycled and utilized in the selected layers of the new pavement
Question 25	The reclaimed selected layers layer can be downcycled and utilized as fill for the project
Question 26	The clients' specifications are a barrier the recycling of materials
Question 27	It is the responsibility of the client to specify minimum % of reclaimable material to be used in each layer of the new pavement
Question 28	There is limited awareness for the need for upcycling of the existing pavement layers
Question 29	The engineer is responsible to design for the upcycling of the existing pavement layers
Question 30	The current testing regime during the design phase is insufficient to inform the upcycling of the existing pavement layers
Question 31	The process of recycling has cost implications and it is easier to spoil materials
Question 32	The process of upcycling has cost implications and it is easier to downcycle materials
Question 33	Contractors need to be incentivised to reclaim and upcycle the existing pavement layers
Question 34	The introduction of a surcharge when spoiling material at a landfill site, will increase efficient utilization of existing pavement layers in the new pavement

PART B	Below is a list of statements relating to a specific scenario for the utilization of materials. Please indicate how strongly you agree or disagree with each statement, based on the below scenario All layers of a flexible pavement layers from the individual projects are excavated and stockpiled at a Central Processing Site. The central processing site is operated independently from the individual projects and is in close proximity to a quarry and the individual projects. The central processing site contractor then has the responsibility to blend the stockpiled materials with virgin material to produce the individual projects desired materials quality. Rating scale 1-5 (1 - Strangle disagree, 5 - Strongly agree)
Question 35	Based on the scenario; The implementation of central processing site will improve the opportunities for upcycling of the material.
Question 36	Based on the scenario; The central processing site will work best if it is managed by the client
Question 37	Based on the scenario; The use of a central processing site will ensure a uniform pavement for the network
Question 38	Based on the scenario; The use of a central processing site will limit the approval of sources of a materials
Question 39	Based on the scenario; The use of a central processing site will reduce the number of trips made by the project to obtain materials from various sources
Question 40	Based on the scenario; The use of a central processing site will reduce the overall transport cost of the individual projects to obtain materials from various sources
Question 41	Based on the scenario; The use of a central processing site will reduce the individual project materials costs.
Question 42	Based on the scenario; Timing is the most aspect that needs to be understood and comprehensively coordinated between projects.
Question 43	Based on the scenario; The client must lead during the design phase and conduct in depth pre-investigation into the materials plan for the construction.

Appendix E: Factor Analysis of the Materials Utilization Questionnaire

The results of the Factor Analysis of the Survey Questionnaire are presented in this section. The results of the Eigenvalues of the Survey Questionnaire are presented in in Table E. 1 below.

Table E. 1: Eigenvalues of the Survey Questionnaire ($n = 32$)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% Of Variance	Cumulative %	Total	% Of Variance	Cumulative %	Total
1	7,922	19,321	19,321	7,922	19,321	19,321	5,751
2	4,813	11,738	31,059	4,813	11,738	31,059	4,931
3	3,627	8,846	39,905	3,627	8,846	39,905	4,899
4	3,475	8,477	48,381	3,475	8,477	48,381	3,984
5	2,555	6,233	54,614	2,555	6,233	54,614	2,790
6	2,262	5,517	60,131	2,262	5,517	60,131	2,810
7	2,075	5,060	65,191	2,075	5,060	65,191	2,538
8	1,894	4,620	69,812	1,894	4,620	69,812	3,542
9	1,565	3,818	73,630				
10	1,486	3,623	77,253				
11	1,280	3,123	80,376				
12	1,180	2,879	83,255				
13	,929	2,265	85,520				
14	,854	2,083	87,602				
15	,792	1,931	89,534				
16	,749	1,828	91,361				
17	,536	1,307	92,668				
18	,495	1,207	93,875				
19	,465	1,134	95,009				
20	,439	1,070	96,079				
21	,359	,875	96,953				
22	,310	,757	97,710				
23	,236	,574	98,284				
24	,180	,439	98,723				
25	,152	,370	99,093				
26	,133	,325	99,418				
27	,080	,196	99,614				
28	,061	,149	99,763				
29	,044	,107	99,870				
30	,031	,075	99,945				
31	,022	,055	100,000				
32	,000	,000	100,000				
33	,000	,000	100,000				
34	,000	,000	100,000				

35	,000	,000	100,000				
36	,000	,000	100,000				
37	,000	,000	100,000				
38	,000	,000	100,000				
39	,000	,000	100,000				
40	,000	,000	100,000				
41	,000	,000	100,000				

Extraction Method Principal Component Analysis.

A total of eight factors can be postulated, explaining about 70% of the variance in the factor space.

A rotated and sorted factor matrix was calculated for the survey questionnaire, as described in Table E. 2 below.

Table E. 2: Rotated and sorted factor matrix of the Materials Utilization Scale (n = 32)

	Component								Extracted communalities
	1	2	3	4	5	6	7	8	
P7: The reclaimed base layer is a source of material for the new pavement layer	,818								0,794
P6: The reclaimed aggregates from the existing surface layer, is a source of materials for the project	,802								0,701
P8: The reclaimed subbase layer is a source of material for the new pavement layer	,792								0,839
P11: The reclaimed surface layer can be downcycled and utilized in the new pavement	,777								0,762
P19: The reclaimed subbase layer can be downcycled and utilized in the new pavement	,674								0,741
P9: The reclaimed selected layers are a source of materials for the new pavement layers	,572								0,587
P15: The reclaimed base layer can be downcycled and utilized in the new pavement	,531								0,627
P20: The reclaimed subbase layer can be downcycled and utilized as fill for the project		,893							0,881
P16: The reclaimed base layer can be can be downcycled and utilized as fill for the project		,874							0,897
P23: The reclaimed selected layers layer can be downcycled and utilized as fill for the project		,838							0,889
P34: Based on the scenario; The central processing site will work best if it is managed by the client		-,681							0,552
P12: The reclaimed surface layer can be downcycled and utilized as fill for the project		,516							0,629
P18: The reclaimed subbase layer can recycle and utilized in the subbase layer of the new pavement			-,806						0,801
P22: The reclaimed selected layers layer can be recycled and utilized in the selected layers of the new pavement			-,797						0,861
P2: The utilization of materials between adjacent projects are limited to surplus reclaimed material			,746						0,592
P14: The reclaimed base layer can be recycled and utilized in the base layer of the new pavement			-,653						0,687
P27: The engineer is responsible to design for the upcycling of the existing pavement layers			-,542						0,396

P36: Based on the scenario; The use of a central processing site will limit the approval of sources for materials			-,427						0,474
P1: The utilization of reclaimed materials within a project, is restricted to the project limits			,422						0,683
P37: Based on the scenario; The use of a central processing site will reduce the number of trips made by the project to obtain materials from various sources				,834					0,880
P39: Based on the scenario; The use of a central processing site will reduce the individual project materials costs.				,810					0,806
P38: Based on the scenario; The use of a central processing site will reduce the overall transport cost of the individual projects to obtain materials from various sources				,799					0,813
P33: Based on the scenario; The implementation of central processing site will improve the opportunities for upcycling of the material.				,548					0,694
P32: The introduction of a surcharge when spoiling material at a landfill site, will increase efficient utilization of existing pavement layers in the new pavement				,515					0,702
P40: Based on the scenario; Timing is the most important aspect that needs to be understood and comprehensively coordinated between projects.					,721				0,670
P35: Based on the scenario; The use of a central processing site will ensure a uniform pavement for the network					,681				0,617
P31: Contractors need to be incentivized to reclaim and upcycle the existing pavement layers					,626				0,615
P41: Based on the scenario; The client must lead during the design phase and conduct in depth pre-investigation into the materials plan for the construction.					,537				0,527
P24: The clients' specifications are a barrier for the recycling of materials					,428				0,599
P21: The reclaimed selected layers layer can be upcycled and utilized in the new pavement						,655			0,859
P13: The reclaimed base layer can be upcycled and utilized in the surface layer of the new pavement						,642			0,610

P17: The reclaimed subbase layer can be upcycled and utilized in the new pavement						,602			0,815
P28: The current testing regime during the design phase is insufficient to inform the upcycling of the existing pavement layers						,583			0,666
P29: The process of recycling has cost implications and it is easier to spoil materials						,428			0,656
P26: There is limited awareness for the need for upcycling of the existing pavement layers							,818		0,737
P25: It is the responsibility of the client to specify minimum % of reclaimable material to be used in each layer of the new pavement							,767		0,675
P30: The process of upcycling has cost implications and it is easier to downcycle materials							,542		0,673
P4: It is economically viable to utilize a quarry owned by the client in close proximity to the project								-,823	0,812
P10: The reclaimed surface layer can be recycled and utilized in the surface layer of the new pavement								-,658	0,703
P5: It is economically viable to utilize a stockpile site owned by the client in close proximity to the project								-,523	0,624
P3: The movement of reclaimed materials between projects imposes a contractual risk								,491	0,477

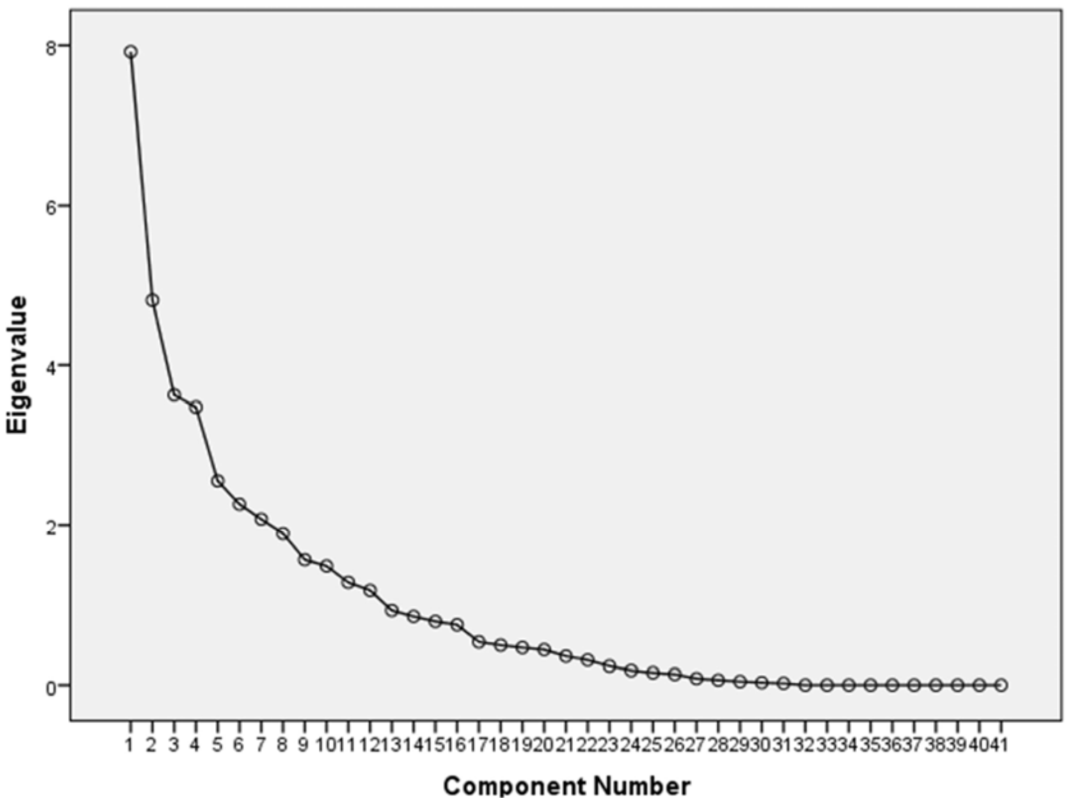
Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 41 iterations.

The Scree Plot of the Eigenvalues of the Survey Questionnaire are presented in Figure E. 1 below.

Figure E. 1: Scree Plot of the Eigenvalues of the Survey Questionnaire (*n* = 32)



Eigenvalue
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
Component Number

Appendix F: Iterative Reliability Analysis Results

The Iterative Reliability Analysis for the questionnaire scales are presented in this section.

Table F. 1: Iterative Reliability Analysis for the Factor 1 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P7: The reclaimed base layer is a source of material for the new pavement layer	24.125	19.984	.839	.806	.837
P6: The reclaimed aggregates from the existing surface layer, is a source of materials for the project	23.938	20.964	.657	.509	.858
P8: The reclaimed subbase layer is a source of material for the new pavement layer	24.281	19.434	.862	.843	.833
P11: The reclaimed surface layer can be downcycled and utilized in the new pavement	24.344	19.975	.740	.618	.847
P19: The reclaimed subbase layer can be downcycled and utilized in the new pavement	24.563	19.673	.591	.487	.869
P9: The reclaimed selected layers are a source of materials for the new pavement layers	24.813	19.190	.560	.521	.879
P15: The reclaimed base layer can be downcycled and utilized in the new pavement	24.188	22.609	.478	.356	.878
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.875		**28.375**	**27.016**	**5.1977**	**7**

As showed in Table F. 1, Factor 1 (measured by seven items), yielded a Cronbach Alpha of 0.88, indicating an acceptable reliability.

Table F. 2: Iterative Reliability Analysis for the Factor 2 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P20: The reclaimed subbase layer can be downcycled and utilized as fill for the project	10.125	11.339	.857	.827	.767
P16: The reclaimed base layer can be can be downcycled and utilized as fill for the project	10.406	10.378	.912	.851	.737
P23: The reclaimed selected layers layer can be downcycled and utilized as fill for the project	9.750	13.613	.593	.681	.871
P12: The reclaimed surface layer can be downcycled and utilized as fill for the project	10.688	12.867	.532	.643	.903
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.864		**13.656**	**20.491**	**4.5267**	**4**

As showed in Table F. 2, Factor 2 (measured by four items), yielded a Cronbach Alpha of 0.86, indicating an acceptable reliability.

Item P34 ("Based on the scenario; The central processing site will work best if it is managed by the client") was excluded due to their negative influence on the Cronbach's Alpha score of the scale.

Table F. 3: Iterative Reliability Analysis for the Factor 3 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P18: The reclaimed subbase layer can recycle and utilized in the subbase layer of the new pavement	14.688	9.060	.884	.842	.619
P22: The reclaimed selected layers layer can be recycled and utilized in the selected layers of the new pavement	14.313	11.770	.631	.492	.726
P14: The reclaimed base layer can be recycled and utilized in the base layer of the new pavement	14.656	11.523	.576	.561	.742
P27: The engineer is responsible to design for the upcycling of the existing pavement layers	14.094	14.088	.304	.294	.818
P36: Based on the scenario; The use of a central processing site will limit the approval of sources for materials	14.875	12.306	.457	.653	.781
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.786		**18.156**	**17.426**	**4.1745**	**5**

As showed in Table F. 3, Factor 3 (measured by five items), yielded a Cronbach Alpha of 0.77, indicating an acceptable reliability.

Table F. 4: Iterative Reliability Analysis for the Factor 4 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P37: Based on the scenario; The use of a central processing site will reduce the number of trips made by the project to obtain materials from various sources	15.031	10.934	.617	.470	.766
P39: Based on the scenario; The use of a central processing site will reduce the individual project materials costs.	15.063	10.577	.755	.622	.723
P38: Based on the scenario; The use of a central processing site will reduce the overall transport cost of the individual projects to obtain materials from various sources	15.125	10.242	.656	.611	.754
P33: Based on the scenario; The implementation of central processing site will improve the opportunities for upcycling of the material.	14.375	13.532	.613	.473	.786
P32: The introduction of a surcharge when spoiling material at a landfill site, will increase efficient utilization of existing pavement layers in the new pavement	14.906	11.765	.447	.362	.823
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.809		**18.625**	**17.016**	**4.1251**	**5**

As showed in Table F.4, Factor 4 (measured by five items), yielded a Cronbach Alpha of 0.81, indicating an acceptable reliability.

Table F. 5: Iterative Reliability Analysis for the Factor 5 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P40: Based on the scenario; Timing is the most important aspect that needs to be understood and comprehensively coordinated between projects.	12.344	3.910	.549	.360	.524
P35: Based on the scenario; The use of a central processing site will ensure a uniform pavement for the network	12.781	3.531	.451	.266	.552
P31: Contractors need to be incentivized to reclaim and upcycle the existing pavement layers	13.125	3.339	.295	.088	.699
P41: Based on the scenario; The client must lead during the design phase and conduct in depth pre-investigation into the materials plan for the construction.	12.469	3.418	.487	.293	.526
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.641		**16.906**	**5.636**	**2.3740**	**4**

As showed in Table F. 5, Factor 5 (measured by four items), yielded a Cronbach Alpha of 0.64, indicating an acceptable reliability.

Item P24 (“The clients’ specifications are a barrier for the recycling of materials”) was excluded due to the negative influence on the Cronbach's Alpha score of the scale.

Table F.6: Iterative Reliability Analysis for the Factor 6 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P21: The reclaimed selected layers layer can be upcycled and utilized in the new pavement	8.656	5.910	.645	.596	.388
P13: The reclaimed base layer can be upcycled and utilized in the surface layer of the new pavement	8.750	8.387	.261	.084	.679
P17: The reclaimed subbase layer can be upcycled and utilized in the new pavement	8.406	6.120	.597	.582	.430
P28: The current testing regime during the design phase is insufficient to inform the upcycling of the existing pavement layers	7.563	9.286	.222	.051	.687
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.641		**11.125**	**11.790**	**3.4337**	**4**

As showed in Table F.6, Factor 6 (measured by four items), yielded a Cronbach Alpha of 0.64, indicating an acceptable reliability.

Item P29 ("The process of recycling has cost implications and it is easier to spoil materials") was excluded due to the negative influence on the Cronbach's Alpha score of the scale.

Table F.7: Iterative Reliability Analysis for the Factor 7 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P26: There is limited awareness for the need for upcycling of the existing pavement layers	6.688	4.738	.434	.223	.497
P25: It is the responsibility of the client to specify minimum % of reclaimable material to be used in each layer of the new pavement	7.563	2.770	.479	.268	.349
P30: The process of upcycling has cost implications and it is easier to downcycle materials	7.625	3.597	.342	.118	.574
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.586		**10.938**	**6.899**	**2.6266**	**3**

As showed in Table F. 7, Factor 2 (measured by three items), yielded a Cronbach Alpha of 0.59, indicating un-acceptable reliability.

Factor 7 was excluded from the analysis due to the un-acceptable reliability Cronbach's Alpha score of the scale.

Table F.8: Iterative Reliability Analysis for the Factor 8 Scale

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
P4: It is economically viable to utilize a quarry owned by the client in close proximity to the project	8.313	2.222	.597	.431	.426
P10: The reclaimed surface layer can be recycled and utilized in the surface layer of the new pavement	8.813	1.383	.461	.221	.732
P5: It is economically viable to utilize a stockpile site owned by the client in close proximity to the project	8.188	2.802	.516	.365	.586
Cronbach's Alpha		**Mean**	**Variance**	**Std. Deviation**	**N of Items**
.658		**12.656**	**4.104**	**2.0258**	**3**

As showed in Table F.8, Factor 8 (measured by three items), yielded a Cronbach Alpha of 0.66, indicating an acceptable reliability.

Item P3 ("The movement of reclaimed materials between projects imposes a contractual risk") was excluded due to the negative influence on the Cronbach's Alpha score of the scale.

Appendix G: Turnitin Report

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Appendix H: Editing Certificate

EDITING CERTIFICATE

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1 December 2022

MASTER'S THESIS

THE FEASIBILITY OF A NETWORK MATERIALS UTILISATION PLAN, WITH AN EMPHASIS ON UP CYCLING OF MATERIAL

has been edited to ensure technically accurate and contextually appropriate use of language, grammar, logical coherency and presentation.

[redacted]

Dr Anita Hiralaal