Non-conformance and rework in construction: a quality management improvement initiative for change

by

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A Thesis Submitted in Fulfilment of the Requirements for

the Degree of Doctor of Philosophy of Cardiff University

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March 2024

Acknowledgements

It would not have been possible to conduct this research and write a doctoral thesis without the help and support of those around me. Specifically, the following:

To my mentors,

Prof. Jonathan Gosling, Prof. Mohamed M. Naim and Prof. Aris Syntetos for your undivided attention, clear direction and tremendous support during my PhD journey. I am sincerely grateful for your enthusiasm, knowledge and wisdom over the years.

To industry leaders in quality management,

Prof. Peter Love, Dr Denis Leonard, Cliff Smith (GIRI) and Jack Baker for your guidance, wisdom, knowledge, and wealth of experience in construction quality management practices. Collectively, your knowledge and expertise are unparalleled.

To Costain,

Special thanks to Bill Hewlett, Rupert Shingleton, Mark Berg, Dave Forbes and Derek Bird for supporting me through my PhD journey, and Costain for its financial aid under flexible, full time employment.

To my parents,

Thank you for supporting us through difficult times with childcare, COVID-19 and inflexible working arrangements to allow me to pursue this journey on a full time basis.

Lastly, to my wife and children,

Thank you Lubi for your patience, consideration and selfless love in supporting me through my PhD journey. And to my kids, you both diverted my mind when times were tough to allow me to focus on the bigger picture of 'life'. Without this, it would not have been possible.

Abstract

Rework plagues the construction industry, with rework costs as high as 12.6% of total contract value. Enormous pressures are put on public spend as a result of significant project cost and time overruns. Non-conformance reports (NCRs) are widely used as a quality assurance tool to record and correct non-compliant works in accordance with standards. Unfortunately, the frequency of NCRs infers the industry is struggling to grapple with right-first-time (RFT) delivery, partly due to a lack of investigation into quality failures on projects, and lessons learning.

The overall aim of this thesis is to derive quality management improvement practices and learning outcomes through NCR analytics and practitioner feedback to enhance construction quality outputs.

The research adopts a mixed method approach in two phases. Phase 1 analyses 1260 NCRs from a unique UK highways mega-project dataset to uncover the most impactful failure themes for improvement. Phase 2 presents a survey within a tier 1 principal contractor to gain further insights into the perceptions of quality from industry professionals.

This research highlights critical failure themes in construction projects through NCR data, gains insight into industry professional perceptions of quality, provides lessons learned outcomes to prevent recurrence, and presents a detailed quality excellence and improvement framework to help transition towards RFT. It also explores the use of cognitive tools like the ‘Cynefin framework’ to aid in quality problem solving with the aid of RCA techniques. Collective findings from each phase are synthesised into a holistic quality management framework to help drive continuous improvement.

The generalisability of the findings is limited to highways projects. However, the learning outcomes and quality management practices developed may be transferrable across other sectors. The framework can be adopted by leaders and quality management practitioners at organisation, sector and industry levels to enhance quality outputs and drive continuous improvement.

Related authored publications

The following academic papers have been produced throughout this research:

Ford, G., Gosling, J. and Naim, M. (2023). On quality and complexity: non-conformance failures, management perspectives and learning outcomes on a highways megaproject. *International Journal of Quality & Reliability Management*. https://doi.org/10.1108/IJQRM-11-2022-0313.

Ford, G., Gosling, J. and Naim, M. (2024). Simplifying complexity? On quality decision-making and non-conformance outcomes of megaprojects. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2024.3359821.

Ford, G., and Gosling, J. (2024). Professional perceptions of right-first-time and quality management in construction projects through open-ended feedback. *International Journal of Quality & Reliability Management*. https://doi.org/10.1108/IJQRM-08-2023-0246

Ford, G., Gosling, J., Naim, M. and Hewlett (2019). On Complexity and Decision Making in Construction Management. *36th Annual ARCOM Conference, 7-8th September 2020, UK (Online).*

Ford, G., Gosling, J. and Naim, M. (2021). Complexity surrounding lessons learnt: shouldn't we learn from our mistakes in construction?. *38th Annual ARCOM Conference, 5-7th September 2022, Glasgow, UK.*

Contents

List of Figures

List of Tables

List of Notations, Acronyms and Abbreviations

α	Test significance level
AI	Artificial Intelligence
AR	Augmented reality
ARCOM	Association of researchers in construction management
BSC	Balanced scorecard
BIM	Building information modelling
C4.0	Construction 4.0
CAM	Competency assessment matrix
CAQDAS	Computer assisted qualitative data analysis software
CIOB	Chartered institute of building
CL	Contract leader
CQI	Chartered quality institute
CQP	Chartered quality professional
DCI	Design change for improvement
DCO	Design changes initiated by owner
d_i	Difference between the two ranks of each group
DL	Dominant logic
EFQM	European Foundation for Quality Management
ERM	Electronic records management
FMEA	Failure mode and effects analysis
GDP	Gross domestic product
GIRI	Get it right initiative
H_a	Alternative hypothesis
HS2	High Speed 2

$\mathbf{H_0}$	Null hypothesis
ICE	Institute of civil engineers
IDT	Integrated delivery team
IQVT	Integrated quality verification team
ISO	International organization for standardization
IJQRM	International journal of quality and reliability management
IJOPM	International journal of operations and production management
JTQC	Japanese total quality control
JV	Joint Venture
KPI	Key performance indicators
MS Forms	Microsoft Forms
$\boldsymbol{n}$	Sample size
NCR	Non-conformance report
OCV	Original contract value
$\boldsymbol{p}$	Significance value of the test statistic
PDCA	Plan, do, check, act
PC	Principal contractor
$\boldsymbol{pf}$	Proportioning factor
PMM	Performance measurement and management
PPCF	Production planning and control function
PPM	Performance measurement and management
PPT	People process technology
Q4.0	Quality 4.0
QC	Quality community
QP	Quality professional
RBPP	Relationship based project procurement
RCA	Root cause analysis
RDM	Research data management

RFT	Right-first-time
RPN	Risk priority number
r_s	Correlation coefficient
SHE	Safety, health and environmental
SHW	Specification for highway works
SOSCM	Sustainable operations and supply chain management
SQEP	Suitably qualified and experienced personnel
t	t-statistic for Spearman rank correlation test
TPS	Toyota production system
TQC	Total quality control
TQM	Total quality management
UK	United Kingdom
US	United States
VR	Virtual reality
WMW	Wilcoxon-Mann-Whitney

Chapter 1: Introduction

1.1 Chapter Overview

This chapter establishes an overview of the context, purpose and motivational drivers for this research. The author, having worked in various construction roles include engineering management, quality management and handover operations management for over a decade, identified noticeable failure trends in these fields had become apparent, triggering an urgent need of enlightenment and change. Furthermore, there are echoing concerns from literature on the failure trends and weaknesses in construction projects. Levels of complexity within construction call for a re-evaluation of decision-making and risk of quality construction problems. One widely recognised tool, the ‘Cynefin framework’, is analysed as to its benefits within construction for the purposes of quality problem solving, rather that its primary purpose to influence leadership decision-making. Further construction literature on non-conformance, rework, quality and the Cynefin framework can be found in Chapter 2: Literature Review.

Following the literature review and gap analysis, research questions that emerged will be presented in section 1.4. This is followed by a conceptual roadmap, thesis structure and chapter summary.

1.2 Research context and purpose of study

Quality has been a recurrent topic through various engineering disciplines over many decades. The automotive industry paved the way for finding methods to eradicate error, remove wastage and deploy efficiencies using Japan as a catalyst for innovative quality initiatives (Deming, 1951; Juran, 1951, 2010; Feigenbaum, 1961; Ohno, 1988). The application of lean practices has seen a drastic improvement of automotive practices. As such, lean techniques are being promoted in construction to create a waste free pathway and provide a linear connection to outcomes (e.g. cost, time and quality). However, within construction, quality execution has continued to prove a challenging hurdle to overcome to satisfy completion with clients (Cnudde *et al.,* 1991).

One potential challenge is that unlike the automotive industry, large scale construction projects are very complex and require multiple measures to align quality with right-first-time outcomes. Although there have been attempts to address quality management in construction, there are scarce examples that provide construction leaders with a holistic, evidenced based framework for infrastructure projects, detailing the reasons for improvement through substantial evidence. Instead, these frameworks typically provide a high level strategy of managing quality.

As a major determinant of gross domestic product (GDP), the construction industry is heavily reliant upon appropriate project management and quality management arrangements in infrastructure projects (Oyegoke, 2006). Highways in particular are attracting a tremendous investment of public funds and are currently on top of the government agendas to improve public accessibility, ease congestion of pre-existing infrastructure and help decrease carbon emissions. Furthermore, they contribute to the improvement of local communities by providing improved infrastructure that can enhance tourism and work commuting times.

Over the past few decades however, non-conformance (i.e. the non-fulfilment of requirements) and rework (i.e. to redo an activity) have been major topics of discussion within the quality management community and the wider construction industry, burdening projects both large and small with significant cost and time overruns as a result of pervasive quality problems and poor decision-making (Love, 2002b; Forcada *et al.,* 2014; Love et al, 2016). However, not all non-conformance results in rework. There are different impact levels within non-conformance reports (NCRs) that dictate whether rework will be required. In more fortunate cases, the works can remain and the defect will get accepted into the works at little cost. In less fortunate cases, rework will be required and the costs of rectifying can be high, affecting a firm's profit margin and its competitiveness in the marketplace (Abdul-Rahman, 1995). In addition, the direct links that quality has on cost, time and safety compound the challenges of scheme delivery. For example, there is a 70% greater probability that someone might be injured during a rework activity (Love and Matthews, 2022). Not only is there a quality consequence for failing to deliver a satisfactory product, but there is a heightened safety consequence to remediate.

The construction sector in particular has seen varying rework figures, some as high as 16.5% of project cost, requesting a need for change (Burati *et al.,* 1992; Abdul-Rahman *et al.,* 1996; Love and Edwards, 2004; Senaratne and Sexton, 2009; Forcada *et al.,* 2014; Ye *et al.,* 2015; Love *et al.,* 2018a; Love *et al.,* 2019; Trach *et al.,* 2021; Mahamid, 2022). High rework costs detrimentally affect company profits, relationships with clients, and a company's competitiveness in the marketplace (Abdul-Rahman, 1995). Furthermore, operational profits set aside for future tendering, work winning and reinvestment are being compromised by rework (Abeku *et al.,* 2016; Ahiaga-Dagbui *et al.,* 2017).

Within the highways sector, introducing a right-first-time (RFT) culture has proven challenging even two decades later, whereby behaviours still appear to be traditional instead of risk adverse and accountable for quality standards (Barber *et al.,* 2000; Ahmed *et al.,* 2021). Unfortunately, many defects are not identified throughout the construction phase but instead realised when "it's too late" (Bunni, 2003). In addition, quantifying the correct root causes and corresponding costs has proved very challenging due to commercial sensitivity and/or negative perceptions if data is made available (Buchanan *et al.,* 2013). Love *et al.* (2023) call for a more proactive approach to quality using similar progressive steps adopted within safety to overcome cultural challenges in construction. They refer to this as Quality II, whereby the paradigm accepts errors will happen, but through a different approach that requires organisations to adapt and respond, rather than the traditional negative error prevention route.

Large scale engineering projects are primarily sponsored by government clients on behalf of the general public, and they involve a complex network of regulators, major engineering contractors, subcontractors, designers and consultants, as well as the communities they impact, who must co-ordinate to realise the value of projects, and typically include 'one-of-a kind' designs (Gosling *et al.,* 2017). There have been government led initiatives to understand the endemic problems in construction (e.g. Latham, 1994; Egan, 1998). There have also been scholars who have targeted the structural problems faced in construction projects (Dubois and Gadde, 2002b). This has led to a collective understanding that the construction industry is complex, owing to industry specific uncertainties and independencies, and inefficient operations.

Furthermore, it indicates the long history of it being a really tough context to get things done right, without any major problems arising.

Complexity is a central issue in management theory (e.g. Simon, 1957), but also, and especially so, in the case of megaprojects. Flyvbjerg *et al.* (2003) suggest that risks in large projects are typically assessed based on the assumption that there are clear and stable cause-and-effect patterns, rather than the highly stochastic outcomes that are seen in reality. However, a more recent view of projects is emerging that accepts their inherent complexities, taking a more complex systems perspective, which accepts a dynamic environment. This is perhaps much more aligned with the challenge of managing the unexpected, or so called "unknown unknowns" (Ramasesh and Browning, 2014; Browning and Ramasesh, 2015). Important research challenges for the operations management discipline include the appropriate responses to ever-changing project complexities, where an underlying theory of explaining how to respond is still absent (Turner *et al.,* 2018), and to better understand different kinds of complexities (Maylor *et al.,* 2018). In addition, it has been noted that the "conceptualisation of complexity and response as a linear system was *[is]* no longer adequate" (Maylor and Turner, 2017).

Going back over 40 years, Philip Crosby advocated that quality is free (Crosby, 1979). He made it clear that "quality is too important to leave to the professionals", meaning that it is everyone's responsibility to understand and manage quality, much like safety. Sadly, the industry keeps making mistakes and there are growing concerns that this pattern will continue for decades to come without a clear change in culture that holds all accountable to quality standards.

As such, the purpose of this study is to explore non-conformance data on a highways construction megaproject to uncover the failure truths and determine whether decision-making under varying levels of complexity have a significant bearing on quality problem outcomes. This thesis focuses specifically on decision-making of quality problems, rather than the broader topic of decision-making.

1.3 Research motivation and personal drivers

Personal motivation

The author has always had a deep personal affiliation with quality due to his professional background. Graduating from Swansea University with a master's degree in civil engineering, the author found himself ascending through the engineering ranks and gravitating towards the quality profession where he attained quality manager status with Costain in 2016 and further chartered status (CQP) with the Chartered Quality Institute (CQI) in 2019. Since then, it has been a major driver to understand why right-first-time has been unachievable to date, and why high quality standards cannot be maintained on construction schemes. Furthermore, witnessing real cases of failure within his organisation and more generally within the construction industry has fuelled his desire to find ways of improvement.

1.3.1. Academic based problem

From an academic perspective, there are many who have uncovered rework costs associated with construction schemes. To name a few, Burati *et al.* (1992), Love and Li (2000), Love and Edwards (2005), Love *et al.* (2018a) and Trach *et al.* (2021) have all uncovered significant rework costs from their studies in the construction sector. However, there are few who have explored non-conformance report data extensively to unearth major lessons learned outcomes for improvement. Furthermore, with an apprehension for major contractors to share their quality failure information, researchers have been unable to explore unique, large scale non-conformance datasets. In tandem, scholars have expressed many concerns on the lack of required information upon which to base reliable and accurate estimations, and how data mining, machine learning and natural language processing can support construction practitioners in making better informed decisions as well as reduce the time and resources spent problem solving (e.g. Ahiaga-Dagbui and Smith, 2013, Ahiaga-Dagbui and Smith, 2014, and Baker *et al.,* 2018). The increasing complexity of schemes over recent years has resulted in the bulk of cost overruns, with the calling for systems thinking to better understand the nature of failure, and support more accurate decisions going forward (Ahiaga-Dagbui *et al.,* 2015).

With the added complexities large scale construction projects bring, many have tried to embrace lean practices to simplify problem solving. Unfortunately, this has resulted in oversimplification of decision-making that has yielded premature remedial and corrective outcomes. For quality problem solving specifically, there is a lack of explanation as to where the pitfalls are and how to address them. A leading decision-making tool, the Cynefin framework, has been seen to offer much benefit to problem solving in challenging environments across various sectors including healthcare and information technology, but has struggled to impact the construction sector. As the framework presents a pattern based approach using cause-and-effect relationships similar to root cause analysis techniques, there appears to be an opportunity to use the framework for the benefit of quality problem solving. Encompassing the above is how projects and businesses reposition quality management practices to reduce failure. Rework experts such as Love *et al.* (2019) have concluded that there is an endemic problem in understanding 'why' and 'how' rework occurs, and how rework can be extinguished altogether. With such high non-conformance and rework numbers being recorded, the author sees an opportunity to re-evaluate the industry, and target weaknesses where immediate improvement can be made

1.3.2 Practice based problem

In practice, the construction industry is struggling to deliver schemes on budget and within agreed timeframes (Love *et al.,* 2018b). The authors parent company was under no illusion that non-conformance and rework is rife both internal within the business and across the sector including its JV partners (Get it Right Initiative, 2018). As a major contractor within the UK construction industry, there were major concerns over why the sector was repetitively failing to get works completed right-first-time. In addition, there was a clear understanding that the construction industry is poor at learning from data and sharing lessons learned for improvement. To do nothing would mean continued failure patterns without tangible data on how to enforce change. With a wealth of NCR data to learn from within the business, the principal contractor took initiative and commissioned a quality professional (i.e. the author) to undertake a detailed exploration into non-conformance data on a major highways scheme for the purposes of continuous improvement.

1.4 Overall aim and research questions

The overall aim of this thesis is *'to investigate quality execution in major construction projects, via NCR data analysis and industry survey with construction professionals, to build a framework to transition towards Right-First-Time'.* To date, the construction industry has been unsuccessful in its efforts to improve quality, and has been burdened by cost and time overruns on many schemes despite the introduction of lean and TQM practices (O'Connor and McDermott, 2022). Furthermore, we see limited lessons learned outcomes being shared as common knowledge for improvement amongst the industry (Williams, 2008). The result of this is that the construction industry continues to haemorrhage significant rework costs that could be avoidable through better knowledge management. This research seeks to share real quality failure outcomes and improvement avenues so that managers, companies and governing bodies take action to move the construction industry forwards.

Four research questions deduced through the literature review phase are summarised below. In addition, two further research questions are raised following the findings from Phase 1 which are also expanded on. Moreover, Section 1.5 presents how each research question emerges through the research and is answered by the author. Lastly, a detailed response to each question is presented in the conclusion portion of this research thesis (Section 7.2).

- **Research question 1a (RQ1a)**:
  What are the most frequent and costly areas of failure from non-conformance report (NCR) data on an infrastructure construction project?
  This question queries the current state of quality execution and right-first-time within the construction industry to re-evaluate and compare

against previous literature. Specifically, this question targets the most frequent and costly avenues of failure through NCR data to understand the most problematic and high risk areas for improvement.

Noting many impactful studies into rework in construction, RQ1a emerges at the end of Section 2.3. The frequency portion of the question is answered in Section 4.2.1 and the cost portion in Section 4.2.2. The outcomes contribute to practical application of construction projects by presenting them with key areas for improvement. In addition, the findings also contribute to the theoretical understanding of non-conformance and rework in construction projects.

- **Research question 1b (RQ1b)**:
  What are the corresponding lessons learned from NCR data that can help transition towards right-first-time delivery in construction projects?
  This question focuses on lessons learned outcomes from specific activities that will have the most benefit to help the construction industry toward right-first-time delivery.

  RQ1b emerges through the lessons learned literature review, whereby projects are not adequately sharing lessons learning within organisations and the wider construction industry (Section 2.3). In addition, this question is answered in Section 4.5.1 with specific learning outcomes through NCR data analysis. The output of this question presents practical contribution for construction projects to prevent re-occurrence.

- **Research question 2a (RQ2a)**:
  How has the Cynefin framework been exploited and adopted within construction projects?

This question focuses on the impact of the Cynefin framework as a sense-making tool within the construction sector to understand if and how it has been used to benefit decision-making in uncertain project delivery conditions.

RQ2a emerges through Section 2.4, and is answered following a detailed literature analysis into the impact of the Cynefin framework within the construction sector (Sections 2.5.4 and 2.5.6.1). It enhances the theoretical understanding of how the Cynefin framework has been received within the construction industry.

- **Research question 2b (RQ2b)**:
  How can the Cynefin framework be applied to better understand uncertainty within quality problems in construction projects?
  This question poses whether the Cynefin framework can positively influence decision-making for those dealing with quality problems under various levels of complexity and uncertainty in construction schemes.

  Concurrently, RQ2b emerges within Section 2.4 alongside RQ2a, and is answered following a systematic review of papers that explore the Cynefin framework more extensively outside of the construction sector (Sections 2.5.5, 2.5.6.2 and 2.5.7). This enhances the theoretical understanding of the Cynefin frameworks impact outside the construction industry, and provides practical contributions by identifying research that has successfully utilised, exploited or adapted the framework for benefit.

- **Research question 3a (RQ3a)**:

  What are practitioner perceptions of the most critical factors that affect quality delivery in construction projects?

This question raises awareness on how industry professionals perceive quality delivery on complex construction projects to better understand whether there are further considerations not discovered through NCR data.

RQ3a emerges in Section 4.5.1, following the quantitative findings (Phase 1), and is answered in Section 5.5.1 where findings from Phase 2 are synthesized and reflected upon. This question provides further substantiation from the quantitative phase by way of practitioner perspectives to enhance the practical contribution of this research.

- **Research question 3b (RQ3b)**:
  How can the construction industry improve quality performance, decision-making, and move closer to achieving right-first-time project delivery?
  This question focuses on how quality management practices can be adjusted to deal with the challenges of non-conformance and rework in the construction industry to help drive continuous improvement.

  RQ3b emerges in concert with RQ3a at the end of Section 4.5.1, and is answered in Section 6.2 by synthesising the findings gained through the literature review (Chapter 2), Phase 1 (Chapter 4) and Phase 2 (Chapter 5), This question contributes to methodology through a bespoke mixed-method approach that adopts both quantitative and qualitative analysis techniques to yield collective outcomes that enhance the theoretical body of knowledge on how the construction industry is managing quality, and provides practical contributions on how to address through an improvement framework.

1.5 Thesis roadmap, layout and structure

At the start of the PhD, a brainstorming exercise was conducted to map the conceptual research path from start through to completion. As such, Figure 1.1 was derived as a marker post for the research to follow specific tasks and stay aligned with the project goals. Furthermore, it proved a very useful image for retrospective reflection when considering the big picture.

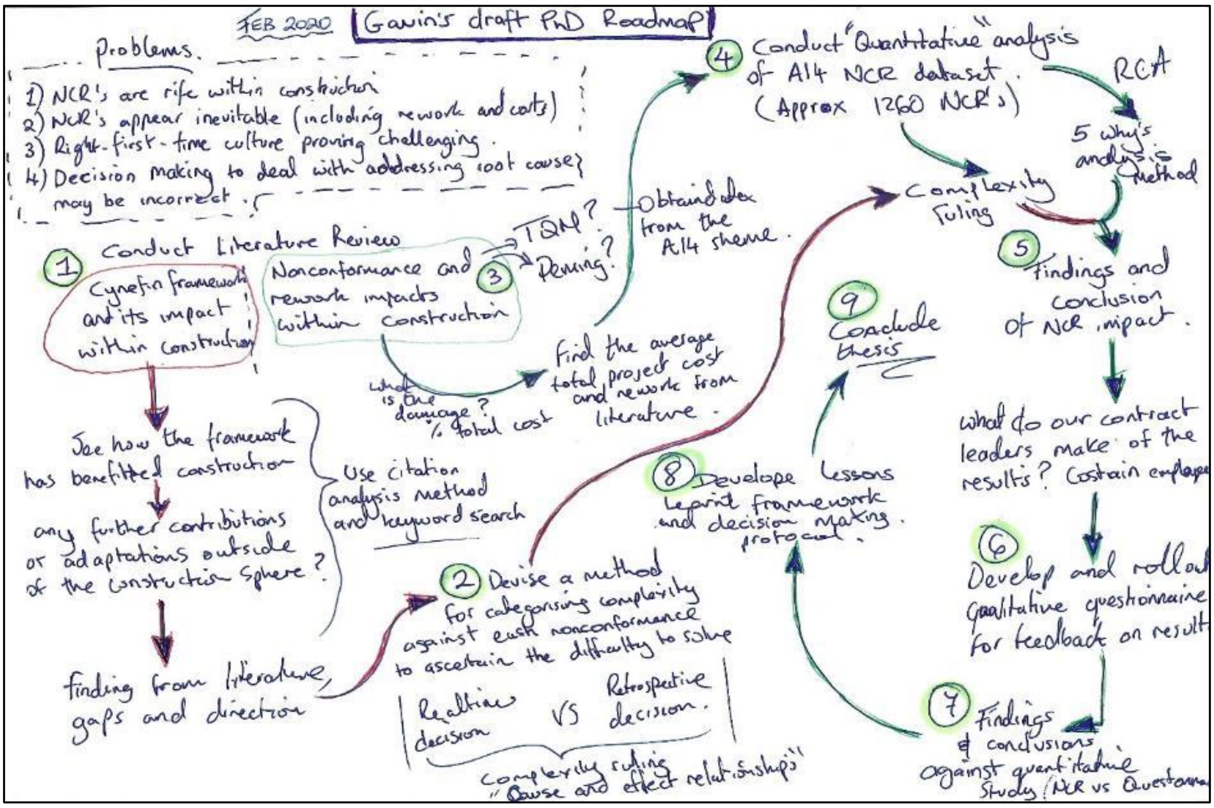


Figure 1.1 – Conceptual roadmap development (2020)

A brief overview of the thesis structure along where each research question was conceived is shown within Figure 1.2 below along with a detailed summary of each chapter.

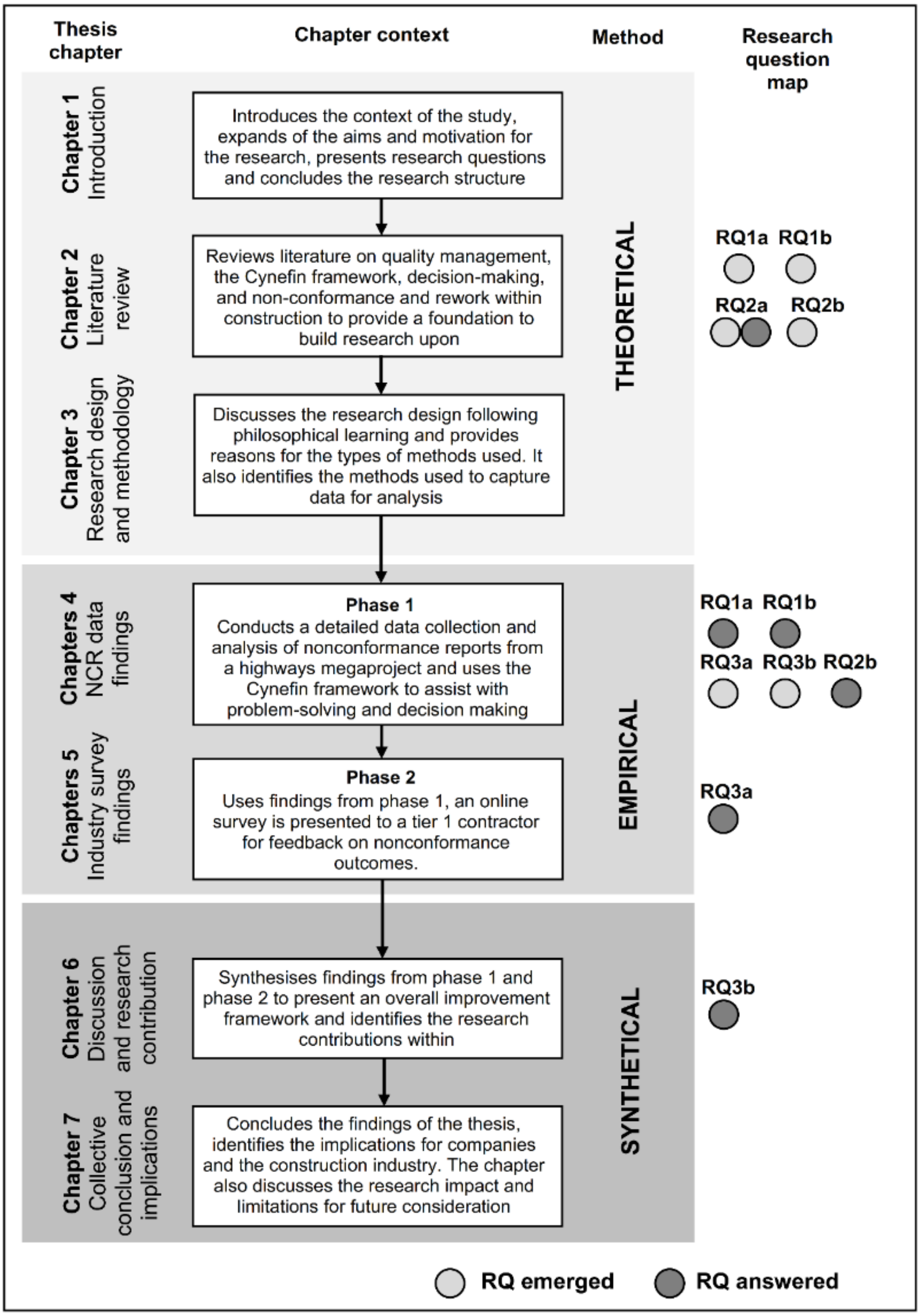


Figure 1.2 – Thesis structure

This thesis can be summarised as follows:

Chapter 1: Introduces the background of the field of research along with its context, aims and motivational drivers to undertake the research. It identifies existing gaps in the literature whilst posing further research and proposition questions to be answered at a later stage of this thesis.

Chapter 2: Conducts a detailed literature review of previous research undertaken in the core areas of this thesis, specifically Cynefin framework, decision-making, and non-conformance and rework research previously undertaken both in construction and other sectors. Furthermore, this chapter concludes gaps in the literature which in turn generates research questions to be answered at a later stage of the research.

Chapter 3: Considers the methodology used to conduct this research including the theoretical underpinning, philosophical positions, research design, methods proposed and tools used. A mixed method approach is adopted to undertake the empirical research in a systematic, logic format. First, root cause analysis (RCA) is performed on a quantitative dataset to unearth problematic areas and yield improvement solutions. In addition, a complexity categorisation ruling is applied to real-time and retrospective decision-making to understand quality problem solving capabilities. Second, a digital online survey formulated from quantitative research findings is conducted within a tier 1 contractor consisting of two independent professional working groups to capture views on how the industry is reacting to quality. The findings from each phase are synthesised to provide a complete perspective of quality performance in construction.

Chapter 4: Describes the first phase of the data analysis using a case study from a highways megaproject. Specifically, non-conformance data was collected and analysed using root cause analysis techniques to identify areas of concern. Initial findings from the analysis were discussed and presented both at an international conference (Association of Researchers in Construction Management, 2022 conference) as well as to a renowned quality management journal (International Journal of Quality and Reliability Management), and a engineering management journal (Transactions on Engineering Management). The complete references of published works are listed below:

- Ford, G., Gosling, J. and Naim, M. (2023). On quality and complexity: non-conformance failures, management perspectives and learning outcomes on a highways megaproject. International *Journal of Quality & Reliability Management*. https://doi.org/10.1108/IJQRM-11-2022-0313.

- Ford, G., Gosling, J. and Naim, M. (2024). Simplifying complexity? On quality decision-making and non-conformance outcomes of megaprojects. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2024.3359821.

Chapter 5: Builds upon chapter 4 by presenting the findings to industry professionals via an online survey. Key outcomes from the NCR data analysis are transposed into a series of questions targeted at contract leaders and quality professionals, all of which have involvement in quality delivery of construction schemes. A tier 1 contractor is selected to participate in the study to gain insight into the thoughts and perceptions of quality execution not only within their organisation but externally with supply chain, clients and designers.

- Ford, G., and Gosling, J. (2024). Professional perceptions of right-first-time and quality management in construction projects through open-ended feedback. *International Journal of Quality & Reliability Management*. https://doi.org/10.1108/IJQRM-08-2023-0246.

Chapter 6: Discusses insights gained from the literature review (Chapter 2) along with quantitative and qualitative findings found through the non-conformance data analysis and industry survey (Chapters 4 and 5) and synthesises into an improvement framework for quality management and decision-making practitioners to address quality failures in construction.

Chapter 7: Concludes the research by answering all research questions. Furthermore, contributions of this research to theory and practice are summarised. Recommendations are made to construction companies, the highways sector, and more generally within the construction sector. Finally, the limitations and potential avenues for future research are discussed.

1.6 Summary

This chapter has provided information on the research background, aims of the study, motivational drivers and the research questions to be addressed within the thesis. The layout of the thesis and its empirical streams have been outlined via visual roadmaps to explain its structure. Finally, the research contributions have been noted to emphasis its relevance. The following chapter details the literature review journey and any gaps in the literature that the thesis seeks to address.

Chapter 2: Literature review

2.1 Introduction

This chapter provides firstly focuses broadly on quality inside and outside the construction sector then details the background and impact of key quality initiatives that have been successful in other industries, including Total Quality Management (TQM), Total Quality Control (TQC) and Quality 4.0, along with the impact of such practices on megaprojects. This is followed by insights into right-first-time delivery using the get it right initiative (GIRI) as a cohort for eliminating error and improving the UK's construction Industry.

Following a broad perspective of quality, a specific stream of quality is discussed. Non-conformance and rework literature streams are discussed to understand the scale of the problem by other academics and determine whether solutions have been developed to address the issue.

As problem solving and decision-making are fundamental steps to quality management, associated literature is discussed along with a detailed overview of a phenomenological framework for decision-making, known as the Cynefin framework to understand it's influence within the construction industry to address complex problems. Finally, the literature summarises the current impact of quality outcomes, decision-making to resolve them and whether sense-making frameworks can help solve the problems faced in construction.

2.2 Quality management: A broad perspective and background

Defined as an integrated approach to achieving and sustaining high quality outcomes (Flynn *et al.,* 1994), quality management focuses on continuous upcycle of processes to drive continuous improvement at all levels within an organisation. Although defined and actioned differently, management of quality, in some form, has been with us for many decades (Shewhart, 1939). However, there are a handful of individuals (Deming, Juran, Crosby, Feigenbaum and Ishikawa) in the early parts of the 20th century that took quality management to new heights, branding them as 'Quality Gurus' (Davies, 2001).

2.2.1 Total Quality Management (TQM), Japanese Total Quality Control (JTQC) and European Organisation of Quality Management (EFQM)

Devised and developed shortly after the second world war, Total Quality Management (TQM) is an amalgamation of practices into a comprehensive set of processes which engage all people within a company to focus on process improvement (Terziovski *et al.,* 1996). Furthermore, there has been a plethora of research into Total Quality Management over previous decades (Sila and Ebrahimpour, 2002). Building on scientific management works of statistical quality control by Shewhart (1939), TQM and quality principals such as Plan-Do-Check-Act (PDCA) were conceptualized in the late 1940's by Walter Edwards Deming (Deming, 1951). Such methods as PDCA have evolved and contributed enormously to continuous quality improvement (Moen and Norman, 2006). Unanimously renowned as the father of quality who brought about the third wave of the industrial revolution, leading Japanese businesses in quality management practices throughout the 1950's. In particular, Deming's most successful contribution was the collaboration with Eiji Toyoda and the Toyota Motor Corporation in which he provided lectures on ways to increase business, eliminate waste and raise levels of quality (Hallam *et al.,* 2010). With support from Deming, Toyota's Production System (TPS) was created and the reputation, quality and performance of the company was renewed (Ohno, 1988).

Whilst quality management practices were shaped and guided by the automotive sector, these principals have been applied extensively in the construction sector. The benefits of TQM have been widely recognised as an enabler to performance improvement in the construction industry, however, the adoption of TQM request organisations to implement change throughout their entire organisation in order to succeed (Love *et al.,* 2000). Sadly, organisational change is slow within construction, where there is an unreceptive nature to deviate from traditional practices (Haupt and Whiteman, 2004). Without fundamental cultural changes that embrace TQM as a standard way of operating, organisations are going to be unsuccessful in its implementation (Harrington *et al.,* 2012). Furthermore, cultural changes cannot be achieved unless management has long-term prospects of quality execution and continuous improvement (Culp *et al.*, 1993).

During the time, TQM was being conceptualized by Deming, an American quality control expert and businessman, known as Armand Vallin Feigenbaum was contributing to the quality body of knowledge with his works on statistical quality control (Feigenbaum, 1951, 1961). Defined as "a network of the management/control and procedure that is required to produce and deliver a product with a specific quality standard" (Chiarini, 2011), Total Quality Control (TQC) is a process management technique that integrates quality development, maintenance and improvement to enhance efficiency and productivity in line with customer expectations (Govers, 1996). Japan adapted TQC for the purposes of companywide quality control, focusing on principles such as cross-functional management, quality control cycles, daily management of process, and training with foresight from Ishikawa (1985). This led to the evolution of the so-called, Japanese TQC (JTQC). Considered a 'quality guru', Ishikawa paved the way for quality problem solving with the creating of cause-and-effect diagrams (*fishbone diagrams*) to execute investigative techniques that could identify root cause to influence corrective and preventative actions to enhance industrial processes (Mizuno, 2020).

Another of the so-called 'quality gurus' that contributed to the quality control initiatives based on the works of Shewhart was engineer and management consultant, Joseph Moses Juran. His significant contribution, the '*Quality Control Handbook*' was first released in 1951 and attract much attention from the management profession and is still a standard reference work for quality management leaders (Godfrey and Kenett, 2007). The initial handbook defines and separates quality in two parts (Juran, 1951). The first, quality of design (i.e. the grade and specification) and second, quality of conformance (i.e. how well the product conforms to the design specification). Fifty years on, the handbook has gone through multiple editions as quality management and lean principles are developed (Juran and De Feo, 2010). These include an adjustment to the two quality parts into eight primary areas (marketplace quality, quality of design, quality of conformance, consumer preference, quality characteristics, expression of general excellence, responsibility and specific department) as listed by Reeves and Bednar (1994). Although the automotive and manufacturing industries have paved the way using TQM and TQC techniques, the construction sector has tried to embrace these approaches along with lean practices to help with the growing topic of complexity on projects (Maylor and Turner, 2017).

In 1991, a European version of TQM was created and branded as the European Foundation for Quality Management (Nenadál, 2020). More defined versions were published in 2013 (EFQM, 2013) and changed significantly in 2020 (EFQM, 2020) to provide organisations with a mission and vision of quality management excellence to achieve sustainable business results. The current model have three different dimensions, direction (why?), execution (how?) and results (what?). Within these three dimensions, there are seven core principles to organisational excellence: 1) Purpose, vision and strategy, 2) Organisational culture and leadership, 3) Engaging stakeholders, 4) Creating sustainable value, 5) Driving performance and transformation, 6) Stakeholder perceptions, and 7) Strategic and operational performance, and has been seen to have several linkages to leveraging of technology with people to improve the quality within an organisation (Fonseca *et al.,* 2021; Murthy *et al.,* 2022). Vukomanovic and Radujkovic (2011) found benefits in integrating the model with the balanced scorecard (BSC) approach in construction to achieve strategic control where BSC could not on its own. However, as noted by Fonseca *et al.* (2021), there is scarcity of scientific papers addressing the novel model in construction. Those that have do mention benefits, however the same group note the following limitations:

First, the description of certain recommendations by way of guidance points have been considered superficial and confusing (Nenadál, 2020). Second, the model is non-prescriptive in nature, and the links between certain components (e.g. direction and organisational culture) are not evident (Fonseca *et al.,* 2021). And third, the EFQM model appears to be unclear and subjective in certain parts, with the assessment being left to the judgement of the assessor or organisation (Murthy *et al.,* 2022).

Noting the interlinks with Industry 4.0 and Quality 4.0 (Nenadál, 2020; Fonseca *et al.,* 2021; Murthy *et al.,* 2022), the following section discusses the literature around digitalisation within construction.

2.2.2 Construction 4.0 and quality 4.0

Construction quality has been the topic of much discussion and debate for many years. Many have become conscious of the role of quality as an essential means to achieving client and stakeholder satisfaction (Battikha, 2000).

In recent decades, the construction industry has seen a rapid increase in complex project delivery due to scaling up of projects into 'megaprojects', requirements to decarbonise and become increasingly self-sustainable, building with limited disruption to the public, political influence and restrictions, wider public influence on deliverable and so on. As a result, this topic has received overwhelming attention from industry practitioners and academics worldwide (Ghaleb *et al.,* 2022). With enhanced levels of complexity and mirroring levels of uncertainty for delivery, this has had a significant bearing on quality execution, resulting in rework and latent defects on all of these types of projects (Love *et al.,* 2020).

At present, the construction sector is making a shift into the concepts of digital delivery by default to keep pace with the 4th industrial revolution (i.e. Industry 4.0). The term 'Industry 4.0' (I4.0), was coined in 2011 to increase German competitiveness in the manufacturing sector from a technological standpoint (Chiarini and Kumar, 2022). Focusing on construction and quality in recent years, the future of quality and organisational excellence within the digital age has recently been branded through two terms, 'Construction 4.0' and 'Quality 4.0'. The first, Construction 4.0 (C4.0), is based on the confluence of trends and technologies to reshape the way projects are designed, constructed and operated (Sawhney *et al.,* 2020). Using the latest technological advancements available such as Building Information Modelling (BIM), augmented reality (AR) and virtual reality (VR), we build a more stable, solid, suitable solution to client problems. This premise applies similarly to Quality 4.0 (Q4.0), whereby digitalisation of TQM principles will help promote, enhance and improve quality technology, processes and individuals at organisational and sector levels (Carvalho *et al.,* 2021). Academics have claimed its benefits to help promote resource efficiencies, improve process development, and implement reduced internal and external failure costs (Antony *et al.,* 2022). Furthermore, by embracing automation, this can reduce human error and have a high impact on quality delivery (Sader *et al.,* 2022). Chiarini and Kumar (2022) find that with Q4.0, it requires a changing role of quality managers to acquire new digital skills and knowledge to implement without the fear of becoming reductant as a result of technology. There are steps to be taken to change the behavioural culture of quality within the construction industry similarly to the risk adverse mindset seen in Safety, Health and Environmental (Ford *et al.,* 2023). Risk are ever present on major projects and appropriate risk management intervention and response time is fundamental to success. However, projects must not fixate purely on financial risk via reduction methods but also address technical risks that have a bearing on quality outputs (Baker *et al.,* 1999).

2.2.3 Megaproject quality delivery

The term 'Megaproject' refers to any scheme with a value in excess of $1 billion (Haynes, 2002). They are large-scale, complex ventures that take many years to build, involving many different stakeholders, and crucial in resolving the world challenges of congestion and energy supply, some of which are life threatening (Garemo *et al,,* 2015). These types of schemes offer unique opportunities to understand the interplay of uncertainty, complexity and value outcomes in the development of infrastructure. Collectively, it is anticipated that such schemes account for over 8 percent of the total Gross domestic product (GDP), which denotes the biggest investment boom in human history (Flyvbjerg, 2014). However, to keep pace with projected global growth, McKinsey and company have assessed that the industry will require an estimated $57 trillion in infrastructure investment between now and 2030 (Richard *et al.,* 2013). Such schemes generate significant interest to explore operations and supply chain issues (Maylor *et al.,* 2018). Turning to the construction sector, there have been noted increases in attention from scholars and practitioners between 2000 and 2010 (Hu *et al.,* 2015). A wide range of reported challenges have been observed with respect to the planning, design and delivery of megaprojects, as well as the value they provide to clients and wider society. Furthermore, megaprojects require tremendous physical and financial resources to meet cost and schedule constraints (Merrow, 1988). As a result, complexity and risk has become rife in megaprojects with no simple formula for the government-business divide (Flyvbjerg, 2003, 2006). In addition, projects are often led by planners and managers without deep domain experience that come and go as the project life-cycle continues, leaving leadership weak (Flyvbjerg, 2014). The uniqueness of megaprojects often results in technology and design being non-standard, and those involved in the managing and planning of these schemes rely on their previous experiences of very different schemes which has impacted performance (Flyvbjerg, 2014). This has also been noted to cause impaired decision-making and quality execution as a result of cost and time pressures, inadequate information fed through the scheme, and knowledge of relevant subject matter (Eweje *et al.,* 2012). This has resulted in nine out of ten megaprojects going overbudget (Flyvbjerg, 2014). McKinsey suggest that trillion dollars *(a 40% reduction in cost*) can be saved annually by taking the following three practical steps (Richard *et al.,* 2013): 1) optimise project portfolios (i.e. choosing the most impactful schemes, and eliminating the wasteful ones), 2) Streamline delivery (i.e. speeding up approval processes, and invest heavily in early stages of project planning and design), 3) make the most of existing infrastructure (i.e. boosting the longevity of existing assets and optimising maintenance planning could save up to $400 billion a year). With regards to planning of schemes, scholars have concluded that accurate formal forecasting method are overlooked in construction megaprojects, resulting in lack of accountability and unrealistic outcomes (Litsiou *et al.,* 2022). Litsiou and the team raised concerns over the uniqueness of megaproject build, and the lack of opportunity to rely on previous project data. They concluded the need to 'provide accurate forecasts of megaprojects' durations, budgets and realised benefits', as a result of their complexity and large capital investment. In conjunction, digital project delivery using artificial intelligence (AI) through an information and organisational economics lens is said to provide significant benefits for managing megaprojects (Wijayasekera *et al.,* 2022).

As for product quality, political pressures of cost and time overruns have had a significant influence on delivered outcomes. For example, works dictated purely by programme and cost constraints has resulted in rushed, sub-standard quality delivery. In many cases, quality control processes are sacrificed altogether for low cost and fast delivery schedules (Merrow, 2011). Projects must take a wider view of delivery rather than fixation on short term goals that are often imposed by clients to release political pressures by the general public. Furthermore, requests have been made for policy-makers to embrace and utilize evidence-based research to make better informed decisions about capital cost investment and risk profiling at the front end of major infrastructure projects (Love and Ahiaga-Dagbui, 2018). In the long run, from a financial perspective, it seems a wiser strategic decision to delay programmes to meeting quality specifications and control measures (e.g. completing quality hold points on inspection and test plans as works are completed, not retrospectively after the works have been completed). In theory, this should minimise defective outputs and consolidate the programme for handover into maintenance.

2.2.4 Error free construction projects

Defined as mistakes that have occurred through performance , knowledge or violation (Lopez et al., 2010), errors are a common occurrence in construction projects. With regards to 'violation', Lopez and the research team define this as 'non-compliance' (i.e. non-conformance), and the most likely outcome is rework. There has been much research over the last few decades on the topic of construction rework as a result of poor project performance and quality execution (e.g. Abdul-Rahman *et al.,* 1996; Battikha, 2008; Love *et al.,* 2019; Mahamid, 2022). The construction industry, in its best endeavours has sought ways of eradicating error on projects to free up money for future opportunities. Literature through the last 30 years, including Woodward (1997), Abdul-Rahman (1997), Love (2002a), and Giao and Trang (2021) have all identified the need for 'right-first-time' in project and quality management on construction schemes, of which to date has been unsuccessful (Ford *et al.,* 2023). Sawhney *et al.* (2020) states that the key to unlocking the potential and pace of a more rapid "right-first-time" mentality is putting the physical-to-digital and digital-to-physical transformation at the heart of the delivery process in line with I4.0, C4.0 and Q4.0.

Recently, a standout independent party that has focused purely on ways of generating significant efficiency improvements in UK construction project is the 'Get It Right Initiative' (GIRI). Launched in 2017 as a not-for-profit organisation, the cohort has adopted a multi-disciplinary approach, labelled 'Strategy for Change' to tackle error in construction, focusing on five key areas:

- Creating a ***culture*** and environment that breeds ‘right-first-time’ from the start of schemes, not as they unfold.
- Change attitudes and harness ***leadership responsibility*** to reduce error, improve quality, productivity and safety outcomes.
- ***Stakeholder engagement*** – A collaborative engagement with all stakeholders on the importance of right-first-time and eliminating error from inception through to completion.
- Share ***knowledge and lessons learned*** on error reduction processes and systems.
- ***Improve skillset and competence*** across all sectors to ensure those are suitably qualified and experienced (SQEP) to perform key roles.

In 2018, GIRI drew focus to design processes and the challenges faced (Get it Right Initiative, 2018). The document sets out a guide to reducing design error and has been bought into by major construction companies such as Costain, Skanska, Balfour Beatty, HS2, Kier and so on to create a construction consortium. Although the organisation has the best intentions to eliminate error, it is up the leaders within each business to communicate and implement the policies for improvement. Unfortunately, there still appears to be a shortfall in quality leadership that requires addressing.

2.3 Non-conformance and Rework in Construction

2.3.1 The impacts of non-conformance and rework

Non-conformance is a significant issue for project teams, and we have long been aware that the costs of rectifying non-conformance can be high and they can affect a firm's profit margin and its competitiveness (Abdul-Rahman *et al.,* 1996). Cost and time overruns appear common outcomes of construction schemes in their efforts to seek contract completion with clients (Flyvbjerg *et al.,* 2003b; Forcada *et al.,* 2014). Flyvbjerg and his research team in their efforts to understanding global cost overruns to transportation infrastructure projects uncovered average cost escalations of 45% in rail, 34% for fixed links such as tunnels and bridges, and 20% for roads (Flyvbjerg *et al.,* 2003b). These figures yield inordinate sums that could have been put to better use such as reinvestment for tendering and work winning (Ford *et al.,* 2023). To add to the above, Flyvbjerg *et al.* (2003b) determined that 90% (9 out of 10) infrastructure projects are likely to fall victim to cost escalations, and are considered a global problem. In addition, length of implementation phase, size of project, and type of ownership are all seen to influence larger percentage cost escalations for construction projects (Flyvbjerg *et al.,* 2004).

To understand and quantify how much non-conformance and rework costs the construction industry we must first define each term. ISO 9000:2015 refers to nonconformity as non-fulfilment of a requirement. Battikha (2008) and Maheswari *et al.* (2016) similarly define non-conformance as a 'finished state of a project and/or its components deviating from established requirements'. For the purposes of this research, the author has chosen to adopt the concise definition made by ISO 9000:2015 as 'any process or product found to be in breach of requirements should have a non-conformance report raised during the project design and build lifecycle'.

Rework on the other hand has been defined differently by many authors and organisations. For example, Ashford (2002) defines rework as "the process by which the output is adapted to conform to make it satisfy the original construction requirements", whereas Sommerville (2007) defines rework as "the unnecessary consumption of effort and resources in re-doing a component part of a process that was incorrectly executed and so failed to meet the required specification". Love and Edwards (2004) on the other hand defines rework as 'the unnecessary efforts of re-doing a process or activity that was incorrectly implemented at the first time'. The Construction Industry Development Agency (1995) defines rework as "activities in the field that have to be done more than once in the field, or activities". For this research, Love and Edwards (2004) definition is adopted as the most suitable for construction practices as it links to the re-doing of a process or product that should have been done right-first-time. To summarise, all of the definitions of 'rework' can be boiled down to three words, "doing something again". It's a wasteful, inefficient process that costs projects unnecessary sums of money to correct what should be done right-first-time (Love, 2002a; Love and Edwards, 2005). As such, rework is a by-product of non-conformance. However, not all nonconformities result in rework. For example, there may be instances where these get accepted into the works due to the cost of correcting the defect significantly outweighs the benefit (e.g. marginally low concrete cube strength). Unsurprisingly, rework is one of the biggest dilemmas on construction projects. It inevitably leads to cost and time overrun which is usually realised during the handover into operational maintenance process as the product is vetted heavily prior to taking ownership by the relevant authority (Trach *et al.,* 2021).

Identifying the cost of rework on schemes over the years has proven a complex and challenging task. Often projects are reluctant to share non-conformance and rework costs to researchers as they have a stigma of substandard performance and poor quality delivery. As a result, this information is categorised as sensitive by project and commercial managers and placed in the archives with very little interrogation (Calantone and Vickery, 2010). *Without interrogation and analysis of failure outcomes, how do we learn from them and suggest avenues for improvement?* It takes a collaborative, open and honest environment to admit to one's failings (Bubshait and Al-Atiq, 1999). There are researchers however who have been fortunate to benefit from data sources to understand projects rework cost in comparison to its total value. Depending on sector type, the percentage of total cost is likely to differ substantially due to frequency of failure, cost of components and penalties associated. On review of rework costs against total project value, there are variances in literature.

Table 2.1 presents the variance of rework findings in chronological order from those who have sought to contribute on the topic of rework costs, causes and the impact it has had.

Table 2.1 – Cost, causes and impact of rework through the years

Author(s) Article	% Rework cost of total project value	Top causes of rework	Impact as a result of rework	Sector
Burati et al. (1992)	Average 12.4% of total project cost (Almost 80% of cost deviation as a result of design) NCR cost 5% of tender value	- Design change for improvement (DCI) - Design changes initiated by owner (DCO) - Design changes, errors and omissions were 79% of total cost	Increased project costs as a result of design errors	Construction (*Various*)
Abdul-Rahman (1995)	5% of total tender cost	- Lack of timely inspections and poor management of - Lack of skilled and experienced labour	Extra cost and time to all members of a project team	Highways

		- Lack of accurate data to facilitate design		
Abdul-Rahman et al. (1996)	6% of total project cost	- Poor workmanship - Design - Subcontractor	Increased project time and cost	Water Treatment Plant
Barber et al. (2000)	Between 16% (project 1) and 23% (project 2)	- Setting out errors - 50% of all failures resulted from the design stage	Costin incurred through unreliability of site access Breakdown of machinery	Highways
Love and Li (2000)	3.15% and 2.40% of project contract value	- Changes initiated by the client - Changes initiated by the designer - Omissions in contract documentation	Loss of profits Increased cost of operations Time and cost overruns	Construction
Love (2002b)	12.6% of total project cost 20.7% schedule growth Rework attributable to 52.1% of cost growth	- Poor management of design and construction process - Client demands and requirements change (e.g. scope)	52% of project cost growth Increased schedule overrun by 22%	Australian construction projects (*Various*)
Josephson et al. (2002)	4.4% total project cost 7.1% time increase	- Erroneous workmanship - Unsuitable or faulty design - Late delivery of materials - Mistakes in planning - Faulty manufacturing	Increased cost and time Resource time to correct rework accounted for 7.1% of total work time	Commercial building
Love and Edwards (2005)	6.4% direct cost and 5.9% indirect cost totalling 12.3% of total project cost	- Many failures were due to scope change of design	Unclassified	Construction (*Various*)
Wasfy (2010)	Between 2 – 30% total project cost	- Supervision - Lack of skilled labour - Improper subcontractor selection	Increased duration ranges between 10% and 77%	Construction (*Various*)
Oyewobi et al. (2011)	5.06% of total project cost	- Lack of communication between construction parties - Omissions - Design mistakes - Change orders	- Increase in construction costs, time, client Dissatisfaction. -Increase construction project rework and demolition and project abandonment.	Educational Residential Buildings
Forcada et al. (2014)	16.5% of project total cost	- Scope change - High complexity - Poor skill levels - Unexpected ground conditions	Project performance Organizations profitability Cost and time overruns	Highways

Ye et al. (2015)	Between 5 – 20% of project total cost	- Unclear project process management - Poor quality of construction technology - Use of poor construction materials - Poor coordination between design and changes to project scope	Unclassified	Construction (*Various*)
Simpeh et al. (2015)	5.12% mean total project cost	- Inconclusive	Likelihood that the project exceeds is 76%	Construction (*Various*)
Mahamid (2016)	Between 10 – 15% of original contract cost	- Poor communication - Use of poor quality materials - Poor site Management	- Cost and time performance impact - Consequential increase in labour Dissatisfaction of the project teams	Residential buildings in Palestine
Abeku et al. (2016)	12.85% additional cost 38% schedule overrun	- Poor planning - Lack of supervision - Change orders - Errors and defects caused by human - Change to project scope - Use of poor materials	- Delays to project schedule (38% overrun) - Cost overrun - Wastages - Conflicts between construction parties	Buildings in Nigeria
Forcada et al. (2017)	Rework was 2.75% of original contract value (OCV) Mean cost growth was 11% of OCV	- Extension of project scopes / scope change	Impacts on project cost and schedule	Spanish construction (*Various*)
Enshassi et al. (2017)	Inconclusive	- Attempt to fraud - High numbers of competitors - Ineffective management and decision-making - Absence of job security - Unqualified personnel	Impacts on construction project performance and productivity	Construction (Palestine)
Love et al. (2018b)	0.39% of contract value	- Concrete quality - Defective installation and /or fabricated items - Design error - Equipment failure - Incorrect exposure classification - Lack of clarification of client/end user expectations - Non-compliance with Australian Standards and specifications - Inadequate supervision (including Inspection and Test Plan)	- Company reputational damage - Cost, time and schedule overruns - Profit loss	Construction (*Various*)
Trach et al. (2021)	11.1% planned project cost	- Ineffective design and construction management	- Growth of total costs and the excess of schedule overruns	Construction (Ukraine)

Mahamid (2022)	4.83%	- Scope change, errors and omissions - Lack of labour skills - Non-conformance with specification requirements - Inadequate supervision,	- Increased rework costs - Material waste increases by 14.04%	Construction (Saudi Arabia)
Average	**9.19%**			

Of the research papers reviewed, the average cost of rework is 9.19% of total contract value between a period of 1992 and 2021. Trach *et al.* (2021), table 2, confirmed an average research rework figure of 7.84% in the Ukrainian construction sector, which is significantly lower than the literature observed.

There are some recurring root cause themes that are found within many of the papers. For example, design errors, scope changes, competence and supervision appears regularly themes within the literature mentioned in Table 1. Kazaz *et al.* (2012) concludes similar trends in construction projects in Turkey, whereas Balouchi *et al.* (2019) identify poor site supervision and unclear project management processes as the highest costing causes of rework in an Iranian housing project. Specifically relating to construction material wastage, Mahamid (2022) concluded untrained labour, frequent design changes, selecting lowest bid contractor/s, and design and construction detail errors were the most frequent and costly avenues of failure.

The associated impact of non-conformance and rework from the body of literature conclude that cost, time and schedule overruns, reputational damage, employee dissatisfaction, increased and prolonged labour resources, and ultimately, wastage are the most damaging to construction projects and stakeholders. Recently, researchers have pondered on why rework, i.e. 'wastage', is occurring and the associated consequences of its presence within construction (Love *et al.,* 2022). One outcome is that construction projects must acknowledge that errors and rework will happen, ensure they measure the cost and consequence of said rework, and raise awareness of its presence in projects. However, extensive literature reviews into cost overruns has uncovered that the bulk of research is deficient in dealing with complexity posed by construction projects, thus calling for more advanced systems thinking (Ahiaga-Dagbui *et al.,* 2015). In addition, Ahiaga-Dagbui *et al.* (2017) note the stagnated development of robust theories to mitigate the problem of cost overruns and reiterate that advanced systems thinking with retrospective sense-making to address interactions between multiple factors is crucial. To improve quality of infrastructure projects, Love *et al.* (2022) suggest projects adopt an error-mastery culture that comprises of strong leadership, error-management orientation, and resilience. Only then can projects realise the benefits of using techniques, tools and technologies for improvement such as Building Information Modelling (BIM). Lastly, the need to learn from failures such as NCRs is essential to breed an environment of psychological safety and collective learning in projects (Love *et al.,* 2019). At this point, the first research question is raised.

> ***RQ1a. What are the most frequent and costly areas of failure from non-conformance report (NCR) data on an infrastructure construction project?***

2.3.2 Lessons learned dissemination

Learning from failures is fundamental to the growth and maturity of construction organisations. Secchi *et al.* (1999) define a lesson learned as "*a knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure*". If used properly, they are able to provide competitive advance by contributing to the organisational learning agenda (Carrillo *et al.,* 2013). Unfortunately, previous studies have concluded the challenges with promoting knowledge sharing through systems, despite significant financial investment (e.g. Weber *et al.,* 2001). For quality management, the general body of knowledge relating to lessons learned has not often been connected to NCRs, so there appears to be a gap in the lessons learned from non-conformance studies. Lessons learned are a major output of non-conformance and rework which generate corrective actions to prevent reoccurrence both real-time and on future schemes. However, lessons learned are typically not being generated, digested or disseminated sufficiently within construction companies for betterment of the projects they currently reside nor future schemes on the horizon (Williams, 2008; Shokri-Ghasabeh and Chileshe, 2014). Instead, it appears this is anticipated collateral damage that happens on all schemes due to a stringent programme and cost allocation that take priority over quality. For example, in one study, defects within concrete works were expected (Koch and Schultz, 2019). One challenge is the logistical challenges to conduct lessons learned at the end of projects when teams have dispersed and moved on (Carrillo, 2005). Another could be the difficulty to determine and quantify lessons learned and corrective actions to prevent reoccurrence of quality problems (Crow, 2006). Perhaps the complex nature of construction schemes yield it an arduous task to ascertain true root causes to make a difference. Love and Edwards (2004) put emphasis on specific cause-and-effect relationships that may exist, highlighting the difficulties and barriers to positively influence schemes. As such, more sophisticated approaches to capturing and sharing lessons have been called for (Williams, 2008). The identification and selection of suitable control measures must be enhanced and used as lessons learned for knowledge management and benchmarking future schemes (Simpeh *et al.,* 2015). This could involve an amalgamation of best practice strategies including quality management, lessons learned and risk management to reduce cost and rework in construction (Safapour and Kermanshachi, 2019). Noting that lessons are not being adequately captured or divulged within the construction industry, the second research question is raised.

> ***RQ1b. What are the corresponding lessons learned from NCR data that can help drive towards right-first-time delivery in construction projects?***

2.4 Complexity and decision-making of quality problems

2.4.1 The challenges of complex construction projects

Construction projects, particularly megaprojects are becoming increasingly complex due to their magnitude, greater political pressure to meet new requirements and higher scrutiny by the public. The inherent degree of uncertainty on infrastructure schemes can often result in many problematic issues, particularly when information is not ready or inaccurate. In addition, these types of projects are typically new and unique, posing more instances of unknown situations yet to be encountered (Ramasesh and Browning, 2014). These unknowns are split into two types. The things we know we don't know (i.e. known unknowns), and the things we don't know that we don't know (i.e. unknown unknowns). Such uncertain situations are proving very difficult to understand how to manage, and often leave projects feeling perplexed on why they failed (Browning and Ramasesh, 2015). Browning and Ramasesh identify the large distinction between what is *knowable* about a project and what is actually *known*, and note that there are 'unknown unknowns' lurking in every project, just waiting to emerge, surprise, and derail from plans'. As a result, managers are often confronted with having to make decisions based on an imperfect and incomplete knowledge of future event (Forcada *et al.,* 2014). Furthermore, risk and uncertainty are having a heavy bearing on cost underestimations that are most frequently caused by optimism bias whereby managers have a positive, rose tinted outlook of project delivery rather than a realistic, risk adverse nature (Ahiaga-Dagbui and Smith, 2014). There are scholars (e.g. Love and Matthews, 2022) who have explored practitioner decision-making in the context of mitigate the risk and uncertainty of rework. They found that heuristics were being used informally due to the absence of information to make appropriate decisions [65]. Likewise, Love *et al.* (2021) concluded that possessing the right knowledge and understanding of rework causations is pivotal to decision-making success of quality problems, and that supportive knowledge engineering systems are a must.

Noting the above, effective decision-making is a fundamental part of managing and delivering schemes successfully. It requires awareness of surroundings and the challenged faced to implement appropriate responses. According to Bakht and El-Diraby (2015), complexity of engineering problems has resulted in a shift from judgemental to rational techniques to substantiate reasoning to respond and remove subjective behaviours. As construction projects are becoming increasingly complex to deliver greater value for less, precise decision-making using accurate information is top priority (Flyvbjerg, 2005). Furthermore, the need for organisations to process information correctly to enable managers to make more effective decisions (Simon, 1957; Senaratne and Sexton, 2009). Decision-making occurs in many different areas including problem solving of non-conformance and other quality issues. A vital step to addressing non-conformance on projects is the way in which we make decisions to detect, remediate and prevent future occurrence (Battikha, 2008). Furthermore, Battikha summarises the need to conduct integrated root cause analysis with commonality and clustering concepts in specific avenues such as design and quality management to enhance systematic analysis and decision-making processes that will lead to organisational performance improvement. There are scholars that have suggested that in complex conditions, many seek to simplify. Unfortunately, the same researchers have concluded that oversimplification under complexity is a rife issue within cognitive decision-making (Feltovich *et al.,* 1989, Spiro *et al.,* 1996). Smith and McCardle (1999) notes that a possible reason could be due to the difficulty of evaluating decision problems in line with the complexity, uncertainty and ambiguity levels they have. As such, there are calls for consideration to complex conditional probability assessments and their corresponding risk (Forcada *et al.,* 2014) .

Lean practices have proven very successful in the manufacturing and automotive industries. In the search for operational improvements, the construction industry has tried to embrace these principles to edge towards right-first-time (Ohno, 1988; Womack *et al.,* 1990; Womack and Jones, 1996). Tezel *et al.* (2018) notes however that there has been mixed success. A possible reason is that such approaches have been developed in stable, predictable and repetitive environments where they are most effective (Browning and de Treville, 2021). However, the desire to minimize variance, uncertainty levels and striving for simplicity in construction operations persists. This is typical of a broader phenomenon – 'the cognitive miser effect' – supported by psychological studies, which suggests that human social cognition has a bias towards simple and less effortful routes to problem solving, decision-making and risk management (Fiske and Taylor, 2013). Management thinkers have also extolled the virtues of simplicity, although only where complexity can be eliminated, and argue that some systems must adapt through simplicity to complexity and back again in order to evolve to a better state (De Bono, 2017).

2.4.2 Decision-making under complexity

Decision-making in complex environments, such as construction projects, has been a major topic of discussion for decades (Klahr, 1969, Howell, 1999, Tommelein, 2015). Decision-making has been regarded as "the missing link" crucial to project success which is often overlooked (Belzer, 2001, Rumeser and Emsley, 2019). However, there still appears to be a high level of ambiguity surrounding the links between uncertainty and complexity in project situations, and the appropriate decision-making approach in projects (Kiridena and Sense, 2016). As recently noted by Maes *et al.* (2022), common project management methodologies and processes do not typically consider the level of uncertainty for determining appropriate task execution. Many project-based industries have looked to manufacturing sectors to learn from 'best practice'. A prevailing assumption flowing from experimentation with such best practice, it is argued that to mitigate complexity, one must simplify the situation (Morris and Lancaster, 2006; Koskela and Kagioglou, 2005).

Building on the work of decision theorists, Alexander *et al.* (2018) notes the importance and pertinent need of sense-making frameworks to understand simplicity and complexity underlying organisational decision-making. Furthermore, researchers have requested projects embrace complexity and make sense of their environment through cognitive decision-making frameworks (Soares *et al.,* 2021). One in particular, 'the Cynefin framework', has proven beneficial in understanding the complexity context organisations find themselves in and identifying appropriate approaches to intervene (McLeod and Childs, 2013; Lepmets *et al.,* 2014; Britt, 2017). The sense-making tool suggests the need to select the right tools, techniques and interventions to deal with the situation managers find themselves in, and help choose an appropriate management intervention. It provides opportunity for enlightened thinking but should be overlayed with knowledge management and risk management practices (Naim *et al.,* 2022).

The premise of understanding one's domain is a vital one, this applies to many projects, but particularly in the construction sector where the environment is volatile to change. Too often decisions are made based on an individual's level of understanding and not necessary the context of their domain. For instance, the situation with Crossrail in the UK (Barsam *et al.,* 2017) where the project was on the brink of disorder due to systems integration issues, centred by disagreement. This called for consensus building to determine the appropriate domain/feasible solution (Horgan, 2019). However, it has been observed that an assumption of predictability of cause-and-effect in studies of projects have often prevailed (Flyvbjerg *et al.,* 2003a). In reality, project activities are typically rife with uncertainties and interdependences that can lead to very complex situations (Dubois and Gadde, 2002b), thus the need for supportive tools.

Noting the above, two further research questions are raised.

> ***RQ2a. How has the Cynefin framework been exploited and adopted within construction projects?***
>
> ***RQ2b. How can the Cynefin framework be applied to better understand decision-making with regards to quality problems in construction projects?***

The following section provides a detailed literature analysis of the Cynefin framework along with its impact across various industries.

2.5 A systematic review of the Cynefin framework

2.5.1 An Overview of the Cynefin framework

The Cynefin framework is a sense-making schema that business leaders can use to help them to make the right types of decisions according to context (Snowden, 2002) consisting of a paradoxical approach that links knowledge management for learning and teaching purposes (Aubry *et al.,* 2022, Maes *et al.,* 2022). The framework was enhanced by Kurtz and Snowden (2003), then by Snowden and Boone (2007) and has since become a widely recognised framework for decision-making (Figure 2.1). There are many similarities within the variants, although the domains themselves have been rearticulated slightly over time to make Cynefin more significant to senior management. Furthermore, change management has become a growing importance to senior management when dealing with the complexity of site operations (Hornstein, 2015, Collyer, 2016). The framework focuses on four key domains (Simple, Complicated, Complex and Chaotic) with a central area (Disorder). Each domain has its own criteria for decision-making and encourages a manager / leader to follow a three-step process to enable effective resolution of problems and determine the correct course of future action.

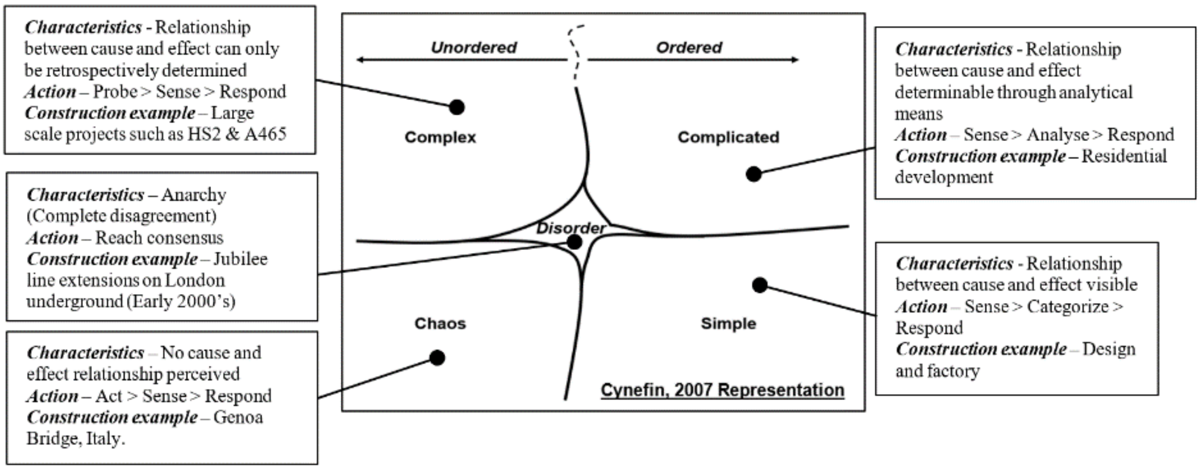


Figure 2.1 – Cynefin diagram representation with characteristics. Source: adapted from Snowden and Boone, 2007

The Simple domain is a context whereby the characteristics are stable and best practice can be implemented. There is a clear link between cause-and-effect relationships, which is easily apparent. Stable systems and processes can be established, which usually consist of few or homogenous components (Kuhn *et al.,* 2018). It is a vital point to reiterate that best practice is, by definition, learned from previous practice (Snowden and Boone, 2007).

According to Snowden and Boone (2007), a common problem in the simple domain is 'entrained thinking' where we become blinded to new ways of thinking through entrenched processes and routines. The biggest danger here, according to Snowden and Boone (2007), is that complacency, over-simplification and entrained thinking combine to collapse a stable situation into the Chaotic domain.

In the Complicated domain, even though there is a clear temporal and spatial relationship between cause-and-effect it is not always visible by all stakeholders. There may be multiple cause-and-effect pathways. The leader must undertake further investigation into root-causes prior to making a further decision. Analysis may often require experts in a specific field to ascertain what went wrong and why.

The transition from Complicated to Complex brings about uncertainty and, as such, decouples the relationship between cause-and-effect. There is at least one right answer to a problem however the waters are so muddied that it cannot immediately be determined. Instead, experimentation is required first and foremost (i.e. root-cause analysis and other post-hoc methods) to determine where the issue arose to prevent repetition.. Leaders find themselves in this domain when constant change puts them in a state of flux. When this happens, management styles usually drift into firefighting and/or Command and Control (Snowden and Boone 2007). The danger here is that leaders' demand fail safe plans that are impractical to fulfil. In particular, Snowden and Boone (2007) highlight the danger of attempting to impose order in the complex domain. It is vital to embrace innovation, creativity and new business processes to advance. However, what comes with innovation is uncertainty (Shenhar, 2001a, Bakhshi *et al.,* 2016).

The above discussion of the complex domain raises some interesting theoretical points of debate. Many thinkers have suggested that seeking simplicity helps in complex situations (e.g. De Bono, 2017). Further, the idea of reductionism states that everything can be reduced completely and perfectly to nothing more than the effects of some limited framework of laws and logic (Bohm, 1957). Alternatively, the complex adaptive systems literature (e.g. Choi *et al.,* 2001) might suggest that the situation is too emergent, too open, too complex and dynamic to apply these tools, so other ways of thinking are needed to enable autonomous actions. Efforts to make it deterministic, if this is at all possible, might exceed the effort of coping with the complexity.

In the Chaotic domain, searching for answers is more challenging. There is no noticeable relation between cause-and-effect due to constant changes with no appreciable management practice being made. The leader must act to establish order then sense outcomes and determine where strengths and weaknesses reside. Snowden and Boone (2007) argue that the danger here is that a leader becomes ineffective once the initial rapid response has been implemented and the situation changes.

Finally, Disorder is the default context if stakeholders do not agree which of the four Domains is predominant. Multiple perspectives and defensive attitudes cause leaders to altercate with one another. See Table 2.2 below which summarises the Cynefin framework with working examples against the construction sector.

Table 2.2 – Overview of the Cynefin domains.

Domain	Generic Characteristics	Action	Construction Example
Simple	Relationship between cause-and-effect visible	Sense → Categorise → Respond	Design and factory build of pre-cast concrete
Complicated	Relationship between cause-and-effect determinable through analytical means	Sense → Analyse → Respond	Residential Development
Complex	Relationship between cause-and-effect can only be retrospectively determined	Probe → Sense → Respond	Large scale construction projects such as HS2, A465, A14 etc.
Chaos	No cause-and-effect relationships perceivable	Act → Sense → Respond	Genoa Bridge, Italy.
Disorder	Anarchy – Complete disagreement	Reach consensus	Jubilee Line Extensions on London Underground (Early 2000's)

The challenge for leaders in this domain is facilitating worldviews to seek accommodation and consensus. A possible way out of this realm is to break down the situation into constituent parts and assign each to one of the other four domains. Leaders can then make decisions and intervene in contextually appropriate ways.

2.5.2 Construction citations associated with the Cynefin framework

To identify cited Cynefin framework documents applicable to Construction, a miniature literature research design was devised as a gap analysis technique.

Two seminal papers were chosen and analysed to ascertain the frameworks influence within the construction sector. The former, Kurtz and Snowden (2003), was the finalized product of Snowden's earlier conceptual, embryonic works (Snowden, 2002) tailored specifically to Knowledge Management then enhanced for the Leadership and Business Management readership within Harvard Business Review (Snowden and Boone, 2007). Both are considered landmark papers and are the most cited with respect to the Cynefin framework. Figure 2.2 summarises the data collection process used to extrapolate the most appropriate citations to the construction sector for two flagship Cynefin framework papers.

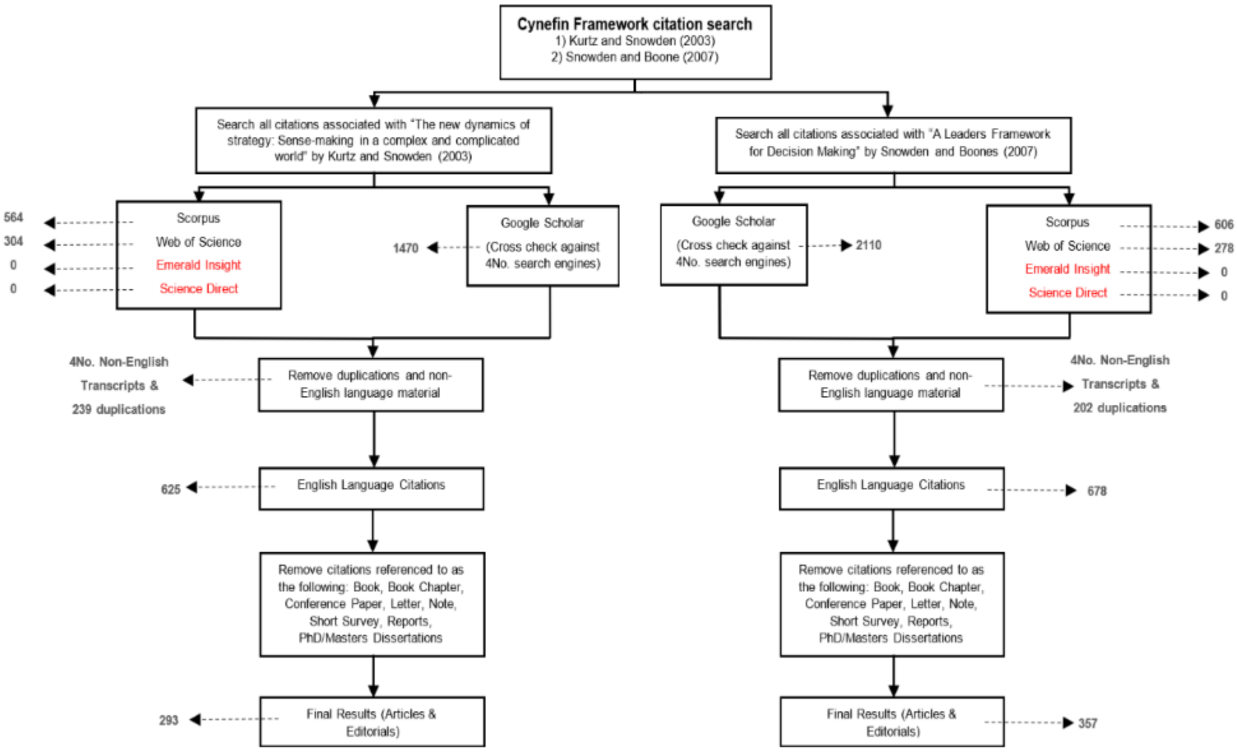


Figure 2.2 – The Cynefin framework citation analysis process and results.

In total, for Kurtz and Snowden (2003), 293 papers were identified; only 138 of which were applicable to the field of Complex Construction. Applicability was judged on its contextual fit to the construction industry via a question filter. "Does the citation in question have clear implications for the application of Cynefin framework in a construction environment?". The categories that passed the question filter were Business Management, Decision Sciences, Engineering, and Environmental, Sustainability and Energy as shown in Table 2.3.

Table 2.3 – Research areas applicable to the construction sector.

Research Area	**Applicable (Yes/No)**	**(Kurtz and Snowden, 2003)**	**(Snowden and Boone, 2007)**
Arts and Humanities	*No*	*5*	*6*
Business, Management	*Yes*	*91*	*79*
Computer Science & Information Technology	*No*	*43*	*35*
Decision Sciences	*Yes*	*14*	*38*
Education & Educational Research	*No*	*20*	*15*
Engineering	*Yes*	*18*	*25*
Environmental, Sustainability & Energy	*Yes*	*15*	*25*
Health Professions & Healthcare Sciences	*No*	*18*	*24*
Medicine, Nursing, Immunology and Microbiology	*No*	*13*	*42*
Non-English	*No*	*4*	*0*
Psychology	*No*	*5*	*25*

Science & Technology - Other Topics	*No*	*22*	*27*
Social Sciences	*No*	*29*	*16*
Applicable Sub-Total (Highlighted Red)		***138***	***167***

With such a substantial quantity of citations and with a view of prioritizing review of works associated with construction, a further keyword search analysis was undertaken on each citation title reference against a specific set of phrases (Complex / Complexity, Conformance, Construction, Cynefin, Decision-making / Decision-making Framework, Quality, Rework, Systematic). Figure 2.3 explains the keyword search process along with values for each phrase. This process streamlined the focus of construction related discussion with a total of 49 papers, discounting overlaps.

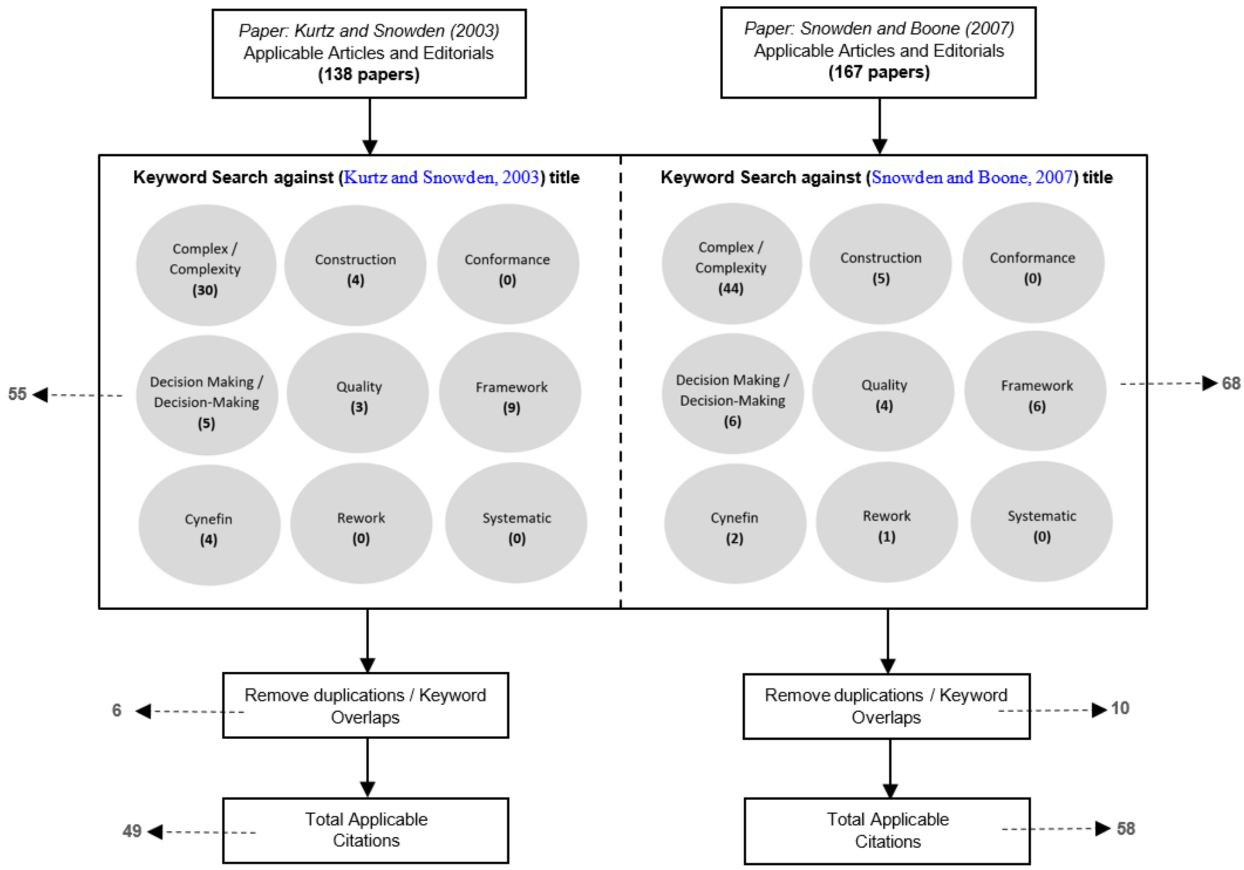


Figure 2.3 – Keyword search elimination.

This analytical process was replicated for Snowden and Boone (2007), resulting in 167 papers applicable to the field of construction (Figure 2.2, Table 2.3 and Figure

2.3). Following a final keyword search, the concluding citations figure was 58 papers (five of which were against keyword 'Construction'). To decipher the correlation between both publications post keyword search filter, all citations associated with both documents were pooled together, totalling 107 applicable citations. Documents referencing both papers were identified (18 duplicated cases), leaving 35 papers that contributed solely to Kurtz and Snowden (2003), 45 papers to Snowden and Boone (2007) and 13 papers citing both articles (Figure 2.4).

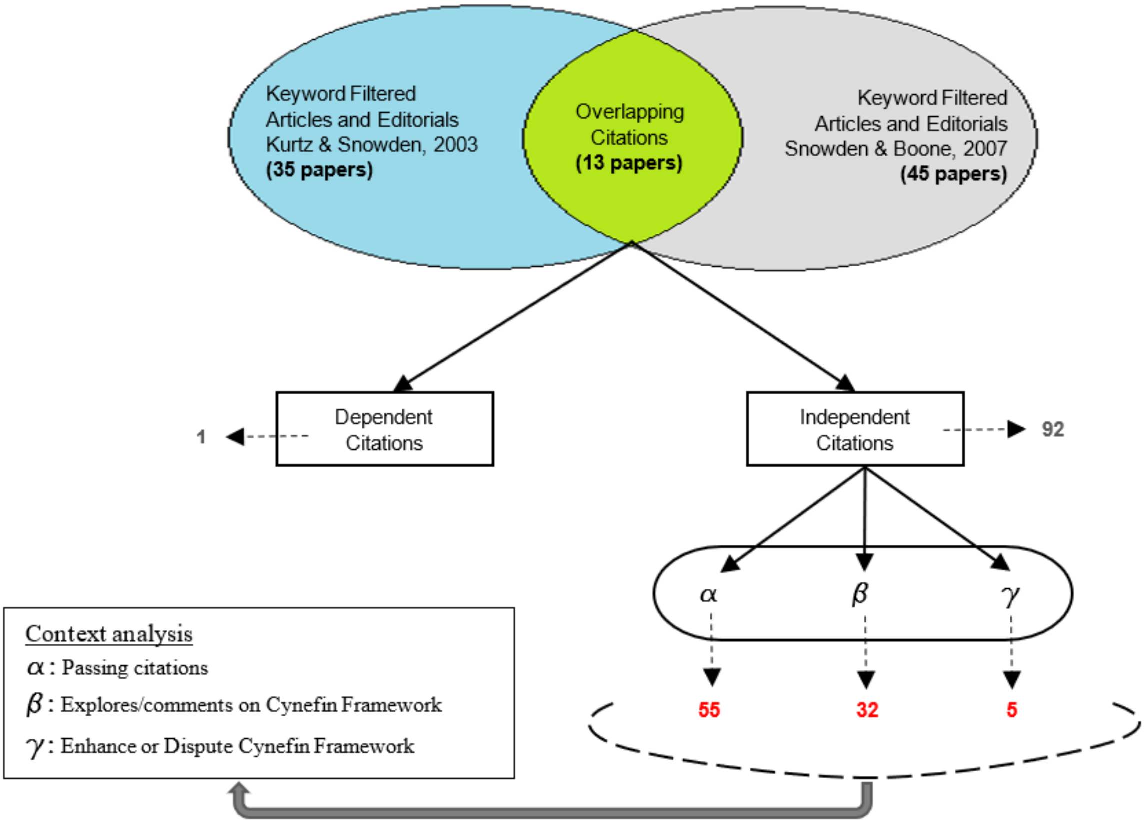


Figure 2.4 – α, β, Ɣ data analysis process. Based on Naim and Gosling (2011) and adapted by Lin *et al.* (2017)

Papers that had been published by either Kurtz, Snowden or Boone and/or their research team (colleagues, staff and students) were categorised as 'dependent citations'. Papers published by an individual that was academically independent of the two authors were classified as 'independent citations'.

From the list of sourced citations, only one ‘dependent citation’ was discovered (Van der Merwe *et al.,* 2019). The remaining 92 citations were classified as ‘independent citations’.

The content of the reviewed papers was further categorised into one of three types: α, β or ɣ (Naim and Gosling, 2011 and adapted by Lin et al,. 2017). The first category, α, referred to passing citations that simply mentioned or used the framework to add some weight to an argument. A total of 55 α citations were identified in this category but were eliminated from the study as they offered little value for this analysis. Of the 55 α citations, only 1no. contained keyword ‘Construction’ within its title (AlSehaimi, Koskela and Tzortzopoulos, 2013). A further 23 α papers were noted to contain keyword ‘Construction’ within their transcript, however all made a passing reference to Cynefin. The β category refers to papers that focus on Cynefin theory and contribute with an idea or critique (32 papers), whereas ɣ category identifies papers that focus more heavily and undertake detailed exploitation or development of the Cynefin framework with a view to enhance, improve or dispute (5 papers).

2.5.3 Cynefin frameworks impact within the construction sector

To determine the extent to which the Cynefin framework has been received by the construction academic community, detailed reviews of the β and ɣ category papers were performed. Firstly, both papers were analysed against citation frequency to demonstrate their impact (positive or negative). Figure 2.5 data indicates that Snowden and Boone (2007) has been cited more extensively than the Kurtz and Snowden (2003) article. This suggests that the 2007 document has been more widely reviewed by the academic community, suggesting greater visibility, perhaps due to its publication in Harvard Business Review, and/or a more extensive interest in the application of Cynefin as a leadership framework.

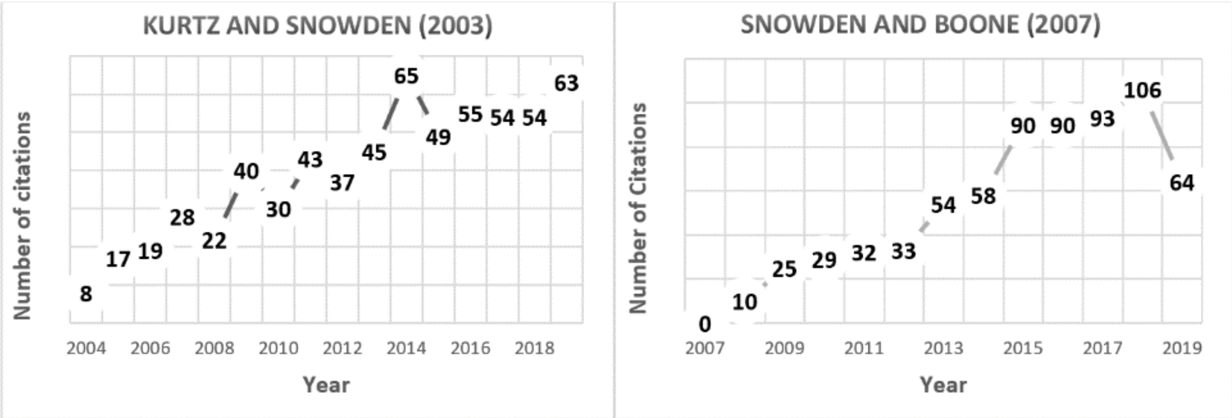


Figure 2.5 – Number of citations per year for each cited document.

Table 2.4 presents the descriptive results of the α, β and Ɣ type papers against each cited article. It indicates a total number of 55 α citations, 32 β citations and five Ɣ citations that were discovered during the in-depth analysis. There was limited evidence to suggest that Cynefin has been adopted as a strategic measure for construction during the citation review.

Table 2.4 – Categorisation of independent citations against each article.

Cited Article	Category			
	α	β	γ	All
Kurtz and Snowden (2003)	23	9	2	34
Snowden and Boone (2007)	30	15	0	45
Kurtz and Snowden (2003) & Snowden and Boone (2007)	2	8	3	13
TOTAL:	**55**	**32**	**5**	**92**

To ascertain which citations were specifically focused on construction, we repeated the keyword search with the original criteria (Complex / Complexity, Conformance, Construction, Cynefin, Decision-making / Decision-making, Framework, Quality, Rework, Systematic). Of the 92 citations in question, only six documents linked Construction to Cynefin, although one of the documents made only a passing reference to Cynefin (α category), and hence was omitted. The five remaining articles that have a direct relationship between Cynefin and construction are Tommelein (2015); Walker and Lloyd-Walker (2016); Bakhshi *et al.* (2016), Zegarra and Alarcón (2017), and Zegarra and Alarcón (2019).

Figure 2.6 presents the total number of citations against each keyword. Although, for the purpose of this literature review, we have discounted α citations, it is clear that the bulk of the citation sources reside within this category, specifically Complex / Complexity theory. In category, β, the results appear more varied. In addition, Figure 2.6 informs that four of the articles related to 'Construction' and one related to 'Complexity' (Bakhshi *et al.,* 2016). As there are no Ɣ citations relating to 'Construction', this indicates that Cynefin framework has not been exploited or developed with a view to enhance, improve or dispute within the construction sector. Therefore, there appears to be an opportunity to explore the framework more thoroughly within construction.

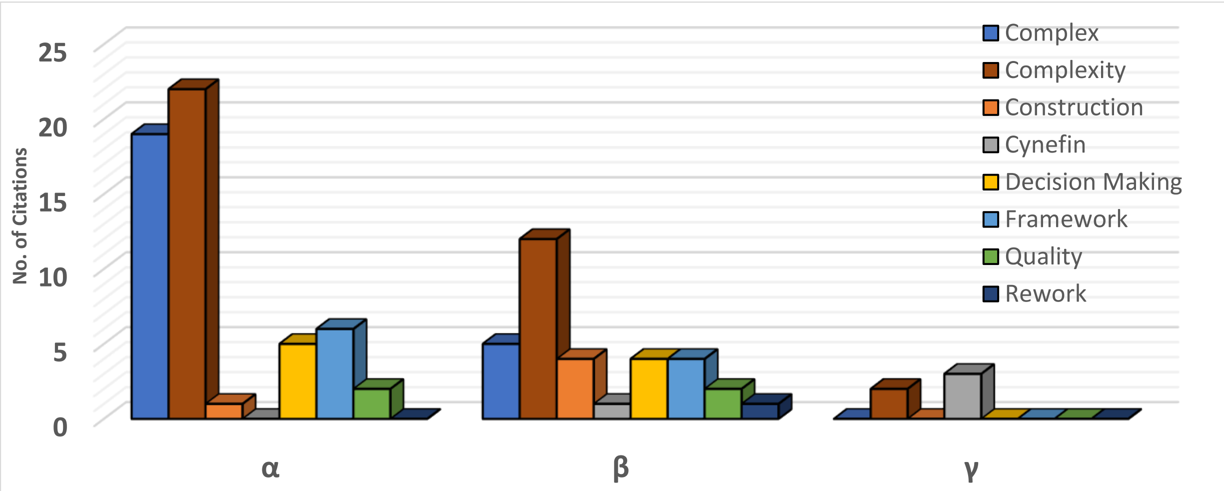


Figure 2.6 – Number of citations against each keyword.

As a cumulative total, both papers (Snowden and Boone, 2007, Kurtz and Snowden, 2003) have seen steady growth in citation referencing over the past 16 years, through category β (32 studies aimed at gaining deeper knowledge about and insights into Cynefin theory) to category Ɣ (five studies have attempted to push the parameters of Snowden's framework). Years 2013 and 2018 saw spikes in contribution by the academic community to Cynefin framework (Figure 2.7).

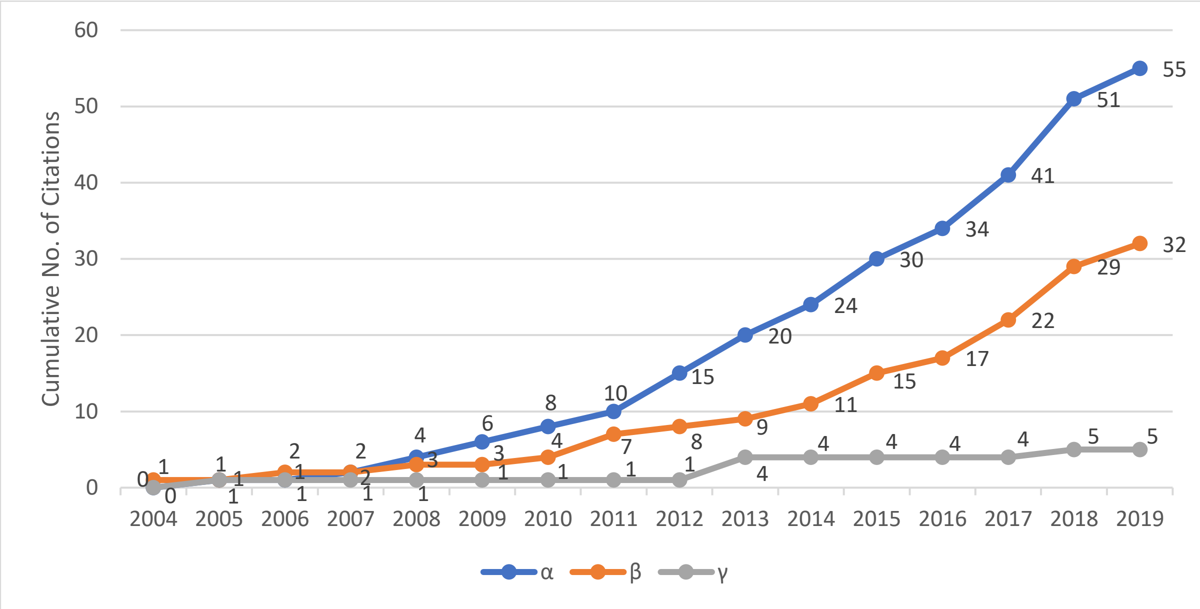


Figure 2.7 – Cumulative citation from 2003 to 2019.

This shows that the framework gains much attention, particularly from 2007 onwards where Snowden's more practitioner based paper from Harvard Business School emerged (Snowden and Boone, 2007).

2.5.4 Review of the Construction Referenced β Papers

Of the five β papers that making specific reference to construction, there is a variance in content posed by each paper. Tommelein (2015) focuses on lean principles and its implementation in construction. Her paper describes Cynefin and its applicability to complex projects (i.e. construction). She also guides the reader's understanding of the Simple and Complicated domains but does not explore the Complex and Chaotic domains in as much detail. Tommelein (2015) does however apply context between Cynefin and Lean Thinking, where the intention is to discard unwanted complexity and reside firmly within the Simple domain.

Walker and Lloyd-Walker (2016) on the other hand grapple with the notion of complexity in construction and how the Cynefin framework expresses relationships between cause-and-effect, specifically in ordered and unordered systems. The paper focuses on Relationship Based Project Procurement (RBPP) taxonomy and explores managing the front-end of complex projects with the importance of choosing an appropriate form of project procurement and delivery to achieve best value. Walker and Lloyd-Walker (2016) discuss the logic behind collaboration and alliance working with the caveats of behavioural factors. However, they do not explore Cynefin in detail.

Bakhshi *et al.* (2016) considers the historical development of complexity, particularly on projects. They discuss differences in previous and contemporary research throughout via a systematic literature review of papers between 1990 to 2015. Complexity theories are mapped throughout the years reviewed with a view to show growth. The Cynefin framework is discussed against adaptivity, flexibility and risk for project purposes including those in construction however there is little adaptation from the authors to dispute or enhance the framework. The paper concludes that projects such as construction have a lower degree of uncertainty whereas projects striving for innovation yield greater levels of uncertainty. The paper unfortunately does not go into the granularity of construction projects with a view to sharing the most appropriate framework.

Zegarra and Alarcón (2017) discuss the concept of complex adaptive systems and the interlink between order and chaos. The document is tailored to the production planning and control function (PPCF). Although the paper is a working representation of live complex delivery projects, it does not go into any great detail into Cynefin and simply explores the relationships between cause-and-effect. Similarly, with Zegarra and Alarcón (2019), the paper expands further on the concepts documented by the authors in their previous paper (Zegarra and Alarcón, 2017), however there is no further explanation into the benefits of Cynefin in construction.

2.5.5 Review of the ɣ Category Papers

On review of the ɣ category papers, whereby the authors have attempted to enhance or dispute the concept of the Cynefin framework, a chronological analysis has been undertaken beginning with Smith (2005) which discusses the notion of knowledge sharing and its direct relationship with the framework. Denis discusses the fact that known and knowable have been considered however that are two further categories to consider. The first is '*discoverable*' which coincides with complex states where the information and knowledge required may only be generated by virtue of a paradigm shift in organizational thinking. The second is '*indeterminate*'. This follows the chaotic domain where experimentation is pointless. There is little, if any, indication that the knowledge exists. Smith (2005) diagram (Figure 2.8) identifies relationships between Tacit and Explicit knowledge against the Cynefin frameworks principles.

As we descend into the layers of uncertainty, the connection of explicit and tacit knowledge becomes muddied. In the Known/Simple domain, we have processes and systems which operate and instigate order amongst organisations. These are used to keep us on the firm and narrow. In more knowable/complicated situations, we start relying more on human interaction to impart experience, knowledge, and competence to positively influence (Snowden, 2002).

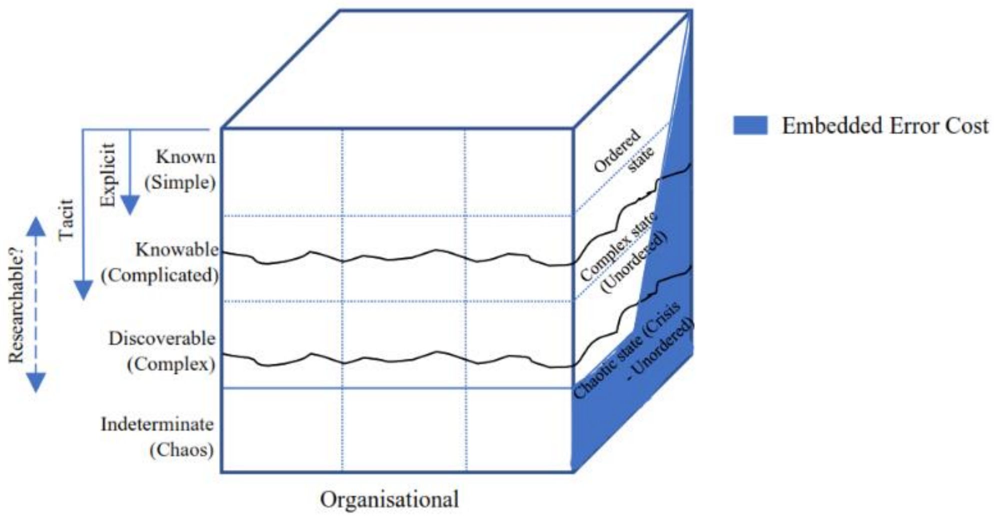


Figure 2.8 – Knowledge, systems states and error cost. Adaptation of Smith (2005)

Snowden states within the complex domain, experimentation is a necessity. By learning lessons from similar situations whereby experimentation had been undertaken, surely research would identify these trends to mitigate the complexity aspect of the situation one finds themselves in. Knowledge management and sharing from project to project is paramount. It appears logical that the question mark against the term ‘researchable?’ on Smith (2005) diagram (Figure 2.8) is more for the domain of chaos where uncertainty is rife. Complex situations would appear researchable, assuming you have accurate, well managed historical datasets to learn from.

Smith (2005) focuses heavily on the healthcare sector which he explains has a complex set of activities in a highly turbulent, political and environmental setting. For example, as we have seen with the COVID-19 pandemic, the point at which an unknown disease is discovered, the public environment boarders on the edge of chaos due to the uncertainty of the situation, calling for drastic decision-making “Crisis Management” techniques to reassure and control (Snowden and Boone, 2007).

The second ɣ citation, McLeod and Childs (2013) explores the context of Cynefin in Electronic Records Management (ERM). Firstly, four new terms are introduced into the framework. These are Coordination, Cooperation, Collaboration and Direct Intervention. Coordination is a ‘simple’ function whereby processes and policies are established then followed. This is considered the realm of best practice. The second term, ‘Cooperation’, has been links with the ‘complicated’ domain whereby success is based on communication and relationships between managers and their staff who in turn engage with their necessary counterparts. This has been categories as ‘Good Practice’ as there may be areas of weakness that desire improvement.

The third term, ‘Collaboration’ sits firmly within the ‘Complex’ domain whereby to probe and sense the situation, one must be in a position of unity and solidarity. The final term, ‘Direct Intervention’, located within the domain ‘Chaos’ is a technical term similar to crisis management whereby leaders find themselves acting without knowing the true state of their environment. A term often used in construction projects that represents similar behaviour is ‘fire-fighting’ which is a reactive term for correcting problems that should not have occurred in the first instance.

McLeod and Childs (2013) discusses how the ERM data set (AC^+ ERM) considered three facets: People, processes and technology (PPT). This refers to the methodology in which the balance of people, process, and technology drives action and improvement, often used as a tool for digital transformation purposes. A representation of the PPT triangle and it's terms are expressed within Figure 2.9.

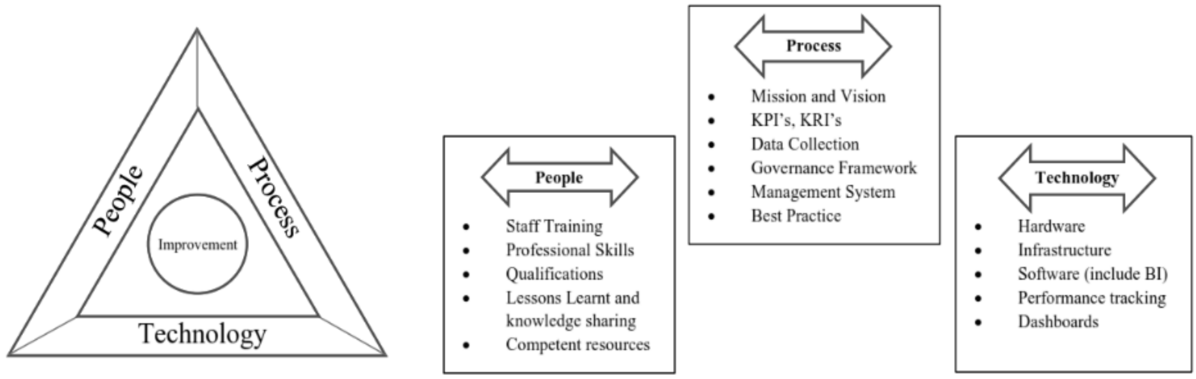


Figure 2.9 – People Process Technology (PPT) diagram. Source: Authors Representation of McLeod and Childs (2013)

McLeod and Childs use the Cynefin framework to categorize individual themes against the three criteria (People, Process, Technology) according to the level of complexity. I.e. standards and policies lack coverage of RM has been categorised within the simple domain. There are grey areas whereby McLeod and Childs (2013) border some of the themes between two domains.

The data presented suggests that most of the themed issues reside within the simple or complicated domains, however a third of the issues sit within the complex domain with only a small percentage indicating the chaos domain. McLeod and Childs (2013) conclude that the Cynefin framework provides a powerful tool to enable individuals to categorize, interpret and respond in the realms of ERM but does not expand further on the benefits, faults or enhancements to the framework.

The third ɣ cited document, Childs and McLeod (2013), is a follow-on from McLeod and Childs (2013) with working examples on tackling wicked problems for Electronic Records Management (ERM). The examples focus on four ERM environment examples. A pertinent point is raised by Childs and McLeod (2013) within example 1 whereby training of staff is categorised in the simple domain. A set curriculum is established to capture learning capabilities and certification is provided upon course completion to ensure staff are suitably trained in their required field. Process is followed with little personal decision-making required, categorizing it as simple.

Within example 2, another valid point is raised in that selection of systems are both complicated and complex. There are standard applications and system processes to follow which are complicated in nature. It relies on experimentation through subject matter experts to devise a process that can be stringently adhered to by humans. The very nature of humans categorizes as complex due to our erratic behaviours, different levels of competency and perceptions. It has much to do with managers' attitudes and perceptions for a desire outcome (Childs and McLeod, 2013). In the case of digital quality capture, without leadership reinforcement, training and a clear perspective (vision/mission), managers cannot successfully engage a workforce to implement a system process that is alien to them.

As mentioned by Childs and McLeod (2013), in certain circumstances things do become politically driven, especially with larger scale construction projects as demands frequently change with the political environment (e.g. HS2, Crossrail or A14).

Example 3, entitled 'Managing chaotic issues' is a difficult quandary to assimilate. As indicated by Snowden (2003) in the realms of unknown unknowns, there is no right answer apparent to the leader and crisis management techniques will most certainly be implemented to stabilize the situation into a complex or even a complicated state if possible.

Example 4 is of particular interest as it poses the notion of how Cynefin could be used in the context of major projects or initiatives. As per examples given of health care and ERM, the construction industry also contains a wide range of problems, from simple through to complex. Childs and McLeod (2013) insinuate that the Cynefin framework could be used to plan Research Data Management (RDM) projects or initiatives at a strategic and/or tactical level, building on the premise provided by Van Beurden *et al.* (2013). Figure 3 of Childs and McLeod (2013) implements actions for the example of RDM and overlaps against the Cynefin framework. The paper concludes that the examples provided illustrate the potential value and power of the Cynefin framework as both a practical and conceptual tool in the context of managing electronic records. The document expresses that the benefits extend to other information and records management challenges. As construction projects have both information management and records management obligations (e.g. document control and a project Health & Safety File), there may be an opportunity to use Cynefin to categorize one's complexity for the challenges they face. The paper however does not expand further on the benefits, faults or enhancements to the framework nor the benefits for delivery of complex projects.

The fourth Ɣ cited article, French (2013), expands further on increasing knowledge within one's organisation whilst deriving links between Cynefin framework and the strategic pyramid (Figure 2.10). The premise is that as you move through the domains of the Cynefin framework, there is direct relationship with increased levels of uncertainty and strategic decision-making (i.e. Known = Instinctive through to Complex = Strategic).

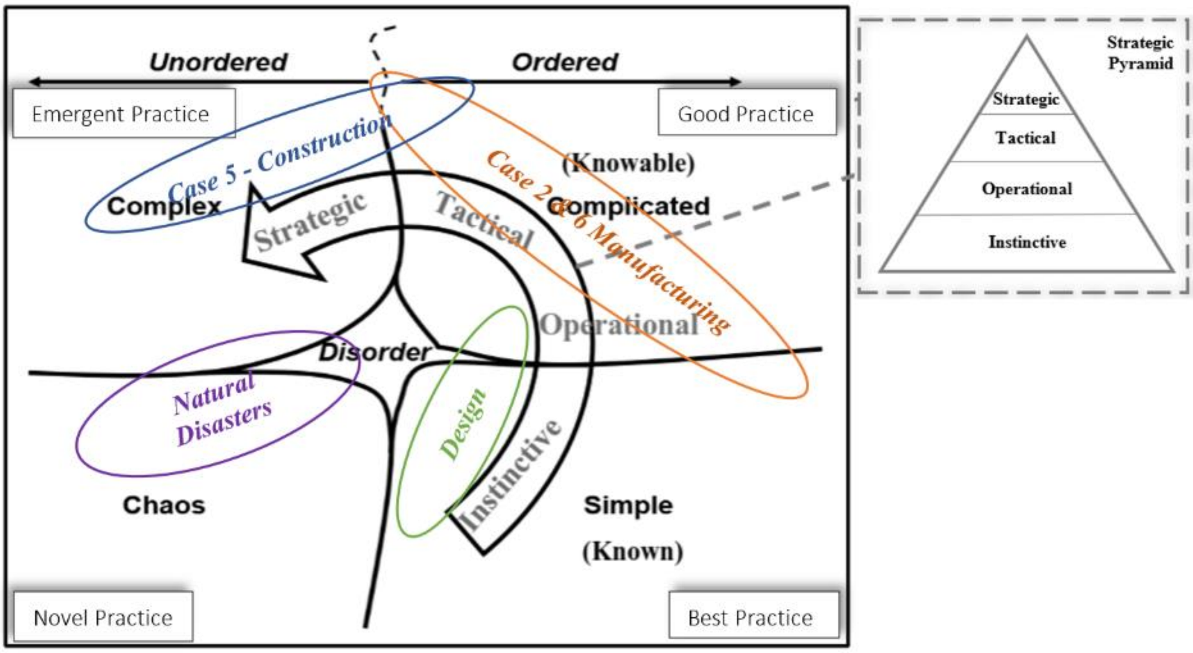


Figure 2.10 – Relationship between Strategic Pyramid and Cynefin framework. Source: authors adaptation from French (2013)

This notion appears logical whereby known/simple states require very limited judgement as processes are already established and rely on intuition to execute (e.g. Design).

French (2013) also discusses Nonaka's SECI cycle (Nonaka, 1999) and the mechanism by which knowledge is created, explored and shared. This involves four key terms: Socialization, Externalization, Combination and Internalization. 'Socialization' is sharing tacit knowledge through various forms of dialogue (Communities, mentoring, lessons learnt, discussions, collaboration etc.), whereas 'Externalization' is representing the same tacit information in documented form (I.e. literature, diagrams, tables, charts, models, information systems etc.). 'Combination' is a term used to describe exploring explicit knowledge with a view to consolidating into a more readable, generic and simplified form which is more widely relevant. The last term, 'Internalization', is effectively understanding the generic explicit knowledge gained from combination and articulating into a tacit understanding to adapt/improve our behaviours and decision-making.

Both Smith (2005) and French (2013) link the relevance of tacit/explicit knowledge as a fundamental part of improvement alongside the Cynefin framework. Figure 2.11 presents tacit and explicit knowledge examples that collectively breed wisdom. Note that implicit knowledge (the application of explicit knowledge) has been overlooked by both Smith (2005) and French (2013), who have followed Nonaka's principles (Nonaka, 1999; Nonaka and Takeuchi, 2007).

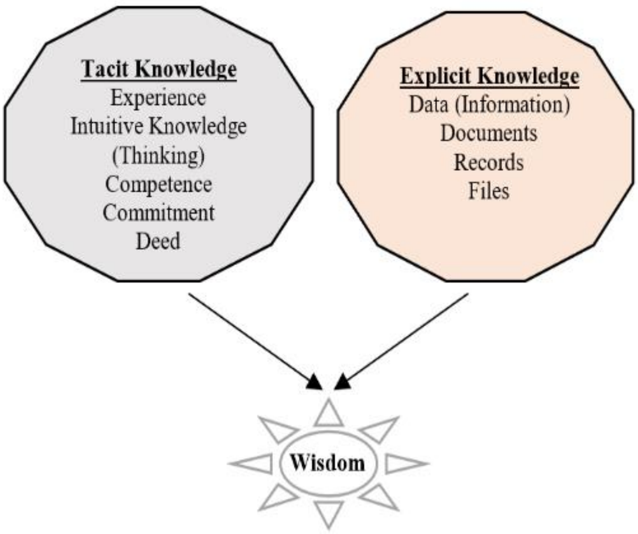


Figure 2.11 – Tacit and Explicit Knowledge Representation.

It appears logical that in order to make correct decisions, leaders must be armed with a wealth of knowledge in their current position to prevent error, impulsive decisions whilst demonstrating appreciation for the level of complexity they find themselves in. Leaders may stumble into complex areas where experimentation is vital to decision-making. By consolidating lessons learned and other forms of knowledge there may be opportunities in the future whereby the leader will not have to experiment as all possibilities have been encountered, recorded and analysed to prevent such occurrences happening. And if a problem is encountered, a sensible, pragmatic solution is already visible to the leader. This ultimately paves the way for future generations. The Chaos domain may be the only exception to this ideology.

French (2013) suggests that knowledge management relies more on socialization in the complex and chaotic spaces. He concludes that effective decision support hinges on facilitating collaboration whereas the simple and complicated domains are data/process driven. There seems a plausible argument that the level of complexity for the situation is directionally proportional to political/financial standing. This may however be unmeasurable.. Similar trends were noted on the A14 Huntingdon Improvement Scheme as a result of the projects size/publicity. At the other end of the spectrum would be natural disasters or unknown diseases that involve crisis management. Not only are decisions politically driven by country leaders, but the levels of complexity and uncertainty firmly position the issue within the chaotic/complex domains (fluctuating between domains as events unfold and uncertainty shifts).

French (2013) makes the connection of increased forecasting and decision-making driven by Data > Information > Knowledge. He concludes that the Cynefin framework seems to offer advantages into decision-making but encourages the reader to strike a balance between qualitative and quantitative method.

The final paper, Alexander *et al.* (2018), discusses the application of Cynefin framework within Performance Measurement and Management (PMM). As previously mentioned, the Cynefin framework appears to have had little consideration within the construction industry to date. Alexander *et al.* (2018) also note this fact within PMM and wider operational management literature. The authors undertook interviews across seven different industries with a view to surmising the dominant logic domain (Cynefin framework domain) for each company strategy/culture description.

Alexander *et al.* (2018) accurately notes that for PMM to be effective it must fit in the environment in which it operates. Taken from Melnyk *et al.* (2014) (p.183), without knowing one's environment, it is not an efficient tactic to make decisions. Especially in unstable environments which are adapting daily. Leaders may find themselves straying from the correct path and not prospectively towards their changing environment. Technology is a prime example. Phones are continuous changing their specifications and user requirements to adapt to an everchanging technological world. Successful phone companies are already looking at the future environment to discover what the customer would want next through innovation. Furthermore, Alexander *et al.* (2018) note that failure to respond to a dynamic environment causes stresses between organisations, external environment and its customers. An unhappy customer is one that may take their business elsewhere. It is vital that requirements and deliverables are understood to prevent hostility.

Alexander *et al.* (2018) also indicates that flexible and strategically aligned PMM are needed in order to adapt within turbulent market conditions. A good example of this during COVID-19 was supermarkets. The supermarkets that suffered the least collateral damage during lockdown periods were businesses that could quickly adapt from in store, on shelf purchasing to an online ordering and delivery services for the masses. Some companies did not have the people, process or technology (PPT) capabilities established to implement fast, effective changes. Note that PPT again plays a vital part in environmental instability and successful decision-making (McLeod and Childs, 2013, Childs and McLeod, 2013). Having the tools necessary to implement the next strategic decision against environmental conditionals appears fundamental, especially in a volatile climate such as the construction sector.

As noted within Table II. of Alexander *et al.* (2018), case 5 – contractor case, the authors interviewed five individuals across various levels of management with 7 associated documents analysed. They also note that the major contractor showed very strong domain 3 dominant logic personalities (Complex Domain). Figure 2.10

superimposes the dominant logic case examples against each Cynefin framework domain.

Within question Q5.2 the researchers reports a very strong decentralized decision-making culture where people follow their own intuition and common sense, rather than blindly following prescriptive rules. This example was in health and safety. Consequence for a fatality/injury is high which in turn adapts an individual's behaviour accordingly to implement effective/efficient processes that are stringently followed. Consequence is a very strong tool to manipulate workforce behaviours. Too often we see lack of incentive for workers to want to drive forward and make a difference with the construction industry. Behavioural intricacies and tendencies swayed by risk aversion play a conflicting role in construction (Farooq *et al.,* 2018; Phillips-Alonge, 2018).

Alexander *et al.* (2018) does explore the Cynefin framework whilst making direct links to environmental, social and organisation factors in the fields of Sustainable Operations and Supply Chain Management (SOSCM) and Performance Measurement and Management (PMM). The document maps case studies against the domains introduced by Snowden (2003). It does however have a strong bearing on construction projects as both SOSCM and PMM are essential for continuous improvement. The authors hint at further conceptual developments being plausible and the need to further investigate the potential of bringing PMM and decision theory together to improve performance of organisations in a fast-changing and unpredictable world.

2.5.6 Synthesis and reflection on β and ɣ category papers

2.5.6.1 Synthesis of β cited papers

Of the four β papers, three papers (Tommelein, 2015, Walker and Lloyd-Walker, 2016, Zegarra and Alarcón, 2017) make reference to both Kurtz and Snowden (2003) and Snowden and Boone (2007), whereas Zegarra and Alarcón (2019) focuses on the latter 2007. None of the papers mentioned in this section challenge or expand as a major part of their argumentation or analysis on the concept of Cynefin framework in Construction. Cynefin is tentatively linked with procurement, project production, as well as planning and control, but only as a minor part of conceptual based studies. No empirical evidence is presented in this category, and prescriptions are largely limited to the ordered domains. This is summarized within Table 2.5 below.

Table 2.5 – Summary of β papers and their potential contributions to construction projects

β Category Paper	Research Method	Research Area	Content associated with the Cynefin framework	Cynefin Contribution in Construction?
Tommelein (2015)	Lean Project Production Theory – Experiential	Construction – Lean Principles	Guides the readers understanding of simple and complicated domains in Construction.	Offers prescriptions for the ordered domains
Walker and Lloyd-Walker (2016)	Conceptual Development – RBP Collaboration Taxonomy Research Approach (Quantitative then Qualitative Methods	Construction - Relationship Based Project Procurement (RBPP) taxonomy	Discusses complexity in construction and how the Cynefin framework expresses relationships between cause-and-effect, specifically in ordered and unordered systems.	Inconclusive
Zegarra and Alarcón (2017)	Conceptual Development – Variability Propagation	Construction – Complex Adaptive Systems (Production Planning and Control Function (PPCF))	Contains minor detail into Cynefin and simply explores the relationships between cause-and-effect	Inconclusive
Zegarra and Alarcón (2019)	Conceptual Development – Expansion on previous works in 2017 paper	Construction – Complex Adaptive Systems (Production Planning and Control Function (PPCF))	Contains minor detail into Cynefin and simply explores the relationships between cause-and-effect	Inconclusive

The findings from the systematic review of the β papers indicate that the Cynefin framework has not been explored or exploited extensively in construction, despite the apparent benefits of doing so. The notion of Cynefin has been embraced by some, however, from the papers reviewed, there is a lack of evidence to suggest that the framework has been effectively considered or implemented within the construction sector to bring about a new way of thinking to an industry which, given that is considered often complex, sometimes chaotic, would clearly benefit.

2.5.6.2 Synthesis of ɣ cited papers

Of the five ɣ cited articles, only two appear to have significantly and explicitly progressed the Cynefin framework (Smith, 2005 and French, 2013). There has been little to no critique of the Cynefin framework principles set by Snowden (2003) with agreement that the complex domain warrants some form of experimentation.

Interesting insights were found in four out of the five documents into how the Cynefin framework domains can be managed via People, Process and Technology based change levers and initiatives (McLeod and Childs, 2013), as well as aligned with external environment conditions (Alexander *et al.,* 2018). See Table 2.6 below for summary of ɣ cited articles and their contributions.

Table 2.6 – Summary of ɣ papers and their potential contributions to the construction sector

ɣ Category Paper	Research Method	Research Area	Contribution / Findings	Applicable / Transferrable within Construction Sector
Smith (2005)	Conceptual Development	Knowledge Management and Complexity Theory – Specifically 'Healthcare Sector'	Derive links between Tacit/Explicit Knowledge with political influencing	Yes – Identifying the need for knowledge sharing through tacit and explicit means.
McLeod and Childs (2013)	Case Study Examples (mixture of primary and secondary data) Qualitative – People Issues AC+ ERM Data	Information Management – Electronic Records Management (ERM)	Driving continuous importance through a three faceted approach (People, Process and Technology – PPT) against Cynefin	Yes – People, Process and Technology is fundamental for driving Continuous Improvement
Childs and McLeod (2013)	Delphi Study Qualitative – Examples against AC+ ERM Data	Information Management – Electronic Records Management (ERM)	Develops and maps a strategic decision process for Research Data Management (RDM) against the Cynefin domains	Inconclusive – No further insights from McLeod and Childs (2013) publication
French (2013)	Conceptual development (with example illustrations). Qualitative – Problem structuring methods (PSM)	Knowledge Management – Decision Analysis	Derive direct links to Strategy Pyramid & Tacit/Explicit Knowledge sharing Sharing benefits of Data>Information>Knowledge to make improved forecasting and decision-making	Yes – Expressing the importance of knowledge transfer in Construction

Alexander *et al.* (2018)	Case Study Qualitative – Interviews	Sustainable Operations and Supply Chain Management - Performance Measurement & Management (PPM)	Determining alignment between Dominant Logic (DL – Cynefin Domains), external environment and Performance Measurement & management (PMM)	Yes – Helps identify domain categorization

2.5.7 Overall Synthesis, reflection and proposition development

Based on the analysis of the Cynefin framework citations, and considering the travel of ideas, Figure 2.12 represents the history and pathway from the original body of work by Snowden (2002) to the relevant β and ɣ cited papers. These have been further colour coded and coupled into research fields to identify where their interests lie. It is interesting to note that the ɣ cited papers are in the broad disciplines of Knowledge Management, Information Management and Supply Chain Management. Specific research areas are captured within Table 2.6, column 3.

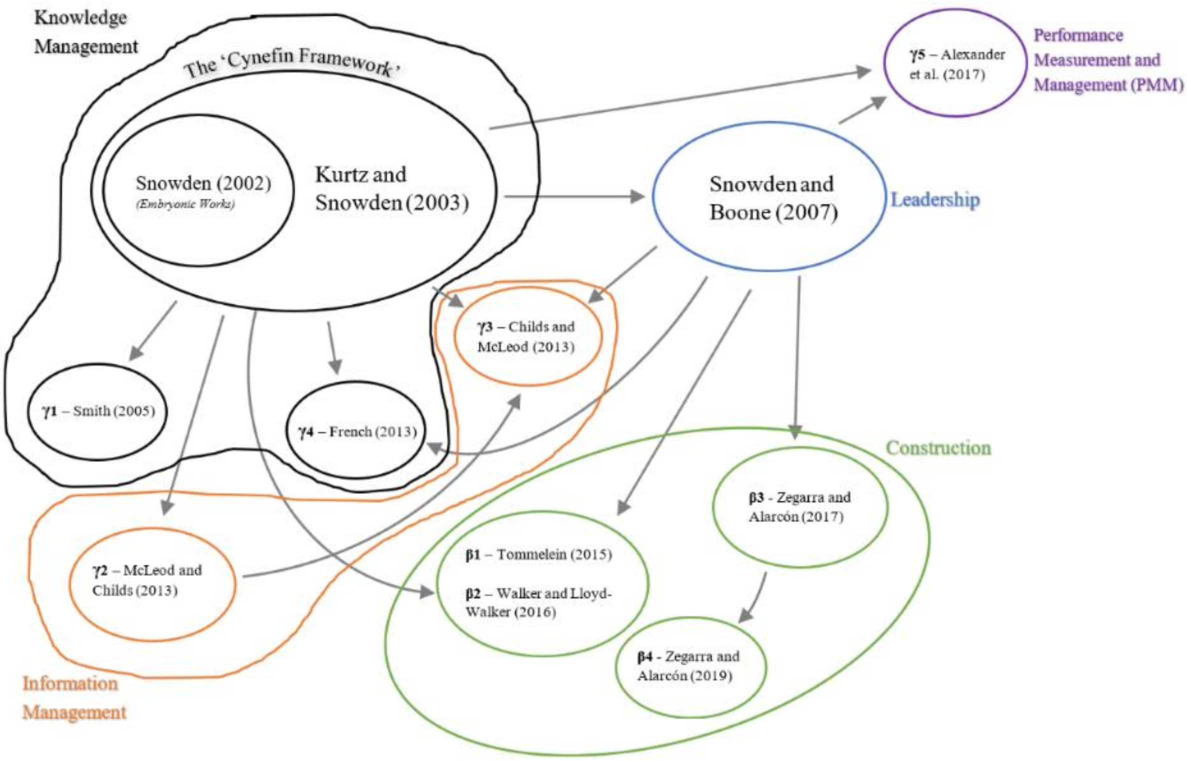


Figure 2.12 – Archaeological travel of the Cynefin framework via citations.

Of the five bodies of literature, knowledge management appears as a prominent theme for successful decision-making. Both Smith (2005) and French (2013) discuss the importance of Tacit/Explicit knowledge sharing. Building on their thinking, Figure 2.13 proposes the shift of Explicit, Implicit and Tacit knowledge through the stages of complexity against the Cynefin framework domains. Knowledge spheres have been created to express where the knowledge originates, whether that be competence, intuition or experience. We have also indicated appropriate learning mechanisms to correspond with the different domains. As previously mentioned, both Smith (2005) and French (2013) do not consider 'implicit' knowledge transfer. However, Taber (2014) expressed the significance of implicit knowledge for learning and teaching which is directly relatable to the construction sector.

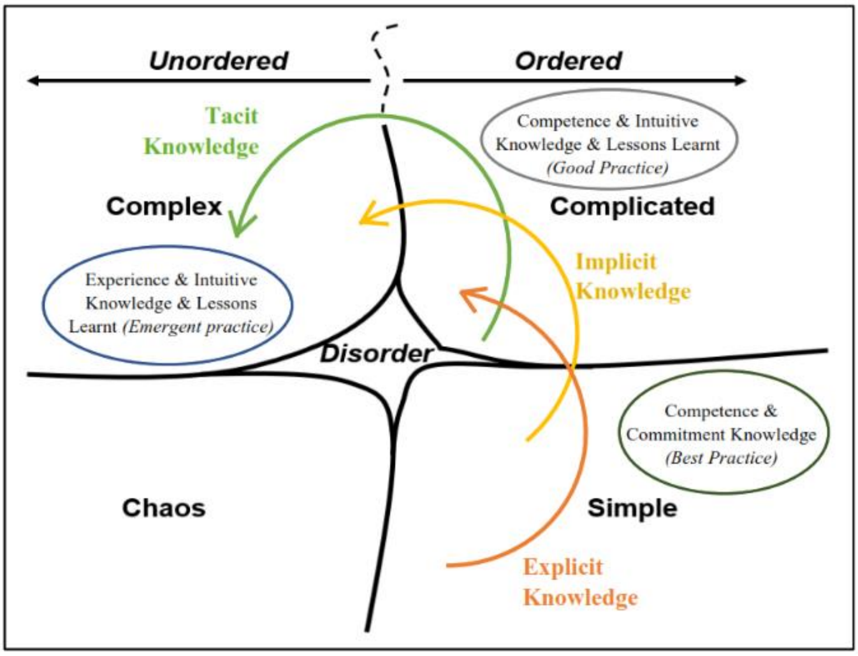


Figure 2.13 – Representation of how explicit, implicit and tacit knowledge influences the Cynefin framework.

At this point, it is possible to introduce Proposition 1 to guide further research: *explicit, implicit and tacit knowledge mechanisms can and should be matched with different Cynefin domains.*

Taking positive influence from the ɣ papers, Figure 2.14 has been formulated which derives links between complexity, knowledge and influence. It represents the direct link between Cynefin's domains and transposing usable data through information management into knowledge. The diagram denotes the potential wealth of raw data at our fingertips; however we currently lack the knowledge within complex and complicated situations to execute best practice. Instead, we strive for ‘good practice’. It is important to note that the domain ‘Chaos’ is not represented on the diagram. As mentioned, in the realms of Chaos, there is no right answer. If a right answer was plausible and knowledge was a fundamental influencer, then the leader would have stabilized the situation rendering their problem either complex or complicated. The diagram also infers that in the simple domain there is a plethora of data to support decision-making. In comparison, knowledge in the complex domain is scarce. The scaling within Figure 2.14 denotes this. Tacit knowledge appears less abundant than explicit knowledge in terms of archived knowledge.

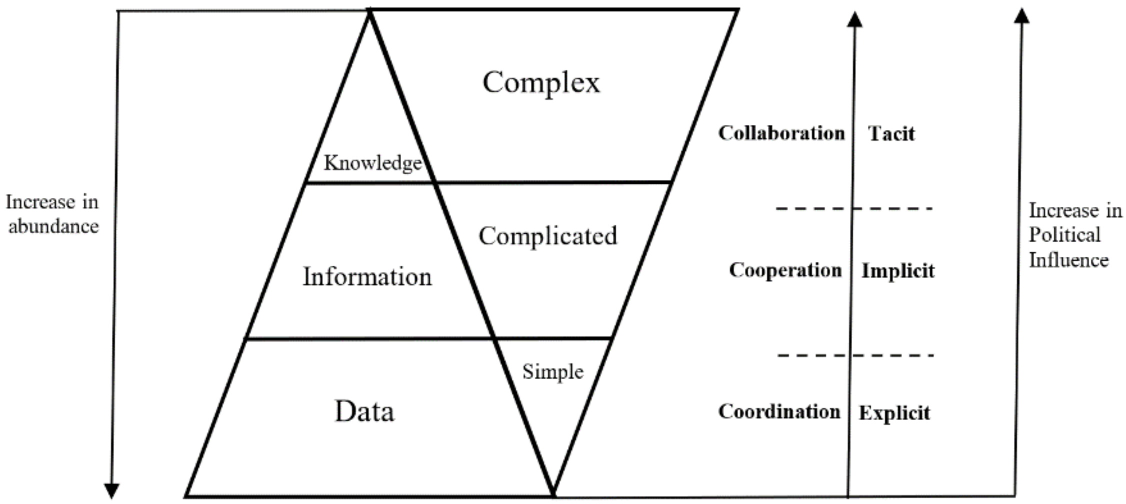


Figure 2.14 – Relationships between Cynefin domains and Data > Information > Knowledge inference. Source: Adaptation of Smith (2005), Childs and McLeod (2013), and French (2013)

It is vital in the construction sector to learn from our mistakes. In conjunction, we must understand our context in order to make more effective decisions. There are insights into how collaboration plays a meaningful part of effective decision-making in complex situations, (McLeod and Childs, 2013). In addition, societal/political influences appear greater with the growing the level of complexity (Childs and McLeod, 2013; French, 2013).

Decision-making is a fundamental part of Cynefin. French (2013) discusses the relationship between data, information and knowledge in an act to make concise forecasting and decisions. A relatable example in construction of capturing data with a view to sharing knowledge for improvement is non-conformance reports (NCRs). Figure 2.15 shows supporting relationships between data (NCRs), Information (RCA outcomes to make informative, precise decisions) and knowledge (lessons learned findings to influence continuous improvement).

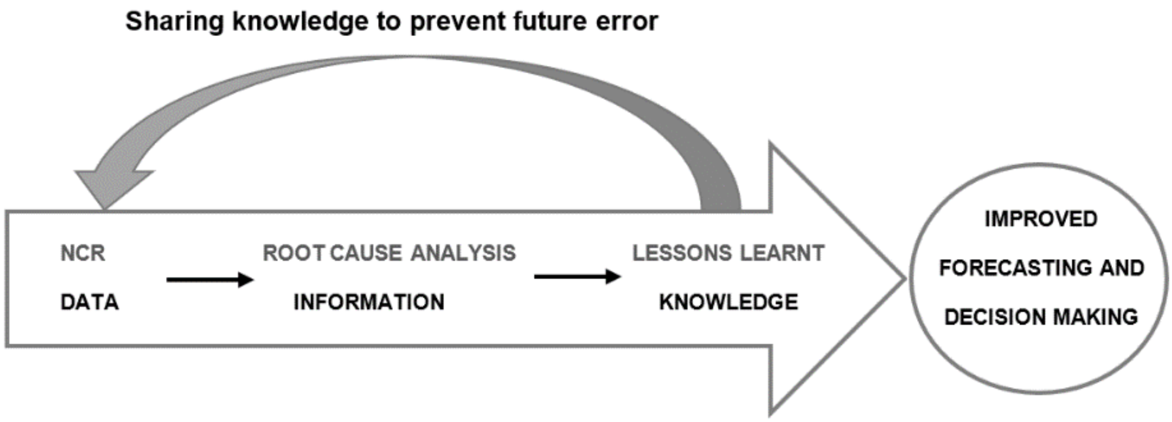


Figure 2.15 – Non-conformance report relationship with data, information and knowledge with a view to improve decision-making. Source: authors adaptation of French (2013)

Non-Conformance Reporting plays a meaningful part of all construction projects in an attempt to assure a project against set criteria, standards and specifications. However, uncovering causes of non-conformance is a difficult task. There are many factors at play that prevent the truth from being uncovered. It takes a collaborative, open and honest environment to admit to one's failings (Bubshait and Al-Atiq, 1999).

There is a wealth of data at our fingertips within the construction industry in which we have the opportunity to learn from and drive continuous improvement. These datasets come in many forms including safety, quality (Non-conformance reporting, Figure 2.15), commercial, programme etc.

2.6 Summary – synthesis of key literature and research gaps

The literature review has focused on the inherent challenges of quality in construction. Namely, the struggles of achieving RFT (Ahmed *et al.,* 2021) and the recurrent issues of rework in the last few decades, costing on average circa 9.19% of total project value (e.g. Abdul-Rahman *et al.,* 1996; Forcada *et al.,* 2014; Ford *et al.,* 2023). In addition, the review concludes that the construction industry has not adequately learned from its failures, nor taken the opportunity to capture, analysis and share learning within organisations and the wider sector (Williams, 2008; Shokri-Ghasabeh and Chileshe, 2014). More is to be done with learning from NCRs and failure events to enhance the productivity and efficiency of construction project delivery.

A further focus area was on the topic of complexity in construction projects. Scholars have concluded that as projects increase in scale, the levels of uncertainty and complexity increase, causing more unknowns to manifest (Ramasesh and Browning, 2014; Browning and Ramasesh, 2015). With the advancements of lean practices, there has been greater emphasis for managers to simplify the problems they find themselves in. This has caused many instances of oversimplification, which unfortunately has resulted in further problems (e.g. Spiro *et al.,* 1996). Researchers have requested projects embrace complexity and make sense of their environment through sense-making frameworks (Forcada *et al.,* 2014; Maes *et al.*, 2022). One in particular, the Cynefin framework, has seen the greatest attention from academics and industry practitioners (McLeod and Childs, 2013; Naim *et al.,* 2022).

Through a detailed analysis of the Cynefin framework, the literature review reveals that the sense-making schema has had minimal impact in the construction sector (Table 2.5). As such, its benefits are not fully understood. However, there are scholars who have exploited the framework within other sectors, have gained insights into how the framework can benefit their field of research, and have expressed the frameworks applicability in other field, including construction (Smith, 2005; McLeod and Childs, 2013; French, 2013; Alexander *et al.*, 2018). However, there is limited research into how the sense making framework can make a positive impact into quality decision-making, and help address the widespread problems of rework in construction.

To conclude the literature review, the following literature gaps have been identified:

Gap 1: The construction industry is continuing to suffer from rework with a lack of empirical research into non-conformance. Therefore, there is a need to understand current failure patterns for improvement through NCRs.

RQ1a: What are the most frequent and costly areas of failure from non-conformance report (NCR) data on an infrastructure construction project?

Gap 2: There has been a lack of lessons learning research in the construction sector, particularly with current projects.

RQ1b: What are the corresponding lessons learned from NCR data that can help transition towards right-first-time delivery in construction projects?

Gap 3: The Cynefin framework as a sense-making tool has seen much attention in the field of knowledge management to help managers understand their environment. However, its impact in construction is not fully understood.

RQ2a: How has the Cynefin framework been exploited and adopted within construction projects?

Gap 4: There is no research as to how the Cynefin framework can help manager assess and problem-solve quality incidents.

RQ2b: How can the Cynefin framework be applied to better understand decision-making with regards to quality problems in construction projects?

Chapter 3: Research design and methodology

3.1 Introduction

The purpose of a research design is to provide a plan of study that permits accurate assessment of cause-and-effect relationships between independent and dependent variables (Jang, 1980). It requires us facilitate clear direction through the various research operations, thereby making research as efficient as possible whilst yielding maximal information with minimal effort and time. Research design has a significant impact on the reliability of the results obtained.

The type of methodology will dictate the right research methodologies that should underpin the research and data-collection methods to be used. It gives the researcher the opportunity to position their research problem in a suitable philosophy, develop a suitable approach to tackle the research problem, select a suitable research strategy that leads to appropriate methods for data collection, and tackle the right unit of study, ensuring the reliability and validity of the results (Opoku *et al.,* 2016).

This section articulates the philosophical underpinning of the research then details the research methods and tools used. It establishes an outline of how the research has been formulated and conducted, including the research design, strategy and instrumentation used. Furthermore, it explains the two types of data collection methods (NCR dataset and online survey), detailing how the information has been collected, cleansed, analysed and used. This is separate to the ethical processes adhered to in obtaining consent to use external data from projects.

3.2 Research philosophy and paradigms

3.2.1 Types of philosophical paradigms

First, what is a research paradigm? It is a set of beliefs and agreements that are commonly shared between scientists. It is about how problems should be understood and addressed (Kuhn, 2012). It is also referred to as the involvement of an ontology, an epistemology and a methodology (Blanche *et al.,* 2007). In general terms, philosophy defines the way in which data should be gathered, analysed and used for research purposes (Saunders *et al.,* 2009). Data is used to develop understanding through information into knowledge and wisdom (French *et al.,* 2009; French, 2013)

The ‘research onion’, coined by Saunders *et al.* (2009), argues that in order to advance our knowledge the following steps are to be followed: Philosophy > Approaches > Strategies > Choices > Time horizons > Techniques and procedures. We begin with the research philosophy and work our way down through the onion layers in a systematic, aligned manner to ensure the approaches and choices taken methodically line up. This ensures that when we get to the core, i.e. data collection and analysis, we have planned effectively, made appropriate assumptions and have the necessary toolkit to execute the research.

A fundamental question for conduction research is: Why do we build a foundation of philosophy within our research? ‘Why bother with philosophy?’. Dobson (2001) looks to Collier (1994, p. 17) for an explanation.

> *“A good part of the answer to the question ‘why philosophy?’ is that the alternative to philosophy is not* ***no*** *philosophy, but* ***bad*** *philosophy. The ‘unphilosophical’ person has an unconscious philosophy, which they apply in their practice – whether of science or politics or daily life.”* (Collier, 1994, p. 17)

Dobson also reflects on the term ‘bothering’ with the premise taken again from Collier (1994, p. 17). They both ponder a two-sided conundrum. On the one hand, through different social groups with the involvement of others, or, on the other hand, through one's own conception of the world. There appears to be benefits to both sides. It is good to challenge one’s thoughts and views with others to reach consensus. However, it also seems logical that to build a pure idea, it must not be negatively influenced by the personal views of others, which may be biased or opinionated.

By way of data, this thesis aims to contribute to knowledge with a view to achieve betterment. Thomas (2004) asks questions such as ‘how is knowledge to be distinguished from belief or opinion…what methods can yield reliable knowledge?’ Understanding the different philosophical paradigms helps justify the research approach used.

3.2.2 Ontological position

First, ontology and epistemology are to research what 'footings' are to a house: they form the foundations and principles upon which we build. (Grix, 2018). Ontology, derived from the Greek word 'on' meaning 'being' refers to 'the nature of our beliefs about reality' (Richards, 2003, p. 33; Saunders *et al.,* 2009). It represents the researcher's perception regarding social reality. It considers two aspects that are important to mention: objectivism and subjectivism. Objectivism, developed by Russian-American writer Ayn Rand, who describes the term as 'the concept of man as a heroic being, with his own happiness as the moral purpose of his life, with productive achievement as his noblest activity, and reason as his only absolute'. It can also be described that social entities exist as an important reality outside the social actors who are concerned with their existence. Subjectivism, on the other hand, has been referred to as 'the social actors create a social phenomenon via their perception and corresponding actions' (Lin, 2018).

As the quality failure information (i.e. non-conformance and rework data) is constructed independently of the research, an objective position is taken. Information within the system is treated as though it obeys processes, standards of governance and regulations, to achieve a targeted objective.

3.2.3 Epistemological position

Epistemology refers to 'the branch of philosophy that studies the nature of knowledge and the process by which knowledge is acquired and validated' (Gall *et al.,* 2003, p. 13). It emphasises how knowledge of social reality is constructed (Saunders *et al.,* 2009). It also manages the relationship between researcher and the research matter. Walliman (2016) suggests that there are two fundamental branches within epistemology. Rationalism, where knowledge is gained through deductive reasoning, and empiricism, where knowledge is acquired through experimental means, such as data analysis. These are deeply contrasting approaches that link theory and research (Bryman and Bell, 2003).

Dudovskiy (2018) summarises deductive reasoning as ‘developing a hypothesis (or hypotheses) based on existing theory, and then designing a research strategy to test the hypothesis’. Gummesson (2000) shares this view and adds that deductive reasoning involves ‘commencing the research with theories and concepts for which hypotheses are formulated and subsequently tested’.

Inductive reasoning, on the other hand, is concerned with ‘starting with real-world data categories, concepts, patterns, models, and eventually, theories emerge from this input’ (Gummesson, 2000). The author intents is to make calculated conclusions and theories based on patterns emerging from the data. Theories can emerge from all kinds of data which are made available to the researcher(s). According to Walliman (2016), the inductive approach is far more prevalent than the deductive approach. This is perhaps because researchers seek to use present-day data to build on existing knowledge, instead of challenging other theories to agree or disprove them. The latter may appear more confrontational.

As inductive and deductive methods are polar opposites, some philosophers suggest that the researcher should strictly limit to either/or. As a result, the hypothetico-deductive method (also known as H-D method) was deduced to give the option of both deductive and inductive reasoning. Walliman (2016) describes this as ‘the to-and-fro process of developing hypotheses research method rationalism (testable theories) inductively from observations, charting their implications by deduction and testing them to refine or reject them in the light of the results’. This is similar to a continuous improvement cycle which seeks to develop > form hypothesis > test > formulate (Littlejohn, 1989).

Gummesson (2000) also argues that after the initial stage of the research process, whether that be inductive or deductive reasoning, an interaction between both persuasions develops, commonly referred to as abductive research. Figure 3.1 demonstrates these relationships.

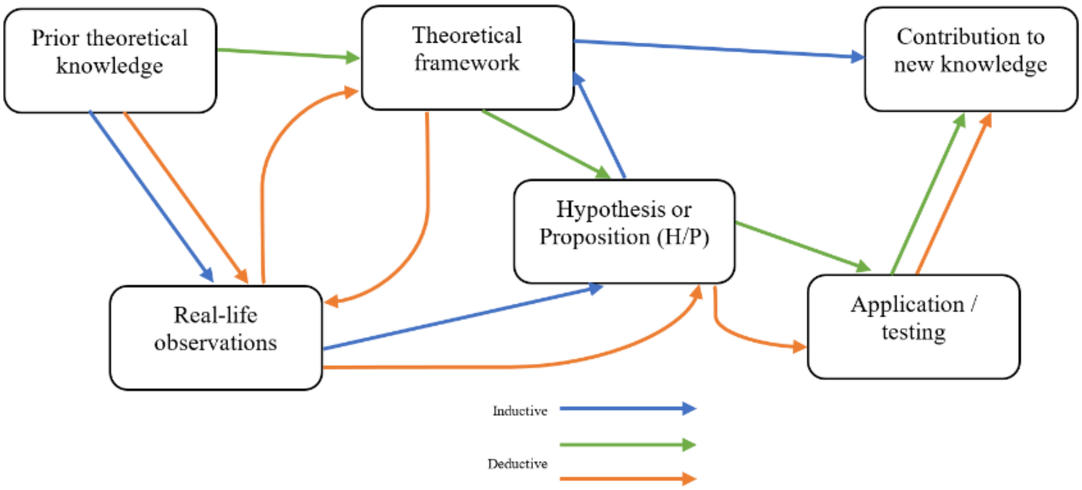


Figure 3.1 – Inductive, deductive and abductive research processes. Source: Kovács and Spens (2005).

However, Dubois and Gadde (2002a) state that an abductive approach in construction is to be seen as different from a mixture of inductive and deductive approaches, particularly when a researcher's objective is to discover new things yet to be conceptualised.

Owing to the above, four epistemological positions that are considered, two of which overshadow other ideologies and are major opposing philosophies in the social sciences: positivism and interpretivism. The remaining are rationalism and critical realism. These are defined as thus:

Positivism – This was founded by Auguste Comte (circa 1830s) and conceptualised with a view to move away from medieval notions of totalitarianism (Park *et al.,* 2020). Positivism is a social and intellectual movement that seeks to formulate abstract and universal laws on the operative dynamics of the social universe, which are to be tested against systematically collected data (Turner, 2001). It seeks to discover laws of nature, expressing them through descriptions of theory. Furthermore, positivism states that if something is not measurable, it cannot be known for certain and is of little or no importance. Positivism is one of the primary representatives of qualitative and quantitative approaches that promote a unified methodology of different branches of natural and social sciences (Saunders *et al.,* 2009). It is also a dominant approach used in construction management research (Dainty, 2008). However, some have noted that within construction management, a potential barrier is the principal action involved within the projects – that is, people (Love *et al.,* 2002).

Interpretivism – This position, on the other hand, argues that the social world is far too complex to lend itself to theorising by defined laws in the same way as the physical sciences (Saunders *et al.,* 2009). Furthermore, interpretivism advocates the necessity to understand differences between humans in social actor roles and emphasises the difference between conducting research with people as opposed to data or objects. Social roles are defined by the way in which we interpret them under our own set of meanings. For example, the way actors portray their parts and create personas for their roles. Interpretivism is based on the assumption that reality is socially constructed, subjective, multiple and dynamic (Schwandt, 1994). It is possible that we can only understand someone's reality through their experience of that reality, which has been shaped by their experiences, and so may be different to the reality of another person with differing circumstances.

Rationalism – This is an epistemological paradigm that includes the beliefs of positivism and some forms of empiricism (Saunders *et al.,* 2009). Rationalism is the philosophical view that knowledge is gained through deductive reasoning without the aid of the senses (Fieser, 2012). It involves adopting scientific approaches via quantitative methodologies to explain phenomena such as modelling, simulations, data analysis, survey methodology and laboratory experiments.

Critical Realism (CR) – This is a philosophical position that relates to scientific enquiry and what we sense is reality, but has an existence independent of the human mind (Saunders *et al.,* 2009). Critical realism (CR) is another epistemological position that shares positivism's perspectives for causality, prediction and objectivity (Bryman, 2016). It distinguishes between the 'real world', which exists independent of human perception, and the 'observable world', which is constructed from our perspectives, experiences and perceptions through observable lenses. More importantly, CR justifies the study of any situation, but only through in-depth research with objective understanding of why things are as they are (Ryan *et al.,* 2012).

Primary characteristics of each of the four philosophical positions aforementioned above are summarised within Table 3.1 below.

Table 3.1 – Primary characteristics of four epistemological positions within research

Philosophical position	**Primary characteristics**
Positivism	Deductive application of theory and data to test hypothesis and explain laws (Turner, 2001; Bryman, 2016) Objectivity with laws generated by gathering facts (Saunders *et al.,* 2009) Moves away from medieval notions of totalitarianism (Park *et al.,* 2020)
Interpretivism	Emphasises the difference between conducting research among people and objects (Saunders *et al.,* 2009) Ontology: socially constructed and subjective (Saunders *et al.,* 2009) Data collection is typically small samples, in-depth investigations and other qualitative data capture approaches (Saunders *et al.,* 2009) Social actors play their part in accordance with their interpretation, the meaning they give their role and align with our own set of meanings (Saunders *et al.,* 2009)
Rationalism	A belief that the phenomenon is being studied exists ‘out there’. Often results in deterministic and prescriptive recommendations (Chan and Räisänen, 2009) Uses scientific methods to explain phenomena with goals to determine the distribution of a set of variables in a population or to verify a set of pre-specific relationships. Uses deductive reasoning to derive logic from a set of premises without the aid of the senses (Saunders *et al.,* 2009; Fieser, 2012)
Critical realism	Shares similar views as positivism (Bryman, 2003) Distinguishes between real world and observable world perceptions (Bryman, 2016) Claims that there are two steps to experiencing the world (Saunders *et al.,* 2009) There is the thing itself and the sensations it conveys There is mental processing that goes on after the sensations meet our senses

3.2.4 Research philosophy and paradigms in construction management

At the present time, positivism and quantitative methods have been the dominant approaches, and have been seen to offer the best way of reducing subjectivity in construction management (Runeson, 1997; Dainty, 2008). However, 'interpretivism' has been a much discussed topic, called for by the construction management community as an alternative paradigm to espouse the importance of understanding human behaviour (Seymour and Rooke, 1995; Seymour *et al.,* 1997; Bryman and Bell, 2003). Along with colleagues, Seymour questioned the dominance of positivist positioning, given that people play a part in most construction management research, and that the interpretive process is largely underestimated in construction management (Dainty, 2008). The concern that 'positivism' (typically involving independent survey research to collect large volumes of statistical data with a view to making generalisations and test hypotheses) lacked the social construct in creating new hypotheses (Seymour *et al.,* 1997). Seeking to understand a practitioners' perspectives on a situation is consistent with interpretivism, but inimical to positivism (Dainty, 2008). As such, the 'interpretivist' approach was adopted to cover the qualitative area of research in construction management. However, Dainty raises concerns as to the ability of the construction management research community to be able to provide a rich and nuanced understanding of industry practice. McCutcheon and Meredith (1993), in the operations management field, claim that 'embracing a field investigation technique, such as case studies, is bound to make the individual researcher, and the field in general, richer and better prepared to solve real problems'. Chan (2020) also notes that 'it is important that we do not privilege qualitative research over quantitative research in construction management and economics, but foster meaningful conversations that draw the best out of both worlds in addressing the problem'. In essence, by considering both philosophical approaches using quantitative methods that are akin to more radical qualitative research methods (i.e. mixed method), construction management researchers are likely to gain richer insights into industry practices (Dainty, 2008). Many support the need for more adventurous research to present untold truths in construction management (e.g. Chan and Räisänen, 2009; Ahiaga-Dagbui *et al.,* 2015). Following an extensive analysis of construction literature tailored toward cost overrun research, Amadi (2023) concludes that deploying a multi-staged mixed-methods case study framework, where findings generated by one approach are used to pose questions, to be answered with the other approach, is the most effective research method.

Flyvbjerg (2006) indicates that good social sciences should be driven by problems not methodology. Methods are to be used to guide research to answer the research question and provide philosophical reasoning for the path that was taken. Before a method is selected, the problem must be identified and categorised, at which point a suitable method is formulated accordingly. Methods may change along the journey but the problem that the researcher is trying to resolve will remain fixed until a new problem is identified. For problem solving, more often than not, a combination of qualitative and quantitative methods (*positivism, interpretivism* and *realism*) will do the task best (Flyvbjerg, 2006). The author is of the opinion that choosing either/or may result in an unproductive approach to problem solving, and thus a middle ground position ('pragmatism') is required. Developed in the late 19th and early 20th century, pragmatism has been deemed the dominant position amongst pragmatists, who argue that there are strengths and weaknesses in opposing philosophical positions (i.e. positivism and interpretivism) and call for more mixed-method research by default in construction management research (Scott, 2016). Saunders *et al.* (2009) state that 'pragmatists recognise that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture and that there may be multiple realities'. They use the appropriate method that allows them to collect credible, well-founded, reliable, and relevant data (Kelemen and Rumens, 2008). By backing up 'quantitative' data analytics with questionnaires and other 'qualitative' methods, we are able to build a fuller picture and justify our conclusions in a more robust manner.

3.2.5 Research philosophy adopted in this thesis

Based on the literature, both positivism and interpretivism can be epistemologically positioned firmly in construction management, and project and quality management practices. However, a middle ground has been advised with a request for researchers to tailor their methods to defined problems, rather than basing their research methods around a predefined set of assumptions, laden in a theory (Scott, 2016).

This research adopts a 'pragmatistic' view, consisting of positivist and interpretivist elements, with a belief that different kinds of research problems require different solutions and methodology choices to uncover complete research outcomes. Figure 3.2 presents the research approach adopted within this thesis, through the layers of the research onion (Saunders *et al.,* 2009).

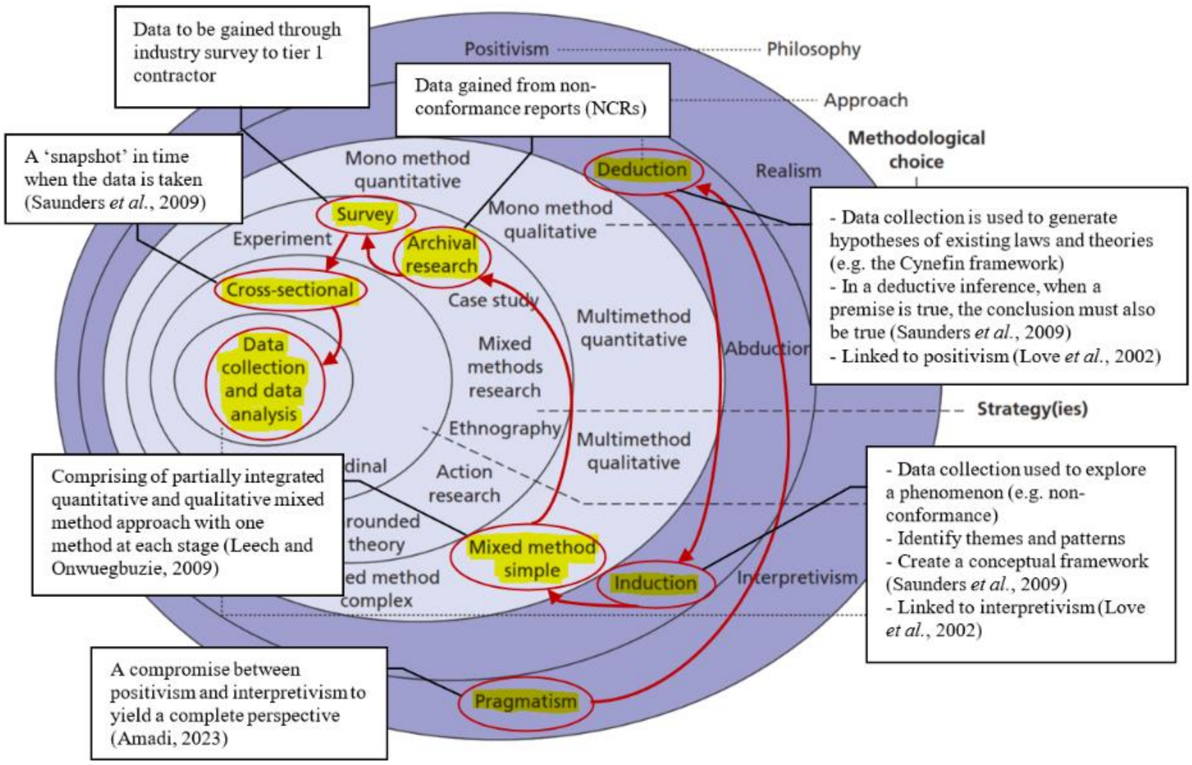


Figure 3.2 – Research approach adopted within thesis. Adapted from Saunders *et al.* (2009).

Pragmatism is adopted for the thesis to strengthen the research outcomes through a blend of positivism (quantitative) and interpretivism (qualitative) methods (Dainty, 2008; Scott, 2016; Chan, 2020). A combination of both methods provides a more powerful, rounded argument and greatly improves the research outcomes (Gable, 1994). Elements of deductive and inductive reasonings are instilled, with the former, 'deduction', to proposition existing frameworks or theories of decision-making and knowledge management (i.e. the Cynefin framework), and the latter, 'induction', to use archival secondary data to explore a phenomenon, identify trends and conceptualise a framework. Specifically, a partially integrated mixed method approach is selected, where one method is deployed at each stage of the research design (Leech and Onwuegbuzie, 2009). This is in the form of cross-sectional 'archival data' (i.e. non-conformance report data) and a 'survey' (i.e. industry questionnaire), requiring the interaction with one or more epistemological position to satisfy the thesis aims (Saunders *et al.,* 2009).

3.3 Research strategy and design method

3.3.1 Methodological path

This study is built upon a foundation of non-conformance report data drawn from a specific source (A14 Huntingdon Improvement Scheme), challenged against the general body of knowledge and industry professional perceptions of how construction is managing quality, to draw a universal conclusion. This A14 Huntingdon Improvement scheme was chosen for the following reasons. First, it is the current largest highways scheme to be built in the UK, referred to as a 'megaproject', costing approximately £1.45bn. Second, the author was an integrated member of the scheme with extensive project knowledge and unrestricted access to quality failure information and supporting evidence (i.e. NCRs). Third, the robust implementation of NCRs on the scheme enhanced the reliability, credibility and validity of the data to be analysed (see Section 3.4.1). Fourth, other projects were considered, but deemed unsuitable as companies are typically unwilling to share sensitive information for fear it may be analysed negatively with potential retribution (Calantone and Vickery, 2010). This has been seen throughout the industry with contractors hiding non-conformance costs and not record them for fear of the reputational damage both as employees and as seen by clients (Abdelsalam and Gad, 2009). The author had been unsuccessful in previous requests to gain access to detailed NCR outputs through other companies (i.e. no response). Fortunately, the A14 project was part of the authors parent company portfolio, and access was a formality. Fifth, the aim of this research is to find solutions to the parent company's' problems with their schemes to drive continuous improvement. Figure 3.3 describes the methodological route taken in the research which expands on the original conceptual roadmap within Figure 1.1.

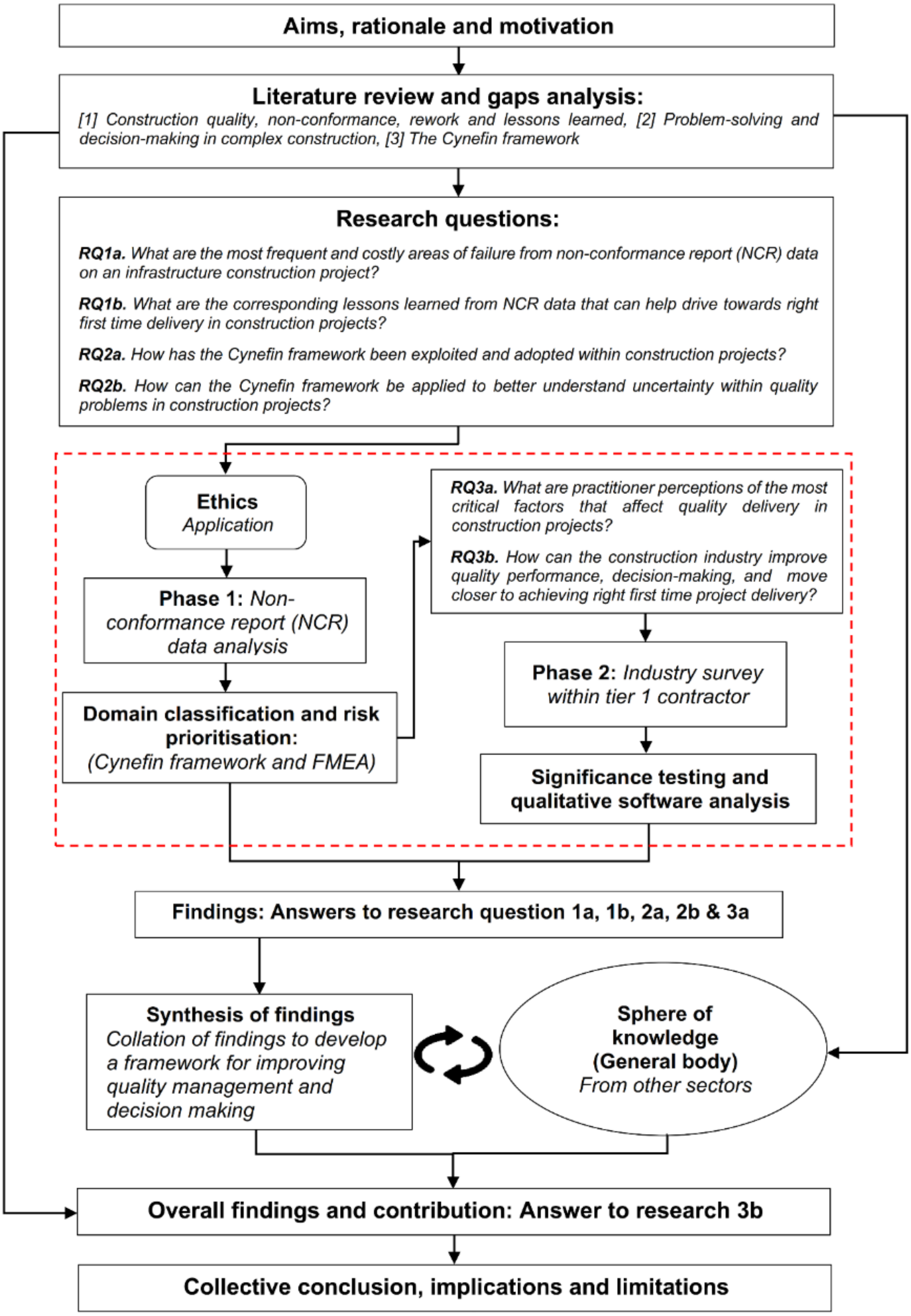


Figure 3.3 – Strategic route in methodological form.

Following the literature review, gaps in knowledge are identified and research questions are established prior to any data analysis. Two empirical data streams are identified as opportunities to understand the impact of quality with construction. These have been split in two phases, beginning with a quantitative data analysis exercise then transitioning into the qualitative exercise. This has been done for the following reasons. First, quantitative information is likely to be more easily integrated into quality problem representations than the other way around (Ploetzner *et al.,* 1999). Furthermore, quantitative data can help with the qualitative design by finding a representative sample and locating deviant areas for discussion that will explicitly support the meaning of quantitative research (Amaratunga *et al.,* 2002). Second, those that are initially taught quantitative methods may fail to realise that qualitative problem representations play a crucial role in quantitative problem solving (Ploetzner *et al.,* 1999). Instead, they exclusively focus on quantitative problem representations without paying attention to the qualitative themes within. Third, as the author seeks to understand what professionals think of quality delivery through non-conformance and rework findings, statistically representative data will enable the researcher to decide whether or not it is necessary to conduct a survey on a particular area or topic (Brannen, 2017). Ivankova *et al.* (2006) concludes a better result is made more likely through taking a mixed method approach instead of taking a singular research methodology approach, but stress the importance of beginning with quantitative methods and following up with qualitative exercises. It is the researcher's belief that quantitative findings through a uniquely rich dataset will provide depth to the qualitative study and allow the researcher to bolster quality-related questions around the analytical findings. Then, sharing the survey with two professional groups of varying levels of expertise and seniority within a tier 1 contractor, will give breadth and enrich the overall research. This approach will also help triangulate the findings to reach a coherent result through existing literature, quantitative data and qualitative data (Jick, 1979). Within construction management, triangulation is considered highly appropriate for extending the scope of rework theory research by leading academics (Love *et al.,* 2002, Dainty, 2008).

For this research, Phase 1 outcomes are compared with Phase 2 outcomes to yield a collective hypothesis that is then presented to answer research questions generated through the detailed literature analysis, which helps provide a complete ‘real world’ perspective and close the triangle (Yin, 2015).

- ***Phase 1*** entails the collection, cleansing, interrogation and analysis of non-conformance report (NCR) data to understand current failure avenues that require intervention. Further domain classifications are assigned in order to understand decision-making of quality problems by comparing real-time (i.e. what was actually done) and retrospective (i.e. what could have been done) action pathways for each case using the Cynefin framework. Lastly, failure mode and effects analysis (FMEA) is undertaken to understand the risk prioritisation of each action pathway (Stamatis, 2003).

- ***Phase 2*** systematically follows the NCR data analysis and complexity categorisation, whereby findings are translated into a series of questions posed to industry professionals in the form of an online survey questionnaire within a tier 1 contractor.

Figure 3.4 demonstrates the research bottleneck within the thesis to show the consolidation of a large dataset down to a number of key outcomes that will pass through the bottleneck and into an industry survey consisting of quantitative and qualitative questions.

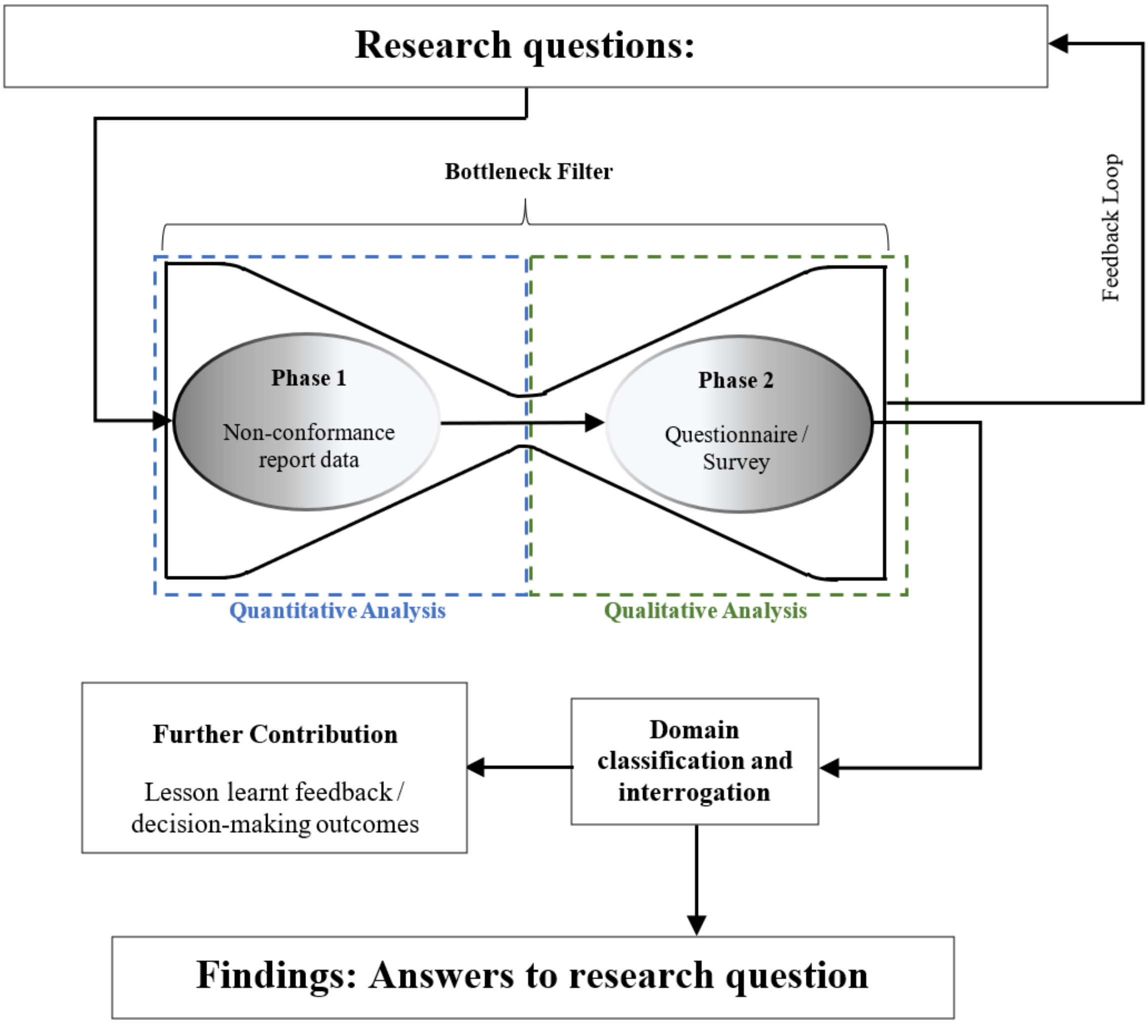


Figure 3.4 – Phase 1 to Phase 2 research bottleneck filter.

Prior to sourcing or analysing any data, ethical arrangements must be made for each phase.

3.3.2 Ethical implications and considerations

This section discusses the important ethical considerations that were made prior to conducting the research. There were two key areas that required careful deliberation to ensure ethical processes and standards set by both Costain and Cardiff University were followed.

The first involved the quantitative aspect of the research (i.e. the non-conformance data) which contained sensitive information relating to the individual who raised the

NCR (i.e. name, email address etc). These fields were hidden from the outset to ensure the inputs remained strictly anonymous to prevent the individual being criticised or blamed for their contribution to the database. To gain acceptance to use the NCR data for the betterment of the research, the author set up detailed discussions with project lead to discuss the intent, aims and benefits of participating. Following this, a request to use email was drafted and issued (Appendix 1).

Secondly, the survey required similar protection. As such, no personal information was disclosed during the questionnaire/survey process. Furthermore, refusal to participate in the survey would not result in any negativity or scrutiny (Hansson, 2006). On the contrary, willingness and enthusiasm to participate are positive traits to receiving open and honest feedback which yield more accurate results.

To bring this approach into action, an 'agreement to participate' statement needed to be generated in which the participant would accept the terms of the questionnaire. A generic email template was constructed with the terms of participating in the survey and the following statement:

> *'Participation in this study is entirely voluntary and you can withdraw any time without giving reason. The information provided by you will be processed and analysed for the purposes of ascertaining correlations and trends that can positively influence the business (Costain group plc). The data will be held confidentially, securely and will only be used for the purpose of this research. Furthermore, all participant names will not be disclosed and will remain confidential following the research outcome.*
>
> *You hereby confirm that you agree with the above and that only the researcher himself can trace the information provided back to you individually. The storage and analysis of this research related data is in accordance with the legal requirements.*
>
> *By clicking on the "I Agree" button below you will gain access to the questionnaire which will take approximately 15 minutes to complete.*

If you have any queries, you can contact the responsible researcher under:

Employee email - Gavin.ford@costain.com

or

University email - FordG9@Cardiff.ac.uk'

I Agree

Upon clicking the 'I Agree' tab, the participant was given access to the online questionnaire via a hyperlink. In doing so, it was possible to resolve the issue of informed consent, where participants must be fully informed about the background and context of why the questionnaire is being proposed and the potential risks of the research (Couper *et al.,* 2008). Furthermore, as the questionnaire was conducted internally within Costain, it explained details of the quantitative data collection and analysis process so as to provide clarification of its origin. Lastly, as the proposed software application (Microsoft Forms) automatically requests the name of the participant, a confidentiality clause was inserted into the questionnaire stating the following:

> *'Although the researcher will be supplied with details of each participant completing the questionnaire, this information will remain confidential at all times and only used to validate the individual's participation. As such, all feedback will remain strictly anonymous during the research by the PhD candidate. By completing the questionnaire, you agree to participate in this research for the benefit of Costain Plc and the wider construction research community.'*

To be absolutely certain of anonymity, all data within this study is presented in aggregate form which makes the identification of an individual impossible.

Adherence to the above process makes it far easier to follow good research practice and prevent any unnecessary negative outcomes. Factoring in that all participants consenting to the questionnaire survey would be employees within Costain and that the dataset has come from a Costain delivered scheme, adhering to the process made it far easier to comply with Cardiff University's formal research ethics process.

In addition to protecting ethical implications within Costain, Cardiff University's ethics approval process was prepared for in two parts:

Cardiff University ethics submission part 1 – Quantitative NCR data

For the quantitative data, a detailed ethics application was generated for the gathering and analysis of non-conformance report data from a major highways scheme. Consideration was made on the type of data to be obtained and whether it would contain sensitive personal information. The author had foresight of the database to understand that the only sensitive information was the raiser's name and company email address, both of which were detailed in the ethics application. Approval from the universities ethics committee can be found in Appendix 2.

Cardiff University ethics submission part 2 – Qualitative survey data

As part 1 of the ethics application focused on NCR data analysis, a further application was presented to Cardiff University's ethics committee, detailing a proposal to conduct a further survey within the author's parent company. The proposal captured the requirement to use NCR outcomes from Phase 1 and present them to industry professionals in a series of questions for feedback. Further approval from the university committee was granted prior to issuing the survey (Appendix 3).

3.3.3 Informed Consent

Informed consent is considered a primary ethical issue when conducting research involving human participants. Informed consent is the process whereby the research is explained to the individual prior to participating. The individual is briefed on elements of the research such as their role and how the research will be conducted. They are provided with as much information as they need in order to make an informed decision of whether to participate or not. Hansson (2006) notes that 'informed consent is associated with individual veto power, but it does not appear realistic to give veto power to all individuals who are affected for instance by an engineering project'. Ideally, informed consent is achieved in writing through a project document explaining the aims, objectives, process of the research, confidentiality and anonymous agreement, as well as the rights of the participant to withdraw at any stage. A dialogue channel is then to be established to regularly update the individual on progress, should they require further information or to discuss associated risks involved in their participation.

In addition, requirements established by the CARBS ethical committee require all participants in the study be provided with both the university's ethics consent form and an access letter (See Appendix 2 and 3), prior to any engagement. These were sent via email to each participant for signature, with the informed consent parameters highlighted. Furthermore, to ensure complete clarity, a verbal telephone discussion was conducted with each participant to field any questions or concerns they had prior to signing.

Once the ethical arrangements were formulated, the quantitative data analysis phase could begin.

3.4 Phase 1 – Quantitative data analysis of NCRs

As part of a project's governance, assurance and improvement model for quality, NCRs are seen as a requirement for capturing non-compliance within process or product delivery, but also as a way of learning from and mitigating the risk of a future recurrence.

Gaining access to NCR data is often challenging as it represents poor quality performance which many project teams are unwilling to share (Buchanan *et al.,* 2013). Non-conformance often has a stigma of substandard performance and poor quality delivery, which is typically linked with a negative blame culture. They often hold commercially sensitive information such as estimated costs of correction, which inhibits information sharing even further. As a result, this information is categorised as sensitive by project and commercial managers and placed in the archives with very little interrogation (Calantone and Vickery, 2010). This is unfortunate from a learning perspective, as to improve, develop and innovate, we must learn from our mistakes rather than simply acknowledging they exist. Similar concerns are discussed by Abdul-Rahman *et al.* (1996) where they conclude that 'by learning from the results, those involved in the industry can reduce the impact of non-conformance'. On the contrary, the researcher argues that non-conformance reporting should be used more positively and proactively to drive continuous improvement. Projects should regularly analyse real-time non-conformance against risk management profiling to identify potential recurrence, negative outcomes, and opportunities for learning.

Prior to analysing the NCR dataset, a sub-research design was required to establish a clear path from data consent to use data through to learning outcomes. Figure 3.5 demonstrates the path followed by the author to assure stability along the quantitative journey.

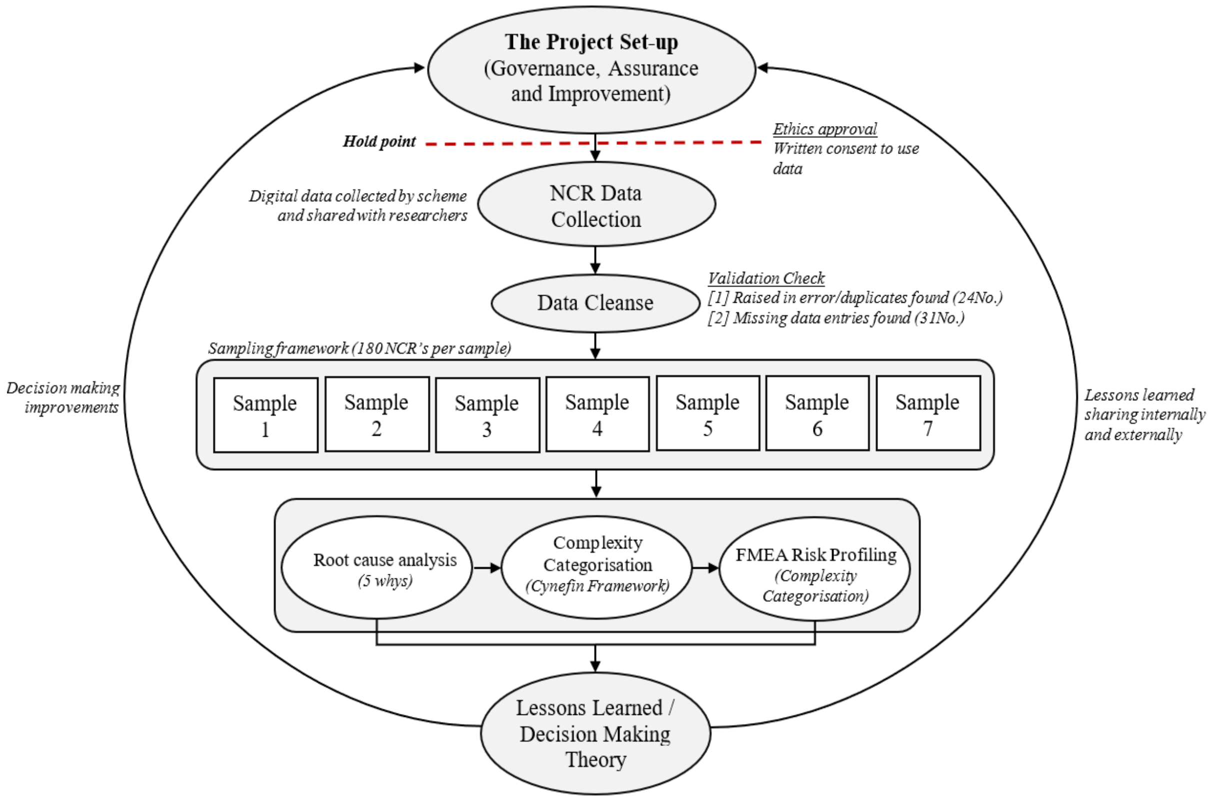


Figure 3.5 – Sub-research process for quantitative study.

Further context, detail and justification of each step within the above process is provided in forthcoming sub-sections.

3.4.1 Written consent to conduct quantitative exercise

Providing consent to use data is a vital step for researchers. Encompassed within the ethical submission, written consent had to be obtained from the A14 project owner, granting access and permission to the project digital system along with consent to interrogate the data.

To promote right-first-time within their organisation and its joint venture partners, the UK's largest highways project commissioned a research exercise to investigate and learn from a rich non-conformance dataset to provide meaningful inputs that can be shared on future schemes. As such, an email was sent to the project director seeking approval. Furthermore, the author, as a member of the A14 integrated delivery team (IDT) who had login details to the data hub, access was a formality pending approval. Written consent was obtained electronically by email (due to COVID-19 restrictions) on 05/02/2021 as shown within Appendix 1, at which point the data collection process could begin.

3.4.2 Non-conformance data collection: 'the dataset'

The data is gathered from a highways megaproject in the UK, led by a joint venture (JV) cohort. Three parent companies, sharing similar strategies for growth and continuous improvement, were contracted to deliver the £1.5bn A14 Cambridge to Huntingdon improvement scheme, consisting of upgrades to 21 miles of existing infrastructure for client, Highways England. Collectively, the JV partners (Balfour Beatty, Costain and Skanska) have over 62,500 employees worldwide, with a multitude of experts in various disciplines including transportation, nuclear, oil and gas, water and aviation. Each party understood the benefits of a collocative JV/client partnership. Table 3.2 summarises the principal benefits for both parent companies and client alike.

Table 3.2 – Principal benefits in the joint venture/client partnerships.

Parent companies	• Improvements to processes resulting in streamlining • Future foresight of potential risks that could affect quality • Improved understanding for areas of uncertainty (*risk*) • Greater resilience in JV partnership arrangements • Enhanced accuracy for future tendering
Client	• Increased understanding of project failings to support development of new approaches • Can use data to assess where funds are best spent • Improved working relationships with parent companies striving to achieve right-first-time (*trust and collaboration*)

The major benefits all parties gain from this research originate in using archival data obtained through the operational lifespan of a major highways scheme.

In order to meet client commitments of driving continuous improvement, an initiative was established to understand the state of play with quality execution through the scheme's design and build lifespan. As such, Business Collaborator (BC), an information management software, was deployed to record non-conformance activities through design and construction, until the point of handover.

To successfully promote collaboration on the scheme, the project was stripped of parent company logos and rebranded as the integrated delivery team (IDT). As a result, a highly collaborative atmosphere was formed to reward quality performance. One major outcome was the development of a stringent NCR process that could record and close out any non-conformities found during design and construction. Data was manually entered via an electronic template which consisted of a seven-stage gate process with multi-level sign-off that involved the responsible contractor, principal contractor, client and, in many cases, the designer. Figure 3.6 describes the process as follows:

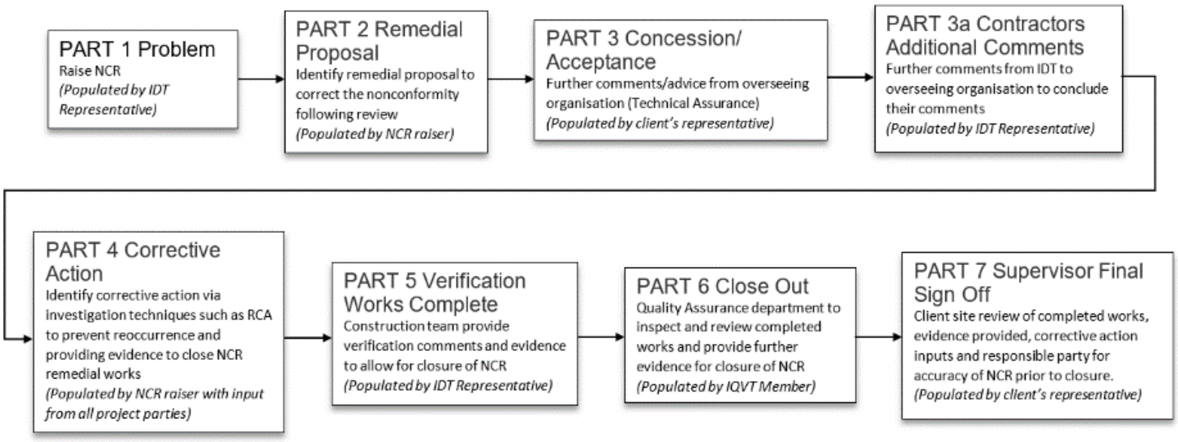


Figure 3.6 – Non-conformance reporting gate process used on highways megaproject

Parts 1, 2, 3a, 4 and 5 were completed primarily by the IDT with input from suppliers as required, and part 6 was completed by the independent quality assurance team who would verify the remedial works against set standards. Parts 3 and 7 were completed by the client to achieve consensus of each NCR remedial action, corrective action, responsible party and associated cost. Furthermore, costs were calculated by the IDT, factoring in administrative time, RCA time, implementation of remedial works and corrective action to prevent reoccurrence. These were then validated by the quality team and client sequentially. Lastly, to ensure validity and consistency of each input, the digital database was regulated independently by the Integrated Quality and Verification Team (IQVT) to log evidence such as meeting minutes, further investigations (e.g. deep dives) and RCA conclusions. Upon closure of part 7, the non-conformity is archived into the project health and safety file, where it is referenced against the relevant as-built and O&M documentation.

For the purpose of this research, all non-conformities are considered, regardless of their overall stage status. Root cause analysis can still be undertaken on any issue with a problem pattern (Battikha, 2008). To that end, 1260 non-conformance reports over a 60 month construction period (from 21/12/2016 to 20/01/2021) were supplied by the scheme for analysis.

3.4.2.1 Bias inputs and data reliability

Potential for bias was considered and acknowledged upon receipt of the data. First, although the researcher had a deep contextual knowledge of where the information had come from and how it was collected, the NCR process was established for the purpose of project improvement and early identification of non-compliant works, therefore its creation is entirely independent of any research consideration (Calantone and Vickery, 2010). This enhances the credibility of the data received on the premise that the researcher could not have influenced data entries. Second, each NCR had to undergo a collective agreement via a rigorous seven-gate sign-off process, thus removing opportunity for bias and only limiting data collection to factual information. For example, if the client differed in opinion of remedial solution or underlying cause, they could challenge the contractor with a question or request further information using part 3 of Figure 3.6. Third, the project benefited from a strong leadership team who advocated for continuous improvement and the benefits of raising NCRs. This in turn bred a nurturing environment to express honest feedback. These three points strengthen the reliability of the data presented to the researcher and reduce the opportunity for biased opinions within the dataset.

3.4.3 NCR Data Cleansing

Prior to analysing the non-conformance data, an important step was to ensure the information had been suitably cleansed from human error and other anomalies. As data is typically entered manually on projects, the entry and acquisition process is prone to human error (Maletic and Marcus, 2000). Unless drastic steps are taken from the outset, data errors will manifest throughout the process, typically yielding error ranges of 5% or more. (Orr, 1998; Redman, 1998). As such, a cleansing approach is vital for weaning out errors and repairing data as necessary.

The data cleansing process commonly consists of three phases:

1) Define and determine error types

2) Search and identify error instances

3) Correct the uncovered errors

Each phase has a set of methods and technologies associated with it. Examples of general methods that can be utilised for error detection are found within Table 3.3.

Table 3.3 – Data cleansing methods (attributes, positives and negatives).

General Method	Attributes	Positives	Negatives
Statistical outlier detection	Identifying outlier fields and records using the values of mean, standard deviation, range, etc	• The number of standard deviations to be considered is customizable • They are mathematically justified and if a probabilistic model is given, the methods are very efficient and it is possible to reveal the meaning of the outliers found • Often presented in a compact form, makes it possible to detect outliers without storing the original datasets that are usually of large sizes	• They are unsuitable even for moderate multi-dimensional data sets • Lack of the prior knowledge regarding the underlying distribution of the dataset makes the distribution-based methods difficult to use in practical applications • Quality of results cannot be guaranteed because they are largely dependent on the distribution chosen to fit the data
Pattern-based	Identify outlier fields and records that do not conform to existing patterns in the data. Combined techniques are used	• Can improve the consistency and quality of information, whether it is persisted in a database or processed by an application	• Real life data proves to be highly un-uniform and difficult to identify patterns
Clustering	Identify outlier records using clustering based on Euclidian (or other) distance	• Can examine the relationships between both internal and external factors • Good for grouping similar objects into subsets, so that the data in each subset according to some defined distance measure	• Computational time is excessive and prohibits multiple runs in an everyday business application, on larger data sets • Clustering algorithms have high computational complexity
Association rules	If/then statements that help discover relationships between seemingly independent relational databases or other data repositories (Can deal with data of different types)	• Can deal with data of different types • The method can be extended to find other kind of associations between groups of data elements	• Various rules that can be interpreted differently, yielding different results

For the purpose of the quantitative analysis, the dataset had to go through a series of changes to remove inaccuracies brought about by human errors. First, a standardisation exercise was conducted to match each NCRs discipline to the

Specification for Highway Works (SHW) series. For example, all NCRs categorised under discipline ‘Earthworks’ were re-categorised as ‘Series 600 – Earthworks’. Another example would be ‘Kerbing’ changing to ‘Series 1100 – Kerbs and Footways’. By doing this, each NCR could be mapped against a set of industry-wide standards used for highway construction work. Second, the ‘responsible contractor’ column within the dataset was reviewed against the project’s supply chain resource and works allocation table to ensure that each NCR correctly identified the party responsible for completing the works. Without doing this, the NCRs could cast blame on parties that had no involvement in the non-conformant works. Finally, the dataset columns were reorganised into a logical sequence for ease of reading and undertaking the analysis, starting with the problem, apparent cause, agreed root cause, remedial proposal, corrective action and lastly close out comments with cost. Additional columns were introduced in the form of ‘5 whys’ root cause analysis (RCA) to allow the researcher to make a retrospective assessment of the non-conformance cause by asking ‘why?’ five times and formulating a response (Ohno, 1988). In order to conduct a real-time versus retrospective outlook of quality problem solving and to understand whether problems were being correctly assessed, four final columns were constructed. These were ‘perceived complexity’ (*real-time decision-making*), actual complexity (*retrospective decision-making*) and ‘lessons learned outcome’ to support prevention of future occurrence.

An important part of cleansing the dataset is to simplify it into a digestible format ready for analysis. To do this, two further tasks were completed. First, any information deemed sensitive (e.g. names, role, employee number, email addresses etc) were hidden, so as not to influence the analysis process. This also protected the individuals if the data was accidentally shared with others (e.g. via a presentation). To that end, all columns within the Excel spreadsheet were cross checked against said criteria and logged within Table 3.4 below.

Table 3.4 – The removal of sensitive information from the dataset.

Column Number	Description	Reason / Justification
T **X**	Raised By (Name) Remedial Proposed By (Name)	All columns that share names of project employees were hidden from view to remain

AB **AF** **AL** **AQ** **AU**	Concession By (Name) Contractors' Comments (Name) Corrective Action (Name) Verification By (Name) Closed Out By (Name)	impartial and have complete anonymity during the data analysis process.
U **Y** **AC** **AG** **AM** **AR** **AV**	Raised By (Role) Remedial Proposed By (Role) Concession By (Role) Contractors' Comments (Role) Corrective Action (Role) Verification By (Role) Closed Out By (Role)	Roles of the personnel that correspond to the names in the columns above were also hidden for the same reason. The research is a member of the A14 team who knows the majority of personnel on the scheme and could determine the person by role.

As the data was collected via an online digital system, columns were created automatically with less relevant information. For example, when completing an NCR form submission, it gives the user opportunity to attach evidence such as photos or other supporting documents. A typical representation of this on the dataset may be in the form of '3.8E+0.8'. For the purposes of the NCR data analysis, this information is irrelevant and required hiding. There were other columns that provided little information to help the analysis. These columns were also hidden to simplify the spreadsheet into a digestible format (Table 3.5).

Table 3.5 – Hiding irrelevant information from the dataset.

Column Number	**Description**	**Reason / Justification**
F	Completion Package No.	Contains information purely for handover series (Column E more relevant)
H	Subcontractor ref. / N/A	The contractor tab (Column B) has been adjusted to make reference to the correct supply chain rending this column redundant
K	Attached Documents	No attachment. Irrelevant
L	Date Proposed Close Out	Date Irrelevant
U	Remedial Proposal Attachment	No attachment. Irrelevant
Z	Concession Attached Documents	No attachment. Irrelevant
AE	Contractors Comments Attached Documents	No attachment. Irrelevant
AP	Verification Attachments	No attachment. Irrelevant
AX	Closed Out Attachments 1	No attachment. Irrelevant
AY	Closed Out Attachments 2	No attachment. Irrelevant
AZ	Closed Out Attachments 3	No attachment. Irrelevant
BA	Concession Attached Documents	No attachment. Irrelevant
BB	Remedial Proposal Attachment	No attachment. Irrelevant

Once the dataset had been simplified into a sequential format for analysis, three further data cleansing exercises were conducted (Figure 3.5). First, to correct notable human errors, such as grammatical mistakes, the spell check function was used. Second, a numerical validation check was conducted to identify duplicate or missing NCR fields within the dataset. As a result, the researcher encountered 24 cases whereby duplications of the same NCR had been raised or raised in error for training purposes. Furthermore, there were 31 cases whereby the non-conformance data entry was missing from the data export altogether. Both cases were classified as 'Example/Duplicate' and discounted from the analysis. Moreover, there were 12 NCRs that contained little information to accurately conclude the root cause of the problem. As such, these were categorised as 'Unclassified' and similarly discounted from the analysis. Third, the identification of plausible root causes for construction schemes was developed ahead of RCA categorisation. An initial root causes list was supplied within the dataset, however, it appeared incomplete. By cross checking other literature against root causes identified by the project, e.g. the thirteen categories classified within Abdul-Rahman *et al.* (1996), eight categories described within Josephson and Hammarlund (1999), and twenty-three rework causes identified by Asadi *et al.* (2023) through the body of literature, twenty-four primary root cause categories with seventy-eight sub-categorise and one-hundred-nineteen sub-cause types were formulated to capture all root cause possibilities (Appendix 4). Following the data cleansing and category allocation process, a sampling framework was devised prior to the commencement of the quantitative analysis.

3.4.4 Sampling method

Due to the quantity of non-conformance data (approximately 1260 non-conformance reports), sampling methods were considered. 'Sampling' is the process of selecting 'a portion, piece, or segment that is representative of a whole' (The American Heritage College Dictionary, 1993, p. 1206). Onwuegbuzie and Collins (2007) express that sampling 'helps to inform the quality of inferences made by the researcher that stem from the underlying findings', whereas Bauer and Aarts (2000) summarise that 'sampling secures efficiency in research by providing a rationale for studying only parts of a population without losing information'. Although Onwuegbuzie and Colins (2007) raise concerns regarding the quantitative sample size that is being analysed by noting 'the majority of quantitative studies utilize sample sizes that are too small to detect statistically significant differences or relationships', this research project examines in excess of 1000 non-conformances, therefore, these concerns are not valid.

3.4.5 Sample frame

To ensure the data was selected without bias, a 'sample frame' was introduced. Defined as a list from which samples will be drawn to represent the population (Stasny, 2015), the sample frame typically consists of two broad sampling avenues with various sampling techniques (Figure 3.7).

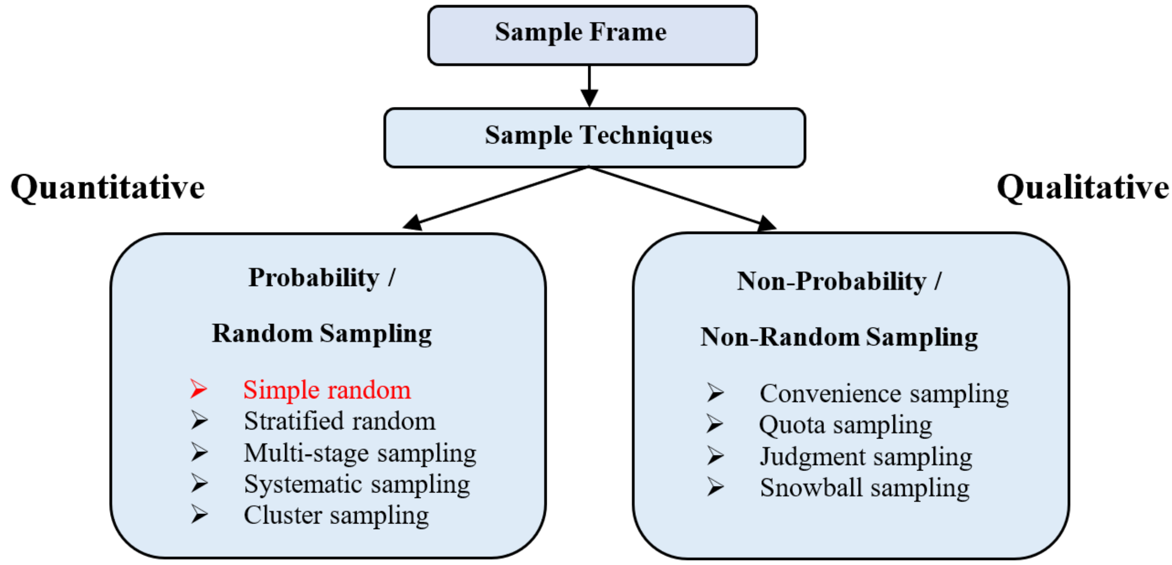


Figure 3.7 – Sampling techniques. Adapted from Taherdoost (2016)

Probability or random sampling is a technique where each sample has an equal probability of being chosen. Each unit included within the sample will have a certain, pre-assigned chance of inclusion (Singh and Masuku, 2014). A sample chosen randomly should also enhance the unbiased selection of data for analysis (e.g. the lottery).

Non-probability or non-random sampling methods are those where elements are chosen according to preference for inclusion into the research study. In contrast to probability sampling, grounded theory can be produced through iterative non-probability sampling until theoretical saturation is reached (Strauss and Corbin, 1998). These include snowball sampling and convenience sampling (Kandola *et al.,* 2014).

Considering each sample frame, a probability/random sampling was deemed most suitable for analysing large digital datasets. Specifically, a 'simple random' method was chosen as it has the greatest freedom from bias (Taherdoost, 2016). However, the downside is that it can be the most-costly sampling approach, in terms of time and energy for a given level of sampling error (Brown, 1947). The researcher concurs with this premise, as a completely randomised sample would sever any bias behaviours affiliated with the data being selected. As such, a random number generation computer programme was selected to sample the non-conformities (Zikmund, 2000). Specifically, https://www.randomizer.org/ was used as an appropriate random number generator with answers to characteristic questions listed within Table 3.6.

Table 3.6 – Random number generator criteria. Source: https://www.randomizer.org/.

Characteristic questions	**Value**
How many sets of numbers do you want to generate?	7
How many numbers per set?	180
Number range	From: 0 To: 1260
Do you wish each number in a set to remain unique? *Selecting "Yes" means that any particular number will appear only once in a given set.* *Selecting "No" means that numbers may repeat within a given set.*	Yes
Do you wish to sort the numbers that are generated?	No
How do you wish to view your random numbers? *Place Markers let you know where in the sequence a particular random number of falls by marking it with a small number immediately to the left* *Place markers off – (e.g. Set #2: 5, 3, 42, 18, 20)* *Place markers within – (e.g. Set #1: p1=5, p2=3, p3=42, p4=18, p5=20)* *Place markers across – (e.g. Set #1: p1=2, p2=17, p3=23, p4=42, p5=50 ; Set #2: p6=5, p7=3, p8=42, p9=18, p10=20)*	Place Markers within
RANDOMIZE NOW!	

Once the values were inputted into the randomizer, the dataset was randomly split into seven equal, whole number portions, each containing 180 NCRs, to ensure the sample was not being selected according to preference by the researcher.

Data saturation is an effective way of understanding the point at which all relevant concepts have been identified and no new insights will be encountered (Gugiu *et al.,* 2020). For large datasets, it is often an unavoidable task due to time and cost constraints. Splitting the dataset into manageable chunks allows parts of the dataset to be analysed to 'saturation'. Using fewer sample sets was considered, however, this would have increased the number of NCRs within each set, and thus resulted in it taking longer to analyse each set before moving onto the next. The hope was to identify trends and patterns between the first few sets, so as to conclude the analysis at the earliest opportunity. A sample set containing less than 200 non-conformance entries was deemed appropriate. Fortunately, there was sufficient time to complete the analysis in full, which allowed for a more detailed analysis and increased the significance of the data outcomes (Onwuegbuzie and Collins, 2007). In conjunction, the random number selection tool was followed for the entire dataset, to ensure the process remained consistent and impartial.

3.4.6 Root cause analysis of the NCR data

Root cause analysis (RCA), if done correctly, is a powerful tool for uncovering underlying causes and suggesting appropriate remedial and corrective actions to solve them. The process is designed to investigate and categorise the root causes of events, not only with quality problems but within safety, health, environmental, reliability and production impacts too (Rooney and Heuvel, 2004). There are many RCA techniques and tools that can be used for the purpose of problem solving. Typically, they can be followed as a process, beginning with brainstorming, then involving collection, analysis, identification, elimination, and finally, implementation (Anderson and Fagerhaug, 2006). Figure 3.8 shows each RCA stage with its corresponding tools and techniques.

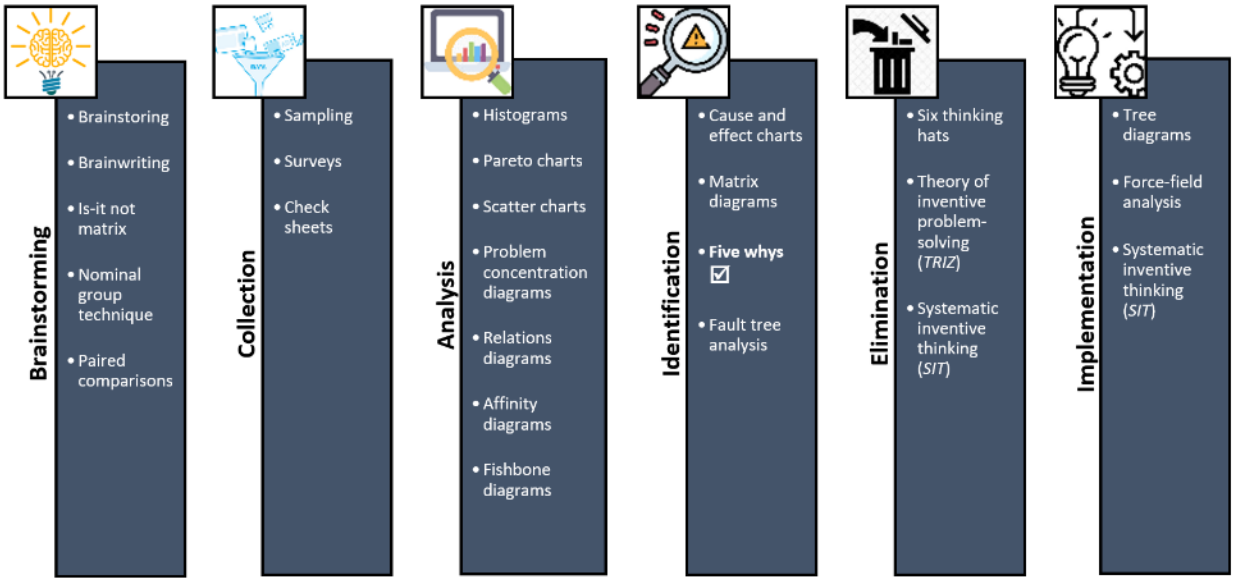


Figure 3.8 – RCA techniques and tools. Adaptation of Andersen and Fagerhaug (2006)

For the purposes of this research, we bypass 'brainstorming' and 'collection' as these were methods created by the scheme supplying non-conformance report data. For example, data was collected by the project using a 'check sheet' non-conformance report process. Before we analyse trends within the data, root causes are redefined to conclude their accuracy from the information supplied within.

3.4.6.1 Application of the '5 whys'

According to Anderson and Fagerhaug (2006), there are four fundamental tools that can be used to identify root causes of problems (Figure 3.8, column 4). Considered one of the most effective RCA methods, the '5 whys' is an iterative interrogation technique which has proved highly effective and powerful for quality problem solving (Murugaiah *et al.*, 2010; Lindhard, 2014; Gangidi, 2018). Taiichi Ohno, the father of Toyota's Production System (TPS) considers the '5 whys' his favourite tool for problem solving (Ohno, 1988). The technique attempts to delve deeply into causal relationships and locate the root cause of a problem by asking 'why?' five times in succession, until an actionable cause is reached (Tsao *et al.*, 2004; Leino and Helfenstein, 2012). In some cases, there are obvious links to cause-and-effect relationships which allow the investigator to conclude an accurate cause in fewer than five 'whys'. In other cases, the cause-and-effect patterns are less obvious and more than five ‘whys’ will be asked until a root cause is revealed (Jones and Despotou, 2016). In isolated cases, we are simply not able to uncover a true root cause, as a result of the information presented before us.

To that end, each non-conformance within the dataset was challenged with the ‘5 whys’ technique to assess the accuracy of root causes and corrective actions identified by the project.

3.4.6.2 Interpretation and validity of retrospective root cause analysis

Interpretive validity of the retrospective RCA was considered and rationalised as follows:

First, the author is a chartered quality professional of the Chartered Quality Institute (CQI) with over 13 years of experience in engineering, quality and handover management. He is highly trained in undertaking root cause analysis techniques, and has participated in a number training events with various organisations during his career. In addition, the researcher has provided training sessions to others on the application of the ‘5 whys’ method, as well as fishbone and Pareto analysis. This satisfies the knowledge and competence criteria to correctly enforce RCA methods.

Second, to enhance the retrospective interpretation, NCRs that yielded a different retrospective root cause to the root cause yielded by the project were discussed and validated by existing senior members of the project, who had strong, detailed understandings of the non-conformities. Specifically, those with extensive experience and an appreciation of the necessity of honest feedback for the purposes of continuous improvement were selected. In total, there were five volunteers, consisting of an engineering manager, a quality manager and three engineers, who offered assistance in explaining why the project concluded the NCR as they did. For these cases, emails were exchanged with the appropriate professional in order to provide a rationale or agreement with the revised (retrospective) conclusion. This was followed up with a phone call to agree the most appropriate outcome to be inserted into the retrospective root cause field. If an agreement had not been reached with the primary contact, a secondary contact was approached to give an additional, impartial view. The researcher's detailed knowledge of the scheme allowed for the selection of appropriate primary, secondary and tertiary contacts.

Third, the information within the dataset was comprehensive at the time it was provided for analysis, moreso than during the construction phase. The documents contained more freely available information for assessing each NCR, than was available at the time of the initial assessment, as evidence had since been provided and conclusions reached. The researcher was therefore in a stronger position than the original project team to assess the NCR as a whole.

3.4.7 Complexity categorisation of quality problems

Recapping on the literature, the construction industry is becoming an increasingly complex environment and decision-making is a fundamental step to keeping projects aligned (Flyvbjerg, 2005). However, Forcada et a. (2014) note that managers not being given all the information and are often left with making decisions prematurely. The uncertain conditions and unknown risk profiles are leaving key decision-makers oblivious to the harsh reality that faces them (Ahiaga-Dagbui and Smith, 2014). Complex project problems in particular have seen the influence of lean practices but with mixed success as a result of site variance, behavioural influences and unforeseen weather events not seen in more controlled environments such as manufacturing (Tezel *et al.,* 2018). Spiro *et al.* (1996) determine that oversimplification under complexity is more common than not within cognitive decision-making. The need to simplify a situation rather than embrace the complexity of a problem is likely to have an adverse effect on decision-making, particularly with quality problems (i.e. non-conformance). Battikha (2008) concluded the need for greater systematic analysis of decision-making processes to help drive organisational improvement. To understand whether quality problems are being oversimplified, the decision-making process of non-conformance reports is interrogated through a before (real-time) and after (retrospective) comparison of decision-making to address an NCR.

To interpret the decision-making processes, a complexity ruling was devised to link cause-and-effect relationships through RCA against the Cynefin framework domains (Kurtz and Snowden, 2003, Snowden and Boone, 2007).

The Cynefin framework was chosen for the following reasons. Firstly, the decision-making framework is highly regarded amongst the academic community and used extensively across various sectors including healthcare and the military with significant benefits noted (Hanafizadeh and Bahadornia, 2023). It offers support to managers to understand the complexities and conditions they find themselves in and enable decision-makers to adaptively monitor and re-evaluate the organisational landscape as changes occur (Snowden, 2021). Furthermore, the framework has been recognised for its impact into decision theory and seen to offer a deeper theoretical explanation about the nature of alignment (Alexander *et al.,* 2018; Naim *et al.,* 2022). Secondly, there has been lack of its application within the construction sector from the extensive literature review undertaken, therefore, the researcher seeks to understand its impact and suitability for quality decision-making in highways schemes, particularly non-conformance and rework cases. Third, the framework consists of ordered (simple and complicated) and unordered (complex and chaos) domains that follow cause-and-effect relationships across varying levels of complexity and uncertainty. It would therefore seem plausible to map quality problem solving at varying levels of complexity through root cause analysis techniques such as the 5 whys. For simple cases, the root cause will be obvious. However, for complex cases, there may be more than one root cause with a need for greater investigative techniques to dig down and unearth the root causes. Other frameworks were considered (e.g. the classic decision-making process (Dewey, 2013), the military model devised by the U.S Army (Vasilescu, 2011), and Mintzberg's General Model of the Strategic Decision Process (Mintzberg and Westley, 2001)), but were not chosen over the Cynefin framework for the following reasons. First, all three of the examples mentioned have limitations with regards to the realities of strategic decision-making and considered worthless in ambiguous situations (Vasilescu, 2011). In addition, for managers and leaders enforcing such frameworks, some of the examples (e.g. Mintzberg and Westley, 2001) are quite complicated and not so easy to understand, which is a necessity for those reacting to many problems at one time on construction projects. The Cynefin framework provides a concise way of interpreting decision-making in different environments whilst providing tools to allow decision maker to act accordingly, therefore is the more appropriate framework for construction projects.

By adapting the Cynefin framework, decision-making profiles are mapped firstly for the real-time decision-making undertaken by the project and then retrospective by the researcher using information within the dataset, supported by a project function (i.e. engineering professionals with strong knowledge of the scheme). Cross examination of the real-time and retrospective decision-making pathways would indicate whether correct decisions were being made to address non-compliant works. Moreover, it would diagnose whether problems are being under/over simplified and the cause of this.

Figure 3.9 presents the complexity ruling used to undertake the categorisation exercise. The rule links cause-and-effect relationships of RCA problem solving (i.e. the '5 whys' method) to each domain within the Cynefin framework, thus allowing the researcher to categorise each NCRs difficulty to problem solve and its level of complexity (Kurtz and Snowden, 2003).

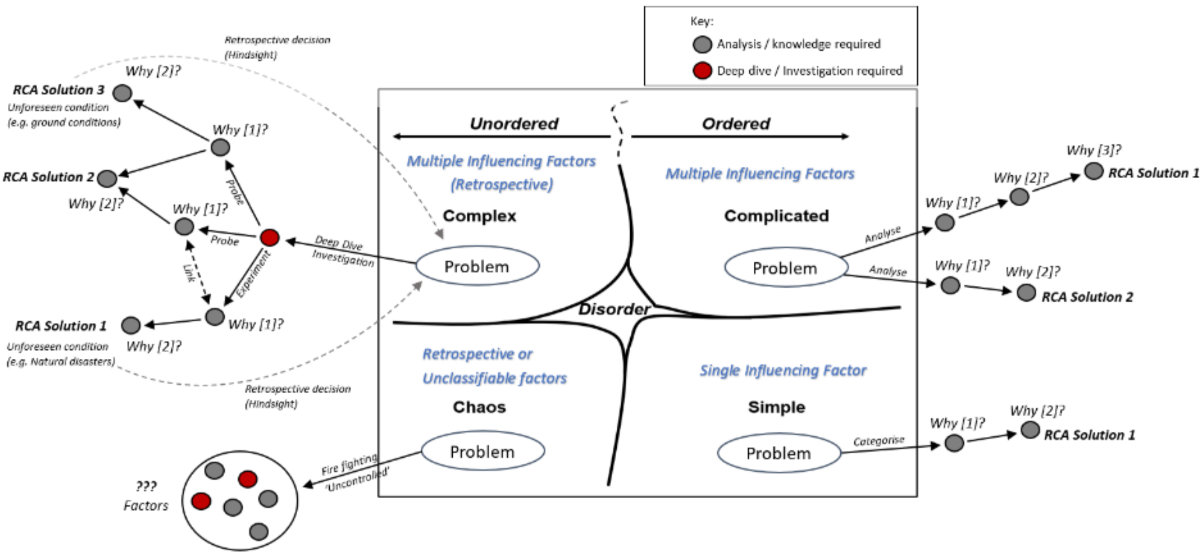


Figure 3.9 – Decision-making complexity ruling for NCR analysis. Adapted from Kurtz and Snowden (2003).

NCRs with obvious cause-and-effect relationships that require little analysis to identify a true root cause were categorised as 'Simple'. Those with up to two attributable root causes were titled ‘Complicated’. Non-conformances that exhibited many root causes, showed signs of experimentation to achieve further understanding or yielded retrospective conditions as a fundamental factor (e.g. unforeseen ground conditions or adverse weather) were classified as ‘Complex’. Finally, those which were either unclassifiable or showed signs of fire-fighting techniques without consideration to the underlying cause were classified as ‘Chaos’. As the RCA pathways were non-determinable from the NCR dataset, real-time categorisation was based on the decision path made by the project team, factoring in the problem, perceived root cause, remedial action to correct the defect and corrective action sequentially. Based on the level of investigation conducted, the researcher was able to match to the appropriate Cynefin framework domain. For example, NCRs that had deep dives, investigation or experimentational measures undertaken, such as material analysis to validate composition, were categorised as ‘Complex’. At the other end, those that yielded an obvious root cause and solution were categorised as ‘Simple’ (e.g. damage to permanent works caused by careless behaviour that resulted in rework). Lastly, those exhibiting erratic, non-compliant behaviour by team members acting on intuition rather than following due process (e.g. site omission of detail without prior design approval) were classed as ‘Chaos’. On completion of the categorisation exercise, the risk profiling exercise could begin.

3.4.8 Failure Mode and Effects Analysis (FMEA) risk prioritisation

Developed by the US Military in the 1940s and primarily used in the manufacturing sector, Failure Mode and Effects Analysis (FMEA) as a structured analytical method of failure and risk interrogation, can provide significant benefit for addressing latent construction problems (Lee and Kim, 2017). As risk management is becoming an increasingly important task in managing schemes with constrained budgets, escalated programmes and greater demands for higher quality, such techniques are advised (Damanab *et al.,* 2015). Moreover, identifying and mitigating project risk has become so crucial in managing successful projects, FMEA has been relabelled risk FMEA (RFMEA) (Carbone and Tippett, 2004).

The logical, structured way FMEA can be deploy in the context of construction problems has made the charting risk assessment technique a standout application for the lean community (Murphy *et al.,* 2011). In addition, an FMEA style risk analysis has been claimed to support quality management practices, decision-making, and help foreseen non-conformity (Mecca and Masera, 1999). Therefore, it is the chosen method for categorising risk.

The process for computing FMEA values involves the evaluation of failure modes for occurrence, severity and detection (Stamatis, 2003). The multiplication of these three parameters computes the numeric assessment of risk value for each failure mode, known as the Risk Priority Number (RPN). The equation is as follows:

$$RPN = P \times S \times D \tag{1}$$

where P is the probability or likelihood of failure (i.e. occurrence), S is the severity of impact, and D is the ease of detection. Action can then be taken for the most significant RPNs to reduce the severity, reduce the probability and improve the design or temporarily improve the controls (Kiran, 2017). The failure mode with the highest RPN number should be given the highest priority in the analysis and corrective action.

To support the notion that problems are often oversimplified, FMEA will be used to exploit and identify risk proportions for each SHW series activity. Furthermore, by comparing the real-time and retrospective decision-making pathways taken to resolve each non-conformance, a clearer picture is presented as to whether problems are oversimplified along with their inherent risks for projects.

To compute the RPN values for non-conformance report data, four exercises will precede (Figure 3.10).

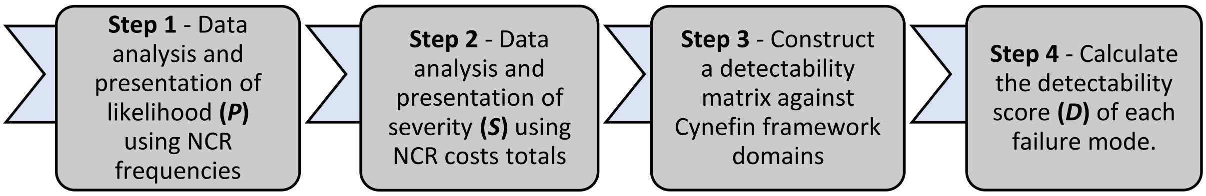


Figure 3.10 – Preparation for calculating RPN values for decision-making pathways

Step 1 – NCR frequency results are to be organised from highest to lowest in line with the Specification for Highway Works series (SHW). The specification governs each project activity against an industry standard (HA *et al.,* 2014). The non-conformance series are then allocated a rating of occurrence (i.e. likelihood of recurring) as per Kmenta and Ishii's (2000) Table 4 and Liu *et al.*'s (2013) Table 1. Each SHW series frequency is calculated against the overall NCR total to determine its probability failure rate and to allocate an appropriate rank. For example, if the frequency of NCRs in a particular SHW series was 250 and the total number of NCRs within the dataset was 1000, this would equate to 25% of the overall total, giving a probability rank of 8, as it is greater than 1 in 8 but less than 1 in 3.

Step 2 – A similar exercise is performed to assign severity ratings for the total costs of each SHW series, and to understand the severity profiling of NCRs against costs to the scheme (Liu *et al.,* 2013). The greater the costs the greater the impact it will have on the scheme (i.e. severity of the situation).

Any series that yields a nil likelihood or severity value would also present a zero RPN value when multiplied. These were discounted, as they have no impact on the risk profiling for the research.

Step 3 – To determine the detectability index (*D*) for each series, each Cynefin framework domain is assigned to its corresponding cause-and-effect profile then mapped within a detectability matrix (Franceschini and Galetto, 2001). Cause-and-effect relationships, risk profiles and uncertainty levels are linked to the likelihood of detection, with 1 being almost certain to be detected, with direct links to cause-and-effect, and 10 being absolutely uncertain, with no links whatsoever. For example, the 'Simple' domain is categorised as being between 1 and 3, 'Complicated' as being between 4 and 5, 'Complex' as being between 6 and 7, 'Chaotic' as being between 8 and 9, leaving 'Disorder' as 10. The researcher refers to this as the 'FMEA detectability wheel' (Figure 3.11).

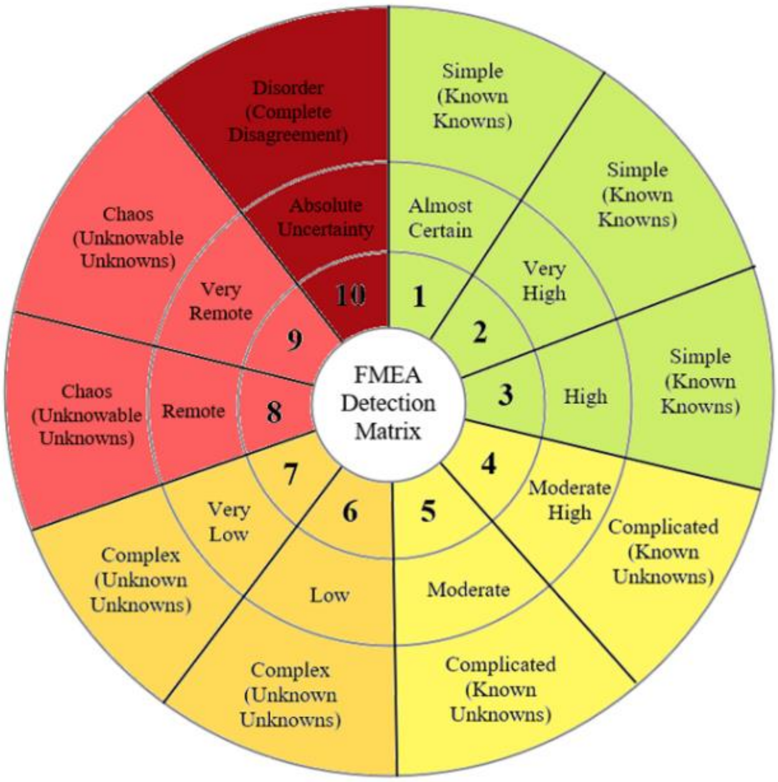


Figure 3.11 – FMEA detectability wheel against the Cynefin framework domains.

Step 4 – Once a clear ruling has been established to assign detectability ranks for each Cynefin framework domain, step 4 quantifies the detectability score for each SHW, to allow the researcher to calculate the Risk Priority Number (RPN). To do so, the real-time and retrospective decision-making pathway data obtained via the complexity categorisation exercise is aggregated by multiplying the total number within each domain by the corresponding likelihood score within the detectability wheel. All domain scores are then totalled and divided by the total number of NCR cases within that series to give an average overall detectability score per series out of 10. With the exception of 'Disorder', each domain spans more than one likelihood score within

Figure 3.11. As such, an average is taken. For example, the 'Simple' domain would use a value of 2 (1 + 2 + 3 / 3), the 'Complicated' domain a value of 4.5 (4 + 5 / 2), 'Complex' a value of 6.5 (6 + 7 / 2) and so on, to compute a median value for each.

An example of how to calculate the detectability score is shown below within Table 3.7 using arbitrary values and a random SHW series as guidance.

Table 3.7 – FMEA detectability calculation example.

	Simple	**Complicated**	**Complex**	**Chaos**	**Disorder**
Detectability index	2	4.5	6.5	8.5	10
Series 1100 – Kerbs (*No. of real-time cases*)	5	12	3	8	2
Sub total	2 * 5 = 10	4.5 * 12 = 54	6.5 * 3 = 19.5	8.5 * 9 = 68	10 * 2 = 20
Detectability Value ***(D)***	$= \frac{sum\ of\ sub\ totals}{total\ NCR\ cases} = \frac{(10 + 54 + 19.5 + 68 + 20)}{(5 + 12 + 3 + 8 + 2)} = 5.72$				

The above research process allows the researcher to analyse NCR data in a way that is logical and methodical to ascertain the following outcomes:

- Most frequent and costly primary root causes of highway non-conformities
- Determine real-time and retrospective decision-making pathways
- Assign corresponding risk profiling to understand the significance of under/oversimplification of quality problem solving
- Generate a series of lessons learned that can be generally applied to highways schemes along with specific focus areas within the business

Once complete, findings from the quantitative exercise are digested and transposed into a series of questions tailored to project professionals. The following section details Phase 2 of the research process.

3.5 Phase 2 – Managerial perceptions through an industry survey

A major part of non-conformance reporting is the human element of identifying, raising, problem solving and actioning close out of quality problems. As such, it is vital that findings from quantitative research are shared with industry professionals that manage these situations on a daily basis, not only to enhance knowledge but to challenge the NCR findings and generate meaningful feedback. Whether to collect feedback via an online survey or through interviews was considered, however, the research opted for an online survey for the following reasons. First, during Covid-19 restrictions, a digital survey was deemed most sensible approach to engaging with industry professionals without compromising the health of the participant or researcher. Secondly, unlike interviews whereby the researcher would have to conduct individually with each participant, many respondents can respond simultaneously to an online survey, thus increasing the response time across a target audience Boyer *et al.* (2001). Third, it was felt that the anonymity of the respondent would help generate more honest feedback than a face to face encounter (Tiene, 2000).

3.5.1 Survey design and data collection method

In order to recommend improvements through detailed research, it was felt that creating a generic understanding of the quality landscape in construction was necessary. Therefore, findings and knowledge gained from previous quantitative data analysis were used to conduct a detailed industry survey similar to that conducted by Barker and Naim (2008). It is important to not lose sight of what the questionnaire will measure. In this instance, the need to explore the cognitive knowledge and beliefs of industry professionals, while understanding the attitudes, emotions and behaviours that fuel failure in construction.

To achieve meaningful outcomes, consideration of the questionnaire research design is a must. As such it is imperative to plan questionnaires from start to finish, to ensure that precise data will be captured that will answer specific research questions and any further objectives set (Saunders *et al.,* 2009). The need to adopt a logical, systematic and structured approach to questionnaire development is a vital step in achieving the necessary outcome (Rowley, 2014). Building on the works of Forza (2002), a research process was devised. Figure 3.12 details the process followed, including ethical considerations, the design and structuring of questions, internal testing, pilot trialling, data collection methods and analysis techniques. This also follows logic stages set by Gray (2018).

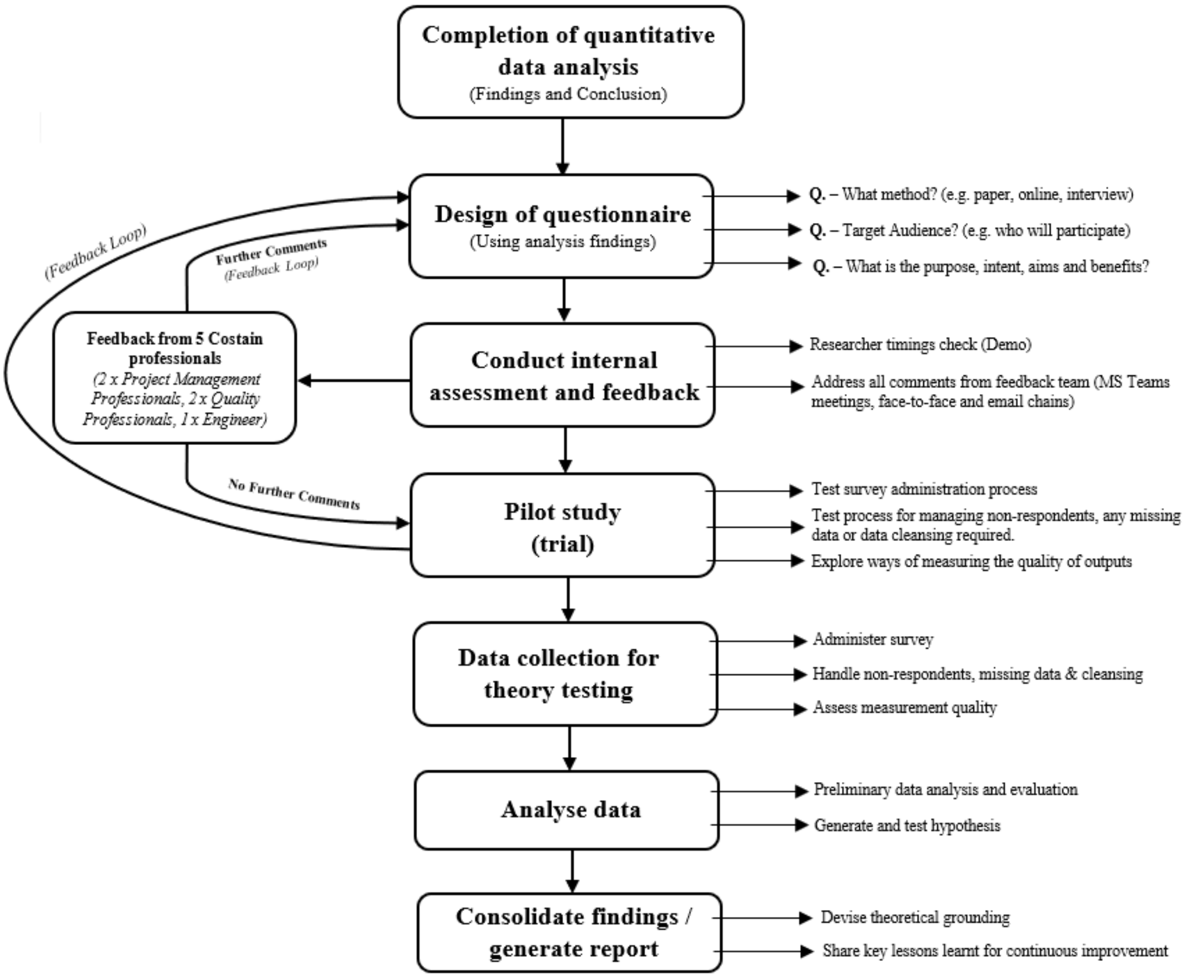


Figure 3.12 – Survey research process (Phase 2).

Providing backup analysis findings for further input is a challenging task. Data should be presented in a way that is understandable, easy to digest and allows the reader to make a suitable response to open-ended or closed-ended questions. Closed questions limit the response by the participant to a ‘Yes’ or ‘No’ answer, for example, and prevent further explanation. They typically restrict the depth of participant responses, thus potentially rendering the response as diminished or incomplete (Bowling, 2014). With regard to open-ended questions, to allow participants to expand upon answers and provide more detailed feedback, a free text response can be facilitated, in addition to a ‘Yes’ or ‘No’ response, for participants to expand upon their view. Some participants may welcome this opportunity, however, while it can provide the analyser with rich qualitive data streams, it can also create difficulties in analysing and interpreting data (Polgar and Thomas, 1995).

For the purposes of this research, to generate complete answers with supporting statements, a hybrid questionnaire was generated, consisting of a mix of closed-ended and open-ended questions. Furthermore, the questionnaire was provided via a digital platform. The status of the survey was considered ‘ad hoc’ as it was a one-off survey specific to the subject matter that followed on from detailed quantitative analysis (Saunders *et al.,* 2003). The addition of qualitative survey methods was proposed to add backing and narrative to the formulated NCR findings. Lastly, an internal questionnaire was considered, as a low cost exercise that gathers data conveniently within a short time frame, in a way that other data collection research methods are unable to do. Before a survey is created, a detailed design proposal with ethical considerations must be formulised and justified. Each activity within the research design (Figure 3.12) is rationalised in the forthcoming sections.

3.5.2 Survey consent

As summarised within Section 3.4, in order to give access to those wishing to participate in the questionnaire, a consent tab was introduced, along with a statement of intent for the research. In doing this, the researcher provided clarity around the questionnaire’s intended purpose and around the need to know parameters, such as data storage and dissemination. This acted as a filter process, separating those willing to participate from those who were unwilling, for reasons not discussed. Upon achieving consent (i.e. clicking on ‘I agree’) the questionnaire would be presented to the participant.

Furthermore, a separate ethics package was generated, in line with Cardiff University’s requirements, that included detail on the types of questions that would be asked, how sensitive data would be stored and for what duration, consent requirements and participant information literature explaining the purpose of the study (Appendix 3).

3.5.3 Formulating an industry survey

3.5.3.1 Survey method selection

Selecting the right questionnaire method is a choice that must be considered (e.g. you must account for your target audience, where these individuals are situated around the globe and how quickly a response is required). There are positives and negatives for different types of surveys.

During the digital revolution, researchers have substituted paper copy data collection methods for more innovative, online methods. It has become a very popular tool to many researchers as it offers both a broader range of capture (e.g. across countries and continents) while also delivering a more sophisticated, improved way to reach out to participants. Furthermore, the ever-increasing internet population is a suitable platform to connect with others. Moreover, digital survey applications offer software that visualise questions effectively, in a user-friendly format, so that users are not discouraged from taking part. These questionnaires are of low cost to generate and enable a wide range of professionals within a business unit to participate and respond over short periods of time (Doolin *et al.,* 2005). There are of course advantages and disadvantages to almost all research data collection methods, as mentioned above. For those pertaining to digital questionnaire surveys, see Table 3.8.

Table 3.8 – Methodological advantages and disadvantages of electronic surveys (Source: Tiene, 2000; Boyer *et al.,* 2001; Brandenburg and Thielsch, 2009).

Advantages	**Disadvantages**
Greater ability to present or record information	Challenges with capturing the attention and time of respondents/participants (concerns of lower response rates as a result)
Questions can be written with more complete descriptions as computer surveys are not space-constrained	Further training on the software may be required which will have an implication on cost

Ability to include pictures, findings, special formatting, audio or video links along with straight text (offer an opportunity to capture attention in creative ways)	Loss of visual interaction that face-to-face discussions would benefit from (e.g. sensing the room via face expressions)
Time efficiency during data collection, analysis and presentation of data	The conditions of the data collection Cannot be controlled, which results in problems with objectivity
May generate more reliable, valid data from anonymous input within comfortable surroundings (e.g. at home)	The programming of the online questionnaire needs more time and there may be a dependency on third parties
Time and effort exerted on questionnaire are far less than conventional printing and distribution of paper copies (no interviewee and data transfer is needed)	Online surveys using the internet will never be suitable for the total population due to a number of factors
Automation, and with this increased objectiveness: no error sources through data transfer, no test supervisor effects, no group effects	Achieving acceptance to participate may be challenging as the respondent may feel it's for either campaign or marketing purposes
Higher acceptance due to voluntariness, flexibility and anonymity	Not all target audiences use the internet or have access to computers with current software capabilities, and as such will not be able to participate.
Online surveys have a greater reach of participants compared to paper distribution and can capture participants from different countries/continents easily at low cost	Multiple participation cannot be ruled out completely
Ethical transparency: online surveys are much more transparent as they are more accessible than offline surveys	Asynchronicity can play its part in time of response. Participants may read and react on their own schedule
Reduction in missed data due to stringent protocols results in a more accurate, higher quality data set	Protection of data from unauthorised access is typically more difficult

The main benefits of online questionnaires are the speed in which they can be completed, their demographical reach, their economical cost to produce and distribute, and that they are typically easy to analyse (Bowling, 1997). A further advantage of using online surveys, specifically digital questionnaires, is that they have the capability to capture additional relevant data for business purposes. As such, it is vital that we carefully consider the research design and those who are proposed to participate (i.e. the target audience). The design should offer as much relevant information as possible without overburdening the participant.

Factoring in the low costs, fast response rates and capabilities of online questionnaires, the researcher chose this method for conducting a survey (Brandenburg and Thielsch, 2009). Using Microsoft Forms (MS Forms), an online survey was created in two distinct sections (Rhodes, 2022). Section 1 of the online survey discusses perceptions and opinions surrounding quality. It aims to challenge the way we think about quality and understand what the respondent consciously believes to be happening. Section 2 follows on and is tailored to discuss the results from quantitative NCR research conducted prior. With the analysed findings, the aim is to share key learning points from the researcher and pose further questions to ascertain the participants' thoughts on where our efforts are best placed to make improvement in construction quality.

3.5.3.2 Target audience

Before selecting a target audience, a sampling method must be considered. As presented in Figure 3.7, there are a few to choose from, including judgement sampling, where participants are selected deliberately because the researcher believes they warrant inclusion, snowball sampling which is used for small populations that are difficult to access, using a few cases to influence many, and convenience sampling, which selects participants that are freely accessible and easy to target (Taherdoost, 2016).

External companies were considered as a target audience, however, one principal contractor was chosen to participate for the following reasons. Firstly, sharing sensitive quality failure information externally for feedback was not seen as appropriate, nor did the researcher have approval to do so. Secondly, assuming permissions were granted, unlike external companies, the researcher's position has a strong profession standing within his tier 1 contractor with many connections that can positively influence a greater response rates with project managers and the quality community. Engaging with external contractors including those from other contractors on the A14 would prove more challenging to access certain groups, take longer to gauge responses and likely have lower response rates as the researcher's influence is significantly smaller. Thirdly, the data collected from a major highways scheme reflects on the quality performance within Costain. Asking other contractors to comment of failure areas may raise sensitive issues. Therefore, a hybrid non-random sampling method consisting of convenience and judgment sampling techniques is adopted.

A wide range of professional levels were considered to take part in the survey. However, in the researcher's professional experience, many simply don't understand the challenges and pitfalls of quality within their organisation and wider projects (e.g. administrators, purchasing department and human resources). Rather than dilute the message and be uncertain of relevance, only those who had significant influence and control of quality outcomes on infrastructure projects were selected to provide feedback. Quality (i.e. depth of knowledge) is more important than quantity (i.e. breadth of respondents) for this study. Specifically, two distinct groups of professionals were targeted separately and independently within the tier 1 contractor. Group 1 consisted of sixty-seven project and commercial management professionals from within the contract leader's forum, while group 2 consisted of ninety-five quality professionals from within the quality engagement community. Figure 3.13 presents the diverse mix of professional roles within each of the groups sought to participate in the online survey.

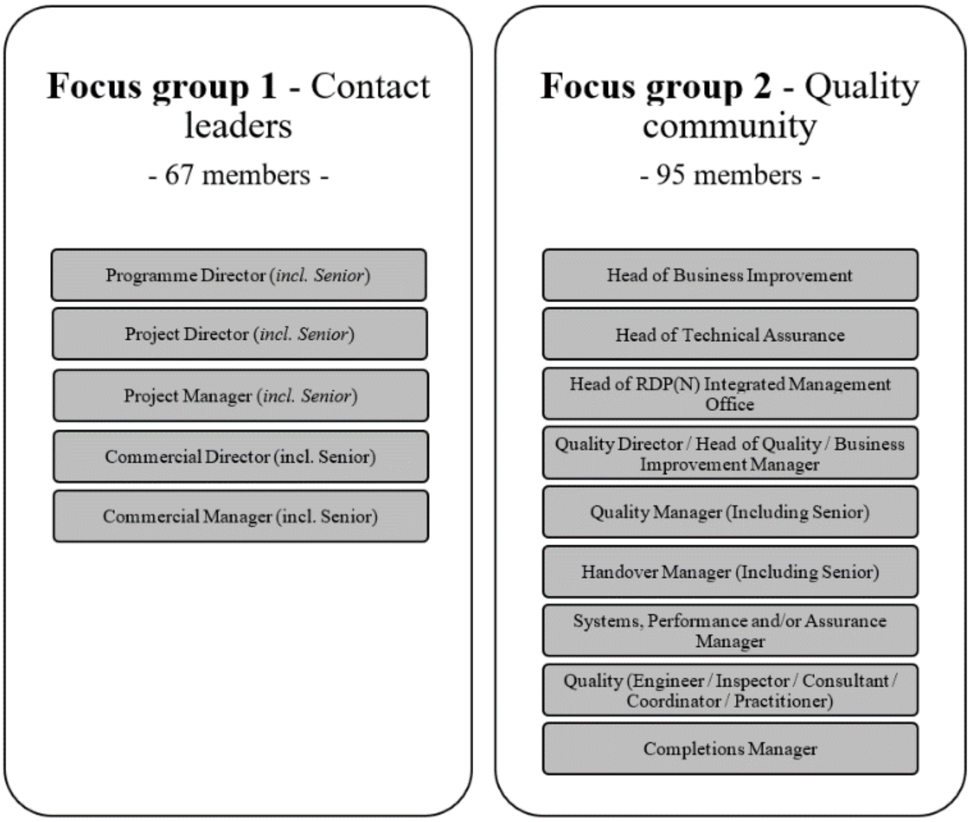


Figure 3.13 – Target audience groups within the principal contractor.

The reason for selecting independent focus groups was to understand whether there were differing perceptions of how quality is being managed on projects. Furthermore, project managers typically have an all-rounded, high level understanding of project delivery including quality, whereas quality professionals are subject matter experts with a deeper understanding of managing quality and the problems projects face. By collecting and comparing responses from the two groups separately, it was possible to identify whether there was a consensus or a divide in opinion.

3.5.3.3 Stating the problem, intent and benefits

To assist participants in their understanding of why the questionnaire had been devised, a clear mission statement was proposed for inclusion at the start of the survey, detailing the problem, intent and benefits of the research. This statement read:

*"**Problem** – Learning from our non-conformance data has proved challenging over the years along with the correct decision-making protocols to prevent future recurrence. Furthermore, similar trends are being found on many other schemes which call for improvements to be made in the quality sphere.*

***Intent** – The aims of this questionnaire are to first understand the perceptions of quality on complex construction projects, secondly to measure how we are learning from our non-conformance data through detailed analysis and Root Cause Analysis (RCA) methods, and finally where our efforts should be focused for continuous improvement.*

***Benefits** – With the support of the participants, the questionnaire findings will divulge where our efforts are best placed in tackling quality issues to get closer to delivering right-first-time within Costain. The questionnaire also helps transfer knowledge from NCR analysis for the betterment of ongoing schemes."*

As all participants in the survey worked for Costain, stating the benefits of the survey encouraged a collective effort to contribute and implement improvement for a company by completing the survey . Furthermore, to establish an open and honest feedback channel, a confidentiality clause was introduced at the end of the introduction, explaining the survey findings would remain strictly anonymous (refer to Section 3.5). For completeness, a closing remark was also introduced stating the deadline date for the questionnaire submission along with information about the researcher, so that participants were able to get in touch in the event of further queries.

3.5.3.4 Reliability and validity

Two important considerations must be made when constructing a questionnaire. The first, 'reliability', concerns the yielding of stable and consistent outcomes, with the ability to give the same result under constant conditions (Taherdoost, 2016). This means that if another researcher was to perform the same research approach with consistent techniques and methods, the same result would be expected (Field, 2003). Furthermore, as data reliability is related to data sources, which are populated by questionnaire participants, they are inextricably linked (Oppenheim, 2000). It is therefore imperative that respondents have detailed knowledge of the topics being discussed, so that they are able to provide sufficient feedback (Love *et al.,* 2005). To facilitate reliability, each step of the overall design process has been outlined in depth, offering a protocol-like account on how the research was conducted. The second consideration is 'validity', which explains how well collected data covers the research topic being investigated (Ghauri *et al.,* 2020). In simple terms, it refers to whether a questionnaire or survey is measuring what it set out to measure (Rattray and Jones, 2007). Furthermore, Rattray and Jones claim that demonstrating both the reliability and validity of questionnaires is essential on the grounds that if not done correctly, this may lead to difficulty interpreting results later on. Lastly, statistical validity and reliability of findings can be determined through statistical testing to measure the correlation between two independent groups of data (Enshassi *et al.,* 2017).

3.5.4 Question design and development

A questionnaire is a primary data collection process consisting of a list of mimeographed or printed questions, with an aim to achieve a desired response outcome. Questionnaires form the backbone of any survey and their success lies in designing questions that will gauge responses (Roopa and Rani, 2012).

Designing questions in a way that is understandable to the reader is paramount. Questions must be clear and concise so as not to lose the reader's interest. Furthermore, a participant must comprehend and interpret the question in a way that allows them to retrieve relevant information from memory and draw on their knowledge in response to the question posed, and formulate an answer (Martin, 2006). There are many factors that must be considered when designing a survey, such as content, presentation, response format and the sequencing of questions. Furthermore, there are ideal requisites for developing a questionnaire (Roopa and Rani, 2012). These include a simplistic format with generic language, yielding truthful, accurate responses in an open and honest setting, accommodating all possible contingencies of a response, and minimising social desirability.

There are four main types of survey question:

- Contingency questions (*Cascade format*) – A question that is provided in lieu of a specific response to a previous question. If the alternative question response is given, the question can be skipped as it will not apply to the participant (Roopa and Rani, 2012).

  Example: Answering yes to a previous question requires the participant to explain in more detail why they thought so.

- Matrix questions – Multiple questions using the same set of response options grouped into a matrix format (Liu and Cernat, 2018).

  Example: Carver and White's BIS/BAS scale (Carver and White, 1994).

- Closed-ended questions – A question that requires a limited response, chosen from a number of pre-defined options. These types of questions come in a few well known forms:
  - Yes/No type questions – The respondent must answer either 'Yes' or 'No'.

    Example: Do you see a problem with quality in the construction industry?

  - Multiple choice questions – Several options are presented for the respondent to choose from.

    Example: What level of quality standard do you see in construction?

    (1) Excellent (2) Good (3) Fair (4) Poor

  - Scaled questions – A question that requires the participant to grade a response between a minimum and maximum value. Types of scaled questions include semantic differential scale (Osgood, 1964) or the very popular psychometric function, Likert scale (Likert, 1932). Likert scales are commonly used in research for measuring social responses to questionnaires. The scale can have varying numbers of response points and it is up to the questionnaire designer to decide on an appropriate point scaling (Chomeya, 2010)

    Example: Decision-making in construction is precise and accurate.

    (1) Strongly disagree (2) Disagree (3) Don't know (4) Agree (5) Strongly agree

- Open-ended questions – A question devised to allow the respondent to detail a response in their own words without constraint. Options or predefined categories are not assigned to the question. These types of questions do not yield as high response rates as closed-ended questions, where respondents are more comfortable providing a restricted response and not elaborating further. Furthermore, there is greater risk of missing data within an open-ended response (Reja *et al.,* 2003).

  Example: You have indicated 'Yes' to the previous question. Please explain why you feel there is a problem with quality in construction.

For the purposes of this research, a collection of closed-ended and open-ended questions in a contingency format were selected as an appropriate form of communicating findings to industry professionals. Closed-ended questions were selected to allow participants to provide precise, simplified responses that could be easily analysed using visual interpretive techniques and open-ended questions were selected to allow participants to elaborate on those responses. Open-ended questions are to follow on from close-ended questions in a 'cascade format', letting participants provide justification for a selected response. Furthermore, open-ended questions allow the respondent to identify any problematic areas not identified elsewhere by the quantitative exercise. However, these questions require more advanced statistical methods to uncover areas of significance (e.g. using a qualitative data analysis computer software, such as NVivo or ATLAS.ti). A data requirements table was deemed essential to justify and rationalise all questions within the proposed survey (Barker and Naim, 2008).

Specifically, eight open-ended questions and twenty-two closed-ended questions were constructed in accordance with the quantitative findings. Of the close-ended question, sixteen were created as traditional 'Yes/No' questions, four were created as multiple choice questions requiring the selection of one or more answers, and three were created as scaled questions (one ranking order scale question, a 6-point Likert scale question split in four parts, and a standard zero to ten scale question) as shown in Table 3.9. A 6-point Likert scale was deemed more suitable than an odd number Likert scale, as they tend to give higher discrimination and reliability values than 5-

point or 7-point scales (Chomeya, 2010). Furthermore, it deters the respondent from selecting a middle value and forces them to choose a side of the scale.

Questions were devised to focus on key failure and lessons learnt outcomes from the data analysis findings, while remaining relevant and relatable to the participant.

Table 3.9 – Data requirements table used for construction survey.

Investigative research questions	Rationale	Question type	Measurement metrics	Question reference
Is the company suffering with quality execution both in house and with its suppliers?	NCR data analysis concludes £1.8mil direct cost and £5.9mil indirect cost to correct on scheme insinuating a largescale quality related issue. Also past literature (Love, 2002a).	Closed-ended	'Yes/No' response	Q1 - 2
Is the company at risk of long-term profitability issues caused by non-conformance defects within the business?	A combined total of £7.7mil is a concerning figure. Other projects within the principal contractor may be reacting similarly.	Closed-ended	'Yes/No' response	Q3
What do you believe the cost of non-conformance was on the highways scheme in question?	Knowledge of business and associated costs within the industry. Also, comparable past literature (Abdul-Rahman *et al.,* 1996, Josephson *et al.,* 2002, Love, 2002b, Love *et al.,* 2018a)	Closed-ended	Multiple choice question ranging of from zero to >1% (one answer only)	Q4
Is right-first-time achievable? Is rework of some kind inevitable?	Professional knowledge of the industry and supportive findings of NCR quantitative analysis suggests no (Get It Right Initiative, 2018)	Closed-ended	'Yes/No' response	Q5
Following on from RCA competence, are we often oversimplifying our problems?	NCR findings indicate over/under simplification of problems in many situations. Others have concluded oversimplification is commonplace in complex situations. Other supporting literature: (Spiro *et al.,* 1996)	Closed-ended	'Yes/No' response	Q6
Are those involved in NCRs sufficiently trained? Is the company struggling with suitably qualified personnel in key roles?	Quantitative analysis suggests poor RCA execution. Furthermore, it raises queries over competence of workforce (Mahamid, 2022)	Closed-ended	Yes/No closed response	Q7 & Q21
Should contract arrangements be re-evaluated to apportion risk and costs? Does the company at times proceed at risk without approved designs?	71 non-conformance at a total cost of £558,100 are because of design related issues Other supporting literature: (Ye *et al.,* 2015, Trach *et al.,* 2021)	Closed-ended	Yes/No closed response	Q8 - 9
Following on from previous question, what are the potential consequences of proceeding at risk without design approval?	Significant cost of £558k observed in NCR dataset as a result of design issues. Other supporting literature: (Ye *et al.,* 2015, Trach *et al.,* 2021)	Open-ended	Free text response – Contingency question in cascade format	Q10
What do you think projects currently priorities for delivery? Rank quality, programme, safety and cost in order of priority.	Concerns over cost and programme taking priority over quality in construction. Findings suggest that critical path is paramount.	Closed-ended	Rank scaled response of four major construction topics (Safety, Quality, Cost and Programme)	Q11

What do projects see as priority from safety, programme, quality and cost? What do our clients think is priority?	Professional knowledge of the industry and supportive findings of NCR quantitative analysis suggests quality is last priority. Other supporting literature: (Xiao and Proverbs, 2002)	Closed-ended	Yes/No closed response	Q12 & Q14
If you agree that quality is treated as lower priority, why do you feel this happens?	Findings suggest 51 NCRs were caused as a result of progressing with critical path works to meet programme not quality delivery Other supporting literature: (Xiao and Proverbs, 2002)	Open-ended	Free text response – Contingency question in cascade format	Q13
Do all parties understand the level of quality to be achieved?	Project experience of handover into operational maintenance suggests a divide in the level of quality to achieve. Data suggests differences in remedial action deemed acceptable.	Closed-ended	Yes/No closed response	Q15
If you answered '*No*' to the above question, why do you believe quality levels are not clearly understood by all?	Findings and knowledge from the researcher queries whether a firm understanding of quality delivery is understood (e.g. what will the acceptable end product quality standard look like?)	Open-ended	Free text response – Contingency question in cascade format	Q16
What do professionals perceive the most likely causes of non-conformance and rework in construction?	Various literature with many different root cause conclusions. Quantitative analysis poses the three most frequent via Pareto analysis. Other supporting literature: (Abdul-Rahman *et al.,* 1996, Josephson *et al.,* 2002, Love, 2002b, Love *et al.,* 2018a, Mahamid, 2022)	Closed-ended	Multiple choice answer (select three most likely root causes of twenty-one possible answers)	Q17
Quantitative data findings yielded a total non-conformance cost of £7.7mil (profit loss of 17%). Is this figure of concern?	Findings from quantitative data analysis and internal knowledge of companies profit margins	Closed-ended	Yes/No closed response	Q18
To understand the participants views of why a profit loss figure of 17% is of concern or not. Open-ended question to understand	A response to the previous question will need further rationale as to why they think so and the consequences thereof.	Open-ended	Free text response – Contingency question in cascade format	Q19
Findings of most frequency NCRs in Pareto format indicate Materials Management, workmanship and supervision are the three most significant root causes. What do you think we should focus on?	Findings from the NCR data analysis suggest three significant failure areas. Question challenges where our efforts should be focused.	Open-ended	Free text response	Q20
If you answered '*Yes*' that the industry is struggling with SQEP resourcing (Q21), what is the solution?	137 cases of poor/lack of supervision (including engineering support and verification) and a further 26 cases of competency/training issues notified Other supporting literature: (Wasfy, 2010; Kazaz *et al.,* 2012; Abeku *et al.,* 2016)	Open-ended	Free text response – Contingency question in cascade format	Q22
If you answered '*No*' that the industry is struggling with SQEP resourcing (Q21), Why do you think such a large figure is occurring?	137 cases of poor/lack of supervision (including engineering support and verification) and a further 26 cases of competency/training issues notified Other supporting literature: (Wasfy, 2010; Kazaz *et al.,* 2012; Abeku *et al.,* 2016)	Open-ended	Free text response – Contingency question in cascade format	Q23

Many of the NCRs observed were within the discipline area of concrete, why do you think the industry continues to make mistakes in concrete operations?	383 NCRs (30% of the dataset) were concrete related activities. Other supporting literature: (Love *et al.,* 2018b; Balouchi *et al.,* 2019)	Open-ended	Free text response	Q24
Should the company re-evaluate our approach to in-situ concrete operations?	351 concrete related non-conformances discovered from the quantitative NCR analysis. Questions the process of quality execution with concrete operations Other supporting literature: (Love *et al.,* 2018b)	Closed-ended	Yes/No closed response	Q25
Are there concerns the company selects supply chains primarily on price and not previous performance?	The majority of the non-conformances are supply chain driven (836 of 1260 NCRs were the responsibility of supply chain). Concerns relating to performance.	Closed-ended	Yes/No closed response	Q26
Of such an enormously high cost and that RECo walls have failed on other schemes, should we continue to build these types of constructions or are they too high risk?	The costliest failure was a RECo panel construction totalling £2,169,500. Knowledge of other schemes suffering similar quality issues.	Closed-ended	Yes/No closed response	Q27
Linked to Q6. Do we often look for the easiest 'simple' solution to correct non-conformance?	NCR finding suggest our problems, linked to cause-and-effect relationships are over/under simplified in many situations	Closed-ended	Scaled (6-point Likert scale) – Cascade format	Q28a
Do we focus more on addressing the remedial solution than targeting the underlying cause?	NCR quantitative analysis concludes many root causes were inaccurate and/or incomplete. A potential factor is looking solely at the remedial solution	Closed-ended	Scaled (6-point Likert scale) – Cascade format	Q28b
Due to complexity, are we unable to identify the true root cause of many NCRs?	There were 85 NCRs within the dataset that were not concluded and left unsolved.	Closed-ended	Scaled (6-point Likert scale) – Cascade format	Q28c
Are NCR processes strictly followed on projects from raising through to close-out?	Dates between opening an NCR and closing in some cases were exceptionally long and often retrospectively as opposed to real-time.	Closed-ended	Scaled (6-point Likert scale) – Cascade format	Q28d
What is your current role within the organisation?	Important to know the seniority and positioning of the participant within their organisation to understand their influence of quality on schemes	Closed-ended	Multiple choice (Select 1 answer)	Q29
How would you rate your interest in the topics being discussed?	To understand the participants interest in the topics being discussed will help the researcher conclude whether the topic is of concern to the respondents.	Closed-ended	Scaled question - From 0 (worst) to 10 (best)	Q30

Once all questions had been formulated and rationalised, the survey could be formally constructed using Microsoft's online digital form.

Survey format

Selecting an appropriate survey tool that offered professional formatting, that would attract industry professionals was ahigh priority. Another vital step was theming and branding the questionnaire to show Costain's logo and business vision within a technological setting. An interstellar backdrop was selected to show a modern, futuristic theme which matched Costain's branding as a digital solutions provider. Figure 3.14 presents the finalised survey format created using MS Forms.

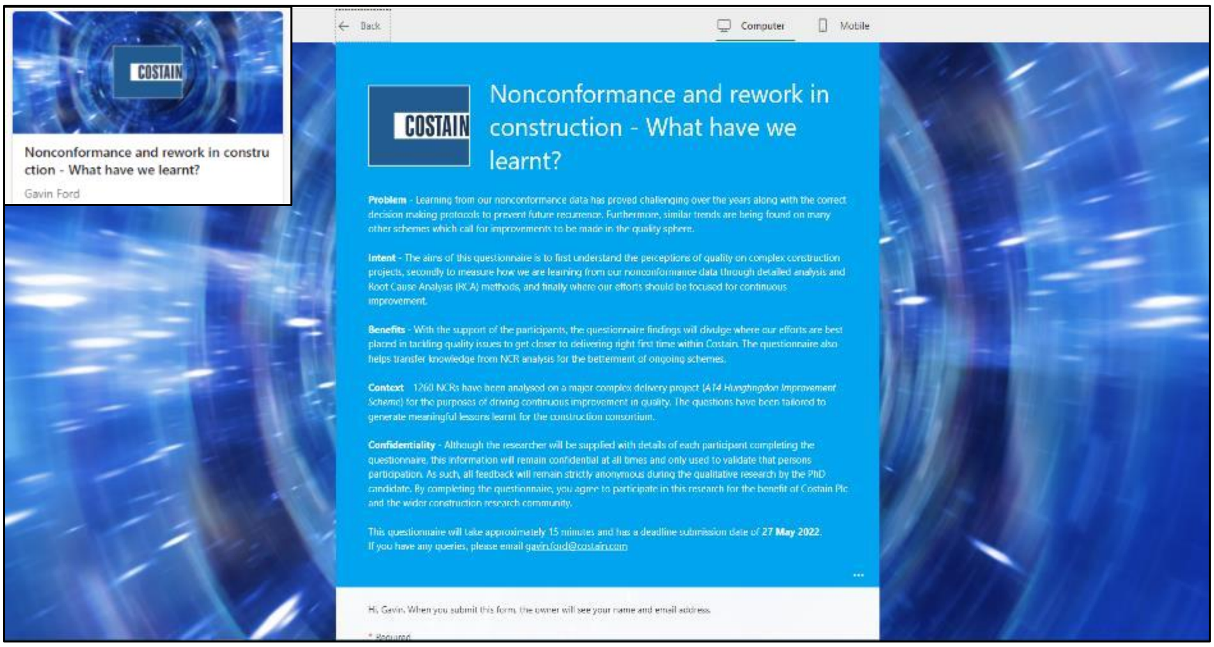


Figure 3.14 – Professional format and layout of the MS Forms survey.

Once the survey form had been fully populated, an internal assessment was conducted by the researcher prior to pilot trialling. The final version of the questionnaire can be found in Appendix 5.

3.5.5 Survey data analysis techniques and testing methods

In order to understand the significance of the data, analysis techniques and testing methods must be devised in line with the question format. For simple closed-ended questions requiring a 'Yes/No' response, visual interpretative techniques of graphical representations were adopted to compare the two sets of results. For the more complicated closed-ended multiple choice and scaling questions that have varying response levels across the two groups, nonparametric statistical testing techniques were explored in order to understand the significance of the findings. Lastly, for the open-ended questions, statistical software was used to interpret the free text paragraphs of data from each participant and identify noteworthy areas for further discussion. Each proposed testing procedure is described in detail below.

3.5.5.1 Descriptive statistics – Visualisations

Descriptive statistics with visualisation techniques offer a simple but effective way of deciphering the meaning of data outcomes. They also allow the researcher to explore and interrogate the data then present it in a format that is striking to the reader. However, identifying the purpose and type of graph is paramount in helping the reader understand the key message from the data (Young and Wessnitzer, 2016).

As closed-ended questions offer a limited opportunity for response, it is suitable to present the findings in graph form and interpret the results visually. Specifically, data outcomes for each closed-ended question will be presented as Excel pie charts, bar charts and histograms, and compared visually.

3.5.5.2 Spearman's rank correlation coefficient method for Likert scale questions

Another nonparametric test found to be highly effective for measuring the statistical dependence between the rankings of two variables is Spearman’s rank correlation coefficient (Spearman, 1904). Developed by Charles Spearman and commonly referred to as ‘Spearman’s rho’, the test assesses how well an arbitrary monotonic function can describe the relationships between two variables, without assumption of frequency distribution (Hauke and Kossowski, 2011). Furthermore, it can be applied to determine the strength and direction of the relationships between the ranking of the two groups with varying response numbers (Chan *et al.,* 2011).

As Likert scale questions offer the opportunity to select a preference from a number of answers, it was anticipated that the survey would likely produce two sets of results with varying response ranges, that were challenging to digest. Spearman’s rho has proven a suitable, widely recognised method for calculating the relationship between the two series of ranks for Likert style questions (Spooren *et al.,* 2007). It is also used to explore whether the probability of said relationships is worthy of discussion or is simply a result of chance (i.e. the null hypothesis (H_0), where there is no statistical difference between the two sample groups).

The Spearman rank correlation coefficient (r_s) is calculated using the following equation:

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{2}$$

Where d_i is the difference between two ascending order ranks, RX_i and RY_i, calculated as $(RX_i - RY_i)$, and n is the sample size of the test (Curran, 2014). Ranks are computed by giving a ranking of '1' to the smallest number in a column, '2' to the second smallest number and so on. For cases where there are more than one of the same number within each response data column, tied scores are given by a mean (average) rank. As a 6-point Likert scaling is chosen as an appropriate scaling question (Table 3.9), there is a possibility of yielding six distinct responses for each group, therefore ($n = 6$) in both instances. Lastly, a significance level must be assigned to the test. However, how do we choose the level of significance? Typically in statistics, and of recent construction applications, the most common value has been 0.05 (e.g. Enshassi *et al.,* 2017), however there is little explanation as to why this is from statistics textbooks (Kim, 2015). In the case of this research, (α) is set at 0.05, meaning that if (ρ < 0.05) it is highly unlikely, with greater than 95% certainty, that another outcome will be observed under the null hypothesis (H_0). We can therefore conclude that the outcome is significant at the 95% probability level and reject the null hypothesis, and accept an alternative hypothesis (H_1).

Following computation of the Spearman rank correlation coefficient (r_s), and knowing the sample size (n), the 't statistic' (t) must be calculated prior to determining the p-value (p). This is calculated as follows using equation 6 of Gauthier (2001) with $d = (n-2)$ to compute the number of degrees of freedom.

$$t = \frac{r_s\sqrt{n-2}}{\sqrt{1-{r_s}^2}} \tag{3}$$

In order to determine if the results of the test are significant at the prescribed probability level (i.e. at $\alpha = 0.05$), the t distribution function can be performed in Excel using formula $= TDIST(t, d, 2)$ to give the p-value, where t is the t-statistic, d is the number of degrees of freedom and 2 is the allocation of a ‘two-tailed’ test. If $p < \alpha$, statistical significance can be claimed.

3.5.5.3 Mann–Whitney *U* test method

A powerful method for understanding the statistical significance of two independent groups of homogeneous data is the Mann–Whitney *U* test (Nachar, 2008). Also referred to as the Wilcoxon-Mann-Whitney test (WMW), this nonparametric test has advantages over other methods as it can be applied across smaller samples and can be used when the measured variables are of ordinal type (Wilcoxon, 1945; Mann and Whitney, 1947; McKnight and Najab, 2010). Mathematically, the Mann–Whitney *U* statistics are defined by the following two equations:

$$U_x = n_x n_y + \frac{n_x(n_x+1)}{2} - R_1 \tag{4}$$

Or

$$U_y = n_x n_y + \frac{n_y(n_y+1)}{2} - R_2 \tag{5}$$

where n_x is the number of observations in group 1, n_y is the number of observations in group 2, R_1 is the sum of the ranks assigned to group 1 and R_2 is the sum of the ranks assigned to group 2.

To compute the rank sums, the data from both samples must first be combined and then ranked in numerical order. In some cases, the dataset may contain data entries with the same value, commonly referred to as ‘ties’. For example, if the third and fourth observations have the same value, the rank will be the mean value of the two ranks (i.e. (3 + 4) / 2 = 3.5). Each case is then assigned this value in the ranking exercise (Oti *et al.,* 2021). As a result of the questions generated within Table 3.9, it is not perceived that the number of observations will be larger than eight, however, ties are a possibility and the normal approximation must be used with an adjustment to the standard deviation (Lehmann and D'Abrera, 1975). The standard deviation is represented as:

$$\sigma_{ties} = \sqrt{\frac{n_x n_y (n_x + n_y + 1)}{12} - \frac{n_x n_y \sum_{k=1}^{K} (t_k^3 - t_k)}{12n(n-1)}} \tag{6}$$

where $n = (n_x + n_y)$, t_k is the number of ties for the kth rank and K is the total number of unique ranks with ties.

Lastly, to compute the test statistic (z) in absolute value and validate the statistical impact of the findings, the z-score with correction for ties (Siegel, 1956) is calculated as:

$$z = \frac{U - \left(\frac{n_x n_y}{2}\right)}{\sigma_{ties}} \tag{7}$$

where U is the lower value of U_x or U_y. The z-score is then normally distributed using Microsoft Excels 'NORMSDIST' function against a 'two-tailed' testing approach for two independent samples to generate the ρ value. A significance level (***α***) is set at 0.05 as per the Spearman rank test to remain consistent throughout the testing exercises. If $\rho < \alpha$, there is sufficient evidence to reject the null hypothesis at a probability greater than 95%.

3.5.5.4 Wilcoxon signed-rank test method

In 1945, Frank Wilcoxon developed a nonparametric test to not only compare the locations of two populations using two independent samples but to rank the differences between the data outputs, and develop statistics over them (Wilcoxon, 1945). This method gained status in the 1950s thanks to a nonparametric statistics textbook (Siegel, 1956).

For a paired sample test, the data will consist of samples ranging from $(X_1, Y_1), (X_2, Y_2), \ldots, (X_n, Y_n)$ on an interval scale. Paired samples are then converted into a one-sample test by way of computing the difference (*D*) between the two data groups, then ordering the data in a metric scale (i.e. $(X_1 - Y_1), (X_2 - Y_2), \ldots, (X_n - Y_n)$.

If a pair of corresponding data entries have the same value (i.e. if $X_1 = Y_1$), the difference will be zero and will be removed prior to assigning ranks (Pratt, 1959). Absolute difference values |*D*| are then summarised to remove positive and negative values for the remaining figures. Ranks are assigned to the absolute difference values once the data has been numerically ordered from lowest to highest comparable to the Mann–Whitney *U* test mentioned previously. Similarly, ties may be present within the dataset that share the same value. Once ranks have been assigned, rank sums of the positive (T_+) and negative (T_-) values are computed, using the lower value as the test statistic $T_{stat} = min\ (T_+ , T_-)$. A critical values table (Appendix 6) is then used to find the critical test value (T_{crit}) by locating the data sample size value n for a two-tailed test with a significance level set at $\alpha = 0.05$. If $T_{stat} < T_{crit}$ we can reject the null hypothesis (H_0). However, to determine (z) and unearth the p-value of the test, i.e. the difference between an observed statistic and its hypothesized population parameter in units of the standard deviation, we must first compute the mean value (μ_T) and the standard deviation value (σ_T) using the following equations:

$$\mu_T = \frac{n(n+1)}{4} \tag{8}$$

and

$$\sigma_T = \sqrt{\frac{n(n+1)(2n+1)}{24}} \tag{9}$$

Once these values have been determined, the z-score is calculated as:

$$z = \mathrm{ABS}(\frac{T_{stat} - \mu_T}{\sigma_T}) \tag{10}$$

Finally, using Microsoft's normal distribution function, the p-value can be computed as:

$$p = 2 * (1 - \mathrm{NORM.S.DIST}(z, \mathrm{TRUE})) \tag{11}$$

If $p < \alpha$, we can reject the null hypothesis (H_0) and consider an alternative hypothesis (H_a) that the effect exists in the population at the prescribed significance level.

3.5.5.5 Computer Assisted Qualitative Data Analysis Software (CAQDAS)

Statistical analysis software has been around for many decades now (Richards, 2002). There are various types of computer-assisted qualitative data analysis software (CAQDAS) that can be applied to assess various forms of qualitative feedback including ATLAS. Ti, SPSS, MAXqda and NVivo (Franzosi *et al.,* 2013; Dhakal, 2022). The latter, NVivo, was developed by QSR international in 1997 and is a prominent software application that has proved effective in helping researchers understand more complicated qualitative datasets. Furthermore, there are researchers who claim that software applications such as NVivo can improve the quality of analysis over more traditional, manual techniques (Dhakal, 2022). NVivo can be used to collect, organise, interrogate, analyse, visualize and report data. The software does not discount the need for a human researcher, but instead assists them in organising and structuring their data (Dhakal, 2022). One benefit of using NVivo is its capabilities to work with files stored either internally or externally to a project database (Franzosi *et al.,* 2013). Another is the number of options developed to sort, label and organise coded data hierarchically (Dhakal, 2022). In addition, the software saves researchers from the arduous, time consuming task of reviewing transcripts and boosts the accuracy and speed of the analysis process (Zamawe, 2015). Analysis of qualitative data has become easier, yields more professional results and reduces the laborious task of sifting through data manually, thus allowing the researcher to focus more time on recognising themes, discovering tendencies and deriving conclusions (Hilal and Alabri, 2013). However, researchers must appreciate that no data analytical software is 100% perfect.

As Microsoft Forms presents the results in an Excel format (.xlsx), these types of files, if organised correctly, can be easily exported into NVivo. Therefore, NVivo 12 was adopted as the CAQDAS for this research. The method of how the software was implemented and used to analyse qualitative data is presented in the next section.

3.5.5.6 NVivo 12 research analysis method

Prior to reviewing qualitative findings from the industry survey, a process map is required to provide logical steps for the researcher to capture and analyse survey data using NVivo software (Figure 3.15).

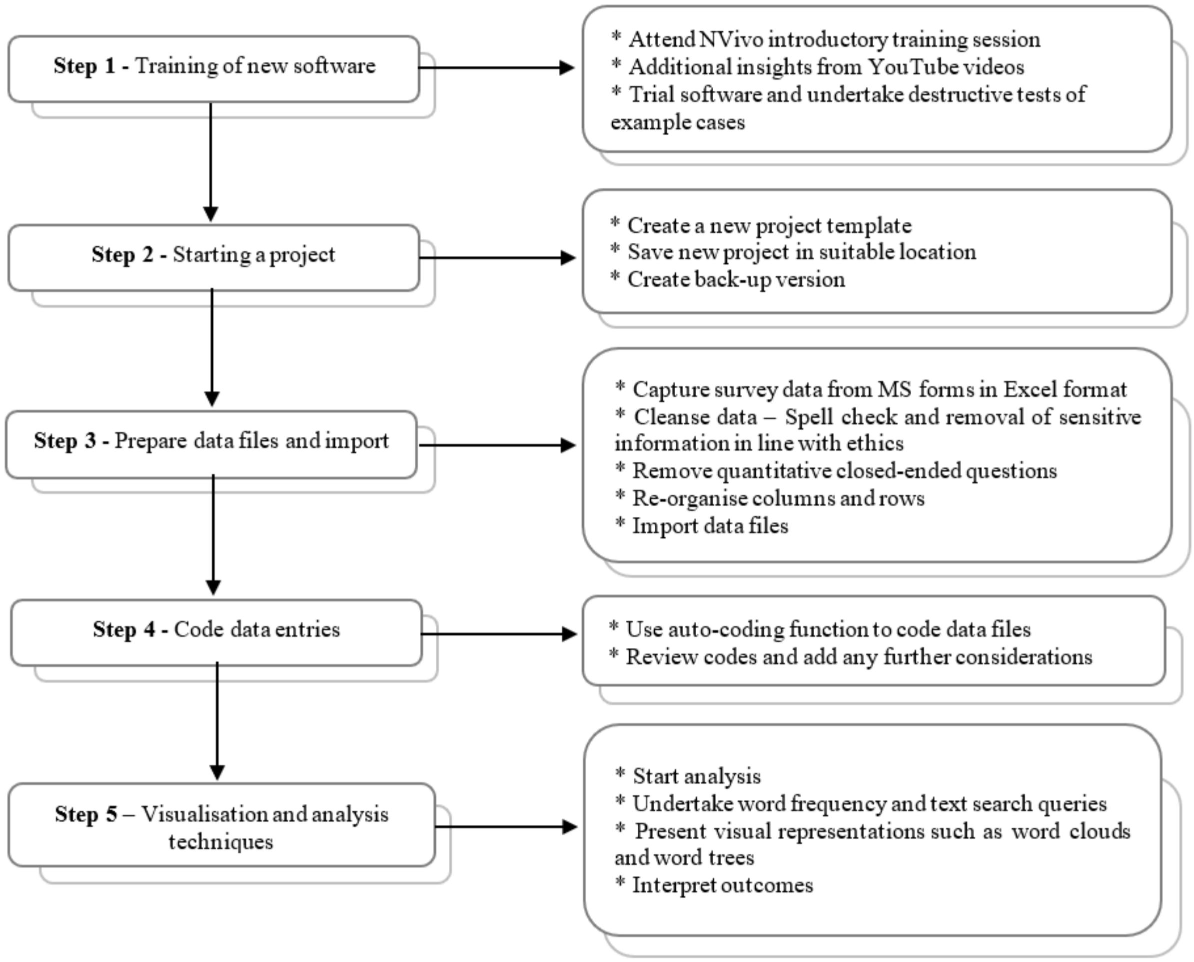


Figure 3.15 – NVivo 12 software analysis procedure for qualitative research.

The procedure for undertaking the analysis is split in five key stages and each step is detailed below and has been supported by the process established by Hilal and Alabri (2013).

Step 1 – Training of new software

The author had a limited understanding of NVivo as a qualitative analysis software. It was therefore essential that some form of training was provided. An appropriate training session to live demonstrate the software's practicalities was requested as the first step to performing the qualitative analysis exercise. Knowledge from other learning applications such as YouTube, online forums and colleagues also helped strengthen the researcher's understanding. In addition, supporting NVivo literature was used as a guiding light during challenging analysis periods (e.g. Welsh, 2002; Hilal and Alabri, 2013; Edhlund and McDougall, 2018; Dhakal, 2022).

Once sufficient knowledge of the software had been gained, the researcher proceeded with the steps below.

Step 2 – Start a project

The next step was to create a new project within NVivo, comprising of imported documents, coded data and supporting information that could assist the analysis process. Furthermore, a password was created to prevent unauthorised access to the files.

Step 3 – Prepare data files and import

Prior to importing the data, five exercises were conducted to organise and remove erroneous, misleading information.

First, a cleansing exercise was required to remove grammatical errors from the dataset using Microsoft's spell checking function in English (United Kingdom) function. Second, any sensitive information, such as names were removed from the dataset to conform to ethical considerations made in Section 3.4. Third, closed-ended questions with a quantitative bearing such as Likert scale, multiple choice and 'Yes/No' response questions were removed, leaving only 'free text' response questions. Fourth, conditional formatting was undertaken to highlight cells with blank information. NVivo does not require this but it was useful in highlighting whether all participants had completed each survey response in full. Fifth, columns were then to be organised to present questions in numerical order and rows were organised to show participants in the order they completed the survey.

Step 4 – Code data entries

A fast and efficient way of coding the data is using NVivo 12's auto-coding function (Hoover and Koerber, 2009). Using this method automated the routine and mechanical aspects of qualitative research, allowing the researcher to spend more time on interpreting and creating new insights from the data. Codes were automatically created for words that had been used frequently within the qualitative data, emphasising the most commonly discussed topics requiring further review. For the purposes of this research, the auto-coding function was used to help reduce coding and analysis times. Once this function had been completed, the data was ready for analysis.

Step 5 – Visualisation and analysis techniques

The primary visual and analysis techniques to be used in this exercise were frequency analysis and follow-up inductive analysis (Feng and Behar-Horenstein, 2019). These methods are highly suitable for open-ended cognitive response questions. Each approach is expanded on below.

<u>Frequency analysis techniques</u>

More specific searches provide insight into qualitative word frequencies and how they behave (Jackson and Bazeley, 2019). These searches were done by text based query searches that were presented visually in the form of word clouds and word trees, text coding and reference extracting, matrix coding queries for specific comparison of two or more attributes against demographics (Hilal and Alabri, 2013). Specifically, the following queries apply to this research:

(1) Run a word frequency query for each question within each group of data to provide a high level understanding of the most commonly used words.

(2) Run a specific text search query on the five most frequently used words found from the word frequency query, with a 100 most frequent display word setting, a minimum letter length of 4, and with stemmed words applied.
(3) Undertake a further matrix coding query for specific words against demographical data.

Visual analysis techniques

Descriptive analysis and visualisation techniques were deployed following the frequency query analysis as per Section 3.5.5.1 (Young and Wessnitzer, 2016). This method helped strengthen the researcher's outlook on the results and present a strengthened conclusion.

3.5.6 Internal assessment, review and pilot

3.5.6.1 Self-assessment

Many stress the importance of questionnaire testing to prove that a survey can respond positively to a normal interview situation (Bethlehem, 2009). Therefore, a self-assessment was performed by the researcher to scrutinise the survey, paying careful consideration to the professionalism of the survey design, target audience (e.g. project leaders and quality professionals), length of the questionnaire and the timescale to complete it. Galesic and Bosnjak (2009) conclude that the length of a survey has a significant impact on the participants' willingness and likelihood of completing it in full. Furthermore, their analysis supports the assumption that by proposing a longer length questionnaire, the increased perceived costs to participate make participants less likely to engage. Others have referred to the longwinded nature of surveys as 'survey fatigue', requiring an excessive amount of time and effort to complete (Sharp and Frankel, 1983). As such, the researcher ran a demonstration of the survey with a stopwatch to accurately log the time taken to complete. All of the questionnaire content was read and digested prior to answering the questions. The researcher did this three times. The average trial time to complete the survey was 14 minutes 40 seconds. Kaplowitz *et al.* (2004) used a similar length of time (15 minutes) to complete their web questionnaire. These figures are considered sufficiently low to engage participants and yield a high response rate (Galesic and Bosnjak, 2009).

3.5.6.2 Internal reviewer feedback

Following the self-assessment close out, the questionnaire was transposed into a PDF printed document and sent by email to five professionals within Costain. To ensure a wide range of comments were received, a selection of project management, quality management and engineering management professionals were considered to represent the target audience. Each panel expert had a minimum experience of 10 years in construction, and excellent knowledge of project and quality management practices to improve the 'content validity' of the questionnaire (Enshassi *et al.,* 2017). Specifically, two project managers, two quality managers and one senior engineer were consulted for feedback. Each reviewer was encouraged to provide their open and honest feedback to strengthen the survey either via email, face-to-face communication or digitally via Microsoft Teams. Each participant was briefed on the purpose, aims and benefits of participation. Table 3.10 documents each reviewer's feedback method, format in which comments were communicated, date of response, and follow-up meeting date.

Table 3.10 – Internal reviewer feedback summary.

Participant number ('Initials')	Feedback method	Response format	Date responded with feedback	Follow-up meeting held
Reviewer 1 (CR)	Face-to-face	Microsoft Teams	20/04/22	25/04/22
Reviewer 2 (KS)	Email	Email comments	19/04/22	19/04/22
Reviewer 3 (JB)	Email	Excel comments	24/04/22	28/04/22
Reviewer 4 (CH)	Email	PDF comments	29/04/22	03/05/22
Reviewer 5 (DM)	Microsoft Teams	PDF comments	10/05/22	10/05/22

Following receipt of all comments, a Microsoft Teams call was scheduled with each reviewer to go through their contributions. All comments were carefully considered for applicability and consensus was achieved with each reviewer prior to progression to the pilot trials.

3.5.6.3 Pilot study

Following the incorporation of all five reviewer comments, the researcher conducted a final trial run to confirm the time to complete the questionnaire remained valid. Upon validation, an email was constructed and issued to the five participants containing a working button link to the Microsoft survey pilot trial survey (Appendix 7).

A useful feature of MS Forms is that once a participant has completed the survey, an automated email is generated by the platform and sent to the survey developer. This proved very useful as a way of identifying when all participants had completed the pilot trial and provided evidence in email form. Table 3.11 summarises the response rate, 'interest of topic' score and response time for each pilot trial participant.

Table 3.11 – Summary of pilot trial response rates and interest scoring.

Number of pilot trial participants	Completed surveys (in full)	Validity	Response rate	Mean 'interest of topic' score (out of 10)	Response times (mins ; secs)
5	5	5	100%	9.6 / 10	57m 56s Average
Participant 1 (CR) – *First respondent*				9	6 mins 00 secs
Participant 2 (KS) – *Third respondent*				9	15 mins 35 secs
Participant 3 (JB) – *Fourth respondent*				10	118 mins 24 secs
Participant 4 (CH) – *Second respondent*				10	116 mins 04 secs
Participant 5 (DM) – *Fifth respondent*				10	33 mins 37 secs
				Usable average response time:	18 mins 24 secs

The pilot study yielded a 100% response rate of the five pilot trial participants with a mean 'interest of topic' score of 9.6 out of 10. A factor that may have had a positive impact on a high response rate was the researcher's position within the company and professional relationship with each participant. The ability to reach out, assess responses and query input helped in achieving this high response. Unfortunately, it is important to note that for the roll-out of the questionnaire to both target groups (group 1 and group 2), the researcher did not have working professional relationships or knowledge of many participants set to complete the form. As a result, it was anticipated that the response rate would be substantially lower than in the pilot trial. However, there was hope that the 'interest of topic' score would remain high, as it is a topic that should appeal to all project managers and quality professionals with high quality managerial attributes (Anderson, 1992).

Reviewing the response times, an anomaly was observed with participants 3 and 4. Each participant recorded a response time of 118 minutes 24 seconds and 116 minutes 4 seconds respectively. As this was of concern, the researcher set up a Microsoft Teams call with each participant to discuss the duration and any difficulties encountered. Participants 3 and 4 both identified the high response time frame root cause as 'working on the questionnaire while dealing with other matters' (e.g. answering emails and dealing with site queries alongside completing the questionnaire). As a result, the questionnaire was left open whilst the Microsoft Forms timer continued to record. On reflection, participants 3 and 4 gave feedback that the questionnaire would take approximately 15-17 minutes to complete if populated without interruptions. For the purposes of this research however, participants 3 and 4's times were discounted from the average response time but considered in the approximate time frame to provide a complete statement (see Table 3.11). Discounting the time anomaly from participant 3 and 4, an average response time of 18 minutes and 24 seconds was recorded. This is marginally higher than the 15 minutes taken by the researcher. A possible reason for this could be varied reading speeds and cognitive processing of each question. To avoid similar response time anomalies in the formal survey, the researcher drafted a clarification statement to explain the need to complete the questionnaire in full without distraction, setting aside an uninterrupted period of 15 minutes.

Reflecting on the pilot testing, no technical issues were encountered by any of the five participants. On the contrary, all five expressed positivity for the way the survey was presented and how easy it was to use. The positive feedback gained from the pilot trial resulted in no further changes to the Microsoft survey form.

3.5.7 Survey dissemination

Upon completion of the pilot study, the questionnaire was formally distributed to sixty-seven contract leaders (focus group 1) and ninety-five quality professionals (focus group 2) for their feedback via an email transmission. Communications to focus group 1 were presented via the contract leader's chair to enhance response rates. Furthermore, it was deemed the most appropriate channel of communication, as it involved a senior member of the construction committee who had direct links and working relationships with all contract leaders, which the researcher did not have. As a result, it was anticipated that the response rate would be greater for the survey coming from a higher authoritative level. For focus group 2, the researcher had integrated roots within the community. Therefore, the email was sent directly from the researcher's employee account. Emails were dispersed electronically on Thursday 9th June 2022 to both working groups, who were given a deadline date of Thursday 30th June 2022 to respond.

3.5.8 Tentative validation of framework

Given the researcher's position in industry, and access to senior industry figures, three industry quality leaders were consulted at the end of the research process. The purpose was to critique the collective findings of these works in the form of a quality management framework. This was to help evaluate the outcomes of the thesis, and the generalizability from a practical perspective. In addition, by seeing things through different perspectives (i.e. other professional experiences), this helps triangulate the findings, and build a most robust conclusion of the framework (Love *et al.,* 2002). The findings from these interviews are presented in Section 6.2, Appendix 18 and Appendix 19.

3.5.9 Chapter summary

This section details the research method, research design, philosophical positions and the way the research was conducted. Four research philosophies have been defined as a result of their applicability within this project and within quality management. This discussion resulted in the researcher adopting a hybrid stance in this project by combining positivism and critical realism, with the stances intertwined by deductive logic.

A methodological research path was reviewed and justified within Figure 3.3 to answer the research questions. Specifically, the combination of quantitative and qualitative methods were chosen to offer robust, analytical insights into non-conformance and rework analysis and help enhance data outcomes.

This section has also provided detailed descriptions of two research streams: analysis of an NCR dataset provided by a major highways scheme and an online survey conducted within a tier 1 contracting organisation. Furthermore, comprehensive approaches for each stream have been given so that the reader can follow the methodological process. The NCR data analysis explains collection techniques, cleansing methods and specific analysis approaches.

With regards to the online survey, different preference measurement techniques have been discussed, including the benefits of using online surveys over other methods. Furthermore, a survey design process is presented in Figure 3.12, with detailed sub-sections on questionnaire design, pilot trialling, survey dissemination techniques and statistical testing techniques used.

Chapter 4: Finding from Phase 1 (NCR data analysis)

This section begins with a brief introduction of the chapter followed by analysis and presentation of results from Phase 1. The key contributions of this chapter are threefold: 1) using a unique and rich empirical dataset, key NCR failure areas are determined and presented as a lessons learned framework. 2) Building on previous work regarding decision theory, and the application of the Cynefin framework, we create a novel approach to categorising decision-making pathways using RCA and FMEA, to resolve quality issues under varying degrees of uncertainty, applying the framework in a new way and in a new context. This will help stimulate more robust quality practices in construction operations. 3) More broadly, the work contributes to the non-conformance and rework body of knowledge to help drive towards an error free industry. Each contribution forms the basis of the online survey conducted in Phase 2.

4.1 Introduction

As a whole, the European construction industry has continued to suffer from poor quality delivery and a myriad of errors (Forcada *et al.,* 2017; Trach *et al.,* 2021; Ford *et al.,* 2023). Non-conformance report data have been seen as a useful lagging indicator to identify what quality problems are present on schemes and to what extent (Abdul-Rahman, 1995; Love and Smith, 2018). There is a desperate calling to re-evaluate how projects are delivered and where efficiencies can be made, to help reduce the risk of failure, as well as to protect what little profit margins organisations make. The challenge is uncovering tangible learning outcomes that can be shared in order to help reduce construction errors and encourage continuous improvement.

The quantitative phase of this research has been conducted within a complex, multifaceted environment where projects are typically bespoke in their construction. Due to the researcher's access to NCR data with a tier 1 contractor, coupled with many examples of non-conformance and rework literature in highways (Table 2.1), the researcher has seen that the sector has shown continuing signs of poor performance which are in need of further exploration. Specifically, 1260 NCRs were provided to the researcher by the UK's largest highways scheme, allowing the researcher to understand the most prevalent and costly failure areas on a current scheme. Access to the project's NCR database was given on 29/01/2021, at which point the data was exported into an Excel format ready for analysis. A project description is presented below.

4.1.1 Project description

The A14 Cambridge to Huntingdon Improvement scheme is a £1.5bn megaproject upgrading 21 miles of highways infrastructure in Cambridge. The project was set up as a three-way joint venture consisting of Costain, Skanska and Balfour Beatty, led by the client, Highways England. Collectively, the three principal contractors have over 62,500 employees, many of whom provide expertise internationally in the fields of transportation, nuclear, oil and gas, and aviation.

To successfully promote collaboration on the scheme, the project team was branded as an integrated delivery team and rebadged accordingly. In recent years, all parties have played their part in seeking right-first-time and delivery without error. Unfortunately, due to various uncertainties highlighted in the analysis, this has proved challenging.

4.2 NCR analysis and results

Following the research design set out in Figure 3.5, the aims of the NCR data analysis were to [1] identify the most prominent areas of failure on a major highways scheme via RCA, [2] derive real-time vs retrospective decision-making pathways to identify whether problems are being over or under simplified using the Cynefin framework, [3] undertake failure mode and effects analysis (FMEA) to understand corresponding risk profiles, and [4] yield key lessons learned that can positively influence improvement within the sector.

4.2.1 Most frequent NCR root causes

Following the completion of the cleansing, sampling and root cause analysis of 1260 NCRs, Pareto analysis was performed to share insight into the most frequent failure areas. Figure 4.1 presents the findings from the highest yielding NCRs according to primary root cause classification.

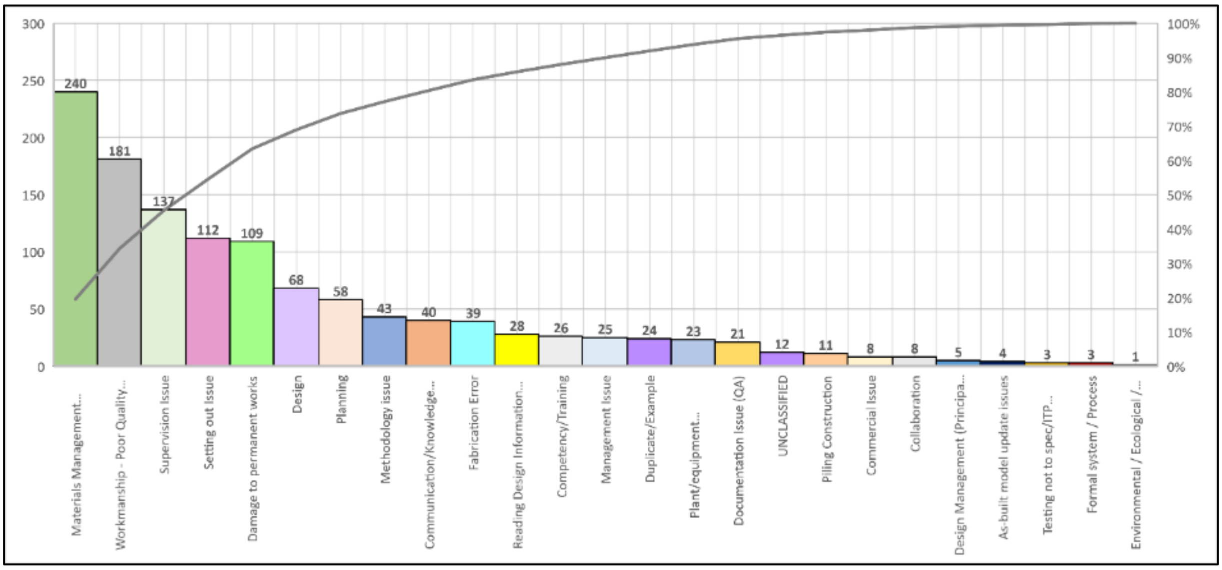


Figure 4.1 – Pareto analysis of most frequently occurring NCR causes.

The results indicate that the five most prominent areas of failure on a current highways construction schemes are 'Materials Management', where either transportation, manufacture, storage or testing of a material had breached specification requirements in its lifecycle (240 NCRs; 19.5%), 'Workmanship/Poor Quality Execution', where quality processes and assurance had not been followed (181 NCRs; 14.7%), 'Supervision', where there had been either an insufficient or unqualified resource to oversee the works (137 NCRs; 11.1%), 'Setting Out Issues', where the design was not followed (112 NCRs; 9.1%), and 'Damage to Permanent Works' (109 NCRs; 8.9%). Combined, these failure areas account for 63.4% of the dataset. Of the 181 workmanship issues, 79.4% were as a result of poor supply chain performance, leaving 20.6% due to self-delivery. Similar patterns have been found by other researchers, who raise notable concerns with supply chain quality performance involving rework and defects (Karim *et al.,* 2006; Love *et al.,* 2018). This is a somewhat unsurprising statistic, given the fact that principal contractors typically outsource the majority of works to a specialist supply chain, reducing the likelihood of an internal error and pushing ownership onto the supplier.

As materials management yielded the most non-conformities and a number of sub-categories, a more granular analysis of this area of failure was conducted to uncover which types of materials were problematic. Of the 240 cases, by far the most frequently failing material was in-situ concrete operations, accounting for 118 NCRs (49.2% of the materials management cases). Examples of non-compliant concrete were a result of material deliveries failing to be delivered to site in accordance with the specified timeframes, pouring during inclement weather outside of specification, failing to test in accordance with specification and general mismanagement/storage of materials. Löfgren and Gylltoft (2001) commented that 'improvement of in-situ concrete construction is necessary', however two decades have passed since this commentary and concrete non-conformance is still prevalent. The challenges of achieving the necessary compressive strength for in-situ concrete has proved arduous and often unreliable (Magalhães *et al.,* 2016).

Figure 4.2 represents the influence each activity had on the materials management elements of the scheme, drawing attention to the most critical areas for improvement. The bubble sizes indicate the magnitude of each problem by cost.

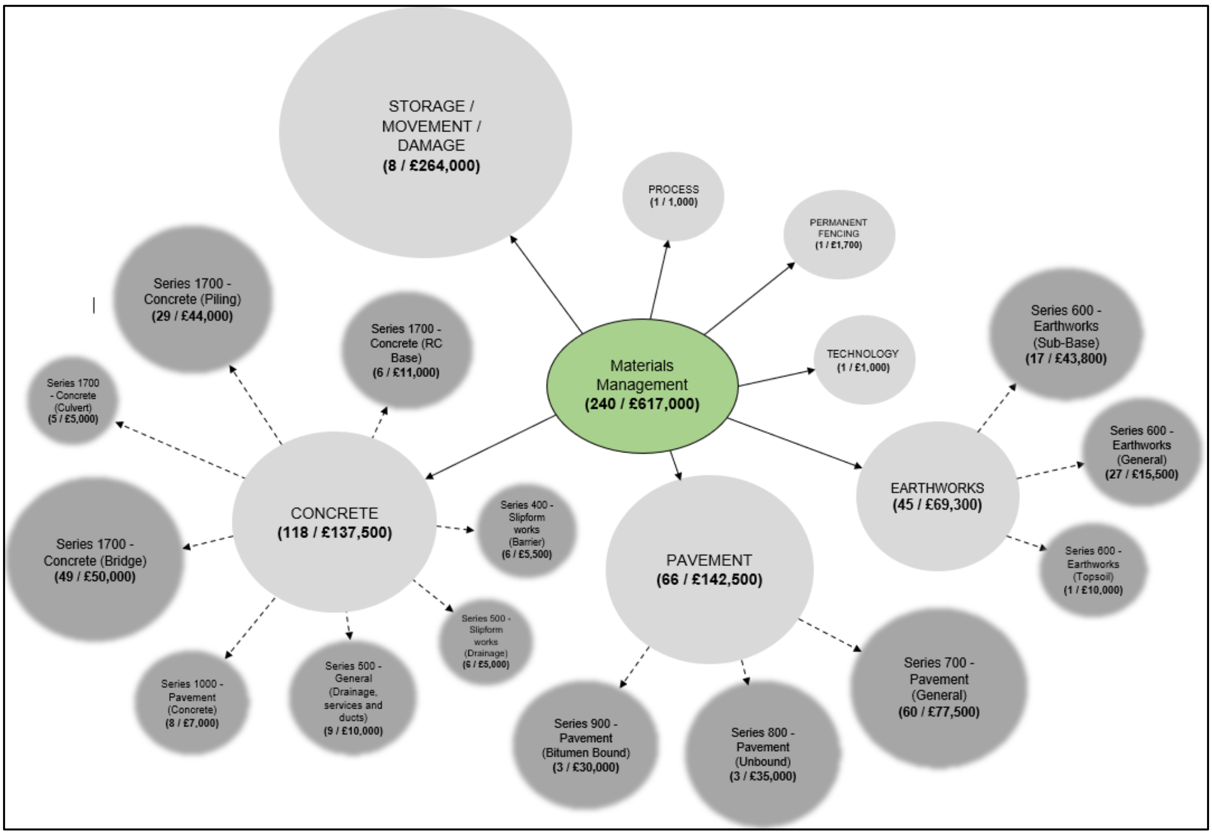


Figure 4.2 – Zoom and focus on materials management primary root cause.

Similar trends were found by Love *et al.* (2018), which denote concrete operations being one of the higher generators of NCRs, particularly due to the supply chain. This also suggests that the number of errors within concrete operations may be unavoidable, unless stringent processes are implemented (e.g. pre-testing at batching facility prior to site delivery and/or real-time traffic forecasting for concrete deliveries to prevent unnecessary delays). The findings also indicated that although concrete was a more prevalent failing activity, storage and handling of project materials, including precast elements, was far more costly, yielding a total cost of £264,000. This was brought about by poor knowledge of how materials should be correctly stored, careless behaviours causing damage during transportation and inadequate management of stockpiles, leaving them exposed for prolonged periods of time, rendering the material non-compliant.

To pinpoint which activities within the highways scheme were struggling with right-first-time, each non-conformance was further categorised into its corresponding activity type. As highways schemes are monitored against requirements set within the

Specification for Highway Works (SHW), each NCR activity was mapped against the relevant series specification under highways standard MCHW, Volume 1 (2014). For example, if the activity involved drainage operations, the NCR would be categorised 'Series – 500 General (Drainage, services and ducts)'. Furthermore, there are many types of major reinforced concrete operations, such as bridges, retaining walls, culverts etc. These were sub-categorised accordingly. Lastly, there were instances where the activity did not match any series within the specification. As such, four further categories were created for Design, Archaeology, Materials Management, Plant Management and Process and Procedural. Figure 4.3 presents the total number of NCRs uncovered per highways series activity.

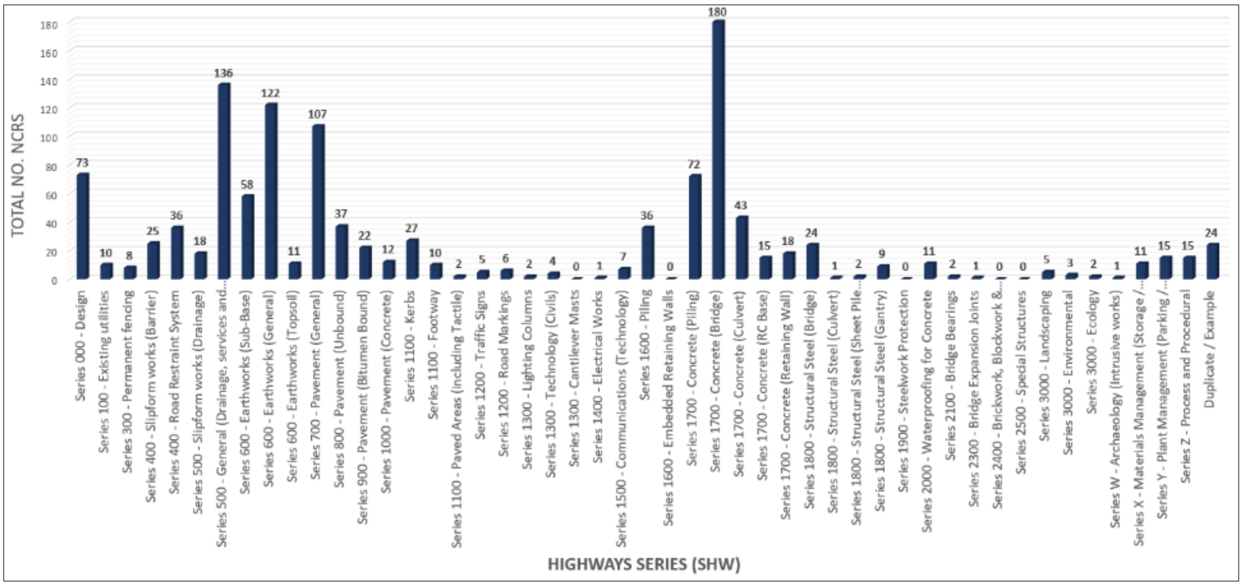


Figure 4.3 – Histogram of most frequent NCRs by highways series (SHW).

On closer inspection of the findings, the data suggests that concrete operations on bridge constructions are the most significant area of failure, generating 180 NCRs for the project lifecycle, followed by drainage (136 NCRs), earthworks (122 NCRs), and pavements (107 NCRs). A potential factor for the frequency of NCRs raised, may be the magnitude of the works being completed. Typically, the four series mentioned above are significantly large packages of work on highways construction schemes, which may offer greater opportunity for error.

4.2.2 Most costly NCR root causes

Factoring cost as a fundamental driver of change, the results were further analysed with a focus on the most costly areas. Of the 1260 NCRs, non-conformance and rework costs were calculated at £7,739,850, equating to 0.5% of the total project value. Figure 4.4 represents the most costly primary root cause categories using Pareto analysis.

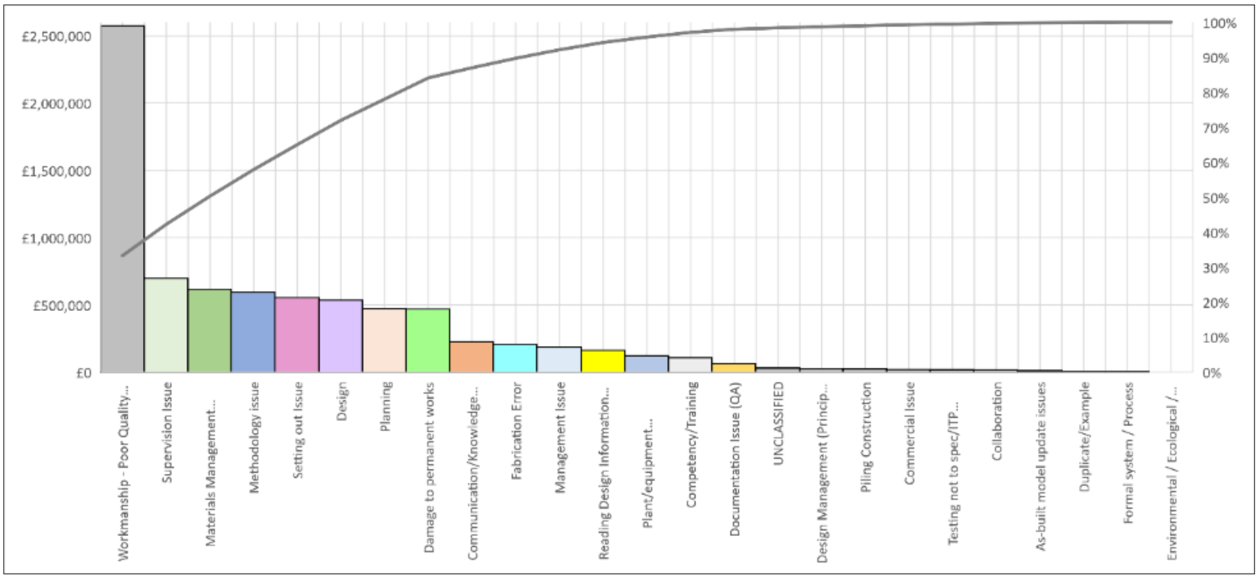


Figure 4.4 – Pareto analysis of most costly NCR causes.

A detailed review of the most costly NCRs revealed that 'Workmanship/Poor Quality Execution' (£2,574,700), 'Supervision' (£697,050), 'Materials Management' (£617,000), 'Methodology' (£593,000) and 'Setting Out' (£552,500) were the five highest root cause values on the scheme, collectively yielding a total cost of £5,034,250. This accounts for approximately 65% of the scheme's overall non-conformance and rework cost. To understand how these costs related to specific highways activities, cost totals were summarised and presented in Appendix 8. From the findings, the highways series activities with the highest non-conformance cost were [1] Series 1700 – Concrete (Retaining Wall) with £2,169,500 (28% of overall cost), [2] Series 500 – General (Drainage, services and ducts) with £786,600 (10.2%), [3] Series 600 – Earthworks (General) with £587,500 (7.6%), [4] Series 1700 – Concrete (Bridge) with £584,500 (7.6%), and Series 000 – Design with £564,100 (7.3%). These five highest activity costs accounted for 60.6% of the total dataset cost, warranting further analysis to understand the severity of the problem by comparing the frequency and cost of each SHW series to yield average NCR costs.

Comparing the statistics of the most frequent and most costly SHW series, the first interesting point to note was that the total cost for each primary cause does not directly coincide with the quantity of NCRs raised (Table 4.1).

Table 4.1 – SHW Series frequency vs cost NCR assessment.

	NCR Quantity Prioritisation		NCR Total Cost Prioritisation			Average cost per NCR
	Total NCR's	SHW Series	SHW Series	Total Cost		
1st	180	Series 1700 - Concrete (Bridge)	Series 1700 - Concrete (Retaining Wall)	£2,169,500	1st	£120,527.78
2nd	136	Series 500 - General (Drainage, services and ducts)	Series 500 - General (Drainage, services and ducts)	£786,600	2nd	£5,783.82
3rd	122	Series 600 - Earthworks (General)	Series 600 - Earthworks (General)	£587,500	3rd	£4,815.57
4th	107	Series 700 - Pavement (General)	Series 1700 - Concrete (Bridge)	£584,500	4th	£3,247.22
5th	73	Series 000 - Design	Series 000 - Design	£564,100	5th	£7,727.40
6th	72	Series 1700 - Concrete (Piling)	Series 600 - Earthworks (Sub-Base)	£415,300	6th	£7,160.34
7th	58	Series 600 - Earthworks (Sub-Base)	Series 700 - Pavement (General)	£357,500	7th	£3,341.12
8th	43	Series 1700 - Concrete (Culvert)	Series X - Materials Management (Storage / Movement)	£271,500	8th	£24,681.82
9th	37	Series 800 - Pavement (Unbound)	Series 800 - Pavement (Unbound)	£203,000	9th	£5,486.49
10th	36	Series 400 - Road Restraint System	Series 400 - Road Restraint System	£149,500	10th	£4,152.78
...	...	...	...	...	...	...
17th	18	Series 1700 - Concrete (Retaining Wall)	Series 1700 - Concrete (Piling)	£135,500	11th	£1,881.94
24th	11	Series X - Materials Management (Storage / Movement)	Series 1700 - Concrete (Culvert)	£134,700	12th	£3,132.56

The data suggests that despite yielding a greater number of NCRs through the lifecycle of the scheme, series 1700 – Concrete (Bridges) did not generate the highest total or average costs per NCR. Rather, it featured 4th on the list of highest total costs (£584,500) and 28th on the average NCR cost (£3,247). This suggests that although non-conformities are frequently raised for concrete works on bridges, each case appears less detrimental to the project budget than other areas such as Drainage, Earthworks and Design.

There are two standout average costs to be explained further. These are Series 1700 – Concrete (Retaining Wall) and Series X – Materials Management (Storage/Movement) which yielded £120,527.78 and £24.681.82 respectively. First, the retaining wall series generated a high cost due to a Reinforced Earth Company (RECo) wall installation non-compliance. There were numerous challenges when installing these prefabricated structures, such as methodology, expertise and supervision, which caused an isolated case of substantial cost and time overruns to the scheme. Specifically, a RECo wall installation (BN25 – Girton Interchange Bridge) cost the scheme £2,145,000 in rework according to the NCR data supplied, accounting for 27.7% of the total dataset cost. A key lesson learned from this data was that the consequence of error on these activities is severe should things go wrong. These types of structures should be planned and managed more strictly with more risk management processes in place. Furthermore, greater focus on the methodology of installation, adhering to QA process (e.g. compaction parameters) and vetting the competence and knowledge of the workforce, including supervisors, is key to the successful installation of these types of structures.

The second standout cost was in materials management, with the poor planning, storage and stockpiling of earthworks fill material rendering the material non-compliant, costing the project circa £250,000 in rework costs (BE02 – Matchams Bridge). A further lesson learned suggested by the researcher is that there should be the implementation of mandatory materials storage training for storemen and compound managers (Patel and Vyas, 2011). In addition, stockpiles of materials should be planned and managed to ensure they are stored in controlled environments, free of inclement weather. If the high isolated non-conformance costs in each of these series were discounted, the data suggests that the three highest average NCR costs would in fact be 'Series 3000 – Landscaping' with an average NCR cost of £20,700, Series Y – Plant Management (Parking/Movement) with a cost of £8,600, and Series 000 – Design, with a cost of £7,727. This emphasises that all three disciplines have significant risk associated with quality failure, which could be highly detrimental to project profits if not managed correctly.

4.2.3 The average lifespan of an NCR

One issue that is seen on projects is the lengthy process of raising an NCR all the way through to closing it out with the client's approval. During this time, remedial action must be agreed by all parties, works must be implemented to address the non-conformance, evidence must be provided to satisfy those signing off the NCR, and agreeing a corrective action that will address the chance of its reoccurrence. This can take considerable time, particularly when other works take precedence. Project teams are pressured into looking for a cost effective solution while trying to prevent the remedial action from compromising key milestones. As such, these are usually left until the end as 'snagging' items, to be resolved after works are substantially complete.

An exercise was conducted to understand the average 'open' duration of an NCR and how long it takes to get from identifying a remedial solution all the way through to site sign-off.

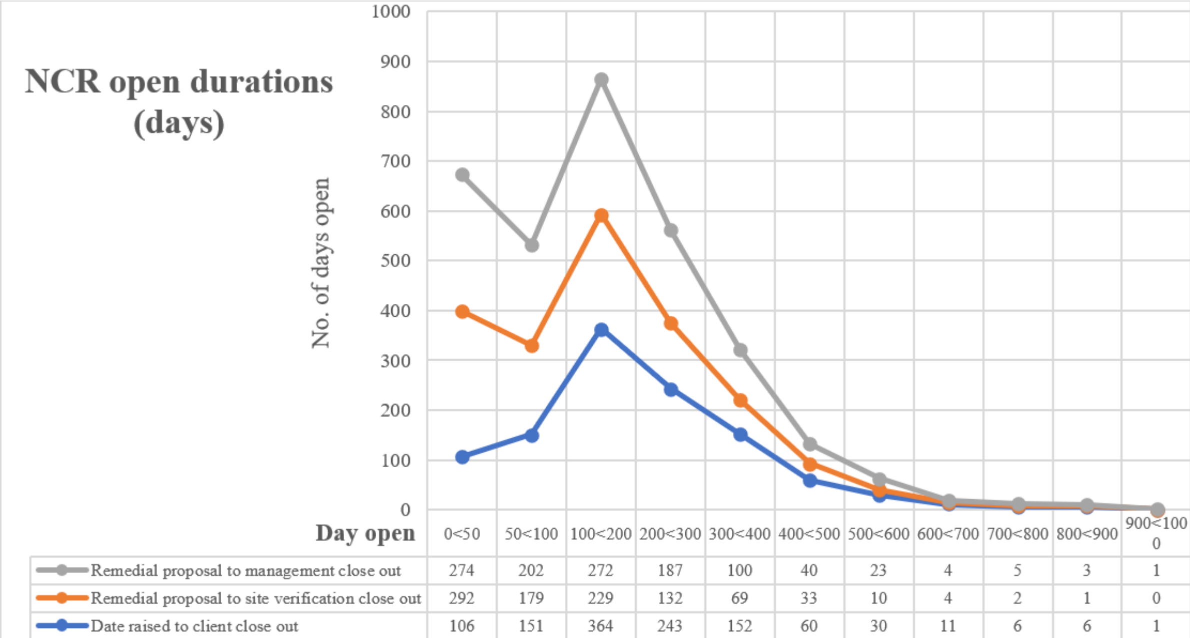
Table 4.2 presents the average time frames taken to close NCRs using three scenarios. The first scenario is the total duration of an NCR (i.e. from date it was raised to the close out by the client). The second is the time taken to implement a remedial solution with the site team's acknowledgement (i.e. from the remedial proposal date to the site verification close out), and the third is the time taken to implement a remedial solution with the management team's acknowledgement.

Table 4.2 – Average time frames taken to close NCRs against three scenarios.

	Scenario (1) Date raised to client close out	**Scenario (2) Remedial proposal to site verification close out**	**Scenario (3) Remedial proposal to management close out**
Number of date counts (dates provided)	1130	951	1111
Number of open counts (no date allocation)	84	252	94
Average open duration (days)	211.8	138.1	162.9

Beginning with the longest duration (scenario 1), which is the full lifespan of an NCR from identifying through to client close out, the data reveals that, on average, an NCR took 211.8 days to close out, which is an extraordinarily long time and brings into question whether the NCR process is being rigidly followed. In addition, it raises concerns around whether non-conformance rectification is on the construction team's priority list. The researcher suspects that outstanding works are the focal point, and activities such as NCRs, snagging and defects, take a backseat. This is a naive approach to take as the correction of these activities will be necessary in securing contract completion. It is far easier to do these types of activities in area packages with a fully-fledged engineering team and supply chain pool on hand, rather than attempting to rectify issues with a skeleton team on an ad hoc basis. Looking at the second scenario, the analysis reveals that the process of identifying a remedial solution through to implementation and sign-off by the site team, took on average 138.1 days to complete. More distressing is the fact that to go ones step further and achieve sign-off by the project management team, this took an average of 162.9 days. This is an additional 24.8 days from site team sign-off and suggests that NCR close out is an onerous task and is not a manager's primary focus. There may also be communication from the site team to management, with NCRs being closed out only when prompted. Table 4.2 also reveals that there were a number of NCRs that did not contain close out dates and were considered 'open' for the purposes of the analysis, and were thus discounted from the calculation. There were 84 of these cases within the first scenario, 252 cases within the second scenario, and 94 cases within the third scenario. During this review, there were more blank fields for the site verification team column (scenario 2), where the management team had reviewed the NCRs but had bypassed site sign off (158 instances). There were a further 10 instances where both the site verification step and management step had been bypassed, straight to client signoff.

To understand the specific open durations for each scenario mentioned above, a graphic representation (data table) was formulated. Data was split into different timeframes (e.g. 0 < 50, 50 < 100, 100 < 200 etc.) to determine the most common average lifespan of an NCR. Figure 4.5 presents the open durations against set timeframes using date entries provided for 'date raised', 'remedial solution proposed', 'site team verification', 'management verification' and 'client close out'.



Day open	0<50	50<100	100<200	200<300	300<400	400<500	500<600	600<700	700<800	800<900	900<1000
Remedial proposal to management close out	274	202	272	187	100	40	23	4	5	3	1
Remedial proposal to site verification close out	292	179	229	132	69	33	10	4	2	1	0
Date raised to client close out	106	151	364	243	152	60	30	11	6	6	1

Figure 4.5 – Open durations of NCRs on a highways megaproject

For scenario 1(i.e. date raised through to client close out), the three time frames that contained the most NCRs were 100 < 200 days (364 cases), followed by 200 < 300 days (243 cases) and 300 < 400 days (152 cases). For scenario 2(i.e. remedial proposal through to site verification), 0 < 50 days (292 cases), 100 < 200 days (229 cases) and 50 < 100 days (179 cases) were the three most common NCR time frames. Lastly, for scenario 3 (i.e. remedial proposal through to management verification), the three most common time frames were 0 < 50 days (274), 100 < 200 days (272 cases) and 50 < 100 days (202 cases), which coincides with scenario 2. Of the extreme cases, there were 165 NCRs that took longer than one year to resolve and 10 NCRs that took longer than two years. According to the data, the longest period an NCR took to close was 929 days from when it was raised. An anomaly perhaps but still a truly unacceptable duration to leave an NCR lingering.

4.3 Decision-making of quality problems: 'The intervention'

On completion of the root cause analysis exercise for each NCR, complexity categorisations were assigned for real-time decision-making made by the project and retrospective decision-making computed by the researcher. Real-time decision-making pathways were linked to the appropriate Cynefin framework action taken to resolve a quality problem (i.e. categorise = simple, analyse = complicated, probe = complex, act = chaos). For the simple domain, this was when NCR resolution followed a systematic pathway with obvious cause-and-effect relationships to categorise the problem. For complicated, a more granular analysis of the problem was performed prior to response. For complex, experimentation or a deep dive into the problem was performed prior to concluding remedial and corrective actions. And finally, where the project acted irrationally without consideration, these were assigned to chaos (refer to Figure 3.9). The findings from this are presented in the next sub-section.

4.3.1 Non-conformance decision complexity categorisation

Using the Cynefin framework as a tool for identifying various complexity levels, each non-conformance was mapped against the framework both in real-time (i.e. by the NCR owner) and retrospectively (i.e. by the researcher) to determine whether oversimplification was occurring.

Figure 4.6 presents the real-time and retrospective complexity classification of the NCRs by the project (red) and by the research team (blue). Differences between the two have been calculated and presented at each domain to understand the shift in decision-making, as not all decisions move linearly to the next domain. For example, there were six cases where a ‘simple’ real-time decision was actually ‘complex’ owing to many attributing causes, such as political pressures, adverse weather conditions etc.

REALTIME		RETROSPECTIVE		diff (Δ)
Domain	**No. Identified**	**Domain**	**No. Identified**	
Sense > Categorize > Respond = SIMPLE	725	Sense > Categorize > Respond = SIMPLE	384	341
Sense > Analyze > Respond = COMPLICATED	216	Sense > Analyze > Respond = COMPLICATED	653	-437
Probe > Sense > Respond = COMPLEX	179	Probe > Sense > Respond = COMPLEX	156	23
Act > Sense > Respond = CHAOTIC	34	Act > Sense > Respond = CHAOTIC	0	34
DISORDER	39	DISORDER	0	39
UNCLASSIFIED	12	UNCLASSIFIED	12	0

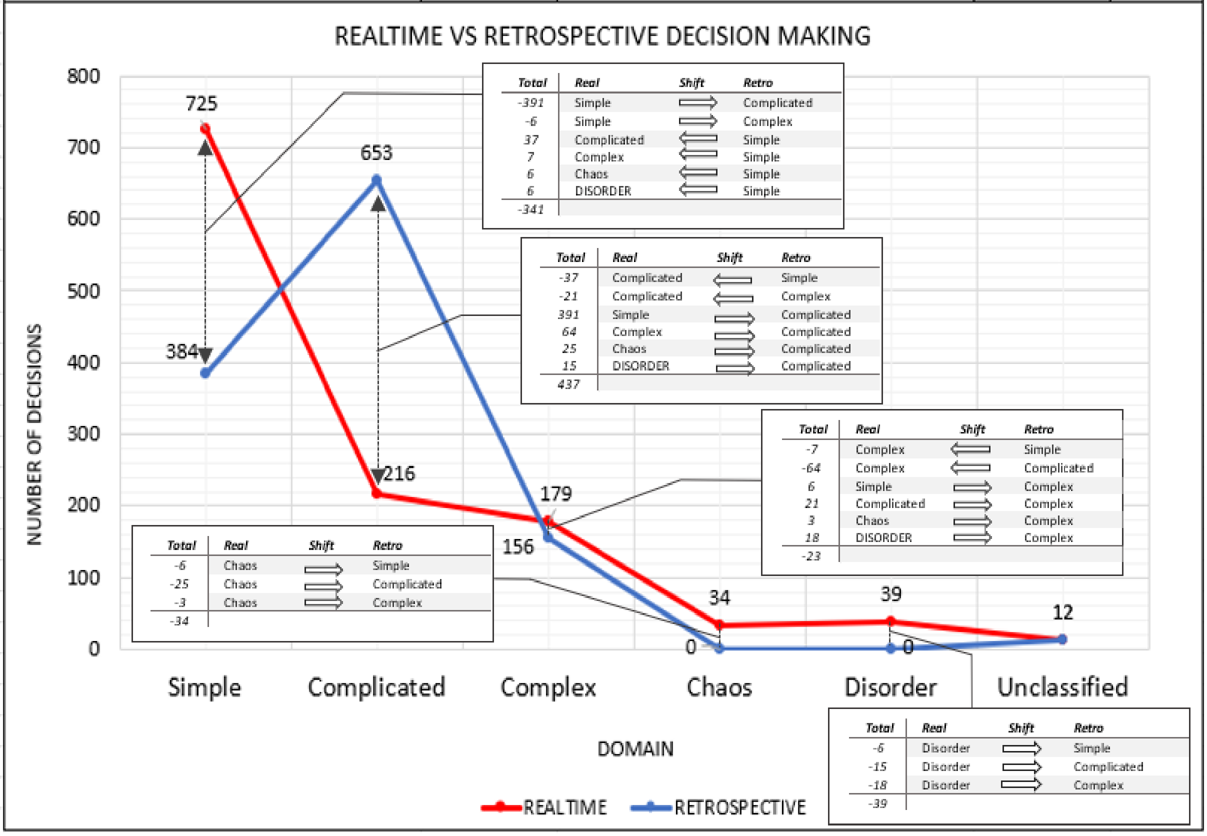


Figure 4.6 – Real-time vs retrospective decision-making categorisation.

There are some obvious trends to note. First, in the Simple and Complicated domains, there was an obvious shift between levels of complexity and uncertainty. Specifically, there were differences of 341 cases for Simple, 437 cases for Complicated, 23 cases for Complex, 34 cases for Chaotic and 39 cases for Disorder. In total, there were 594 instances where no change had occurred between the real-time and retrospective decision-making pathways, accounting for 49% of decision-making for the entire NCR dataset.

It is important to note that during the retrospective decision-making analysis, no Chaotic or Disorder cases were logged. However, in a world of hindsight and retrospective thinking, why would there be any? At worst, the situation would be Complex, with many perceivable root causes to a problem.

To be specific as to which work activities experienced the greatest difference between decision-making pathways (i.e. under or oversimplification difference), the results were also categorised against the SHW series and colour coded to identify where decision-making pathways had changed (Appendix 9). There were five series that featured zero non-conformities (Series 1300 – Cantilever Masts, Series 1600 – Embedded Retaining Walls, Series 1900 – Steelwork Protection, Series 2400 – Brickwork, Blockwork and Stonework, and Series 2500 – Special Structures). As such, these were discounted to further consolidate the appendix.

By comparing the two decision-making categories it becomes clear that there were significant differences between the real-time and retrospective categorisations (i.e. red and green colour coding values). For example, it was apparent that the Series 1700 – Concrete (Bridges) category had many Simple categorisations within the real-time data where the project team had not taken appropriate action to uncover the underlying causes of non-conformance but instead only scratched the surface (117 cases). For these cases, a difference of 63 cases were identified where many NCRs were far more complicated than initially perceived by the project, concluding that many of the interventions to address NCRs were made prematurely. In many of these non-conformities there was more than one root cause of the problem and more than one solution required to address it (i.e. a lack of supervision on site and a poor leadership mandate to instil the right site behaviours). The data provides a perspective on the levels of uncertainty projects face but also flag the capabilities of those in problem solving roles. Project teams should re-evaluate the way they perceive complexity when dealing with problems, particularly the mindset of oversimplifying. Rather, it is best practice to think of the worst then work backwards from there, turning over every stone until a clear picture is reached, similar to forensic investigative techniques used in safety (Yates and Lockley, 2002).

To add further justification, of the five most frequently raised NCR SHW categories listed within Appendix 9, each decision-making intervention was categorised. Figure

4.7 depicts the domain allocation for real-time and retrospective decision-making pathways.

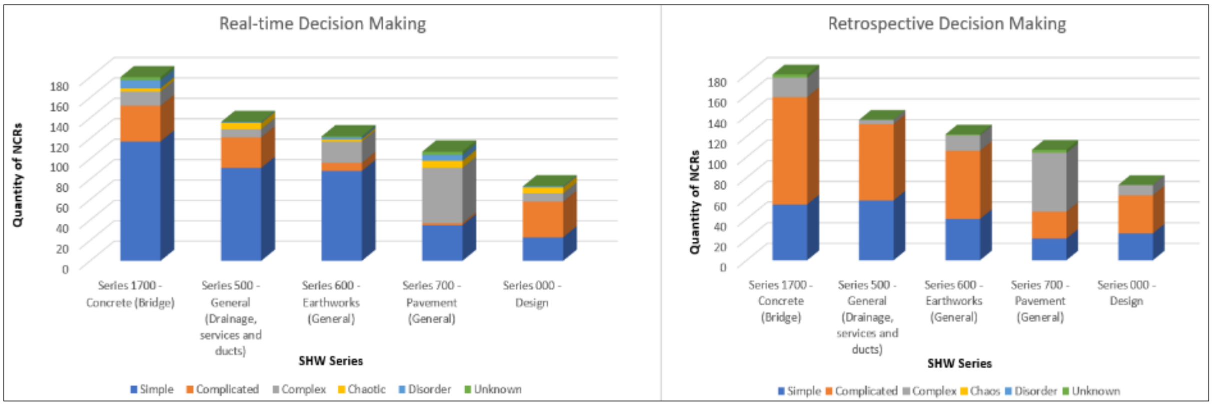


Figure 4.7 – Real-time vs retrospective decision-making of the five most frequently raised SHW categories.

There are clear visual patterns within Figure 4.7 that warrant further discussion for these five high yielding series. First, many of the oversimplified cases that were categorised as 'Simple' were in fact far more complicated than initially envisaged (397 cases). Detailed root cause analysis indicates that in the majority of these cases, more than one kind of corrective action was necessary to address and mitigate the problem. Second, there were 24 cases of 'Chaotic' behaviour where no thought or judgement had gone into resolving the problem in line with process and specifications. Instead, a 'quick fix' attitude was deployed without having all the facts to address the problem in full. In these cases, the retrospective decision-making suggests a far less complex solution could have resolved each problem. Third, there were 18 cases of 'Disorder', due to a lack of consensus achieved over how to resolve the issue, or due to the issue being left stagnant with no resolution proposed or concluded. All 18 cases contained sufficient information to adequately assign a retrospective decision-making pathway within either the Simple (1 case), Complicated (6 cases) or Complex (11 cases) domains. Fourth, retrospective root cause analysis by the researcher using '5 whys' suggests that RCA is not being used efficiently or effectively by those problem solving non-conformance. This is likely to be down to a lack of training and a lack of competence in using such techniques (Braithwaite *et al.,* 2006) resulting in poorly executed, premature decisions. To reiterate the concern that if problems are not correctly analysed, the result will likely be incomplete or insufficient for making an accurate decision to prevent recurrence. One must consider all realms of complexity with a view to finding the most appropriate fit. Only then should a decision be made.

4.4 Failure Mode and Effects Analysis (FMEA) on quality interventions

Following on from the decision-making categorisation exercise and to support the significance of problems being oversimplified, FMEA was used to identify the risk proportions for each SHW series activity (refer to Section 3.4.7) . Real-time and retrospective NCR decision-making pathways were compared to build a clearer picture of the inherent risks associated with under/oversimplification (Appendix 10). Those with zero NCRs raised were of nil risk and discounted. Findings were numerically ordered from maximum negative value through to maximum positive value prior to interpreting the data.

On reviewing the findings and paying particular attention to the RPN difference number (Appendix 10, Column 11), it is noticeable that those yielding a high negative value have been underestimated as activities. In reality, they pose greater levels of uncertainty and risk that should be managed far more carefully. For example, with activities such as bridge concrete piling and bitumen bound pavement operations, the researcher saw significant oversimplification from the data that yielded high negative RPN values of -48.5 and -45.8 respectively. At the other end of the scale, those that displayed high positive RPN figures, i.e. sheet pile retaining walls (+48.0) and plant management (+42.0) showed signs of over complicating matters rather than addressing underlying causes to provide simple, concise solutions. As the detectability scoring is a pivotal value that influences the RPN number, the complexity categorisation is important. In the three examples mentioned above, each showed a higher detectability score for the real-time category than the retrospective. This indicates that there were more Complicated and Complex cases within the real-time space than the retrospective, and that the project struggled to deal with the complex and uncertain situations. With hindsight, the root causes of these cases were more determinable, however, this did not dismiss the fact that RCA undertaken by the project to address many NCRs was substandard, bringing into question whether the project teams engaging with quality problem solving are adequately skilled in root cause analysis techniques (i.e. SQEP).

4.5 Discussion and reflection of Phase 1 findings

There are a number of discussion and reflection points that arise from the NCR quantitative exercise. Two fundamental avenues were explored to unearth what and why NCRs are still prevalent in the construction sector. These were the frequency and cost of NCRs, along with the corresponding lessons learned outcomes and the decision-making of quality problems. These are separated and synthesised below.

4.5.1 The impact and lessons from nonconformance data

In short, the NCR data analysis findings raise concerns about the continuing high volume of non-conformance and rework problems in the construction industry. Recurring quality problems are continuing to have a detrimental impact on the sector, compromising programmes, cost and ultimately quality (Ford *et al.,* 2023). The findings also suggest that organisations are not adequately learning from previous failures and preventing occurrence on future schemes (i.e. lessons learned). The short-term fixation on productivity and key milestones is having a blinding effect on companies, preventing them from innovating and learning (Dubois and Gadde, 2002b).

Reflecting on the most frequent NCR root causes, there are specific areas where organisations should prioritise improvement, in particular, materials management, workmanship and supervision issues, which accounted for a large portion of NCR problems. There are a number of lessons learned outcomes that are to be made in order to change these recurring themes for the better. Table 4.3 presents a series of lessons learned from NCR data in the form of a framework for further consideration. The findings were compiled with a mix of the project's contributions and the researcher's contributions to form a complete record of suggested improvement avenues.

Table 4.3 – Lessons learned framework to address materials management, workmanship and supervision.

Root cause category	Key learning outcome
Materials Management Frequency: 240 cases Cost: £617,000	**Material deliveries and use** - Implement live materials tracking system for batching lorries so projects understand any potential delays and can validate specifications real time. - Stricter audits and reviews to ensure materials are checked for consistency and accuracy against specification, prior to leaving the facility - Materials delivered to site to be validated by an engineer, prior to being incorporated into the works to ensure they conform with the design detail and specification - Wrong materials to be discarded from site and not incorporated into the works **Material storage included recyclables** - Materials to be stored in a controlled environment and free from elements as required - Recycled material to be cleaned, tested and categorised accordingly, prior to use, to avoid non-compliant use - Stockpiled materials to be blended thoroughly as required, prior to being tested, so as not to yield failure results due to poor rotation and consistency - Ensure RAMS and ITP cover storing of concrete elements, such as structural slabs, in a controlled manner that is protected, to avoid damage or deterioration **Concrete operations** - Implement mandatory policies to follow concrete specifications during inclement weather conditions (i.e. excessively hot or cold periods) - Non-compliant concrete following slump test to be returned or worked within allowable tolerances and retested in accordance with specification (batching plant to be informed of sub-standard materials to learn from mistake) - Consider the colour of concrete pours and the consistency of the pour - Use the same cement and maintain ratios using a stringent process - Mixes for key structural pours should be validated prior to leaving the batching plant **Precast** - Choose a more local supply chain that can be regularly audited for quality purposes - Monitor and audit precast supply chain regularly to ensure adequate quantities of cement and rapid hardener are applied to mixes (*avoid cost cutting*) **Material testing** - No materials to be supplied without prior testing/approval to ensure standards are compliant and to prevent site refusal - Electronic test certification to be provided before delivery to prevent failure of testing on site - Testing requirements, frequency, monitoring and resource provisions (i.e. criteria) to be clearly defined prior to the works being undertaken **Materials training** - Implement mandatory materials storage training for storemen and compound managers to avoid mis-management - Stockpiles to be stored in controlled environments (i.e. free from excessive water or contaminating substances)

Workmanship

Frequency: 181 cases
Cost: £2,574,700

Competence and training

- All works to be supervised under SQEP resources at all times (mandate)
- Competence engineering resources to verify works as per ITP hold points (mandate)
- Supervision, engineers and inspector resources to have competence assessments in line with their roles and responsibilities
- Ensure site specific training for quality by default to empower those to stop works if something isn't right
- For digital systems (e.g. digital checksheets), appropriate training and guidance to be provided
- More behavioural management sessions to be provided to enforce the importance of quality

Validation and progressive assurance

- Works to be validated by supervisors, engineers and the quality team as per ITP hold points
- No works to progress without appropriate sign off (enforce consequence)
- Checksheets to be signed
- All setting out to be validated by others prior to works beginning to reduce human errors
- Digital QA records to be kept by default to reduce administration times

Leadership, culture and accountability

- Greater leadership enforcement to change site behaviours and advocate the importance of right-first-time delivery
- Leaders to provide accountability and consequences for fixating on programme rather than quality outputs
- Incentivisation and reward to be provided for those exceeding quality expectations

Supply chain

- Greater vetting of supply chain prior to appointment (not selected on price)
- Improve management and communication of supply chain
- Supply chain to fully understand the design, specification and requirements
- No works to start without suitably competent supervision resource
- Project to instil consequences for poor quality execution via appropriate KPIs and regular inspections of work
- Collaboration between supply chains is essential to ensure a seamless transition to the next activity
- Talk to supply chain supervisors and managers regarding workmanship and the importance of following process

Design and specification

- Designs should be read and fully understood prior to any build (any questions should be concluded within collaborative planning briefings to avoid confusion)
- Works not to progress in conditions outside of specification tolerances (e.g. weather)
- Design detail and specification to be followed at all times (if something requires amendment, stop and seek approval prior to works continuing)
- Consequences implemented for deviating from design without prior formal agreement

Structural concrete

- Consider more advanced methods of removing trapped air within concrete pours
- Finishing of concrete to be done right-first-time, not considered by default as a snagging item when striking shutters

	Planning - Consider weather modelling within programmes to help reduce the risk of operating outside of design parameters - Quality hold points to be tracked within programme
Supervision Frequency: 137 cases Cost: £697,050	**Resources** - Improve assumptions of front line supervision in budget assumptions (*including supply chain*) - Mandatory requirement for full time supervision across all works and an increase in supervision for key, high risk work activities - Appropriate supporting engineering supervision in accordance with ITP requirements (i.e. hold point activities) - Works not to progress without appropriate engineering guidance and approval **Competence and training (SQEP)** - Greater vetting and assessment of front line supervision and engineering supervision - Ensure a complete understanding of ITPs and specification requirements - Routine audit of knowledge and understanding of work requirements - Mandatory appointment of trade specific training and quality training sessions to all supervision and engineering resources appointed to schemes - Improve the awareness and understanding of the importance of secondary checks prior to, during and post completion of concrete works through daily briefings and quality team presentations - More frequent quality alerts, sharing good practices (dos and don'ts) **Consequence and reward** - Greater focus on quality behaviours through appropriate positive and negative reinforcement (e.g. performance reviews) - Consequences and reward to be akin to safety (led by leadership) **Communication** - Undertake detailed handovers between frontline and stand-in supervisors - Better communication and knowledge sharing between trades - Supervisors to be made knowledgeable about access of machinery into permanent works areas so as not to cause damage - Thorough briefings ahead of works, with collaborative planning meetings to discuss any potential risks or blockers

In addition to presenting lessons learned findings for improvement, Figure 4.8 provides context on how the author moved from a problem found within his research through to a solution, whilst linking to similar conclusions gained through previous studies. The figure highlights the problems found with the root causes of materials management, workmanship and supervision, draws in existing literature with a similar perspective and a presents a feasible solution in addressing.

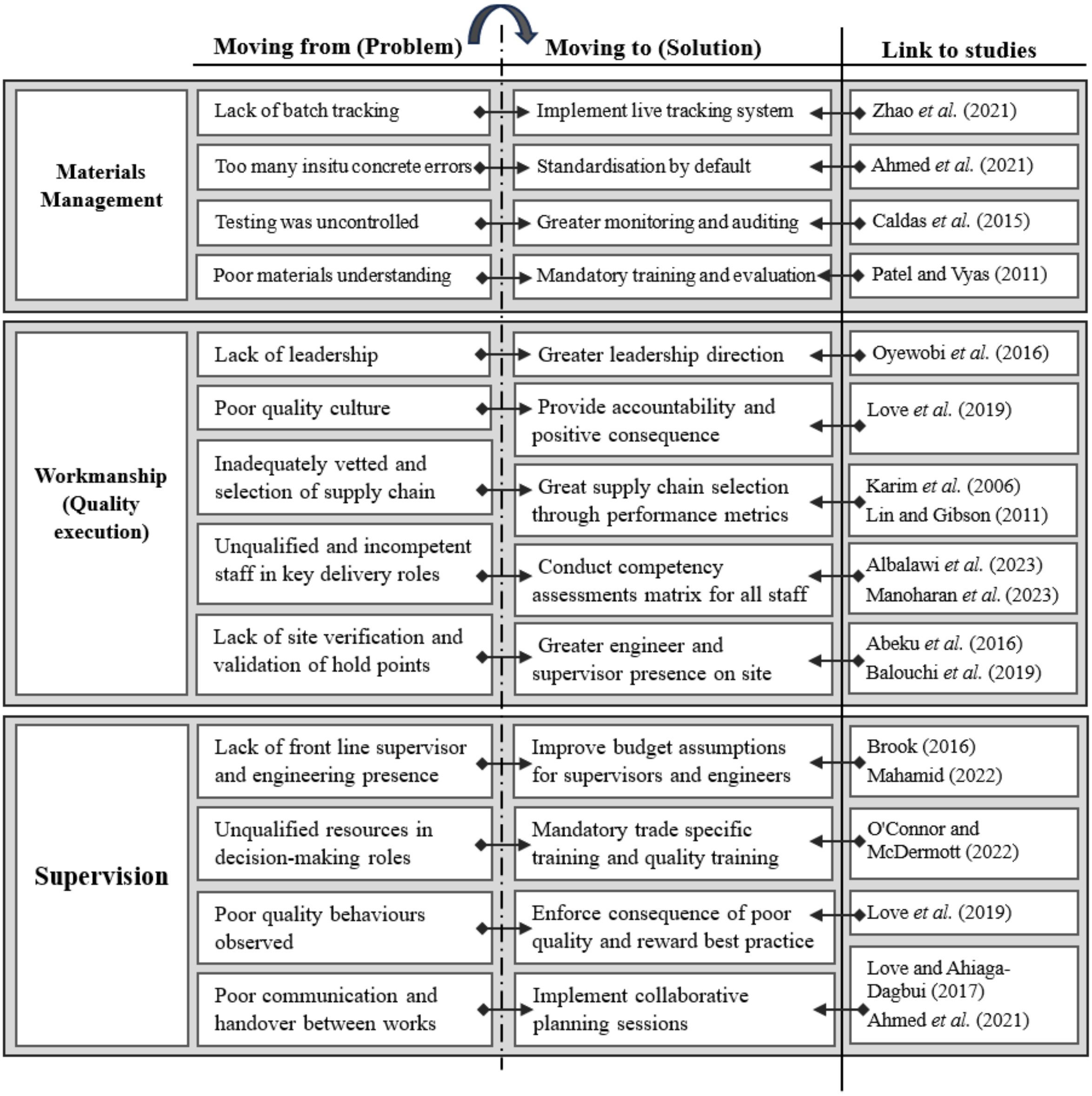


Figure 4.8 – Solutions to address materials management, workmanship and supervision issues.

From the insights gained through quantitative NCR data, there are some key discussion points to expand on. Firstly, as defined by other studies including this research, workmanship (i.e. quality execution) is an underperforming characteristic within construction, particularly in recent decades (e.g. Josephson *et al.,* 2002; Wasfy, 2010; Neuman *et al.,* 2015; Ye *et al.,* 2015; Mahamid, 2017; Maseti *et al.,* 2022). Greater emphasis on quality culture via a clear leadership mandate to instil consequence for sub-standard performance is essential. Without consequence and reward, there is lack of accountability to hold those responsible, and employees will lack inspiration to deliver value for the company (O'Connor and McDermott, 2022). Furthermore, processes must be followed no matter how inconvenient for those less technologically savvy. Although new innovative digital QA methods are being introduced on projects, without clear direction and training to use, we are likely to revert back to paper methods or skip the process altogether. There should be a strong message from leaders as to why we should embrace such method (e.g. to improved efficiency, reduced time dealing with QA records at the end of projects or simply to meet a client requirement). Whatever the case may be, strong leadership mandate is the backbone to success and needs similar time spent on quality advocation as has been the case with Safety, Health and Environment (SHE) over recent years, particularly now the industry is transitioning across to digital construction delivery (e.g. Antony *et al.,* 2022; Chiarini and Kumar, 2022; Wijayasekera *et al.,* 2022). Lesson learnt (1).

Second. the NCR analysis revealed that we are desperately struggling with SQEP resource in the construction industry, particularly with front line supervision and engineers. There are three areas for improvement that should be considered. Firstly, coaching and mentoring by senior members who are knowledgeable and can impart wisdom onto the younger, less experience members requires improvement and documenting. There are many currently within the industry seeking retirement within the next five years and it's imperative this wisdom is not lost. On the flipside, less experienced personnel should be more inquisitive and learn from good practice senior members can impart but more importantly the mistakes that have previously been made (e.g. nonconformance). This could form part of their Continuing Professional Development (CPD). In addition, a robust training syllabus is required to address any knowledge gaps and enhance professional development. There are expectations that employees will have to learn on the job, therefore, appropriate training and close supervision seems entirely appropriate until competence levels have been achieved (Love *et al.,* 2020). Secondly, supply chain should be remeasured against performance and competency not price. Therefore, the author suggests projects implement a competency assessment matrix (CAM) for all individuals to satisfy competence against the requirements set for a particular role and should include supply chain as a vetting measure. Other scholars have concluded the significant benefits of implement such practices to enhance productivity and upskill workforces (e.g. Albalawi *et al.,* 2023; Manoharan *et al.,* 2023). Lesson Learnt (2).

Third. The way in which projects manage materials needs re-evaluating. There are cases that fall into the competency/training category (e.g. a storeman not knowing the correct procedure to store a specific material) but there are many cases where alternative methods could drastically improve material compliance and efficiency. Specifically, how we efficiently manage concrete operations from plant manufacturer to onsite pours. The data suggests a disjointed process is causing much of our concrete operations to become noncompliant due to many factors including late deliveries causing materials to be out of specification, wrong spec material provided, lack of testing conducted etc. The research opts for more advanced methods of recording, testing and delivering materials throughout projects. Greater calling for technology to aid the process via a digital batching and tracking system that can be accessed by all (Zhao *et al.,* 2021). The benefit of this is so engineers can verify the data ahead of site delivery to confirm specification and testing requirements have been pre-achieved which will save time and reduce waste. Furthermore, during the delivery of materials, a live vehicle tracking system via GPS would help engineers assess the impact between pours and make appropriate decisions to resolve. Lu *et al.* (2007) suggested a platform for optimising the operations and logistics of concrete productions to help decision-making, however, the appears little development in the highways sector to collaboratively track concrete operations since 2007. A more drastic consideration would be to omit in-situ works altogether and opt for standardised precast alternatives that can be constructed in a controlled environment (Kim *et al.,* 2016). Lesson learnt (3).

Lastly, how projects capture, manage and close out non-conformance has been brought into question from this research. On average, the project took 211.8 days to close out an NCRs, which challenges whether NCRs are being accurately tracked and progressively closed as works are corrected. This figure is significantly higher than the maximum of a few weeks noted by Abdul-Rahman (1995) which poses the question whether non-conformance processes have become to convoluted. Furthermore, with such long NCR durations, it is unlikely that corresponding lessons learned findings are being sufficiently disseminated throughout the project or sector, and if they are, it's likely too late. The research suggests leaders enforce the importance of accurately tracking non-conformance for the benefit of scheme delivery, not as a mechanism to inflict consequence. In addition, sufficient resources should be allocated to administer the arduous task of raising, tracking, collating evidence and close out of records to satisfy client acceptance. Furthermore, providing necessary expertise to understand the data, analyse and formulate lessons learned should be a fundamental driver for every scheme to progressively evaluate the progress of quality delivery. To assist this task, prediction methods (i.e. machine learning) may be a viable solution to identify trends, cluster results, and minimise expected costs as has been seen in manufacturing (Ji *et al.,* 2021). Whatever the solution, the industry must embrace failure events and learn from non-conformance data to move closer to achieving right-first-time. Lesson learnt (4).

The four focus areas above will most certainly go a long way in steering the construction industry closer to right-first-time. To build a clearer outlook more generally within construction, we must ask what do project professionals think? To date, there is scarce literature on how industry professionals perceive quality delivery through qualitative feedback. As such, two final research questions are raised.

> ***RQ3a. What are practitioner perceptions of the most critical factors that affect quality delivery in construction projects?***
>
> ***RQ3b. How can the construction industry improve quality performance, decision-making, and move closer to achieving right-first-time project delivery?***

4.5.2 Decision-making with the support of the Cynefin framework

Using the Cynefin framework as a sense-making tool, coupled with a complexity categorisation ruling that has been devised to map decision-making through cause-and-effect relationships of NCRs (Figure 3.9), this research provides support in addressing quality problem solving in construction and in understanding the complexity of situations projects encounter. Using the framework and ruling, the researcher was able to demonstrate that many NCR decisions were oversimplified, along with the action pathways to address remedial and corrective actions. Cases that were categorised as 'Simple' were in fact far more complicated than first envisaged (397 cases). In addition, there were 34 cases of 'Chaotic' behaviours whereby no thought or judgement had gone into resolving the problem. Decades later, oversimplification of complexity is still commonplace (Spiro *et al.,* 1996). Such premature decision-making is having a lasting impact on project quality and impeding continuous improvement as incorrect outcomes are being formulated in many instances. The Cynefin framework offers decision-makers support in understanding the context of problems they face and is most certainly appropriate for the construction industry. For quality problem solvers, a complexity ruling that uses RCA cause-and-effect relationships to resolve non-conformance is considered a worthy addition. However, only those who possess the necessary problem solving skill set (e.g. root cause analysis competence) should perform such activities.

Reflecting on the risk profiling of NCRs, real-time and retrospective decision-making pathways from the complexity categorisation ruling were compared to uncover the inherent risks through FMEA. In doing so, each NCR was apportioned a likelihood, severity and detectability score to yield its risk priority number for the real-time and retrospective events. The difference between the two values demonstrated under simplification (a positive value) or oversimplification (a negative value). The risk profiling inferred many cases of oversimplification, including concrete bridge piling and bitumen bound pavements, through high negative values. At the other end of the spectrum, there were cases that presented an over complication of the problem and a failure to come to a more rational root cause, or worse, a failure to conclude at all. These areas include sheet piled retaining walls and plant management, where a far more rational root cause was uncovered. Projects are clearly struggling with the assessment of quality problems as a result of a lack of RCA competence and decision-making prowess, and a need to follow lean practices of simplifying processes. The need for effective leadership to enforce the positive impacts of accurate non-conformance assessments is required but is currently missing from projects.

Alexander *et al.* (2018) conclude there are benefits in elaborating on conceptualisations of unpredictability and complexity, and the subsequent problems of misalignment, in Performance Measurement and Management (PMM). Rather than simplifying problems using lean practices, the most appropriate course of action would be to embrace uncertainty, understand the context of the situation, uncover the root cause through appropriate investigative techniques and assign an appropriate course of action. Lean practices have their place in helping to streamline processes, however construction projects are more complex and cannot be compared to an automotive assembly line, where the same product is replicated over and over again.

Noting the ongoing struggles with quality problem solving, a generalised quality decision-making improvement framework for the construction industry has been created to provide companies and projects with a holistic tool of how to address oversimplification and explains a more proactive approach to early identification of quality events (Figure 4.9).

Figure 4.9 – Decision-making improvement framework for quality non-conformance.

The framework utilises the traditions of a plan, do, check, act (PDCA) cycle, created by Deming, but in the form of capturing quality events through leading and lagging indicators (Simpeh *et al.,* 2015; Safapour and Kermanshachi, 2019). The former (leading indicators) allow early identification of possible quality events that may occur through activities such as quality risk reviews (QRRs), and the latter (lagging indicators) allow learning from quality failures, such as non-conformities, defects etc. Following the establishment of indicators, outputs are then to be analysed and assessed through RCA techniques (Figures 3.8 and 3.9) and an appropriate response through a complexity categorisation and risk profiling can be presented by the project. In the monitoring and reporting phase, lessons learned insight can also be gained through trend analysis and data driven insight with the support of machine learning to remove the manual interrogation element of non-conformance interrogation that is often overlooked (Ji *et al.,* 2021; Ahiaga-Dagbui and Smith, 2014; Baker *et al.,* 2018). Furthermore, comparison against KPI baseline values will present a clearer picture of project performance and identify opportunities as construction progresses. Following the monitoring and reporting process, continuous improvement initiatives can be enforced through organisational learning and innovative practices explored through appropriate risk analysis (Murphy *et al.,* 2011). At an organisational level, greater leadership (Oyewobi *et al.,* 2016a), cultural change (Love *et al.,* 2019), relevant quality target setting and baselines, and a robust competency and training process (Manoharan *et al.,* 2023), are imperative to success. Outputs at a project level should positively improve quality performance, drive down the number of non-conformance and rework issues raised, and improve decision-making to resolve the mis-allocation of remedial and corrective actions. Lastly, the ongoing learning from leading and lagging quality metrics should improve future project decision-making, with leaders going into projects with a clearer perspective on quality risks.

Linking to the decision-making framework (Figure 4.9), and to support a continuous learning initiative through quality indicators, a further framework has been developed in connection with the NCR process to give projects better direction on learning from quality events (Figure 4.10).

The framework is split into lagging indicators, leading indicators and propositional avenues. The first is lagging indicators whereby NCRs are analysed through RCA, a categorisation ruling and risk based prioritisation using and risk based prioritisation through FMEA to uncover accurate remedial and corrective actions to prevent reoccurrence (Figures 3.9 and 3.10).

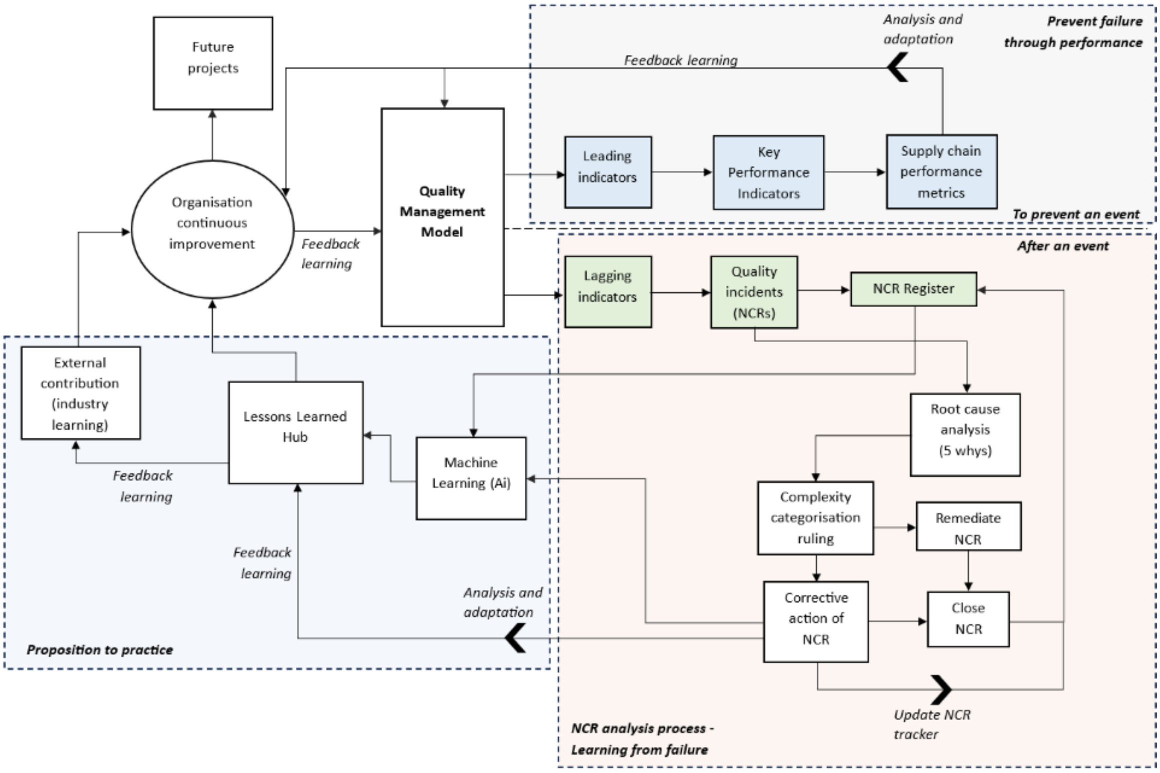


Figure 4.10 – Adaptive learning framework through NCR analysis and leading indicators

The second is leading indicators that measure and report potential risks as construction progresses. By doing so, projects and companies can routinely assess their quality practices and ensure they are on the right path (Safapour and Kermanshachi, 2019). Noting the imbalance for companies to focus primarily on lagging indicators, it's become increasingly important to focus more on prediction-based leading indicators to catch a potential failures before they arise (Zheng *et al.,* 2019). With quality leading and lagging indicator streams, organisations should see more obvious trends for improvement and can intervene more rapidly.

There are propositions within the framework to help organisations harness learning. The first is the need for machine learning (artificial intelligence) to help projects in the laborious, time consume task of analysing and reporting on NCR data (Ji *et al.,* 2021; Ahiaga-Dagbui and Smith, 2014; Baker *et al.,* 2018). The second is for companies to have a lessons learned hub by default, managed by the organisations improvement team that is regularly accessible by all projects. Learning outcomes should then be analysed for patterns and findings routinely distributed back to projects for improvement (Shokri-Ghasabeh and Chileshe, 2014). The third is absorbing learning outcomes from external factors such as shared industry best practice through membership bodies, client learning, emergent literature and JV and supply chain partner learning to build a complete picture into the pitfalls of quality. This process of continual learning with the support of internal and external factors will make construction companies more agile within their changing environment, and help improve the quality management of future projects.

4.6 Conclusion

The above findings indicate key improvement avenues that can help develop organisational quality strategies for the better. A framework has been developed, consisting of lessons learned in three critical areas (materials management, workmanship and supervision), to guide the industry in strengthening these areas through reducing non-conformance outcomes. Great attention in the aforementioned key areas will go a long way in addressing quality standards within construction.

The complexity categorisation exercise draws attention to the convoluted nature of quality problem solving. Oversimplification is of concern, particularly when trying to uncover the underlying cause of quality problems. Projects are struggling to grapple with problem solving under varying levels of uncertainty and complexity. If a problem is left untreated, it may grow or spread like a tumour. Using the Cynefin framework, coupled with RCA techniques that link cause-and-effect relationship, a framework for decision-making has been presented to offer support in quality problems. At a broader level, the industry and its operational leaders must be more spatially aware of quality problems and their inherent risks. Greater attention through meticulous analysis of failures is key to not making the same mistakes again. The following section undertakes practitioner analysis to understand how project professionals feel above quality performance in construction projects, and allow the author to answer RQ3a and RQ3b.

Chapter 5: Finding from Phase 2 (online survey)

This chapter begins with a brief introduction followed by the analysis and presentation of results from an online survey within a tier 1 principal contracting organisation (Phase 2). The key contributions of this chapter are the collection and analysis of professional viewpoints through a digital survey. Two professional working groups within Costain were presented with a questionnaire specific to the topics of non-conformance, rework and RFT in construction. Statistical testing was performed to compare the means of two groups' survey results, along with the use of statistical analysis software (NVivo 12) to uncover prominent themes for discussion and comparison against quantitative NCR findings (Phase 1).

5.1 Introduction

There have been a number of researchers who have analysed rework trends and cost outcomes through the years (e.g. Abdul-Rahman *et al.,* 1996; Hwang *et al.,* 2005; Eze and Idiake, 2018). With the exception of scholars such as Oyewobi *et al.* (2016a), Love *et al.* (2019) and Ford *et al.* (2023), who have applied mixed method approaches to build on their rework research, there are few who have bolstered their quantitative findings with qualitative feedback to get a full reflection of how the construction industry is coping with quality, from client level down through to supply chain level (i.e. what do the people working on projects really think about quality? And what are the challenges to address?) As such, the forthcoming chapters present the analysis and findings of an intricate industry survey through a series of open-ended and closed-ended questions, to reach a conclusion as to what construction professionals truly believe is happening in the industry.

5.2 Survey response summary

The purpose of the survey was to identify whether two distinct working groups within a major contractor concurred with the findings from the NCR data analysis findings. In total, thirty non-conformance and rework related questions were presented to industry professionals with findings taken from Phase 1 (NCR data analysis), with a mix of eight open-ended and twenty-two closed-ended questions for comment, as per Table 3.9.

Initial email requests were disseminated on 09/06/2022 to each professional group within the tier 1 principal contractor to inform industry professionals the survey could commence. Within the email contained a working hyperlink button to take the participant to the survey location as planned for within research design sections (3.5.2 and 3.5.4) (also Appendix 11 and 12). Between 09/06/2022 and 30/06/2022, reminder emails were issued to stress the importance of participating and providing honest, anonymous feedback for the purposes of continuous improvement within the business. For the quality community, these were reiterated by the head of continuous improvement via emails on 16/06/2022 and 27/06/2022, followed by a final day reminder email from the researcher on 30/06/23. Separately, for the contract leaders, a reminder email was issued by the contract leaders' chair (operational excellence director) on 28/06/2022, followed by a final day email reminder on 30/06/2022.

During the participation time frame mentioned above, there were sixteen out of office email responses explaining that the participant was either on annual leave, sick leave or maternity leave during the survey rollout period. Of these automated Microsoft Outlook replies, six quality professionals did manage to participate prior to the survey closing. Furthermore, as a result of other work commitments, there was one quality professional who completed the questionnaire on 01/07/2022, agreed with the researcher in advance of the deadline date through a series of email exchanges. For the contract leaders, there were no 'out of office' replies observed through email transmissions, resulting in an assumption that all requested participants within this group were present and available.

Once the survey deadline date had passed, a data export from Microsoft Forms was obtained on 01/07/2022 in an Excel format along with native software prints. Prior to analysing the open-ended and closed-ended question responses, the information was cleansed and organised into a logical sequence ready for interrogation.

Of the 162 employees within the two groups who were requested to participate in the study, across a period of 22 days, 21 of 67 contract leaders and 39 of 95 quality professionals took part in the survey, yielding response rates of 31.3% and 41%

respectively. However, one member of the quality team did not complete the survey correctly and was discounted from the research. This anomaly adjusts the response rate to 40%. The researcher envisaged greater response rates due to his influence within the company, and the use of senior leadership to convey email reminders sharing the wider benefits of employee participation. However, the rates are deemed adequate as they exceed the average response rates received by other academics (Nulty, 2008). Snowball sampling was initially considered whereby the target respondents have the opportunity to forward the email link to others for comment (Bradley, 1999). However, this would open the survey up to those less familiar with quality management practices and reduce the logic of selecting a target audience (i.e. supervisors, works managers, quantity surveyors etc). Furthermore, it would also likely embed greater bias, subjectivity and unrealistic responses from those not so close to quality problem solving. During the survey dissemination, there were no responses as a result of snowballing from either group.

Appendix 13 presents exported web visuals of contract leader survey responses and Appendix 14 presents the same for the quality community. Each appendix provides results as presented by the software, including the total number of responses and average time taken to complete. In addition, tables containing the participants' ID refence, gender, job role, start time, completion time and time to complete were formulised to provide information on the survey respondents. Noting that the pilot trial recorded an average time of 14 minutes 40 seconds (Section 3.6.8.3), and an estimated completion time of 14 minutes for the suggestion section of MS Forms, it is unlikely that participants would take less than 10 minutes or more than 30 minutes to complete the survey. Therefore, to identify any unusual response times, each table has been colour-coded accordingly. Times less than 10 minutes have been coded 'purple', times between 30 minutes and 60 minutes have been coded 'red', and times greater than 60 minutes have been coloured 'green'. Table 5.1 presents these findings for all twenty-one contract leaders who took part in the survey.

Table 5.1 – Survey response statistics for contract leaders (Group 1).

Contract leader survey response summary					
ID	**Gender**	**Job Role**	**Start time**	**Completion time**	**Time to complete**
CL01	Male	Project Director (Including Senior)	6/9/22 14:11:18	6/9/22 14:26:27	15 minutes 09 seconds
CL02	Female	Project Manager (Including Senior)	6/9/22 14:37:16	6/9/22 14:57:27	20 minutes 12 seconds
CL03	Male	Programme Director (Including Senior)	6/9/22 14:39:53	6/9/22 15:29:14	49 minutes 21 seconds
CL04	Male	Programme Director (Including Senior)	6/10/22 9:06:55	6/10/22 10:44:39	97 minutes 44 seconds
CL05	Male	Project Director (Including Senior)	6/10/22 9:45:37	6/10/22 10:58:17	72 minutes 40 seconds
CL06	Male	Project Manager (Including Senior)	6/9/22 14:10:52	6/10/22 14:30:01	1459 minutes 10 seconds
CL07	Male	Project Manager (Including Senior)	6/16/22 9:08:02	6/16/22 9:25:04	17 minutes 03 seconds
CL08	Male	Project Manager (Including Senior)	6/16/22 9:48:49	6/16/22 10:21:16	32 minutes 27 seconds
CL09	Male	Programme Director (Including Senior)	6/16/22 11:03:45	6/16/22 11:29:57	26 minutes 13 seconds
CL10	Male	Project Director (Including Senior)	6/16/22 12:50:11	6/16/22 13:37:33	47 minutes 23 seconds
CL11	Male	Programme Director (Including Senior)	6/20/22 8:34:43	6/20/22 8:47:03	12 minutes 20 seconds
CL12	Male	Project Manager (Including Senior)	6/20/22 13:08:22	6/20/22 13:21:19	12 minutes 57 seconds
CL13	Male	Project Director (Including Senior)	6/27/22 11:32:19	6/27/22 11:46:02	13 minutes 44 seconds
CL14	Male	Project Manager (Including Senior)	6/28/22 10:14:48	6/28/22 10:30:12	15 minutes 25 seconds
CL15	Male	Project Director (Including Senior)	6/28/22 10:29:49	6/28/22 10:57:18	27 minutes 30 seconds
CL16	Male	Project Manager (Including Senior)	6/28/22 10:22:13	6/28/22 11:03:05	40 minutes 52 seconds
CL17	Male	Project Director (Including Senior)	6/28/22 13:26:37	6/28/22 13:52:51	26 minutes 15 seconds
CL18	Male	Project Manager (Including Senior)	6/28/22 15:23:59	6/28/22 15:53:00	29 minutes 02 seconds
CL19	Male	Project Manager (Including Senior)	6/30/22 15:29:55	6/30/22 18:25:26	175 minutes 31 seconds
CL20	Female	Project Manager (Including Senior)	6/30/22 21:45:58	6/30/22 22:23:07	37 minutes 10 seconds
CL21	Male	Programme Director (Including Senior)	6/30/22 22:55:24	6/30/22 23:10:17	14 minutes 53 seconds

For contract leaders, the average time to complete the survey was 94 minutes and 24 seconds. However, closer inspection of the response time showed there were five contract leaders who took between 30 – 60 minutes to complete the survey, and a further four who took longer than 60 minutes. As per the trial, it is highly likely that these individuals, who are in positions of authority, got distracted with other work commitments while working on the survey. The survey clock continued and recorded a very high response time (e.g. CL06 took 1459 minutes 10 seconds and CL19 took 175 minutes 31 seconds to complete). Therefore, these readings have exaggerated the average response times and which would be considerably lower if the survey had been completed without any of the participants being distracted.

Table 5.2 presents similar findings, with colour-coding for all thirty-eight quality community professionals who took part. Microsoft Forms suggested that, on average, the response time from the quality community was 30 minutes 56 seconds. This is significantly quicker than the contract leaders' average time, however it also warrants further explanation, as it is still double the anticipated response time.

Table 5.2 – Survey response statistics for quality community (Group 2).

Quality community survey response summary					
ID	**Gender**	**Job Role**	**Start time**	**Completion time**	**Time to complete**
QC01	Male	Quality Manager (Including Senior)	6/9/22 14:16:45	6/9/22 14:45:21	28 minutes 36 seconds
QC02	Female	Head of Business Improvement	6/9/22 15:08:49	6/9/22 15:37:46	28 minutes 58 seconds
QC03	Male	Systems, Performance and/or Assurance Manager	6/9/22 15:49:26	6/9/22 15:49:38	00 minutes 13 seconds
QC04	Female	Quality Manager (Including Senior)	6/9/22 15:27:13	6/9/22 15:52:08	24 minutes 56 seconds
QC05	Female	Systems, Performance and/or Assurance Manager	6/9/22 15:06:01	6/9/22 17:11:34	125 minutes 34 seconds
QC06	Male	Quality Manager (Including Senior)	6/10/22 7:53:19	6/10/22 8:08:29	15 minutes 11 seconds
QC07	Female	Quality Manager (Including Senior)	6/10/22 7:55:09	6/10/22 8:09:10	14 minutes 01 seconds
QC08	Male	Head of RDP(N) Integrated Management Office	6/10/22 8:01:11	6/10/22 8:27:41	26 minutes 31 seconds
QC09	Female	Completions Manager	6/10/22 10:43:51	6/10/22 12:42:53	119 minutes 02 seconds
QC10	Male	Quality Manager (Including Senior)	6/10/22 13:07:58	6/10/22 14:27:46	79 minutes 48 seconds
QC11	Female	Quality Manager (Including Senior)	6/10/22 14:42:37	6/10/22 15:11:50	29 minutes 14 seconds
QC12	Female	Systems, Performance and/or Assurance Manager	6/13/22 8:59:41	6/13/22 10:01:48	62 minutes 07 seconds
QC13	Male	Head of Technical Assurance	6/13/22 9:54:46	6/13/22 10:14:36	19 minutes 50 seconds
QC14	Female	Quality Manager (Including Senior)	6/15/22 18:14:47	6/15/22 18:15:00	00 minutes 13 seconds
QC15	Male	Project Manager (Including Senior)	6/16/22 8:54:30	6/16/22 9:18:35	24 minutes 06 seconds
QC16	Female	Handover Manager (Including Senior)	6/16/22 9:17:22	6/16/22 9:35:28	18 minutes 07 seconds
QC17	Male	Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)	6/16/22 9:16:00	6/16/22 9:53:36	37 minutes 37 seconds
QC18	Male	Project Director (Including Senior)	6/16/22 12:22:35	6/16/22 12:48:31	25 minutes 56 seconds
QC19	Male	Quality Manager (Including Senior)	6/16/22 13:44:11	6/16/22 13:44:47	00 minutes 36 seconds
QC20	Male	Handover Manager (Including Senior)	6/16/22 15:00:38	6/16/22 15:24:19	23 minutes 41 seconds
QC21	Male	Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)	6/16/22 16:45:10	6/16/22 17:11:34	26 minutes 25 seconds
QC22	Female	Systems, Performance and/or Assurance Manager	6/20/22 14:38:18	6/20/22 15:03:23	25 minutes 05 seconds
QC23	Male	Quality Manager (Including Senior)	6/27/22 9:18:38	6/27/22 9:30:21	11 minutes 43 seconds
QC24	Male	Quality Director / Head of Quality / Business Improvement Manager	6/27/22 11:29:16	6/27/22 12:34:19	65 minutes 04 seconds
QC25	Male	Quality Manager (Including Senior)	6/27/22 11:46:09	6/27/22 12:53:19	67 minutes 11 seconds
QC26	Male	Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)	6/27/22 12:02:31	6/27/22 12:54:06	51 minutes 35 seconds
QC27	Female	Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)	6/27/22 13:01:16	6/27/22 13:01:40	00 minutes 25 seconds
QC28	Male	Quality Manager (Including Senior)	6/27/22 13:50:04	6/27/22 14:15:26	25 minutes 23 seconds
QC29	Male	Quality Manager (Including Senior)	6/27/22 13:33:39	6/27/22 14:26:34	52 minutes 55 seconds
QC30	Female	Quality Delivery Manager	6/29/22 10:01:18	6/29/22 10:41:38	40 minutes 20 seconds
QC31	Female	Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)	6/30/22 9:18:02	6/30/22 9:28:06	10 minutes 05 seconds
QC32	Male	Quality Manager (Including Senior)	6/30/22 9:21:47	6/30/22 9:33:32	11 minutes 45 seconds
QC33	Female	Handover Manager (Including Senior)	6/30/22 9:21:34	6/30/22 9:35:02	13 minutes 28 seconds
QC34	Male	Quality Manager (Including Senior)	6/30/22 9:15:56	6/30/22 9:49:25	33 minutes 29 seconds
QC35	Male	Quality Manager (Including Senior)	6/30/22 10:08:34	6/30/22 10:34:01	25 minutes 28 seconds
QC36	Female	Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)	6/30/22 10:34:47	6/30/22 11:03:32	28 minutes 46 seconds
QC37	Male	Product Quality Manager/Materials Manager	6/30/22 11:10:32	6/30/22 11:20:39	10 minutes 08 seconds
QC38	Male	Quality Manager (Including Senior)	6/30/22 14:58:53	6/30/22 15:01:13	02 minutes 21 seconds

A closer review of the response times showed that there were five instances where the quality community took less than 10 minutes to complete the survey (purple colour coding). There appeared to be an issue with the software as it recorded completion times in five cases state as being between 13 seconds and 2 minutes 21 seconds. This is not possible. In the open-ended responses, each of the five participants commented with detailed descriptions of their thoughts in response to the open-ended questions. As such, the only conclusion is that these results are caused by a software error during the recording phase. In addition, there are five quality professionals who took between 30 – 60 minutes to complete the survey, and a further six who took longer than 60 minutes to complete. As with contract leaders, quality professionals are heavily involved in managing and reacting to ongoing works and may have had quality related problems to address when completing the survey. For example, QC05 took 125 minutes 34 seconds and QC09 took 119 minutes 02 seconds to complete the survey, which would have been highly unlikely to have been the case if they had been able to apply undivided attention to the task.

Once the data had been organised, all closed-ended questions were presented in graph format, linking the two groups ahead of undertaking descriptive analysis (Appendix 15). Each question was analysed and the findings are presented in the forthcoming chapter.

5.2 Analysis and results of closed-ended survey questions

This section provides findings on the closed-ended questions within the industry survey. Specifically, 22 questions were analysed and results are presented below, with additional statistical testing for the more complicated, multiple choice responses. The first section begins with descriptive analysis of the simple 'Yes/No' response questions to identify consensus between the groups, using results from Appendix 15. This is followed by statistical testing of the multiple choice, rank scaled and Likert scaled questions (Q4, Q17 and Q28).

5.2.1 Quantitative feedback of non-conformance and rework in construction

Using descriptive techniques to compare responses from two professional groups, there were some noteworthy outcomes that warrant further discussion (Appendix 15). Beginning with the 'Yes / No' closed-ended responses, Table 5.3 presents the total number of 'Yes' or 'No' responses along with associated percentages. An abbreviation is used to reference each group, with contract leaders and the quality community referred to as CL and QC respectively.

Table 5.3 – Results of closed-ended 'Yes / No' response questions from both groups.

Question No.	Closed question description (Yes/No answer)	Contract Leaders *[21 in total]*		Quality Community *[38 in total]*	
		Yes response	**No response**	**Yes response**	**No response**
Q1	Do you see quality execution as a problem within Costain?	17 81.0%	4 19.0%	22 57.9%	16 42.1%
Q2	Do you see quality execution as a problem with our supply chain?	20 95.2%	1 4.8%	32 84.2%	6 15.8%
Q3	Are we at risk of post project completion latent defects causing long term profitability issues for the business?	19 90.5%	2 9.5%	27 71.1%	11 28.9%
Q5	On complex construction projects, is there an expectation that 'rework' in some form is inevitable and that 'right-first-time' from start to end of a scheme is unachievable?	18 85.7%	3 14.3%	33 86.8%	5 13.2%
Q6	Problem solving and decision-making are vital steps to preventing future non-conformance. However, the data suggests that many NCR problems are often 'oversimplified' and that the underlying cause of the problem has not been discovered via appropriate Root Cause Analysis (RCA) methods thus providing incomplete corrective action to address and prevent repetition . Do you agree with this statement?	18 85.7%	3 14.3%	35 92.1%	3 7.9%
Q7	Root Cause Analysis (RCA) is a fundamental tool for identifying underlying causes to prevent future occurrence. Do you feel our team members who manage non-conformance data are Suitably Qualified and Experienced (SQEP) with the necessary training to perform such analysis techniques as 5 whys, Pareto, Fishbone etc?	4 19.0%	17 81.0%	14 36.8%	24 63.2%
Q8	Design issues have significant knock-on effects on our schemes, especially cost. Such issues as **[1]** Late/incorrect design details, **[2]** Insufficient ground investigation & surveys conducted and **[3]** Lack of designer site presence to support builds were fundamental issues that caused non-conformance. Should our contractual arrangements with designers be re-evaluated so as to apportion cost associated for non-conformance as a result of poor design?	21 100.0%	0 0.0%	35 92.1%	3 7.9%
Q9	Due to stringent programme constraints, do we at times progress at risk without approved design details as a result of design delay to stay on the critical path? *Note: Approximately*	20 95.2%	1 4.8%	36 94.7%	2 5.3%

	68 NCRs we found to be attributable due to design related issues costing £534,600				
Q12	Our schemes appear heavily dictated by programme and cost. Of the 1260 NCRs, approximately 51 were caused as a result of continuation of the next activity before finishing the previous in order to meet the programmes critical path. This had significant impacts on the quality of the end product which resulted in rework. Do you believe cost and programme are treated as higher priority than quality delivery on our projects?	21 100.0%	0 0.0%	38 100.0%	0 0.0%
Q14	Further to question 12, do you think our clients value cost and programme over quality delivery on infrastructure schemes?	15 71.4%	6 28.6%	25 65.8%	13 34.2%
Q15	'Quality standard' is the level of quality to be achieved that is acceptable by our clients. However, on various schemes, this term differs in understanding between Costain and its clients. Do all parties on our project fully appreciate and understand the level of quality to be achieved? (e.g. it may be a mid-range product as opposed to high-end)	8 38.1%	13 61.9%	14 36.8%	24 63.2%
Q18	Analysis of 1260 non-conformances (NCRs) on a successful major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (**£7,739,850**). Based on a 3% profit margin, that is a potential profit loss of 17% of what could have been achieved. In reality, this figure is conservative and likely to be far higher. Is this figure of concern?	20 95.2%	1 4.8%	37 97.4%	1 2.6%
Q21	The data suggests we are struggling with Suitably Qualified and Experienced Personnel (SQEP) resources in key project delivery roles (e.g. engineers, supervisors). Do you agree with this statement?	19 90.5%	2 9.5%	36 94.7%	2 5.3%
Q25	Should we re-evaluate our approach to concrete operations by using more effective methods such as precast as our primary choice? These can be completed outside of other works under controlled conditions to improve quality delivery. *Note: We must consider defects resolution and project total life cycle costs in our evaluation of appropriate options*	16 76.2%	5 23.8%	33 86.8%	5 13.2%
Q26	As the principal contractor on many of our projects, we typically outsource the majority of our works to specialist supply chain. The data suggests that supply chain were responsible for 66.3% (**836 cases**) of the total NCR failures with notable commentary raised over performance that resulted in removal from the contract. Are there concerns that typically we select supply chain primarily on price and not previous performance/track record? (The saying "*You get what you pay for*".)	16 76.2%	5 23.8%	32 84.2%	6 15.8%
Q27	One of the most costly NCRs amounted from RECo panel retaining walls which cost the scheme £2,169,500 (*Note: Similar trends have been noted on the A465 Heads of the Valley Scheme*). Knowing this, should we continue with these types of constructions?	12 57.1%	9 42.9%	20 52.6%	18 47.4%

Question 1 and 2 (Q1 & Q2) findings

It is apparent from the question Q1 findings that the majority of both groups felt there were ongoing quality execution issues within the tier 1 principal contractor. Specifically, 81% of contract leaders and 57.9% of quality professionals were of the opinion quality was suffering. In addition, the extent of the problem was exacerbated by the outputs of Q2 whereby both groups were far more critical of quality extending down through the roots of the company's suppliers, with 95.2% of contract leaders and 84.2% of quality professionals raising concerns of poor quality execution within the supply chain pool (Appendix 15, Q1 and Q2). With these figures, there is an overwhelming consensus that supply chain quality performance is of major concern and is in desperate need of change. Lin (2011) notes similar concerns that supply chain performance is at the core of construction industry quality failure and suggests KPIs to address supplier performance through operational levels. As the vast majority of works are outsourced to suppliers, it is far more likely that supply chain delivery is the primary factor causing poor quality (Lin and Gibson, 2011). However, it is still the responsibility of the principal contractor to ensure supply chains are properly managed and routine performance is evaluated to meet contract requirements. Of the two sets of respondents, it was surprising to note that the contract leaders indicated a more negative picture of internal quality within the organisation than the quality community. One explanation is that responses made by the quality participants adopted a more defensive position. Another potential reason could be that contract leaders are part of a consortium within the business that shares progress on different projects in monthly meetings (i.e. the contract leaders' forum). As such, their knowledge of collective project performance within the organisation is far more extensive than that of their quality counterparts. There may be quality performance issues within a particular sector that the quality team are simply unaware of.

Question 3 (Q3) findings

Noting that the project in question had suffered from non-conformance and rework figures in excess of 0.5% total project value (£7,739,850), each group was asked whether they were concerned that post completion defects and latent non-conformance on the scheme was resulting in long term profitability issues within their organisation. The findings indicate that 90.5% of contract leaders and 71.1% of quality professionals were concerned that the company was at risk of experiencing long term profitability issues through post completion latent defects (Appendix 15, Q3). Such high agreement figures could indicate that such rework losses are frequent on other schemes within the business. Furthermore, for those who are present through to project completion, i.e. contract leaders and quality professionals, may see latent defects as common and ultimately, inevitable. Talib and Sulieman (2020) and Forcada *et al.* (2014) note similar latent defect patterns in building construction, and emphasise the need to systematically catalogue latent defects for the purposes of continuous improvement with enhanced quality control techniques.

Question 5 (Q5) findings

To understand the impact of working without error, question Q5 was posed to understand whether right-first-time within construction is achievable (i.e. Get It Right Initiative, 2018). Noting that a large amount of non-conformance reports were sources from a major current highways scheme, these records indicate that the industry is far from perfect in its delivery of works without error. From the closed-ended responses, a pessimistic (and disheartening) statistic was uncovered whereby 85.7% of contract leaders and 86.8% of quality professionals believed completing construction schemes without error was an unattainable goal (Appendix 15, Q5). These findings question the existence of the required mental mindset needed for quality delivery within the profession. Love *et al.* (2020) comment that most contractors have a limited understanding of their rework costs and consequential impact these have on their organisation. As a result, non-conformance and rework are not seen as a huge problem, but as an expected byproduct of project delivery. Clearly, this is the incorrect mindset to have and projects must endeavour to eradicate failure at every turn with more stringent measures, as has been seen in safety during the last few years. The researcher is of the opinion that unlike with safety, many quality related incidents are not seen until the responsible party has left the project and it is no longer their problem to deal with. Whereas, with safety, there is always a direct consequence involved with incidents and accidents. The penalties for not following process are severe and can directly impact the person responsible, which usually resonates with the individual in question. Greater investment in quality to create better digital systems and processes that can help construction teams at the start of a project should support RFT delivery and reduce human error (Sawhney *et al.,* 2020). In addition, enhanced accountability and consequence that have been seen in safety are fundamental to changing behaviours, driving expected quality outputs and improving construction practice (Sohail and Cavill, 2008).

Question 6 (Q6) findings

Following our decision-making complexity ruling and categorisation, it was noted that sub-standard analysis is leading to under/oversimplification (Figures 4.6 and 4.7, Appendix 9). As such, question 6 (Q6) was formulated on the premise that quality problems are often oversimplified. The survey results indicate that the vast majority from both groups agreed that we often look at problems too simply, 85.7% (CL) and 92.1% (QP) respectively (Appendix 15, Q6). In reality, there may be other influencing factors that cause complications (for example, political influence to meet unrealistic programmes could contribute to a non-conformance). From the results, it is likely that many NCRs are yielding incorrect remedial and corrective actions, and are thus not addressing issues in full. Hoerl *et al.* (2021) claim that there is a lack of understanding of how political and organisational complexities interfere with technical problem solving to deploy an appropriate solution. Greater focus on holistic problem solving approaches with a broader view of complexity has been called for to give those involved in quality problem solving the tools to succeed (Forcada *et al.,* 2014). The researcher agrees with the premise that appreciating problems are complex by default is a wise strategy, as is adopting a suitable approach for navigating complexity (e.g. the Cynefin framework).

Question 7 (Q7) findings

On reviewing the NCR data, it was apparent that in many cases, those determining remedial and corrective action solutions were not exhibiting effective root cause analysis techniques to uncover the underlying cause. As such, many NCR solutions were incorrect, resulting in further occurrences through the project lifecycle. We therefore asked both groups whether those managing and interacting with non-conformance issues were sufficiently trained in RCA techniques (Q7). The findings indicate that both groups were of a strong opinion that those engaging with NCRs are not sufficiently trained in RCA techniques such as Pareto, Fishbone, and the 5 whys. Specifically, 81.0% of contract leaders and 63.2% of quality professions were concerned about the competence of those undertaking RCA on NCRs (Appendix 15, Q7). Love *et al.* (2022) rightly point out flaws with narrowing focus on one or few root causes, promoting a reductionist view of causation. More often than not, and especially in complexity construction schemes, multiple interacting contributions are at play. Oversimplification has therefore hindered employees' ability to fully understand causes of rework, including their context and the conditions that lead to them.

Ma *et al.* (2021) suggests an attributing factor is that, too often, projects are hindered by large numbers of quality problems that cause heavy workloads to experts and prevent them from spending sufficient time on individual problems. The application of RCA machine learning to interrogate quality problem solving has been advised to support schemes. The researcher supports this advice, however, this would likely introduce a steep learning curve and additional training in order to facilitate understanding of data outputs from machine learning (Ji *et al.,* 2021). Unless the correct investigative technique to uncover the underlying causes of problems is executed, efforts to remedy the defect and eliminate the possibility of future recurrence are likely to fail. The industry needs to improve its problem solving accuracy.

Question 8 (Q8) findings

During the NCR data analysis, it was evident that from the responses within the 73 design change related non-conformance cases that there was difficulty in recouping costs from designers as a result of late design changes or inaccuracies. As a result, the principal contractor typically covers the costs of such change under their contractual terms. From the researcher's 13 years of experience on complex construction projects, many unforeseen but necessary changes are not being captured contractually to apportion risk and cost to changing a design during construction. For example, a stage 3 road safety audit (RSA3) is completed prior to opening a highway to ensure it is safe for the public. In many cases, the auditors notify the project of necessary changes that are to be made to de-risk certain areas. This includes changing design details that in turn cause further construction adjustments. Although these are ‘recommendations’, more often than not, the designer will confirm the necessity of changing the design detail to limit liabilities. This has a knock on effect on projects, causing rework and spiralling costs. The typical split of the costs is that the designer captures their design change costs (i.e. design risk assessments, drawing updates etc) and the contractor covers the cost to remedy the RSA3 recommendation (i.e. management time, traffic management, supply chain cost etc). As such, question 8 (Q8) challenged both groups as to the adequacy of contractual arrangements, raising the suggestion of designers being responsible for the full costs for design changes that could have been avoided. Unsurprisingly, there is an overwhelming consensus in the findings that designer contracts must be re-evaluated to protect the business with 100% of contract leaders and 92.1% of the quality community in agreement that this is an area in need of improvement (Appendix 15, Q8). Scholars believe as much as 92% of late design changes are avoidable (Tranøy and Muller, 2014). Of the other 8% that are unforeseen, prior cost and risk profiling is required in contracts to fairly distribute cost and risk between the principal contractor and designer, in order to avoid later conflict. Currently, within the tier 1 contractor in question, these contractual terms are skewed towards the contractor, who must be more commercially savvy.

Question 9 (Q9) findings

Coupled with Q8, projects often find themselves waiting for approved design details and lack defined requirements from clients, causing additions, omissions or design deviations as project gear up for construction (Love *et al.,* 2010; Oyewobi *et al.,* 2016b). In certain cases, projects take risks, hoping that no further design change will occur through the design approval phase whilst construction proceeds. Trach *et al.* (2021) note that incomplete designs at time of tender and poor design coordination featured as the highest impact rework causes for a Ukraine construction scheme, causing significant delays. Mahamid (2017) notes similar trends in Palestine.

Findings from the quantitative analysis noted many trends of late design changes resulting in non-conforming outputs, i.e. works being built to the previous design that has been superseded. Noting this, each group was asked whether it was a fair assessment that projects often take risks to proceed with construction without approved design details in order to meet critical path milestones. The results from the survey revealed that 95.2% of contract leaders and 94.7% of quality professionals agreed with this conclusion (Appendix 15, Q9). The unfortunate nature of these statistics is that more often than not, projects are faced with a dilemma of choosing whether to continue at risk or wait for designs to be approved in full. Such decisions should not be necessary with clearly defined project requirements and robust design solutions. Furthermore, principal contractors should not find themselves politically pressured into delivering works at risk by clients and stakeholders. Instead, designers should improve the constructability of design through effective communication on projects, and clients providing optimum pre-delivery stages to complete designs in full ahead of construction (Ye *et al.,* 2015).

Question 12 and 14 (Q12 &Q14) findings

Noting that projects often take risks to prioritise critical path milestones (i.e. programme) and considering that cost is a fundamental driver for decision-making on schemes, each group was challenged whether, much like safety, cost and programme are treated as a greater priority than quality delivery (Q12). In addition, a further question was posed as to whether clients have the same values (Q14). Beginning with question 12, 100% of contract leaders and the quality community confirmed the suspicion that quality is pushed to the wayside while projects fixate on cost and programme (Appendix 15, Q12). This is such an overwhelming statistic that not one person could present a case whereby quality drove how their project operated. Similar but less significant findings from question 14 suggest that 71.4% of contract leaders and 65.8% of quality professionals also felt that cost and programme were of greater importance to clients (Appendix 15, Q14). It appears the industry is still struggling with the notion that if efforts are focused on quality delivery throughout the lifecycle of a scheme, projects are more likely to meet target costs, maintain schedules and meet handover obligations. Simply chasing cost and critical paths are behaviours that need to be eradicated on projects. There is overwhelming consensus from the responses that cost and programme are being valued more than quality delivery. Much like how the construction industry has dealt with Accident Frequency Rates (AFR) in the safety space, the sector needs to show progression within quality and prioritise efforts towards quality improvement.

Question 15 (Q15) findings

The expectations of quality between various stakeholders on projects is a very contentious topic. Depending on where the party sits in the hierarchy (i.e. client, principal contractor, local authority or supply chain), there are varying levels of quality expectations. Garemo *et al.* (2015) note the weaknesses in organisational setup, and the convoluted hierarchical layering (5 layers) from supply chain through to project sponsor which can compound problems of cost, time and quality. Sommerville (2007) notes the differing requirements and expectations between clients (i.e. house buyers) and house builders in the house building industry. The researcher's years of experience in the construction sector confirms a divide in expectations over the level of quality to be achieved, and confirms that there is likely to be a compromise in some form. In addition, from the quantitative analysis, the suggested remedial action to address the non-conformance is mixed in many cases. For example, the contract proposes the use of a plastic product that fulfils the purpose of covering cabling, however, the client insists on a more expensive stainless steel option, as it will be more aesthetically pleasing. The outcome to fulfil requirements is the same, but cost is a primary driver for the contractor.

Noting the above, both groups were challenged as to whether projects (including client and stakeholders) fully appreciate and understand the level of quality to be achieved (Appendix 15, Q15). The results indicate that 61.9% of contract leaders and 63.2% of quality professionals did not believe that project teams fully understand what is expected of them to achieve completion. Although far less significant, the majority do feel that more thought, discussion and confirmation must go into clearly stipulating quality requirements that are signed up to by all.

Question 18 (Q18) findings

Of 1260 NCRs, the total cost of rework was calculated at a conservative figure of £7,739,850. As the project was valued at £1.435B, this equated to 0.5% of total project value. To understand project profit loss, while using a typical profit margin of 3% on complex construction schemes, this results in a total profit loss of approximately 17%. Both groups were asked within the survey whether this figure was of concern. Unsurprisingly, 95.2% of contract leaders and 97.4% of quality professionals were concerned that such profit losses were being seen on major infrastructure schemes (Appendix 15, Q18). Josephson *et al.* (2002) also note that with tight profit margins on construction schemes, such losses to rework are unacceptable. It's an unwanted menace on schemes that must be stopped in order to see cost and schedule improvements (Abeku *et al.,* 2016).

From the responses, the researcher was surprised to see that there was one individual from each group who didn't see an issue with the values. Each follow on open-ended response is discussed later to understand why they were not concerned.

Question 21 (Q21) findings

Many of the NCR root causes found within the quantitative analysis suggested that competence of workforces is of paramount concern. For example, there were 26 specific cases of competence/training issues discovered from the data. In addition, there were 181 cases of workmanship issues that showed signs of not following process, attributable to a lack of competence and knowledge in performing tasks. The quantitative research concludes that the industry is struggling to place Suitably Qualified and Experienced Personnel (SQEP) in key construction roles. As such, question 21 was presented to contract leaders and quality professionals as to whether they agreed with this conclusion (Appendix 15, Q21). The responses indicate similar concerns that there are competence issues within the construction industry and many are not suitably skilled to perform the roles they are in. An overwhelming statistic that 90.5% of contract leaders and 94.7% of the quality community confirmed that SQEP is an area in need of improvement. A shortage of knowledgeable and experienced people in key construction roles is apparent, which is undoubtedly leading to project non-conformance. Linking to rework, Alwi *et al.* (1999) conclude that more money spent on training can reduce rework costs by between 11% and 22%. In addition, Garemo *et al.* (2015) note the need for the right mix of abilities to support scheme delivery, with well-rounded project members who understand many important facets of construction (e.g. buildability, design, commercial, people management etc.). Hence, increased coaching, training, and vetting of internal employees and external staff employed in the supply chain, is needed to ensure the right people are in key delivery roles. Furthermore, it opens opportunities for those wishing to develop and progress their professional careers with a concise set of role requirements.

Question 25 (Q25) findings

From the dataset, there were 371 non-conformance cases of concrete related activities. This accounted for 30.2% of the entire dataset at a cost of £3,231,550. Similarly, high levels of concrete wastages and rework costs have been documented by other scholars, calling for radical review of how projects manage such operations (Agyekum *et al.,* 2013; Mahamid, 2022). As such, both groups were asked whether projects should re-evaluate approaches to in-situ works and consider precast methods as standard. The results indicate that 76.2% of contract leaders and 86.8% of quality professionals concede that the industry should re-evaluate its approach to in-situ operations (Appendix 15, Q25). A potential reason for a higher agreement percentage from the quality community may be down to the onerous task of monitoring site quality assurance against variables such as inclement weather and temperature, whereas these variables can be controlled in a precast facility. For contract leaders, the appeal to go with a cheaper, in-situ option may be a reason why 23.8% felt there is no need to reassess approaches to concrete operations. In addition, cast-in-situ solutions intrinsically allow building moment-resisting frames, which is usually hard to achieve with precast alternatives (Breccolotti *et al.,* 2016). Kim *et al.* (2016) recommend using precast components to standardize the highways sector and simplify the design process to reduce risk of errors in fabrication and installation. The researcher supports this recommendation and sees much benefit in standardization to reduce the complexity of construction builds.

Question 26 (Q26) findings

Appreciating that cost, time and scope all have a fundamental impact on quality if one is chosen over the other (i.e. the iron triangle) and noting the short term fixations on cost and programme when delivering construction schemes (e.g. Bronte-Stewart, 2015), each group was asked whether there were concerns that principal contractors typically select supply chains based on price rather than previous performance and track record. The findings indicate that 76.2% of contract leaders and 84.2% of the quality community were in agreement that the primary reason for selecting a supplier is cost (Appendix 15, Q26). Inclusive of Q12 and Q14 findings, these results indicate that cost is a primary driver for clients and all the way down through to supply chain selection. It is unfortunate that projects still appear to select supply chains based on price/cost quotations and not on their previous performance or standing within the industry. Decision-making based solely on cost could be construed as risky and narrow minded. Evidence shows that longer term relationships lead to more consistent outcomes and better learning, but that monitoring, evaluation and support for suppliers are key to achieving those positive outcomes (Gosling *et al.,* 2015, Gosling *et al.,* 2019). With clear and concise metrics, supply chains can be measured against key performance indicators and supported throughout project lifecycles. This will also allow projects to intervene at critical dips in performance. Note, however, that project teams must be wary of replacing suppliers without consideration of project knowledge, particularly for companies that outsource the majority of their works.

Question 27 (Q27) findings

The most costly NCR incident encountered on the A14 Huntingdon Improvement scheme was a RECo panel installation that set the project back approximately £2.19 million (Section 4.2.2). These types of constructions have tight installation tolerances and should be installed by knowledgeable and skilled professionals who abide by the installation methodology at all times. Some scholars have expressed the economic benefits of reinforced earth retaining walls and the practicalities they bring (e.g. Carrier and Wajdzik, 2019), however, the quantitative findings suggest that projects are struggling to build these types of structures without succumbing to non-conformance. As such, a specific question tailored to RECo panel wall installations was presented to industry professionals to understand their views on the topic.

Feedback from the survey indicates that there is a mixed response from both groups, with 57.1% of contract leaders and 52.6% of quality professionals suggesting that projects continue with these types of builds (Appendix 15, Q27). However, there were 9 contract leaders and 18 quality professionals who felt that the risks were too high to consider these types of builds going forward. In hindsight, considering that many of the respondents are from different sectors where these types of constructions are uncommon, there may be a lack of knowledge as to what these types of wall constructions entail. The researcher acknowledges that the question is overly specific and that responses may have been made on intuition rather than understanding.

5.3 Statistical testing outcomes

To understand the statistical significance of the more complex multiple choice and scaling questions, nonparametric statistical testing was performed via statistical inference. Data yielded from the survey responses was sorted, categorized and tested to infer properties of an underlying distribution of probability (Upton and Cook, 2006). Specifically, three questions were tested using pre-selected nonparametric testing methods (Q4, Q17 and Q28). The following sub-sections present test findings for each question.

5.3.1 Results from Q4 including Mann–Whitney *U* test

It is clear from past literature (i.e. Abdul-Rahman *et al.*, 1996; Josephson *et al.*, 2002; Love, 2002b; Love *et al.*, 2018 etc.) and findings from the quantitative NCR analysis research within this thesis (i.e. Phase 1) that profit margins are being compromised for poor quality and necessary rework on schemes. Prior to sharing Phase 1 results which showed that the project suffered 0.5% total contract value to non-conformance and rework, question Q4 asked each group what they believed would be a realistic figure expected on schemes with a typical profit margin of 3%. This was in the form of a multiple choice question ranging from zero to greater than 1% with only one possible answer (Appendix 15, Q4). Descriptive interpretation of the results initially indicates that the vast majority of each group feel that rework percentages are on average in excess of 1% total contract value, with 52.4% (CL) and 52.6% (QC). With exception of this obvious data visual, other responses are mixed with 21.1% of quality professionals but only 4.8% of contract leaders selecting a figure between 0.8 – 1.0%. Slightly more consistent results are observed for 0.6 – 0.8% with 19.0% (CL) and 10.5% (QC), 0.4 – 0.6% with 14.3% (CL) and 13.2% (QC), and 0.2 – 0.4% with 4.8% (CL) and 2.6% (QC). Lastly, 4.8% of contract leaders and 0% of the quality community felt the figure was between 0 – 0.2% of total contract value. The researcher does not wish to put a negative spin on the individuals who selected ranges of 0 – 0.2% and 0.2 – 0.4%, however these are very unlikely for the following reasons. First, non-conformance and rework cost estimates are predominately inaccurate, and in most cases, overly conservative. This means that even if a project noted a figure of 0.15% or 0.25% from their NCR cost totals, these values are likely to be compounded by missing rework costs that have not been considered by the scheme (e.g. traffic management to correct the non-conformance or administrative time to open, track and close the NCR). The researcher has experienced the poor practice of quantifying rework many times on numerous schemes. This has been noted by other scholars, whereby inaccurate cost calculations can mislead the severity of the issue (e.g. Flyvbjerg *et al.,* 2003b; Love *et al.*, 2018; Foroutan Mirhosseini *et al.*, 2022). Second, there are many contractor facing organisations (i.e. GIRI and ICE) who have presented their views to the industry that rework cost estimates are typically between 10% and 25% (Get it Right Initiative, 2018). Initial reflection on the three collective responses who selected these two categories, finds that there is either a level of naivety or defensiveness over their projects or an unrealist optimism around project success.

To understand whether these results are statistically significant or a result of chance, the Mann–Whitney *U* test was selected as the most appropriate method for testing the difference between rank sums of two groups of data. In the instance of this research, the data obtained from Q4 is uneven (i.e. with varying frequencies of responses and a zero response for one group), and thus does not meet the parametric assumptions of a t-test. As such, the researcher has opted for the Mann–Whitney *U* test method for smaller sample sizes (i.e. six possible responses) that are not normally distributed (Nachar, 2008; McKnight and Najab, 2010). The null hypothesis (H_0) of the Mann–Whitney *U* test stipulates that the two groups come from the same population and are homogeneous, with the same distribution. As the results come from two independent groups, a two-tailed test is required. In order to challenge the null hypothesis (H_0) and claim statistical significance, the alternative hypothesis must demonstrate that the first group's data (i.e. contract leaders) distributes differently to the second group's data (i.e. quality community).

Data from the survey was taken and presented in Table 5.4, along with the parameters of the test. The testing method (provided within Section 3.8.5) followed, beginning with the first exercise to compute the rank sums of the data by assigning values (Nachar, 2008). Collectively, there were twelve response categorises to be assigned ranks (i.e. a multiple choice question containing six potential responses from two independent groups). To assign ranks, all twelve response frequencies within the CL responses column and QC responses column were given a number from 1 onwards, beginning with the lowest value, which in this instance was 0. For tied ranks (i.e. where there were multiples of the same value), an average of the ranks was taken and allocated to each case. For example, the dataset yielded four cases of 1 response at ranks 2, 3, 4 and 5. The sum of all four ranks is 14 (2 + 3 + 4 + 5) which is then divided by the number of cases (i.e. 4) to give 3.5. Once the ranks had been assigned, rank sums were totalled for each groups (i.e. *R1* and *R2*). For group 1 (CL), *R1* equalled 35 and for group 2 (QC), *R2* equalled 42.

Table 5.4 – Responses and ranks to multiple choice question Q4.

Question Q4 multiple choice option	**No. of participants (CL)**	**No. of participants (QP)**		
			***α* =**	0.05
			n_x =	6
	21	38	**n_y =**	5
			***R1* =**	35
			***R2* =**	42

	CL responses	Ranks (*R1*)	QC responses	Ranks (*R1*)	
0 – 0.2%	1	3.5	0	1	
0.2 – 0.4%	1	3.5	1	3.5	
0.4 – 0.6%	3	6	5	9	
0.6 – 0.8%	4	7.5	4	6.5	
0.8 – 1.0%	1	3.5	8	10	
In excess of 1%	11	11	20	12	
	6	**35**	**5**	**42**	**SUM**

Following calculations of the rank sums for each group, U statistics are calculated. Refer to formulas (4) and (5) within Section 3.5.5.3.

$$U_x = 6 * 5 + \frac{6(6+1)}{2} - 35 = 16 \text{ and } U_y = 6 * 5 + \frac{5(5+1)}{2} - 42 = 3$$

Noting that ties were present in the dataset, the standard deviation for ties is applied as per equation (6) of Section 3.5.5.3 (Lehmann and D'Abrera, 1975; Nachar, 2008). Prior to the calculation, few values must be determined. The collective sample size $n = (6 + 5) = 11$, the number of ties for the kth rank $t_{k1} = 4$ and $t_{k2} = 2$, with the total number of unique ranks with ties $K = 2$. With these values, the standard deviation of ties was calculated as follows:

$$\sigma_{ties} = \sqrt{(\frac{(6 * 5) * (6 + 5 + 1)}{12}) - (\frac{(6 * 5) * ((4^3 - 4) - (2^3 - 2))}{(12 * 11) * (11 - 1)})} = 5.33854$$

Following on, the test statistic for ties (z) was calculated using equation (7) with the minimum value of $U = \min(U_x, U_y) = 3$.

$$z = \frac{3 - \left(\frac{6 * 5}{2}\right)}{5.33854} = -2.24781$$

Finally, the statistical significance value (ρ) was computed using the normal distribution function in Excel for a two tailed test by applying formula = $\mathrm{NORMSDIST}(z) * 2$. This calculated the statistical significance value at:

$$\rho = \mathrm{NORSDIST}(-2.24781) * 2 = 0.02459$$

The findings of the test conclude that $\rho < \alpha$, meaning that there is a 97.54% probability that the results observed are not by chance. Therefore, there is sufficient evidence to reject the null hypothesis (H_0) and claim statistical significance via an alternative hypothesis (H_a) at a probability greater than 95%. As concluded by Nachar (2008), the Mann–Whitney U test is a powerful nonparametric test for understanding the significance of independent, small data samples. Furthermore, unlike a t-test, this method appears to be more capable of computing significance results with disproportionate values.

5.3.2 Results from Q17 including Wilcoxon signed-rank test

From Phase 1 quantitative findings, the three most fundamental areas of failure (i.e. root causes) from 1260 NCRs were materials management (240 cases), workmanship (181 cases) and supervision (137 cases). To understand where project professionals felt the most prevalent areas of failure originated, each group was where they perceived the three most likely causes of non-conformance and rework in construction (Appendix 15, Q17). Descriptive analysis was deployed once more to interpret the results. Beginning with the contract leaders, the three most frequently suggested root cause failures on schemes were quality execution/workmanship (6 votes), supervision (5 votes) and an even split of 4 votes between communication and planning. For the quality community, the three most frequently selected root causes were quality execution/workmanship (12 votes), supervision (11 votes) and competency/training (8 votes). These figures account for 38.5% of contract leader responses and 43.1% of quality professionals responses. It is therefore likely that these three root cause types are most prevalent on schemes and are a priority to address.

On reviewing the data export, the researcher noticed that the total responses for each group did not tally to a total for each participant selecting three responses. For contract leaders, there were 21 respondents who should have made three responses. This would give a sum value of 63. However, the sum value was in fact 39, indicating that there were individuals who did not answer the question in full or that the software malfunctioned, causing an incomplete or blank response. Specifically, eight respondents (CL01, CL07, CL08, CL09, CL10, CL11, CL13 and CL21) were affected, presenting incomplete data within the exported Excel spreadsheet, which had to be discounted from the research, as none of the respondents selected their three most likely root causes.

Similarly for the quality community, the sum value of 38 responses should have been 114. However, the actual sum value was 72, indicating that 14 respondents had not contributed to the question in full (QC04, QC06, QC09, QC19, QC21, QC23, QC27, QC28, QC29, QC30, QC31, QC32, QC33, QC34). Although the results do not represent the entire response group, the findings do present notable areas of concern that had to be addressed in order to work towards construction without error.

Although there were clear visual patterns in the data, the complexity around how the responses were proportioned across different root causes warranted statistical testing to understand the patterns. As the results from the survey were not normally distributed, the researcher chose to use the Wilcoxon signed-rank test for the following reasons (Voraprateep, 2013): 1) the tests do not depend on the normal population distribution, 2) the computations can be quickly and easily performed, 3) the test can be applied with weak measurement scale data, and 4) the testing method and procedure is easy to understand with minimum mathematical and statistical preparation.

Prior to undertaking the test, the data was sorted and each group's results were presented in Table 5.5, in order of how the root causes appeared within the survey (i.e. from (A) to (U)). Group 1's results (contract leaders) were presented in the X_n column and Group 2's (quality community) were presented in the X_y column.

Table 5.5 – Computation of ranks using Wilcoxon signed-rank test.

Root Cause	CL (X_n)	QC (X_y)	diff = $(X_n - X_y)$	Abs Diff (*D*)	Remove zeros	Ranks	Positive rank sum (T_+)	Negative rank sum (T_-)
(A)	0	0	0	0				
(B)	2	4	-2	2	2	7		7
(C)	1	1	0	0				
(D)	4	5	-1	1	1	3		3

(E)	3	8	-5	5	5	11		11
(F)	2	2	0	0				
(G)	3	5	-2	2	2	7		7
(H)	0	4	-4	4	4	10		10
(I)	0	6	-6	6	6	13		13
(J)	0	0	0	0				
(K)	0	3	-3	3	3	9		9
(L)	2	1	1	1	1	3	3	
(M)	3	1	2	2	2	7	7	
(N)	2	1	1	1	1	3	3	
(O)	0	1	-1	1	1	3		3
(P)	4	4	0	0				
(Q)	0	0	0	0				
(R)	6	12	-6	6	6	13		13
(S)	1	1	0	0				
(T)	1	2	-1	1	1	3		3
(U)	5	11	-6	6	6	13		13
SUM	**39**	**72**				**SUM**	**13**	**92**

The first exercise was to compute the difference between Group 1 and Group 2's results, prior to ranking the data (column 4). Green represents the positive value and red represents the negative values. Following this, absolute values were presented to remove the zeros from the results (column 5). As zeros cannot be included in the ranking, these were removed, leaving only positive values greater than zero (column 6). Once zeros had been removed, the data was then ranked similarly to the Mann-Whitney *U* test, mentioned above, where an average is taken for tied ranks (column 7). In order to compute the test statistic (T_{stat}), we must take the lowest value of positive rank sum (T_+) and the negative rank sum (T_-). In this instance, $T_{stat} = 13$. To compute the critical value, we must first identify the significance level of the test (α) and the sample size (n). Similar to the Mann-Whitney *U* test, α was set at 0.05 and the sample size was computed by counting the whole value cells within column 6 to give $n = 14$. Once these figures were determined, a Wilcoxon Signed-Rank table of critical values was used for a two-tailed test (Wilcoxon *et al.*, 1970). At a significant level of 0.05 and with a sample size of 14, the critical value (T_{crit}) for a two-tailed dataset is 21. Next, the mean value (μ_T) and standard deviation (σ_T) were calculated using formulas (8) and (9) from Section 3.8.5.

$$\mu_T = \frac{14*(14+1)}{4} = 52.5 \text{ and } \sigma_T = \frac{\mu(2n+1)}{6} = \frac{52.5*((2*14)+1)}{6} = 253.75$$

Once these values had been determined, the z-score was determined using formula (10).

$$z = \text{ABS}\left(\frac{13 - 52.5}{253.75}\right) = 2.479671$$

Lastly, using Microsoft Excel's normal distribution function and formula (11), the p-value was calculated as:

$$p = 2 * (1 - \text{NORM.S.DIST}(2.479671, \text{TRUE})) = 0.01315$$

The test reveal that $p < \alpha$ at a significance level of 0.05 and can be considered statistically significant with certainty greater than 95%. The null hypothesis (H_0) can therefore be rejected and consider an alternative hypothesis (H_a) with a probability of 98.68%.

5.3.3 Results from Q28 including Spearman's rank correlation coefficient test

Focusing on how projects address quality problems (i.e. NCR rectification), the quantitative analysis identified many instances where NCRs were prematurely concluded (Section 4.3.1). Specifically, there were 397 cases where the project had oversimplified the problem, and provided a corrective solution that did not address the root cause in full. As such, there were instances where the NCR was free to be replicated elsewhere on the scheme. This raised concerns as to the level of competence of those engaging in root cause analysis, as well as with the behavioural decision-making taking place (e.g. looking for the easiest outcome, rather than eradicating the problem altogether). In addition, the open and close out dates of the NCRs were long (i.e. many months), raising concerns over the effective implementation of the process. Four statements were developed within a 6-point Likert scale, to challenge each group on quality problem- solving. To differentiate each statement, these were labelled Q28a through to Q28d (Appendix 15, Q28).

From an initial observation of the graphical data, there are clear patterns to note. For statement Q28a, where each group was asked whether they agreed that on projects we tend to look for the easiest solution to address a non-conformance, the majority of each group agreed this was the case. Specifically, there were 6 contract leaders and 8 quality professionals who voted ‘strongly agree’, with a further 10 contract leaders and 22 quality professionals who voted ‘agree’. Collectively, these figures represent 24.8% (strongly agree) and 52.8% (agree). There were a further 4 contract leaders and 3 quality members who selected ‘slightly agree’ (13.5%). For those who did not agree with this statement (i.e. strongly disagree, disagree or slightly disagree), there was only 1 contract leader and a further 5 quality professionals (9% collectively). The results therefore confirm suspicions that project teams fixate on addressing non-conformance at minimal impact to the project (e.g. cheapest solution that has minimal impact to the programme).

A similar but more significant trend was observed in Q28b where each group was presented with the statement that we typically focus on addressing remedial solutions instead of eradicating the underlying cause. The results revealed that there were 6 contract leaders and 17 members from the quality community who voted ‘strongly agree’, collectively accounting for 36.7% of the responses. There were a further 13 contract leaders and 16 quality professionals who voted ‘agree’ (52.0%). This indicates that 88.7% of all participants were in agreement that projects narrow focus on addressing the defect (i.e. remedial action) rather than exploring ways of preventing the non-conformance reoccurring (i.e. corrective action). Note that there was only 1 individual from the quality community who disagreed with this statement, for reasons unknown (1.3% of all respondents). The overwhelming consensus of results indicating agreement with the statement suggests this response can be ignored.

To challenge project professionals on their problem solving abilities under complex situations, statement Q28c claims that projects are unable to identify the true root causes of many of their NCRs, as a result of complexity and uncertainty. As there are many factors that can influence non-conformance, such as political pressures, unpredicted weather conditions and freak events (e.g. COVID-19), there are certain problems that are difficult to solve, owing to their complexity.

Positively, many were of the view that with the correct investigative techniques, most root causes are determinable. This view was expressed particularly within the quality community. In fact, the survey encountered more responses in disagreement with the statement between the ranges ‘strongly agree’ and ‘slightly agree’ (59.1%), leaving 40.1% of the opinion that there are NCR cases too difficult to problem solve. Of those who disagreed with the statement, there was 1 contract leader and 4 quality professionals who voted ‘strongly disagree’, 6 contract leaders and 11 quality professionals who voted ‘disagree’, and 4 contract leaders and 10 quality professionals who voted ‘slightly agree’. From the graphic visual in Appendix 15 (Q28c), the graph shows an almost equal loading of responses for contract leaders. For the quality community on the other hand, there is a far clearer pattern that root causes are identifiable, regardless of their complexity.

Lastly, on reviewing the NCR ‘raised date’ and ‘signed-off date’, analysis was undertaken to determine the average time frame to rectify an NCR (Section 4.2.3).

Across the dataset, the average time taken to close out an NCR from the date it was raised was 211.8 days (Table 4.2). Such a long time frame led the researcher to question whether NCRs were being adequately managed and how effectively the process was being followed by projects. Noting the above, question Q28d made a final statement that NCR processes are not strictly followed on schemes. Again, another mixed response was observed with responses for and against this statement (Appendix 15, Q28d). However, there were 62% of contract leaders and 71% of the quality community who were in agreement, with responses ranging from ‘strongly agree’ to ‘slightly agree’ that processes are not adequately followed during construction. This indicates that, although not unanimous, there is general agreement that there is an issue with how NCR processes are executed on projects, particularly around the lack of proactivity to capture all NCRs as they are uncovered, undertake robust analysis to unearth appropriate solutions to address the problem, and provide evidence for close out in a timely manner to the satisfaction of clients.

An effective way to assess the statistical significance of these four response findings is to conduct a t-test. In the case of rank and Likert scale questions, Spearman's rank is a leading nonparametric test for ordinal data and so was chosen to understand the significance of Q28 findings (Spooren *et al.*, 2007). Similar to the other tests conducted, a significance level for α was set at 0.05. As there were 21 contract leaders and 38 quality professionals who participated in the survey, a proportioning factor (pf) was required to normalize the variance into a comparable range. To compute pf, the lowest value (21) was divided by the highest (38) to give a proportioning value of pf = 0.553. Data from the 38 quality respondents was then multiplied by 0.553 to equal the response before testing. Prior to performing the test, the data was organised for each question from strongly agree to strongly disagree with corresponding response numbers. In addition, the data was ranked independently for each group using the same logic deployed in the previous tests, including the necessity to rank zero entries.

Table 5.6 presents the exported data and ranking of entries with proportional factor and difference of ranks incorporated. Note that from the table, there are six entries within each question. This is the sample size (n) of the data with $n = 6$.

Table 5.6 – Results and ranking of Q28 data for Spearman's rank test.

Question No.	Entry	Likert scale response	Contract Leaders (CL)	Rank RX_i (CL)	Quality Community (QC)	Quality Community (QC*pf*)	Rank RY_i (QP*pf*)	d_i	d_i^2
Q28a)	1	Strongly agree	6	5	8	4.4211	5	0	0
	2	Agree	10	6	22	12.1579	6	0	0
	3	Slightly agree	4	4	3	1.6579	3.5	0.5	0.25
	4	Slightly disagree	0	1.5	2	1.1053	2	-0.5	0.25
	5	Disagree	1	3	3	1.6579	3.5	-0.5	0.25
	6	Strongly disagree	0	1.5	0	0.0000	1	0.5	0.25
								SUM	1
Q28b)	1	Strongly agree	6	5	17	9.3947	6	-1	1
	2	Agree	13	6	16	8.8421	5	1	1
	3	Slightly agree	2	4	4	2.2105	4	0	0
	4	Slightly disagree	0	2	0	0.0000	1.5	0.5	0.25

	5	Disagree	0	2	1	0.5526	3	-1	1
	6	Strongly disagree	0	2	0	0.0000	1.5	0.5	0.25
								SUM	3.5
Q28c)	1	Strongly agree	0	1	2	1.1053	1	0	0
	2	Agree	6	5.5	3	1.6579	2	3.5	12.25
	3	Slightly agree	4	3.5	8	4.4211	4	-0.5	0.25
	4	Slightly disagree	4	3.5	10	5.5263	5	-1.5	2.25
	5	Disagree	6	5.5	11	6.0789	6	-0.5	0.25
	6	Strongly disagree	1	2	4	2.2105	3	-1	1
								SUM	16
Q28d)	1	Strongly agree	1	2	8	4.4211	5	-3	9
	2	Agree	7	6	7	3.8684	3.5	2.5	6.25
	3	Slightly agree	5	4.5	12	6.6316	6	-1.5	2.25
	4	Slightly disagree	3	3	3	1.6579	2	1	1
	5	Disagree	5	4.5	7	3.8684	3.5	1	1
	6	Strongly disagree	0	1	1	0.5526	1	0	0
								SUM	19.5
			21		**38**	**21**			

Once the data was ranked, the Spearman rank correlation coefficient (r_s) was calculated for each question using equation (1) from Section 3.5.5.2, along with the t-statistic (t) using equation (2). The p-value was then computed using Excel code $= TDIST(t, d, 2)$. Table 5.7 presents these findings, including the conclusion of each question's statistical significance and corresponding probability values.

Table 5.7 – Comparable findings from Spearman's rank test.

No. of participants (CL)	No. of participants (QP)		
		$\alpha =$	0.05
21	38	$pf =$	0.553
		$n =$	6
		$d =$	4

Question	Correlation Coefficient (r_s)	t-statistic (t)	p value	Statistically Significant? ($p < \alpha$)	Probabilit y (%)
Q28a)	0.97059	8.06318	0.00128	Yes	99.87%
Q28b)	0.89326	3.97409	0.01648	Yes	98.35%
Q28c)	0.52964	1.24883	0.27983	No	72.02%
Q28d)	0.42647	0.94300	0.39908	No	60.09%

Of the four Likert scale statements presented to each of the professional groups, there are noteworthy trends to be elaborated on further. First, we see a high significance outcome for questions Q28a ($p = 0.00128$) and Q28b ($p = 0.01648$), where the p-value is less than the significance level set by the test (i.e. 0.05). For each case, there is a statistically significant difference between two populations of data with different medians for the same risk factor. Therefore, we have sufficient evidence to reject the null hypothesis ($H_0: \theta 1 = \theta 2$) at a significance level of 0.05 and accept the alternative hypothesis ($H_a: \theta 1 \neq \theta 2$) with a greater than 95% probability level that the results did not occur by chance. This supports the obvious visual trends of Q28a and Q28b in Appendix 15 that show a clear majority agreement with each statement. However, the test results for Q28c and Q28d do not yield similar findings. For Q28c, the results reveal a value of $p = 0.27983$ (72.02% probability), which is greater than the significance level value. Similarly for Q28d, a value of $p = 0.39908$ (60.09% probability) is derived from the test, indicating that the two samples (i.e. groups) are consistent and are drawn from the same population. These results indicate that at a probability level of 95%, we cannot reject the null hypothesis (H_0).

5.4 NVivo 12 qualitative analysis findings

A step by step procedure of how NVivo 12 was implemented is presented in Appendix 16 to show the path taken by the researcher.

As this was the first time the researcher had used the qualitative software, NVivo 12, a training session was arranged to provide an overview of how the software operates and the ways in which data can be analysed from open-ended transcripts. Training was provided by Cardiff University on 18/04/2023, over the course of three hours, in which time the presenter detailed how to set up a project and demonstrated the types of analysis that could be performed to understand the data. Although the session was informative, the researcher felt the training was basic and required additional insights on detailed analysis techniques and visualisation methods that could be used to present the findings professionally. Other researchers have noted the steep learning curve of using NVivo and have resorted to online help for further guidance (Hoover and Koerber, 2009). Therefore, the researcher did the same, but with the addition of guidance videos from YouTube and supporting literature, specifically on the process of how NVivo operates (e.g. Welsh, 2002; Hilal and Alabri, 2013; Edhlund and McDougall, 2018; Dhakal, 2022).

Once sufficient knowledge of the software had been gained, the researcher conducted a number of test cases on NVivo to interrogate the data. This helped provide a more ‘hands on’ learning experience that was not gained from the other learning methods.

On completion of the training, a new project was created within NVivo 12 to allow the data to be imported prior to analysis. In addition, to secure the sensitive information within the file, a password was created to prevent unauthorised access. Following this, the data was cleansed in accordance with the five exercised listed in step 3 of Section 3.5.5.6 (i.e. removing grammatical errors, sensitive information, closed-ended questions, and conditional formatting of the blank cells, and numerically and chronologically organising the data).

To interpret the data, coding was performed using NVivo 12’s auto-coding function to help reduce coding time frames. It took approximately one minute to finish processing both survey files and to auto-code the data, which is staggering, given that this would likely take days manually.

Following this, analysis of the data was performed using a word frequency query and a text search query function to identify prominent patterns with the qualitative data. Using the aforementioned techniques, analysis was performed following the auto-coding feature. Beginning with an explore function of the most frequently occurring themes within the qualitative data, these words were used as a proxy that represented participant perspectives collectively. Furthermore, an assumption was made that important and significant words would be used most frequently (Carley, 1993).

Moreover, researchers claim that analysing word frequency improves analytic rigor, and decreases bias regarding overweighting, to maintain analytic integrity (Onwuegbuzie and Leech, 2007). To avoid decontextualization, a minimum letter word count was implemented to prevent words being selected that lacked meaning. For example, words like 'we', 'is', 'the', 'that' etc. are used in most sentences but lack significance and do not increase understanding of a phenomenon. Therefore, it has been advised that words with five or more letters are selected for analysis using NVivo's word count feature (Feng and Behar-Horenstein, 2019). However, the researcher observed that there were important words that must be included in the analysis that contain four letters, such as 'work', 'cost' and 'risk', which are fundamental terms used to describe quality within construction. Therefore, words with a letter count of four or more were considered in the query.

To analyse word frequency of each question, the 'word frequency query' function was performed with stemmed variants selected to calculate the weighted percentages of each file (e.g. 'design, designed, designs' were counted as 'design'). This function was run for all questions, beginning with the first free text question (Q10). Tables 5.1 and 5.2 present the corresponding referencing of respondents relating to any quotes or opinions made through the qualitative findings. In addition, Appendix 17 presents the statistical outputs for each question including word frequency summaries, word clouds and corresponding word frequency trees. These are further analysed and discussed below.

Question 10 – What do you believe is the potential consequence for proceeding at risk without approved designs (both positive and negative)?

Previous quantitative findings suggest that projects are proceeding at risk, without design approvals, many times throughout a project lifecycle (Appendix 15, Q9). There is an overwhelming agreement from industry professionals that meeting programme and taking risks is happening more often than not. Therefore, contract leaders and quality professionals were asked for their views on proceeding at risk without design approvals.

Qualitative analysis suggests that for contract leaders, the five highest frequency words in order were ‘design’, ‘cost’, ‘programme’, ‘risk’ and ‘work’. Of these words, 10 contract leaders made reference to ‘design’, 11 to ‘cost’, 11 to ‘programme’, 9 to ‘risk’ and 11 to ‘work’. Furthermore, from these words, a deep dive was conducted to understand the significance of each word. As for the quality community, ‘design’, ‘work’, ‘rework’, ‘risk’ and ‘cost’ were the highest yielding response words. Specifically, 20 quality professionals commented on ‘design’, 30 on ‘work’, 17 on ‘rework’, 10 on ‘risk’ and 12 on ‘cost’. But what does this information mean?

Although NVivo is a powerful tool for rapidly organising data to focus on trends, outcomes must still be interpreted to contextualise against each question posed. As such, a manual exercise was performed to understand why each professional group mentioned a specific word. A keyword filter was applied to fixate on specific responses to each frequency word, which were then interpreted by the researcher. Table 5.8 presents the positive and negative outcomes that the project professionals felt were valid for proceeding at risk with trailing design approvals.

Table 5.8 – Positives and negatives of proceeding without approved designs (question Q10).

Group	Word references	Positive and negative outcomes

Contract Leaders	10 references to ‘design’ 11 references to ‘cost’ 11 references to ‘programme’ 9 references to ‘risk’ 11 references to ‘work’	**Positives** ● The project remains on programme ● Critical path activities are not compromised ● Reduces overhead (prelim) costs ● Provides a continuing stream of work for supply chain ● Delay costs and penalties often outweigh rework costs **Negatives** ● Higher likelihood of defects and rework ● Enhanced risks and responsibilities for the contractor not the designer ● Scope creep (design becomes elongated) ● Unstable programme without a defined design scope ● Cost and time escalations due to protracted contract close out ● Greater difficulty managing handover and contract completion ● Commercial onslaught (mis-management allegations, commercial claims and potential loss of future work) ● Drives negative behaviour where proceeding at risk is acceptable which will continue on future schemes ● Design changes through review processes as more information becomes available (e.g. ground investigation) ● Further poor decision-making as the true impact is not realised **Standout quote (CL03):** *‘Time is often more expensive than rectification of defective works’*
Quality Community	20 references to ‘design’ 30 references to ‘work’ 17 references to ‘rework’ 10 references to ‘risk’ 12 references to ‘costs’	**Positives** ● Possibilities to meet or improve on programme pending sufficient risk review analysis ● Time saving if no design change is required ● Time and cost to carry out rework may be less impactful than waiting for design approval ● Provides supply chain with a continued stream of work with limited downtime **Negatives** ● Rework including wider re-design and site changes to fix ● Quality outputs decrease (e.g. more defects) ● Ambiguity of scope (i.e. building something that doesn’t work) ● Unforeseen design clashes on site ● Cost escalations (delay damages and disallowed costs) ● Failure to meeting target dates within programme ● Commercial pain ● Personnel implications of proceeding without approval ● Affects relationships with clients and supply chain (arguments) ● Reduces morale and confidence of workforce ● Increased safety issues ● End product may not be what the client wants ● Short term and long term reputational damage resulting in loss of work and alternative delivery partners **Standout quote (QC15):** *‘There are no positives. In the end, it catches up with us. Use the safety analogy…Is it OK to have a quantity of accidents? No.’*

As shown, both groups validate concerns that the negatives significantly outweigh the positives when proceeding at risk without approved design details. Contract leaders presented 5 positive and 10 negative outcomes. Some of the negative outcomes include higher risks of rework, scope uncertainty, greater quality and safety issues, cost and time escalations, behaviour issues, reputational damage and relationship breakdowns. Of the positive responses, the need to meet critical programme deadline dates and alleviate project overheads on the next scheme appear the most influential drivers for contract leaders. There are some who feel that delay damages from not meeting key project milestones are far more significant than rectifying defective works, which likely influences their behaviour (CL03). Quality professionals on the other hand gave 4 positive and 13 negative views, with similar feedback. However, there was far more negativity around making decisions to proceed at risk. In fact, a few individuals from the quality community were strongly of the opinion that there are no positives to proceeding at risk (e.g. QC15). Much like safety, they felt that one incident is more than enough and deemed unacceptable. Accurate designs and early design freezes have been considered a critical success factor to project delivery that must not be overlooked (Wuni and Shen, 2020). Garemo *et al.* (2015) support the premise that if project sponsors commit to investing more in the preliminary design phase and early engineering phases of schemes (circa 3 to 5 percent of capital cost), far better results are envisaged with regards to time and budget delivery. The author strongly agrees with this premise, and has experienced shortfalls in this area on schemes with a lack of preliminary investigation to validate ground conditions.

One benefit stated by a number of contract leaders is that proceeding at risk to meet programmes will reduce overhead costs. This can only be true if their assumptions are correct about the design and that no further changes occur. From the researcher’s experience, handover operations, where projects resolve defects, respond to queries, consolidate late quality assurance deliverables and other missed tasks, have a far greater effect on resources. In fact, some schemes (e.g. Crossrail) have succumbed to years of testing, commissioning and handover pain to satisfy completion, some of which may be down to late design changes and proceeding at risk (Landis, 2022). In addition, design changes have been considered important causing factors of project delays and cost overruns that burden project handover (Burati *et al.,* 1992; Abdul-Rahman *et al.,* 1996).

Question 13 – If you answered 'Yes' to the previous question, do you think that cost and programme are more important than quality delivery? Please explain.

Noting that 100% of both groups felt that cost and programme are treated as a higher priority than quality delivery (Appendix 15, Q12), they were asked whether they felt cost and programme are more important than quality and to explain why.

For contract leaders, the five most frequently occurring words within their responses were ‘costs’, ‘quality’, ‘programme’, ‘works’ and ‘time’. Of the results, 17 made reference to cost, 15 referenced ‘quality’, 12 commented on ‘programme’, 7 on ‘works’ and 8 on ‘time’. The quality community results similarly discuss ‘quality’, ‘cost’, ‘programme’ and ‘time’ as the most frequent words; however, they make greater reference to ‘project’ as opposed to ‘works’. Specifically, 23 quality professionals commented on quality, 23 on cost, 23 on programme, 11 on time and 11 on project.

Of the responses, there were 14 contract leaders who stated directly that they did not believe cost and programme are of greater importance than quality, accounting for 66.67% of the group. There were a further 6 responses (28.57%) that skirted around a direct response and commented purely on why this phenomenon occurs, and 1 respondent who felt that cost and programme are of greater importance (4.76%). Similarly with the quality community, there were 23 professionals (60.53%) who were strongly of the opinion that quality is equally important as cost and programme, and 15 respondents (39.47%) who did not provide a direct response, instead focusing on justifying why cost and programme take precedence. Both groups identify the intertwined nature of cost, time and quality within the iron triangle, with these factors having a direct consequence on one another, as other researchers have alluded to previously (Pollack et el., 2018). Furthermore, they acknowledge and appreciate the knock-on effects cost or programme have on quality. Moreover, both parties expand on their concerns that failing to deliver quality leads to unplanned and un-forecasted cost and time events which are more damaging, as they will take longer to resolve.

This links to concerns made by Litsiou *et al.* (2022) that accurate formal forecasting is a weakness for construction projects.

Focusing on ‘why’ decision-making is geared toward prioritising cost and programme, the findings from the responses are summarised below.

Of the contract leader responses, the following themes encountered:

[1] ***Client and stakeholder requirement*** – The majority of comments made regarding cost, time and programme were geared toward clients requirements. There were many concerns that it is fundamentally clients who set unrealistic cost and programme expectations, that have been driven through political pressures to mitigate taxpayer spend and limit disruption. As such, the influence of prioritising cost and programme over quality is heavily influenced from above, which drives greater focus on these areas down through to project teams.

In addition, client organisations have been perceived as focusing on cost and programme with the expectation that quality will ‘just happen’. Furthermore, there are notes of a lack of understanding and appreciation from clients of how challenging right-first-time delivery is. There are key performance indicators (KPI) that most projects to continually re-evaluate a scheme against, however, contract leaders have raised concerns that projects are set up to monitor cost, time and safety primarily. Quality-related strategic objectives have been considered as an afterthought by both clients and project leaders, and do not measure the correct metrics (i.e. RFT delivery, quality culture scoring etc). The need to re-evaluate the metrics for quality delivery to focus on RFT, rather than using lagging indicators (i.e. non-conformance outcomes) when the damage is already done, is fundamental. Schemes need leading indicators to be made accurately and in advance decisions, before issues occur. Noting the above, contract leaders felt that their clients drive behaviours to complete works and deal with defects outside of key funding milestones. To the researcher, this is concerning. It may be more financially viable to delay programme and achieve high quality outputs, than chase financial settlements at the cost of poor quality, which will undoubtably lead to prolonged handovers and long defect rectification periods.

It would appear that if clients significantly influence decision-making in order to prioritise cost and programme, re-education on the impact these variables have on quality is needed at a senior leadership level. If we get quality right, our ability to maintain schedule and cost projections should increase. Therefore, priority must be on quality and safe scheme delivery at all times. This directly influences the next topic discussed: culture and behaviours.

[2] ***Culture and behaviours*** – There were multiple comments on the project delivery mindset of narrowly focusing on cost and time, as these are tangible, measurable lagging indicators used to monitor performance, whereas quality performance measures were noted as being less accurate and more challenging to report on (CL07). As such, projects typically take a short term look ahead (e.g. twelve weeks) instead of recognising the long term consequences of contract completion (CL04, CL07 and CL11). Again, if clients are driving expectations that project milestones must be achieved as cheaply as possible, knowing that quality may be compromised, it paints the wrong picture for the workforce, who will follow this leadership direction.

From the 21 responses, only 1 individual (CL03) gave interesting insight as to why cost and programme are more important in their view. They commented: *'Because they are. There is no point creating a perfect quality scheme that is late and over budget. Sometimes we have to accept that we will do an imperfect job on certain activities in order to achieve the overall aim of the scheme.'* A perfectly valid point is that if we fixate purely on perfect quality delivery, cost and programme will be compromised. Project teams, clients and stakeholders must strike a balance that meets the expectations of all parties, including clearly defined requirements for a quality end product that meets cost and time assumptions, i.e. the iron triangle (Caccamese and Bragantini, 2012).

Reflecting on the quality community responses, similar patterns are shared with contract leaders. First, quality professionals concur there is a lack of maturity from clients who do not appreciate the benefits of achieving RFT over hastily delivered projects. More concerning, they believe this behaviour is unlikely to change anytime soon with ever tightening budgets, greater public awareness and heightened political pressures to deliver.

Second, there are concerns that a lack of quality investment is making it more challenging to measure quality metrics that should be measured (i.e. supply chain performance, right-first-time execution, quality behaviours and quality risks) (QC24). One quality professional quoted, *'Cost and programme first is a false economy with incorrect perceptions that projects will find time at the end of programmes to rectify issues.'* In essence, without clearly defined quality metrics, there are concerns that the construction industry is unlikely to improve and will continue to *'lag behind more mature sectors, most of which have realised the importance of quality by adjusting their way of thinking'* (QC17). Ensuring quality and safety performance demonstrate right-first-time delivery was concluded as a number one priority without exception. By embedding this cultural approach in project thinking, quality professionals feel it will help correctly drive programme, along with providing adequate time and resources to plan the work, while maintaining cost performance projections (QC34).

In addition to areas discussed, quality professionals had further concerns around leadership that was not identified by contract leaders.

[3] ***Leadership*** – There were numerous links to the words 'quality' and 'project' from quality professionals which made concerns over the minimal direction and vision that leaders instil on their projects. Specifically, leaders are failing to provide clear 'quality' objectives, continually advocate and promote quality performance, and assign accountability, consequence and reward for quality outcomes. For example, there were two quality practitioners (QC34 and QC38) who noted the lack of quality strategy and planning, and a failure to provide a clear vision of quality on equal terms to safety, cost and programme objectives that would develop a right-first-time culture, and a 'stop if not right' culture if poor quality performance ensues. Contract leaders and quality professionals are in agreement that projects do not see the same willingness from front line workforces to stop works on the grounds of failing quality, as would be seen on the grounds of breaching safety standards. In safety, there is no hesitation to interject, whereas in quality, individuals carefully consider their decisions so as not to compromise programme, led by pressures from above to meet key delivery dates. In certain cases, teams may progress knowing the works are defective, so as not to compromise critical path milestones, hoping they will find enough time at the end to rectify issues. This is very risky, narrow minded behaviour, led by industry leaders. In the end, quality will always catch up with the project and inflict greater damages than stopping works to do them correctly. An important point, noted by both parties, is that, at present, the construction industry does not understand the full impact of proceeding at risk with live quality defects against doing works right-first-time with programme compromise as required.

The second generalised comment made by the quality team was that contract leaders are failing to consider the role and perception of the quality team, which is discussed further below:

[4] ***A quality team's image*** – More than 50% of the responses made comments about how quality personnel are perceived on projects, such as being seen as *'quality police or pedantic / fussy'* rather than embedded members who are committed to helping drive project success (QC08). This reinforces concerns of risky site behaviours from personnel who are under tremendous pressure to deliver schemes as quickly and cheaply as possible, driven by cost and programme expectations from leadership. These behaviours have filtered all the way up to leadership, resulting in that quality professionals do not feel their voices are heard or valued when faced with quality issues. One individual commented *'who cares what quality professionals think'* (QC03), bringing into question whether quality personnel are being included and given the authority to make impactful decisions for the betterment of projects.

Question 16 – Do all parties on our project fully appreciate and understand the level of quality to be achieved? If 'No', why do you believe this is the case?

Previous findings indicate that 13 of 21 (61.9%) contract leaders and 24 of 38 (63.2%) quality professionals felt that quality standards were not fully understood by all parties. They were therefore asked why they believed this to be the case (Appendix 15, Q15).

NVivo results indicate that the most frequently discussed words from contract leaders were 'client' (7 counts), 'quality' (6 counts), 'standard' (6 counts), 'different' (5 counts) and 'often' (5 counts). Similar results were found with the quality community group where the five most frequently raised comments were 'client' (17 counts), 'expects' (14 counts), 'quality' (13 counts), 'project' (10 counts) and 'time' (10 counts).

A deep dive into the five most frequently discussed words indicates an overwhelming agreement that project stakeholders and the teams managing them have varying expectations of quality standards, including what is deemed acceptable (i.e. fit for purpose). The subjective nature of what is deemed acceptable has proven challenging to date. Both groups acknowledge that the likely cause of this is a lack of early engagement, communication of proposed requirements and agreement at the beginning of projects. Instead, a siloed atmosphere ensues, presenting further challenges with a mixed understanding of what is to be delivered. For example, one contract leader explained that they have experienced client business silos with different and competing objectives/drivers. Architects may require a fine finish, operations will insist on a minimal maintenance solution, the technical approval department will expect recognised engineering standard outputs, commercial management want the cheapest solution and project sponsors want a minimal impact solution that does not disrupt the public.

Agreeing quality requirements between clients, principal contractors and stakeholders is one thing, however there were comments from contract leaders that such discussions are not shared with the supply chain, nor have supply chain personnel been invited to contribute to quality output discussions. As a result, if and when communications are disseminated down to the supply chain, it is too late.

Lastly, there were comments that a lack of training and education of quality requirements is clouding the issue of what is deemed acceptable. Instead, individuals or groups revert to previous project experiences, which may not correspond to the same standards (i.e. applying quality standards from rail to highways). One contract leader (CL16) stated, *'People remember the quality requirements of the previous longest serving project they had been involved in and therefore breaking habits are often difficult'*. This causes challenging behaviours on projects with habits that are challenging to break.

On reviewing the quality community responses, personnel perceive quality standards as somewhat tactically benefiting each party's interests. Unfortunately, in many cases, these interests are not aligned, so a balance must be struck. For example, one quality professional (QC01) presented an example using the quality of cars: *'Clients want a*

Rolls Royce finish, specifications and requirements accept a Ford, and project managers want to deliver the most basic car possible'. Most own a car and understand the nuanced differences between low, medium and high quality outputs (e.g. between a luxurious Rolls Royce and a mid-range Ford).

To visualise the expected quality levels both groups have made, Table 5.9 provides examples using automobiles, with annotation of what parties at different hierarchical levels expect, from clients through to the supply chain.

Table 5.9 – Quality expectation from project parties using automobile examples.

Project party	Vision of quality expectations in the example of 'automobiles'	Typical expected level of quality output
Client		Highest expectations of quality at conservative, unrealistic prices.
Designer		High quality with robust, overdesigned capabilities for its intended purpose.
Principal contractor		A mid-range solution sometimes boarding on a basic specification level to meet cost

Supply chain		Lower range quality solution but meets specification

A vital point regarding the cars listed above is the significant variance of costs which projects may not have budgeted for. If the sponsor has not budgeted for a superior product (i.e. a Rolls Royce), it would therefore seem unfeasible to expect more than what has been priced (i.e. a Ford). Unfortunately, quality professionals have growing concerns that clients do try and get as high a quality finish as possible and expect more than what they are prepared to pay for. Therefore, expectations must be managed. This specific example of Rolls Royce was commented on by two contract leaders (CL02 & CL05) and three quality professionals (QC01, QC20 and QC38) as a way of expressing the sliding scale of quality expectations.

Another similar claim made by the quality community was the poor communication of agreed requirements down through to the supply chain, who sometimes have different outlooks on quality requirements. With projects often starting abruptly, quality expectations are not always defined, agreed on and communicated effectively through kick off meetings, that involve the client, designer and supply chain (QC02). Instead, projects are proceeding with the mentality *'that is the way it's always been done'* (QC26). Furthermore, quality professionals are concerned that clients and designers do not willingly contribute to discussions on quality requirements, and instead just leave it for the project team to interpret. This reinforces the message that clients and designers should take time to reflect on quality expectations and requirements that are within each scheme's budget (Kaur *et al.*, 2019).

Question 19 – Analysis of 1260 non-conformances (NCRs) on a successful major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (£7,739,850). Based on a 3% profit margin, that is

a potential profit loss of 17% of what could have been achieved. In reality, this figure is conservative and likely to be far higher. Is this figure of concern? Please explain your answer.

From the quantitative results, a major highways scheme experienced a 17% profit loss figure to rework (Appendix 15, Q18). 20 contract leaders (95.2%) and 37 quality professionals (97.4%) were seriously perturbed with the 17% profit loss, but why? Question 19 provided the respondents with an opportunity to share their reasoning via a free text response option.

NVivo was again deployed to present word frequency tables, word clouds and word trees for both groups, to draw out significant themes.

Contract leaders commented on ‘cost’, ‘profit’, ‘margin’, ‘quality’ and ‘work’ most frequently, whereas ‘cost’, ‘projects’, ‘profit’, ‘rework’ and ‘loss’ were more prominent words with the quality community.

On closer review of the responses, there were seven contract leaders who feared that a figure of 17% is likely to be conservative as costs are not accurately or correctly recorded. In reality, they believe this figure to be significantly higher and pose an even greater risk to company profits. Furthermore, when factoring in direct and indirect costs, there are likely to be hidden costs unaccounted for, such as design change, process overhaul, investigative time etc. Contract leaders blame the stigma of quality and its associated commercial implications for negative outcomes.

Another concern made by contract leaders was the impact that such rework costs have on projects and their parent organisations. Not only did they mention the obvious fact that such outcomes will affect profitability, but they also mentioned the logistics of rectifying rework (i.e. rectifying non-conformance requires additional time and effort to resolve, and takes resources away from closing out remaining works within contract scope). Furthermore, there were concerns that huge effort and teamwork go into delivering slim profit margins that need to be more carefully protected. If companies look at the energy expended in delivering these levels of profits in relation to turnover, they will see big risk for little gain.

Any impact on profit margins has been commented on as concerning, as this is how business proves viability to its stakeholders. One contract leader stated, *‘17% margin erosion is massive’* (CL12). Another stated, *‘effectively this is profit going needlessly out the door, and to recoup this profit loss would take a significant amount of future turnover’* (CL04). The dataset is based on the largest construction company in the UK. Not all schemes are of this magnitude, and so will take longer to recover. However this is conditional on no reworking occurring, which seems unlikely.

Of the quality community responses, they too agree with contract leaders that the figure is low and believe this cost only scratches the surface. For example, respondent QC15 commented, *‘The figure could be significantly higher - refer to Get It Right Initiative (GIRI) data - up to 25% of project costs, therefore the problem or opportunity is also larger’*. Latent defects and other late changes are rarely incorporated within non-conformance and rework figures as teams and their processes have disbanded. Quality professionals also identify issues with the accuracy of indirect costs from supply chains, designers and clients that have been previously identified as up to six times the actual (direct) cost of rectification (Love, 2002a). Separately, the direct costs that principal contractors incur, such as management, administrative time, traffic management, further inspections, evidence reviews, field supervision, additional safety implementation and programme impacts, have been commented on as some of the missing costs of non-conformance and rework (QC13 and QC38). Eight quality community respondents conclude that in reality, without question, non-conformance costs are undervalued and exponentially higher than reported, both directly and indirectly (QC04, QC13, QC15, QC17, QC21, QC23, QC24 and QC26). More significant cost outcomes will have a more significant impact on profit loss, reputation and growth within the construction sector.

Other concerning factors raised by the quality community included behaviours, training and competence, which have great impact on profits. Five respondents elaborated that the culture of quality at present does not appear to have progressed towards ‘right-first-time’ delivery and is still geared towards cost and programme outputs. Unless this changes, similar outcomes will continue to occur as works are rushed, corners are cut and mistakes are made. Quality professionals have called for leaders to invest more heavily in people, processes, systems and technology to help adapt the culture of quality in construction, with a greater emphasis on leadership direction, which is severely lacking in the many sectors, not just highways (QC02 and QC04).

A separate concern raised only by the quality community was the reputational damage such quality outputs and profit losses have with clients and shareholders (QC10, QC12, QC13 and QC21). Clients will lose confidence and be less likely to award future work to contractors who continue to demonstrate poor quality execution. Likewise, shareholders will be unwilling to invest in failing, high risk portfolios and will look elsewhere.

Continuing high rework costs on current highways schemes indicate that the company is still not learning lessons from non-conformance and is continuing to make unnecessary mistakes (QC06 and QC16). Furthermore, high costs reflect that the prime causes of rework are not being addressed and can continue to manifest elsewhere. The group responses reiterate that quality awareness and behavioural changes need to be led by leadership as a fundamental step change, inflicting consequence and reward for quality outcomes.

In conjunction with leadership changes, there need to be changes to how the organisation budgets schemes to de-risk and protect profit margins (i.e. at tender phase). Quality professionals acknowledge that human error will happen and delivering projects with zero rework cost is extremely unlikely. However, during tender and budget agreements, no rework cost is accounted for, immediately eroding profit margin (QC27). It is even more important that leaders re-evaluate their initiatives with this knowledge to reduce error and protect profits, by not chasing programme and the cheapest options. A proportional cost of error assumption should be built into projects to transfer a portion of risk onto clients, where they pressure contractors to focus on key milestones instead of delivering a quality product. One quality professional (QC35) likened it to *‘supermarkets budgeting for shoplifting’*. It’s about having a fair understanding of risk and apportioning that risk between engaged stakeholders.

Question 20 – The most frequent NCR root causes were found to be materials management, poor workmanship and supervision. What do you believe we should focus on to prevent repetition of future schemes? Please list.

Question 20 presented the three most frequent non-conformance root causes from the quantitative data analysis as materials management, poor workmanship and supervision (Ford *et al.*, 2023). From this, both groups were asked where they would focus efforts to prevent repetition on future schemes.

With the hope that NVivo would summarise the key areas for improvement, a word frequency query was performed. For contract leaders, the five most influential keywords within their responses were 'quality' (10 counts), 'management' (6 counts), 'engineering' (4 counts), 'materials' (6 counts) and 'right' (8 counts). In the quality community responses, the most frequent five words were 'quality' (18 counts), 'materials' (14 counts), 'work' (18 counts), 'supervision' (13 counts) and 'management' (11 counts). As the word 'management' factors in the broader picture of quality as well as the materials management root cause, it is unsurprising that this was such a highly discussed topic.

Although the word frequency findings broadly identified areas for improvement, the lack of specific detail around the 'what' and 'why' behind each area called for further interrogation. As such, an intrusive review of each response was performed and summarised in Table 5.10. The table presents figures on consolidated themes where each party felt improvements were vital for future scheme success.

Table 5.10 – Quality improvement areas suggested by two professional working groups.

Group 1 – Contract Leaders		**Group 2 – Quality Community**	
Area for improvement	**Counts**	**Area for improvement**	**Counts**
Workforce competence (*training, education and coaching to SQEP level*)	12	**Workforce competence** (*training, education and coaching to SQEP level*)	16
Quality culture (*behaviours, accountability, incentivisation to appreciate and understand quality)*	8	**Materials Management** (*overall management of materials from manufacture through to installation*)	12
Supervision (*engineering and frontline supervision resource*)	4	**Supervision** (*engineering and frontline supervision resource*)	10

Leadership (*increased quality management mandate and clearer vision*)	4	**Quality culture** (*behaviours, accountability, incentivisation to appreciate and understand quality)*	10
Materials Management (*overall management of materials from manufacture through to installation*)	3	**Leadership** (*increased quality management mandate and clearer vision*)	9
Resource and planning (*review of engineering, supervision and quality resources on project, and plan for RFT*)	3	**Workmanship** (*address poor quality execution at project and company level including supply chain and designers*)	6
Collaboration (*breeding better collaboration with clients, designers and supply chain*)	1	**Resource and planning** (*review of engineering, supervision and quality resources on project, and plan for RFT*)	3
Standardisation (*more consistent off the shelf solutions rather than bespoke complex builds*)	1	**Supply chain procurement** (*greater vetting and performance evaluation of supply chain*)	2
		Standardisation (*more consistent off the shelf solutions rather than bespoke complex builds*)	1
		Change management (*adaptive change control not retrospectively*)	1

On reviewing Table 5.10, there are interesting collective themes worth discussing. First, both groups confirmed the same five most fundamental areas requiring improvement both at a project level and company level. These are [1] workforce competence (SQEP) with 28 collective counts, [2] quality culture with 18 counts, [3] materials management with 15 counts, [4] supervision with 14 counts and [5] leadership with 13 counts. Of these areas for improvement, workforce competence was by far the most discussed topic, with many raising concerns that within engineering as a whole, workforces are not being adequately trained, educated and coached through their professional development journey, to allow for the building of greater levels of expertise and knowledge in key delivery roles (i.e. engineers, supervisors, works managers, surveyors etc). With regard to training and education, both groups felt strongly that particularly engineers and supervisors would benefit from mandatory institutionalised training from a certified organisation, such as ICE, CQI or GIRI (CL21 and QC17). In conjunction, there should be onsite grass roots training on how to put methods into practice, with support from more experienced, knowledgeable team members. With many in the industry likely to retire in the next decade, this is a vital action in ensuring lessons are being cascaded to the next generation of engineers, and the same mistakes are not being repeated. In connection with workforce competence, both groups confirm the current struggle of securing and retaining experienced, knowledgeable engineering professionals who see quality as a key delivery requirement (QC14). Instead, once a certain maturity level has been reached, competent personnel often opt for more substantial, challenging roles. Lack of appreciation, role progression and incentivisation have been listed as attributing factors (CL08 and CL12). This topic transitions across to the quality culture of projects and companies, where there were 18 comments made relating to a poor or lack of culture within quality. Both parties raise the concern that quality culture has not progressed to date, unlike in safety, which has been at the forefront of leadership agendas (CL04, CL05, QC06 and QC21). It would appear workforces continue to lack accountability, consequence and incentivisation for quality outcomes (CL12 and QC13). Furthermore, project professionals acknowledge that leadership continues to lack vision, investment and priority of quality requirements. Without this, projects will lack direction and continue to chase programmes. Much like Brook (2016) and Mahamid (2022), there were suggestions from both groups to re-assess project engineering, supervision and quality resources to ensure schemes are properly managed, rather than overworked. In addition, both groups felt that better systems setups (i.e. in advance of construction) and processes for managing quality, along with more applicable, performance related quality KPIs, would help address leadership, culture and SQEP resource challenges (i.e. quality culture and leadership improvement through business initiatives focusing on poor performing areas).

Regarding materials management, there were suggestions that better technologies, systems and processes, along with enhanced planning, may help to overcome the challenges of material non-conformance, as well as helping to alleviate miss-communication, and identify potential issues before materials are delivered to site. There is a need for digitalisation to play a part in helping to track weather events, live traffic conditions and other uncertain variables, though this would require buy in from suppliers.

Question 22 – You've selected 'Yes' to the previous question. Of the data, there were 137 cases of poor/lack of supervision and a further 26 cases of competency/training issues notified. What do you believe the solution to be?

The prior question (Appendix 15, Q21) suggested that 90.5% of contract leaders and 94.7% of the quality community agreed that the industry is struggling with SQEP resourcing. Supervision, in particular, yielded 137 root cause cases, along with a further 26 specific cases of competence and/or training issues from the highways megaproject. Question 22 was created to determine whether professionals felt improvements could be made and where. These were the five most frequently discussed words by contract leaders: ‘quality’ (9 references), ‘engineers’ (10 references), ‘training’ (8 references), ‘managers’ (7 references) and ‘work’ (7 references). Separately, the quality community referenced ‘engineers’ (13 counts), ‘quality’ (8 counts), ‘works’ (12 counts), ‘training’ (14 counts) and ‘projects’ (7 counts) as the five most frequent words. A similar interrogation method to that performed on question 20 was repeated on question 22 to understand where professionals felt efforts could be best spent in addressing supervision and competence issues. Each response was carefully reviewed and the collective themes were identified. Figure 5.1 presents the most frequently discussed topics for improvement by contract leaders. Of the suggest topics, the three most discussed themes were [1] the need for investment and a roll out of applicable, mandatory training for specific key project roles (7 counts), [2] further quality awareness and behavioural management sessions internally and within supply chain (6 counts), and [3] the need to re-evaluate tender resources and time allocations to provide adequate provisions to complete works in accordance with quality requirements (5 counts). Note that the findings tally up to 33 counts from 21 contract leaders and 57 counts for the quality community, as there were multiple responses that contained multiple suggestions from a single respondent.

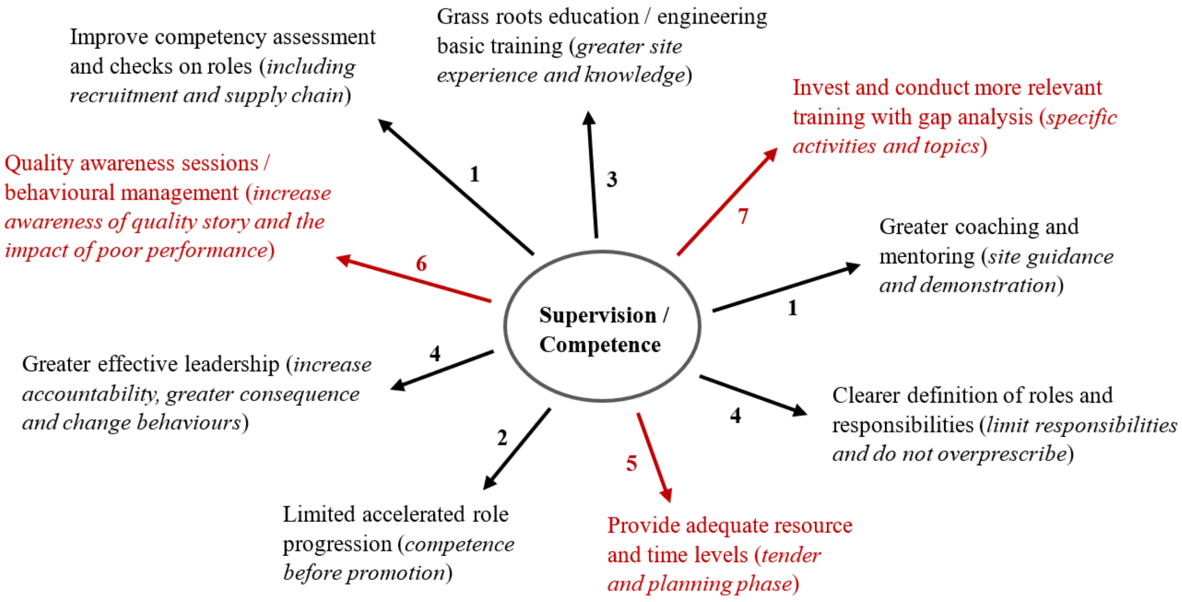


Figure 5.1 – Suggested improvement themes to address supervision and competence cases (Contract leaders).

Beginning with the need for further investment and clarity of training requirements, contract leaders felt that engineering and supervisory resources are becoming less specialist and more generalised in their knowledge and capabilities (CL01, CL02, CL09, CL10, CL17, CL20 and CL21). Furthermore, there were comments that historically, engineering training and site experience, such as setting out tasks, have proved invaluable in the engineers' knowledge skillset, reiterating the need for greater site experience via coaching, more relevant training material that educates and shares best practice techniques in a trade specific format, that shares the dos and don'ts, and that innovates ways to achieve RFT outcomes. In addition, there were 6 contract leaders who felt that the rapid progression of engineers into PM roles, without them developing core engineering skills via on site engineering experience and specific training in key trades, had become an issue. Engineers have been seen by contract leaders to move rapidly from graduation through the ranks into leadership roles, without having been trained specifically on how to be managers, as well as engineering experts who understand specifications, requirements and standards. It dilutes the skillset of an engineer to focus more broadly on projects and managing packages of supply chain work. One contract leader commented that *'The element of "bringing people on" has disappeared and engineers just want to be Project Managers* *straight away. Working with the gangs is an invaluable experience'* (CL01). Another called for *'reinstating back to basics site training'* (CL21), reinforcing the need for trade specific training with site experience. When it comes to new projects, particularly megaprojects, Garemo *et al.* (2015) confirms concerns over the lack of skilled workers needed to execute a right first time delivery, and has reservations over the capabilities of contractors.

The second suggested area for improvement was greater quality awareness training and behavioural management practices, to change ways of thinking around project delivery (CL01, CL02, CL04, CL09, CL10, CL15 and CL17). Concerns were raised that training and behavioural management sessions relating to safety are deployed regularly on projects to ensure works are done safely, but for engineering and quality in construction there is a missing link, resulting in particular to a lack of quality courses that *'give insight into the rights, the wrongs, and the common shortcuts'* (CL02). There was a suggestion to *'raise the profile'* and awareness of quality by providing education on the impacts, risks and opportunities for quality execution (CL10). Many simply don't know or appreciate how important quality practices are until something happens to them in an accountable position. While contract leaders appreciate that training is important, change must be driven by top management to embed accountability, consequence and reward for all (CL18).

The third suggested improvement area was resource and time allocations on projects (CL02, CL03, CL06, CL10 and CL13). Concerns were raised that many schemes are under resourced, causing workloads to pile up on staff. More paperwork, increased responsibilities and less site presence have become attributing factors in not providing engineering support to front line workers, resulting in quality issues. For example, one respondent (CL02) commented *'Our foremen used to have time to educate engineers and they in turn could coach and guide new foremen and engineers. Reporting, paperwork and permits have taken that time away'*. Contract leaders have suggested the need for the company to re-consider the amount of time and resources required to deliver schemes. SQEP engineers, supervisors and quality resources required to deliver schemes successfully must be priced for within budget and tendering assumptions, rather than allowing project teams to struggle. In the end, one task will get compromised over another, and it will likely be quality deliverables. Specifically for quality resources, there is a need to employ more quality practitioners who can focus on quality leadership, management and control in order to support the project team and offer early insight through quality risk management techniques.

A similar exercise was conducted for the quality community group responses. Figure 5.2 presents the most frequently discussed topics for improvement by the quality community.

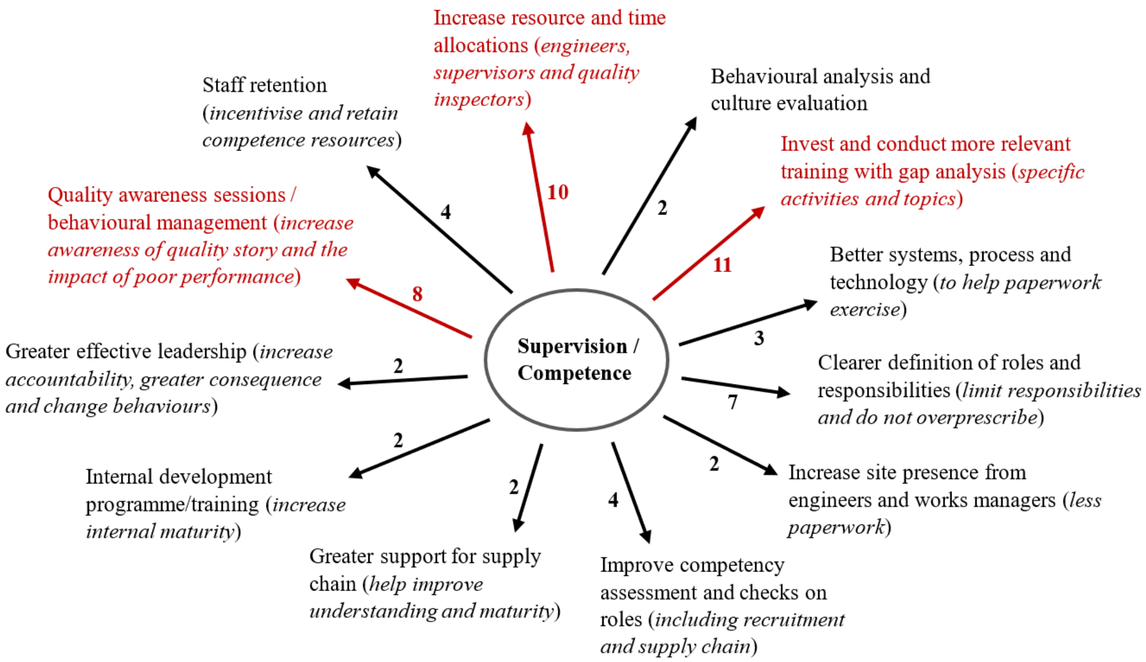


Figure 5.2 – Suggested improvement themes to address supervision and competence cases (Quality community).

Of the findings, the same three improvement areas were suggested by the quality community but in a different order. These were, [1] the need for greater investment and deployment of specific mandatory training (11 counts), [2] greater provision of engineering and quality resources with sufficient time allocated to complete the works against quality requirements (10 counts), and [3] more quality specific training, awareness and behavioural management practices to shape quality culture on projects (8 counts).

These three suggested areas for improvement are exactly the same as the ones highlighted by contract leaders, which strengthens the argument for leaders to make changes.

First, quality professionals felt that the company needs to provide a more robust syllabus of training for specific roles, with supporting training gaps analysis to help develop engineers, supervisors and quality inspectors into highly knowledgeable, experienced resources that treat quality delivery as a priority (QC03, QC04, QC12, QC16, QC29, QC30, QC31, QC33, QC34, QC36 and QC38). This needs to be carried out alongside onsite training, with more experienced personnel in a coaching capacity, to ensure supervisors have a nurturing environment to learn in before being deployed, rather than being *'thrown into the deep end'* (as commented by one quality respondent, QC22). Furthermore, the quality community shares similar suggestions of introducing routine quality awareness training and behavioural management sessions, in order to adjust the way the industry sees quality. Project specific sessions would require the inclusion of supply chain professionals, designers and clients, to ensure all involved in project delivery appreciated the impact and implications of not adhering to processes.

The second improvement also called for by contract leaders was more front line engineering supervision, supervisors, inspectors and quality assurance personnel on projects (QC01, QC06, QC12, QC13, QC15, QC26, QC27, QC30, QC35 and QC36). Better tender assumptions relating to resources is required to ensure projects can perform adequately, with better planning of process implementation to ensure quality assurance hold points are not missed (i.e. inspections and paperwork deliverables that must be satisfied in order to assure schemes). Furthermore, there were concerns that time spent managing additional responsibilities reduces site presence. One quality professional (QC05) quoted, *'we need to let them do some engineering instead of endless paperwork and supervision of sub-contractors'*, insinuating that engineers are being given ever widening project responsibilities rather than being allowed to focus on engineering delivery. For example, managing a large tier 2 supply chain package in itself is a full time role, that often gets bolted onto an engineer's responsibilities.

Third, the quality community shared similar suggestions of introducing routine quality awareness training and behavioural management sessions to adjust industry culture and ethos relating to quality, with the inclusion of supply chain professionals, designers and clients to ensure all involved in project delivery appreciate the impact and implications of not adhering to processes (QC02, QC07, QC08, QC17, QC23, QC31, QC36 and QC38). One quality professional commented on the need to undertake *'mandated quality awareness sessions looking at the requirements and expectations from the client'* to re-invigorate the importance of quality delivery and understand what clients expect. Sadly, there were claims from quality practitioners that *'a lack of commitment and interest from project management teams to either allow a quality section in the main project inductions or a separate quality induction'* is hindering a clear quality message (QC38).

Question 23 – You've selected 'No' to the previous question. Of the data, there were 137 cases of poor/lack of supervision and a further 26 cases of competency/training issues notified. Why do you think such large figures are occurring?

From the survey, there were only two contract leaders (CL07 and CL12) and two quality professionals (QC09 and QC18) who answered 'No' to the suggestion that the industry is struggling with SQEP engineering and supervisor resources (Appendix 15, Q21). A follow on free text response question was created to provide feedback on why such a high number of supervision and competence cases are being encountered.

Both contract leaders were of the belief that the industry has more than enough capable engineers to deliver works, however suggested that wrong behaviours are being driven by a lack of leadership and accountability. CL12 stated that projects *'do not create the right environment for accountability'* and *'we are supply chain driven and I believe we take too much of a hands off approach'*. This implies a lack of leadership presence to correctly apportion accountability and consequence is driving the wrong behaviours when managing supply chain. CL07 advises the company should *'bring quality in house and all own it!'*, which echoes the need to get more hands on with managing quality and take control.

On the other hand, there were two quality professionals who commented that the fundamental reason for branding personnel as SQEP is the lack of regular training updates, appropriate coaching and clear definition of work responsibilities, particularly when roles change. Respondent QC18 raised concerns that inappropriate role allocation and insufficient coaching means that *'managers set them up to fail'*.

Question 24 – Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme. Why do you think we are continuing to make mistakes in concrete operations?

Noting that approximately one third of the non-conformance dataset (383 NCRs) were in the discipline of concrete operations (Ford *et al.*, 2023), question 24 queried each group on why they thought projects are continuing to make mistakes in concrete works.

A final word frequency query was run on NVivo 12 to identify specific themes worth discussing. For the contract leader responses, the five most prevalent words were 'often' (6 counts), 'quality' (6 counts), 'work' (5 counts), 'poor' (3 counts) and 'pour' (3 counts), whereas the quality community discussed the following most frequently: 'concrete' (10 counts), 'works' (10 counts), 'time' (7 counts), 'issues' (6 counts) and 'lack' (8 counts).

From these five phrases, a deep dive was conducted on each response to understand why specific words were mentioned.

In the contract leaders' responses, concerns were raised over the lack of site presence to witness, check and validate pours, causing essential hold points to be missed, and increasing the likelihood of error at the end of the process. There were further concerns that a lack of clarity around roles and responsibilities is undermining the understanding of who's responsible for what, causing inspections to be missed or arranged at the eleventh hour (CL02). For precast works, similar issues are being seen, with a lack of engineering presence to audit the quality assurance of precast facilities and confirm processes are being followed (CL19). In addition, a lack of knowledge and experience has severely affected concrete build accuracy (Cl10 and CL19). For example, a lack of validation checks on key dimensions has resulted in unnecessary non-compliant concrete products that could have been avoided. Caldas *et al.* (2015) specify the need for greater levels of monitoring and auditing to ensure standards are being met, and Patel and Vyas (2011) call for mandatory training with knowledge evaluations to ensure those managing materials understanding specifications.

The second major area of concern raised by the contract leaders was planning (CL05, CL18 and CL19). There are claims of a fundamental issue with how projects plan their activities, and a failure to allow sufficient time for project teams to verify their works and sign off quality assurance paperwork. Not enough time has been factored into programmes for the undertaking of routine inspections, plan and witness testing, and the signing off of concrete operations records during pre, during and post pour inspections. In addition, planning schemes in general have been brought into question. Specifically, there were responses that blamed the poor planning and organisation of schemes, for the failure to consider precast methods as priority at all times, with in-situ works as a last resort. This extends to include how projects source suitable precast facility supply chain partners, opting for cheaper options who may be less local to the scheme, rather than those who are readily accessible and can be audited more easily. Instead, projects appear to progress construction with less certainty of what will be built and consequently encounter in-situ works along the way. Less consideration of the sequencing and interlinking of precast elements has resulted in more site errors that could have been avoided (e.g. if works were carried out in precast facilities with temperature controlled environments, rather than on site in adverse weather conditions).

The contract leaders' responses showed there is a harsh reality that programme pressures to meet the critical path often dictate in-situ works, *'pushing the schedule rather than quality'* (CL16). Furthermore, these pressures extend to site behaviours, where there have been accusations of projects progressing with builds, even when something isn't right. One contract leader (CL14) made reference to *'significant punitive measures if pours are cancelled last minute which results in risk taking'*. There is a recurrent theme that programme and cost pressures override good quality performance and affect the behaviours of not only front line workforces, but of managers too.

A further concern was raised that lessons learned from failures are not being communicated back to head office (CL19). As a result, future projects are less aware of poor concrete performance and the same issues arise again and again.

From the quality responses, the first area to be brought to light was the sheer quantity of concrete works compared to other activities. Quality professionals note that concrete works in particular are far more rigorously inspected and verified, especially those involving structural elements with higher risk. As schemes have high amounts of concrete works, coupled with higher frequencies of testing, with tighter tolerances, this may be a factor behind concrete works yielding higher NCR numbers (QC14). Furthermore, one quality professional (QC26) commented that *'concrete specifications are more robust, and there are a lot more criteria to meet, meaning there are more opportunities for criteria to not be met'*.

Regarding validation, there were four quality professionals (QC13, QC15, QC19 and QC22) who raised concerns over poor planning and consideration of assurance processes within programmes. Site inspections, pre checks, in progress checks and post pour checks are not adequately planned and are done on an ad hoc basis with little notice to engineers and quality inspectors. This results in resources being unavailable or unprepared when called upon. Furthermore, the complacent behaviours, such as overlooking weather conditions, reinforces the message that pressures to achieve programme outweigh quality execution (QC22). Similar issues have been noted at precast facilities, where a lack of engineering presence to regularly audit and check components before they are delivered to site, has proven problematic (Caldas *et al.,* 2015). The lack of site presence from engineers and supervisors for in-situ and precast activities is an avenue that quality professionals insist needs exploring in order for improvement to be made.

The next areas discussed by four members of the quality community (QC06, QC14, QC21 and QC34) is the culture and behaviours that impact concrete operations. One respondent (QC34) commented, *'Improving our quality cultural behaviour and implementing more stringent KPIs should be considered to clearly demonstrate our performance to both our senior leaders and clients'*. Furthermore, the high yield of concrete non-conformities indicates *'that the culture is not right and that the RCA is not sufficient'* to drive continuous improvement.

The last major topic discussed by the quality group was supply chain performance. Specifically, the lack of competent, knowledgeable, supply chain specialists is having a significant impact on concrete non-conformance (QC14). Also, a lack of concrete supply chain partnerships to help drive greater quality outputs and efficiencies has been commented on as a missing link (QC06).

5.4.1 Challenges and limitations of NVivo 12

During the data import and analysis using NVivo 12, the researcher encountered a few issues. First, the software uses a large amount of processing memory which caused the researcher's computer to crash on a few occasions. When the software did function, it ran extremely slowly. This causes trivial tasks such as word frequency queries to take far longer than expected. In hindsight, a higher performing machine should have been requested to conduct the analysis.

Second, although NVivo did help with interrogating data, the user must have an idea of what to look for, with specific knowledge of the topic being discussed. Without this, the data can be overwhelming. Reflecting on the questions posed in the survey helped centre the analysis and generate outcomes in the context of this research. Finally, there were challenges during initial analysis where all questions were imported together. Unfortunately, the software sees the data collectively and so presents trends collectively. This made it difficult to analyse each question independently. As such, the researcher reverted to splitting the original dataset into separate Excel spreadsheets, with one for each open-ended question, containing all respondents and their corresponding demographic information. In doing this, the researcher was able to guide the software to specifically focus on one question at a time and not consolidate the analysis. This task was done for each group prior to coding the data.

5.4.2 Behaviours within qualitative feedback

There were obvious behavioural patterns within the free-text responses that should be noted. First, respondent QC37 responded to all free text sections with a full stop, enabling the respondent to bypass the questions without responding. This shows lack of commitment to help contribute to the study, and demonstrates the work-shy attitude of some within the sector.

5.5 Discussion and reflection of phase 2 findings

An industry survey was conducted within two professional working groups of a tier 1 contractor in the UK to understand perceptions of quality within construction, and where leaders should focus efforts for improvement. In addition, NVivo 12 was deployed to analyse open-ended ‘qualitative’ data and record the collective views of those who participated in the study. All findings from Phase 2 are collated and synthesised below.

5.5.1 The significance of an industry survey

On reflection of the iron triangle debate (Q10), it is apparent that contract leaders see a greater benefit of proceeding at risk to maintain critical path delivery milestones, whereas quality professionals are far more risk averse. For quality professions, late design changes, non-conformance and rework outcomes all play a major part in their project roles. By adopting a risk-averse point of view, opportunities will be evaluated cautiously (Cretu *et al.*, 2011). Furthermore, limiting risk and change in the construction phase will help deliver stronger quality management for schemes rather than fixating on resolving issues brought about by late design changes (Wuni and Shen, 2020). Both parties discussed risk management extensively in their responses, with relation to the benefits of doing something against the long term impacts (e.g. cost and time overruns). Flyvbjerg *et al.* (2004) expressed the need for organisations and projects to be set up and operated in a way that minimises risks of delays, rather than a narrowminded outlook on project delivery. Unfortunately, the industry still does not appear to be in a position where there is sufficient evidence to substantiate the stance that long term costs of rework outweigh the costs of delay damages from critical path programme milestones. As such, there are statements resulting from both groups speculating that remaining on programme and correcting defective works as they manifest is more financially beneficial than waiting for designs to be approved. In short, if projects are still going to proceed at risk, they need all the facts available to ensure they substantiate their decisions via robust risk assessments that yield a low to nil result.

Regarding design change, there is a call for a re-evaluation of how contracts are set up and how they apportion risk and consequence fairly. Both groups acknowledge that even though late designs are the primary responsibility of the designer, the principal contractor appears to be burdened most by risk and its associated cost and time implications. Similar experiences have been noted by Kazaz *et al.* (2012) in the Turkish construction sector. It may be prudent for clients to employ designers to complete design details in full, prior to awarding works to a contractor. This could help negate design change and prevent tensions building up between parties.. If design change is a client risk, there may be greater reluctance to change details, as requested by various stakeholders. Jackson (2002) called for clients to take greater accountability for design change as a primary risk causing project delays, two decades ago. In the intervening time, this has remained a challenge, and at present, there is little consequence to designers and clients for making unnecessary design changes.

Lastly, proceeding at risk on late designs sends the wrong message. It enforces that it is OK to proceed at risk, without consequence, even if things change and costs spiral. This behaviour may extend to not completing quality assurance hold-point records, where required. Before we know it, workforce ethics have diminished and complacency sets in.

Fixation on cost and programme has been a recurring theme throughout the findings (Q9, Q10, Q12, Q13 and Q14). Although most professionals do not believe cost and programme are more important than quality, delivery teams feel their hands are tied by political pressures from clients, as well as by a lack of effective leadership and cultural maturity within the industry. Collectively, there are four influential areas that requiring addressing in order to reduce the behaviour of chasing programmes. These are (i) client and stakeholder requirements that need to be driven more clearly, with great focus on quality delivery as opposed to chasing key delivery milestones, (ii) the need to change quality culture and associated behaviours arising from a focus on cost and programme over quality (i.e. the iron triangle), (iii) greater leadership to instil a clear quality vision, with appropriate accountability, responsibility, and consequence and reward levels, disseminated through the hierarchy, and (iv) the image and contributions of a quality team to be seen as positively energising production rather than creating a barrier (Q13). It appears that the highways construction industry has not managed to move past the unhealthy focus on cost and time, even in two decades (Bowen *et al.*, 2002). The researcher concurs with Mateo (2019) that there is a need for a much greater degree of interaction between the planning and scheduling phases, and improved focus on how to balance the four critical factors of project delivery (i.e. time, cost, quality and safety).

With regard to quality outputs, it is apparent that there is still confusion as to what good looks like (Q16). Striking a balance that satisfies all parties has proven no easy feat. Better early engagement with enhanced collaboration, and improved interaction with the supply chain, is fundamental in creating clear project understanding (Kaur *et al.*, 2019). Summarising the points from both professional working groups, there is consensus that there is a lack of fundamental understanding and appreciation of expected levels of quality on schemes. The most advisable solution is that project members must work together (including the client, designers, supply chain professionals and other stakeholders) to resolve varying levels of quality expectations, through the use of regular communication channels, to ensure all parties contribute to and agree with suggested outputs. This will help prevent requirements from changing during the project life cycle, especially at a late stage of construction when works are almost finished. Love *et al.* (2020) confirm the need to establish and monitor quality standards as the project life cycle progresses. Depending on the phase, the inclusion of supply chain professionals in discussions may offer specialist insight as to what is acceptable or help provide an alternative within budget constraints. Lastly, greater education and training on quality requirements (including contract price and documentation) will help raise awareness and manage expectations through the scheme’s development (Ali and Rahmat, 2010).

For Q19, the results were alarming to project professionals. It is understood that in reality, costs are far more significant than those calculated, as calculations are still incorrect(i.e. they do not include administrative time, management time, investigative costs etc). Furthermore, the financial and reputational damages may be more severe than perceived. In addition, continuing to yield high non-conformance and rework numbers informed both groups that the industry is not learning from mistakes and that quality culture is stagnated. Behavioural issues, a lack of training and a lack of competence have been noted as factors behind project quality failures that need addressing immediately, (this has also been noted by Love *et al.* 2022). A further concern made by the contract leader group is around the behavioural element of how losses are perceived. For example, there will be some who see 0.5% total rework cost as insignificant and acceptable if their programme and safety requirements are upheld. Behaviourally, projects should not consider any amount of rework cost as 'acceptable' and should strive for perfection, even if it is not possible. You would not see the same behaviours within safety, where the mindset has changed and even a single incident is considered unacceptable.

The author's synopsis regarding rework costs is that these costs are still significantly underestimated, due to behavioural and commercial implications around failure. Furthermore, such rework costs are alarming to both parties, who feel the risks extend to reputational damage, loss of future work, a continued poor quality perspective of project delivery (i.e. cost and programme are priority) and inefficient use of resources to rectify works, that should have been done right-first-time. Recurrent trends of non-conformance and rework on the current highways scheme indicate the challenges projects still face, with lessons not being learnt or not being sufficiently communicated within the organisation. To remove subjectivity and uncertainty in calculating NCR costs, Martinez and Selles (2015) suggest using fuzzy logic to present more accurate, realistic rework estimates that consider 'hidden costs'. Using some form of artificial intelligence or digital estimation model would be a sensible choice in unearthing true rework values (Wijayasekera *et al.,* 2022).

To reduce materials management, poor workmanship and supervision issues identified through quantitative NCR analysis, project professionals suggest that the company and the wider sector should focus on (i) workforce competence, including competency checking, training and onsite coaching to enhance skill sets in key delivery roles, (ii) greater and clearer focus on quality culture to enhance on the same lines of safety, and (iii) targeting materials management as a specific area that generates massive amounts of concrete and granular fill by way of embedding digital capabilities, to better plan, manage and track materials from manufacture through to installation (i.e. live weather and traffic tracking so deliveries on site are completed under compliant conditions). To tackle quality culture and to motivate individuals to report errors, analyse them and learn from them, requires a nurturing environment where fruitful discussion can be instigated and collaborative problem solving carried out through error management (Edmondson and Lei, 2014; Frese and Keith, 2015).

With an overwhelming agreement that the industry is struggling with SQEP resourcing, both groups feel the need for greater investment in training and competence gap analysis, to enhance professional development, rather than simply acknowledging they don't have the right person for a specific role. In addition, specific quality awareness and behavioural management sessions must be rolled out at regular intervals to increase the importance of quality and preach the impacts of poor performance, beyond cost and time. Many professionals, including the researcher, support the need for awareness and training around quality management practices throughout the hierarchy to enhance project quality (e.g. Mallawaarachchi and Senaratne, 2015). In fact, education and training, involvement and teamwork are considered the most important factors which affect quality across the construction sector (Jraisat *et al.*, 2016). Unfortunately, the engineering profession appears to be losing the core expertise and skill sets necessary to understand how to build schemes correctly, with issues usually being identified by more knowledgeable, experienced personnel. A call has been made to increase the importance of engineering expertise for engineers, supervisors, works managers, foremen and quality inspectors, by encouraging operational and engineering teams to gain more hands-on experience and knowledge, beyond undertaking PM roles. In addition to greater site experience, there must be more training material that educates and shares best practice techniques in a trade specific format, and that shares the 'dos and don'ts', and that innovates ways to achieve RFT. Construction projects cannot afford to make mistakes and must learn from historical ones that others have made, reiterating the need for trade specific training of what has or hasn't worked through the years. This will help change the culture and ethos of the way projects are managed and how quality requirements are communicated.

As well as the training and changed behaviours, is the need for appropriate resource and time provisions to complete projects in accordance with quality standards. Better tendered assumptions and improved planning phases should help to identify clear responsibilities and factor deliverables into contract programmes. To date, projects have struggled to cope with the resources they have been given and quality appears to have been the sacrificial lamb, sacrificed over pressures to meet programme. Some respondents did not feel there was a SQEP issue within the industry, and chalked problems down to a lack of leadership to embed responsibility, accountability and consequence within internal teams and the external supply chain (Q23). There appears to have been too much of a hands off approach with suppliers and a need to bring quality control back in house. Furthermore, infrequent training and a lack of coaching means resources are placed in roles they are not ready for.

Lastly, to tackle the challenges relating to concrete operations, industry professionals believe that clarity around roles and responsibilities, with appropriate planning of activities, should improve conformance of concrete outputs (i.e. considering assurance hold points within contract programmes, such as cube testing and inspections). Currently, projects appear to progress works despite uncertainty around what will be built and may consider in-situ works along the way. A lack of consideration of the sequencing and interlinking of precast elements has resulted in more on site errors that could have been avoided, if works were carried out in precast facilities under controlled conditions (e.g. in temperature controlled environments rather than on building sites in excessively hot weather conditions). The need for the construction industry to standardise precast components appears vitally important in reducing on site errors (Kim *et al.*, 2016). However, improved auditing of precast facilities is also required to ensure suppliers are assuring works adequately (Caldas *et al.,* 2015). With such high volumes of concrete non-conformances, both groups concluded that appropriate levels of lessons learned are not being shared within the organisation and the wider industry.

5.6 Conclusion

The findings and improvement outcomes developed in Chapter 5 focus on organisational improvements, by way of employee feedback. The results of an online survey which engaged two distinct professional working groups within a principal contractor have been presented, with a mix of quantitative and qualitative outputs, to provide unique insights into the perceptions of quality non-conformance and rework, both internally and across the construction sector. The findings confirm the suspicions drawn from the non-conformance data through quantitative data analysis in Chapter 4. Specifically, that the expectations and priorities set by government and clients down through the contractor to supply chain are currently skewed towards programme and cost. This puts projects in a challenging position of trying to meet client requirements without compromising quality outputs.

Chapter 6: A quality improvement initiative to address non-conformance and rework in construction

This chapter summarises the insights gained through the research process. With the support of previous literature (Chapter 2) and findings obtained through Phase 1 (Chapter 4) and Phase 2 (Chapter 5) emergent practices are presented to offer support in quality management and decision-making practices. The key contributions of this chapter is the presentation of an improvement framework that can be transferrable across various sectors within construction.

6.1 Summary of findings

To understand the state of quality execution in construction projects, a detailed literature review was undertaken to note current learning from other scholars, and identify any knowledge gaps on which the research questions are based (Chapter 2). Following on, a research design was formulated including the novel approach of using the Cynefin framework to unearth quality decision-making patterns through root cause analysis, and apportion risk profiling to understand the severity of incorrect quality problem solving (Chapter 3). Once a research design had been formulated, NCR data from a major highways scheme was captured and analysed to determine the most frequent and costly root cause avenues that are currently present. In addition, to understand whether quality problem solving and decision-making is being done accurately, a categorisation exercise was undertaken using ‘5 whys’ RCA for real-time and retrospective decisions. This helped substantiate concerns of oversimplification of quality problem solving in construction projects. Lastly, lessons learned were uncovered and presented for improvement (Phase 1).

On completion of Phase 1, an industry survey was generated using findings from the quantitative phase. They survey was presented to two professionals groups within a tier 1 contractor to understand the perceptions of quality within the construction sector through a series of closed-ended and open-ended questions (Phase 2). Findings from each phase were compared to build a clearer, more defined perspective of how quality is performing in construction. Figure 6.1 presents the collective insights gained through all phases of the research.

LITERATURE REVIEW

- The construction industry is struggling to apply TQM principals over traditional practices (Haupt and Whiteman, 2004; O'Connor and McDermott, 2022)
- Lean practices have presented cases of oversimplification of problem solving of quality related issues and has seen mixed success (Spiro *et al.,* 1996; Battikha, 2008; Forcada *et al.*, 2014; Tezel *et al.*, 2018)
- The construction industry is still plagued with quality failures with an average rework cost of 9.19% of total contract value, demonstrating little success for continuous improvement initiatives (Burati *et al.*, 1992; Abdul-Rahman *et al.*, 1996; Love and Edwards, 2005; Forcada *et al.*, 2014; Love *et al.*, 2018a; Trach *et al.*, 2021)
- Right first time in construction appears farfetched with ongoing high quantities of quality failures (as above)
- A lack of leadership direction (Oyewobi *et al.,* 2016; Love *et al.,* 2022), poor quality culture and error management (Barber *et al.*, 2000; Love *et al.,* 2019), and substandard workforce competence and training (Wasfy, 2010; Forcada *et al.*, 2014; Manoharan *et al.*, 2023) are all have a detrimental impact on moving forward towards RFT.
- Lessons are not being translated into remedies for future schemes to avoid making similar mistakes (Simpeh *et al.*, 2015), nor are sophisticated approaches being devised to help capture and disseminate (Williams, 2008).
- Decision-makers are struggling to grapple with quality problem-solving as a result of uncertainties and interdependences within construction projects (Dubois and Gadde, 2002b; Forcada *et al.*, 2014; Tommelein, 2015).
- Although the Cynefin framework has seen benefit and application in other sectors, it's impact in construction is limited (Chapter 2.5). There are cases of adaptation to the framework outside of the construction sector to create links with tacit and explicit knowledge, collaboration, political influence and dominant logic (Smith, 2005; Childs and McLeod, 2013; McLeod and Childs, 2013; French, 2013; Alexander *et al.,* 2018).

NCR DATA ANALYSIS (PHASE 1)

- Materials management, workmanship, supervision, setting out and damage to permanent works were the five most frequently occurring NCR root causes (Figures 4.1, 4.2 and 4.3).
- Workmanship, supervision, materials management, methodology and setting out were the five most costly NCR root causes (Figure 4.4, Appendix 8, Table 4.1).
- High volumes of NCRs demonstrating recurring root cause themes with an average open period of 162.9 days (Table 4.2 and Figure 4.5) supports lack of lessons learning within projects, organisations and the wider construction sector (Simpeh *et al.*, 2015).
- The need for greater leadership to shape a stronger quality culture, a focus on workforce competence through matrix assessments, technological advancements and digitalisation to streamline processes, and machine learning to help interpret quality indicators and help suggest improvement themes (Table 4.3 and Chapter 4.5.1).
- Oversimplification of quality problems is stifling decision-making, causing premature actions to address non-conformities through RCA incompetence (Figures 4.6 and 4.7).
- Two frameworks are presented. The first for addressing quality and risk based decision-making (Figure 4.8), and the second for organisational learning through leading and lagging indicators (Figure 4.9).

INDUSTRY SURVEY (PHASE 2)

- Cost and programme are consistently prioritised over quality on construction projects and heavily led by client and political pressures from above (Appendix 15, Q12 – Q14).
- Lack of effective leadership, cultural maturity, planning and client requirements are all having adverse effects on construction project priorities.
- Projects are still proceeding at risk without finalised designs to remain on critical path programme (Appendix 15, Q9 and Q10).
- There are varying subjective expectations of quality amongst stakeholders that is causing confusion (Appendix 15, Q15 and Q16; Table 5.9).
- With rework costs seriously underestimated and inaccurately calculated in construction projects, contract leaders and quality professionals are deeply concerned of rework costs at 0.5% of total contract value (Appendix 15, Q18 and Q19).
- Project professionals believe that workmanship, supervision, competency, communication and design top the five most frequently occurring NCR root causes (Appendix 15, Q17).
- To address materials management, poor workmanship and supervision, there is a need for companies to prioritise workforce competence, quality culture, and target materials management by embedding digital capabilities to see the most benefit (Table 5.10).
- Contract leaders and quality professionals concur that there are major challenges with supervision and SQEP resources that can be overcome with greater investment in training, coaching and mentoring, site experience, competency gap analysis, and quality specific sessions to increase the profile of quality delivery. In addition, suggestions to re-evaluate tender assumptions and allocate appropriate quantities of resources on schemes is fundamental to success (Figures 5.1 and 5.2).
- Risk and change management are becoming increasingly important on projects to ensure decisions are not being made without considering the implications to scheme completion (Cretu *et al.,* 2011).

Figure 6.1 – Collective insights gained through research journey

The above simplification of findings were then used to create a generalisability framework for quality management that could be applied within any construction sector.

6.2 Developing a quality management and improvement framework for the construction industry

To provide more greater direction to projects, companies and the construction industry, all findings obtained through this research has been collated and synthesized into a quality management improvement framework built around the core principles of EFQM (i.e. direction, execution and improvement). Figure 6.2 presents a quality excellence and improvement framework that has been developed by the author to address major quality management failings in construction delivery. The framework has been developed with the support of existing literature, and findings that have emerged through the quantitative and qualitative phases of this research (Figure 6.3).

To most, the framework will look complex. However, to address quality management challenges within a complex construction environment, a simplified solution won't do. As mentioned, the frameworks outer principles align with EFQM, 2020 (direction, execution and improvement) but with the addition of 'analysis'. As a result of existing literature and industry feedback, which reveals that the construction industry does not learn sufficiently through analysis and exploration of quality failures, the addition of analysis is a fundamental step to a PDCA cycle (e.g. Simpeh *et al.,* 2015; Shokri-Ghasabeh and Chileshe, 2014; Safapour and Kermanshachi, 2019). Furthermore, the use of quality lagging indicators appears non-existent to help early identify quality events. As such, the author felt it was immensely important to separate the term 'analysis' from 'improvement' to ensure data interrogation is not overlooked.

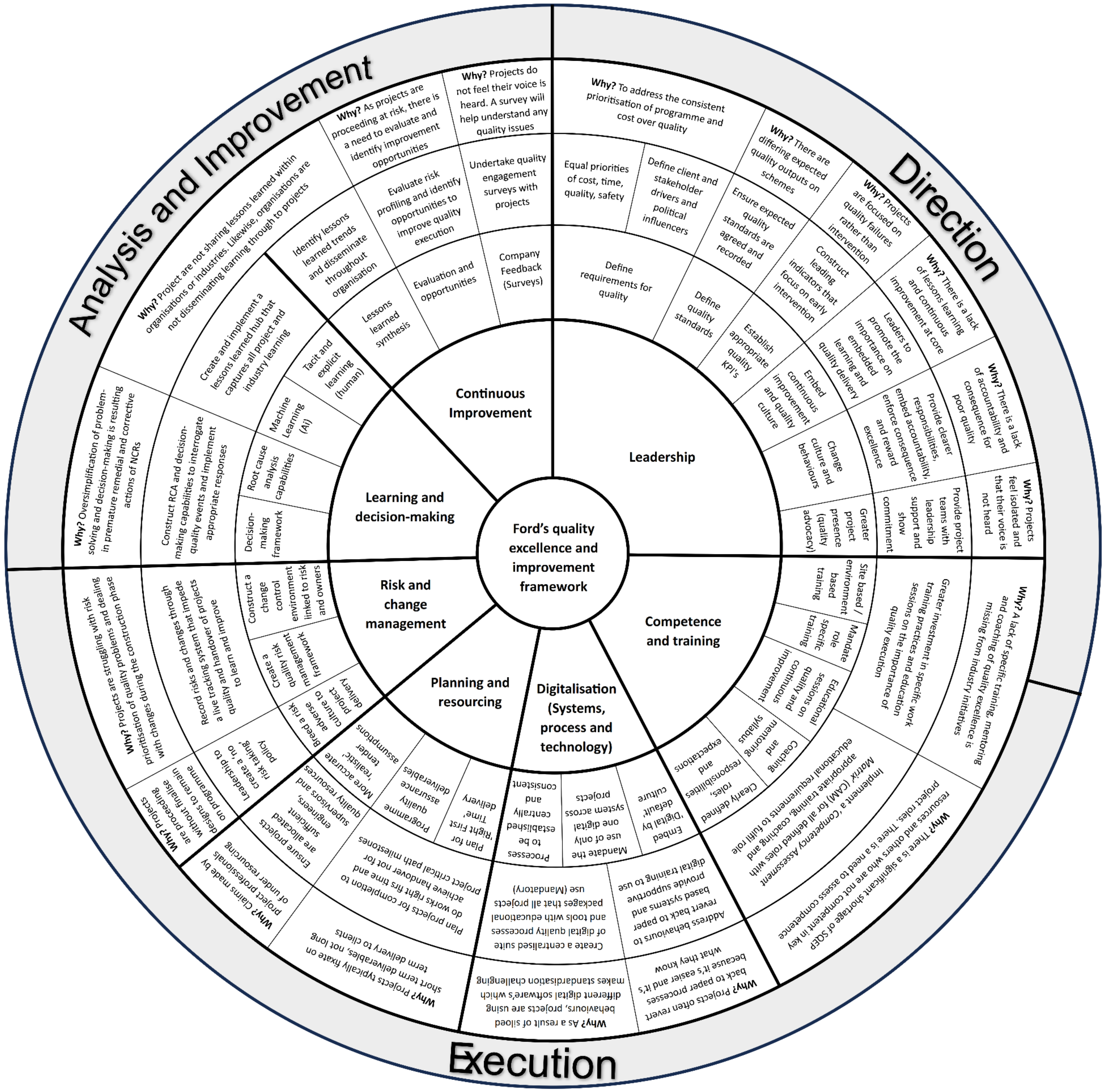


Figure 6.2 - Ford's Quality Excellence and Improvement Framework

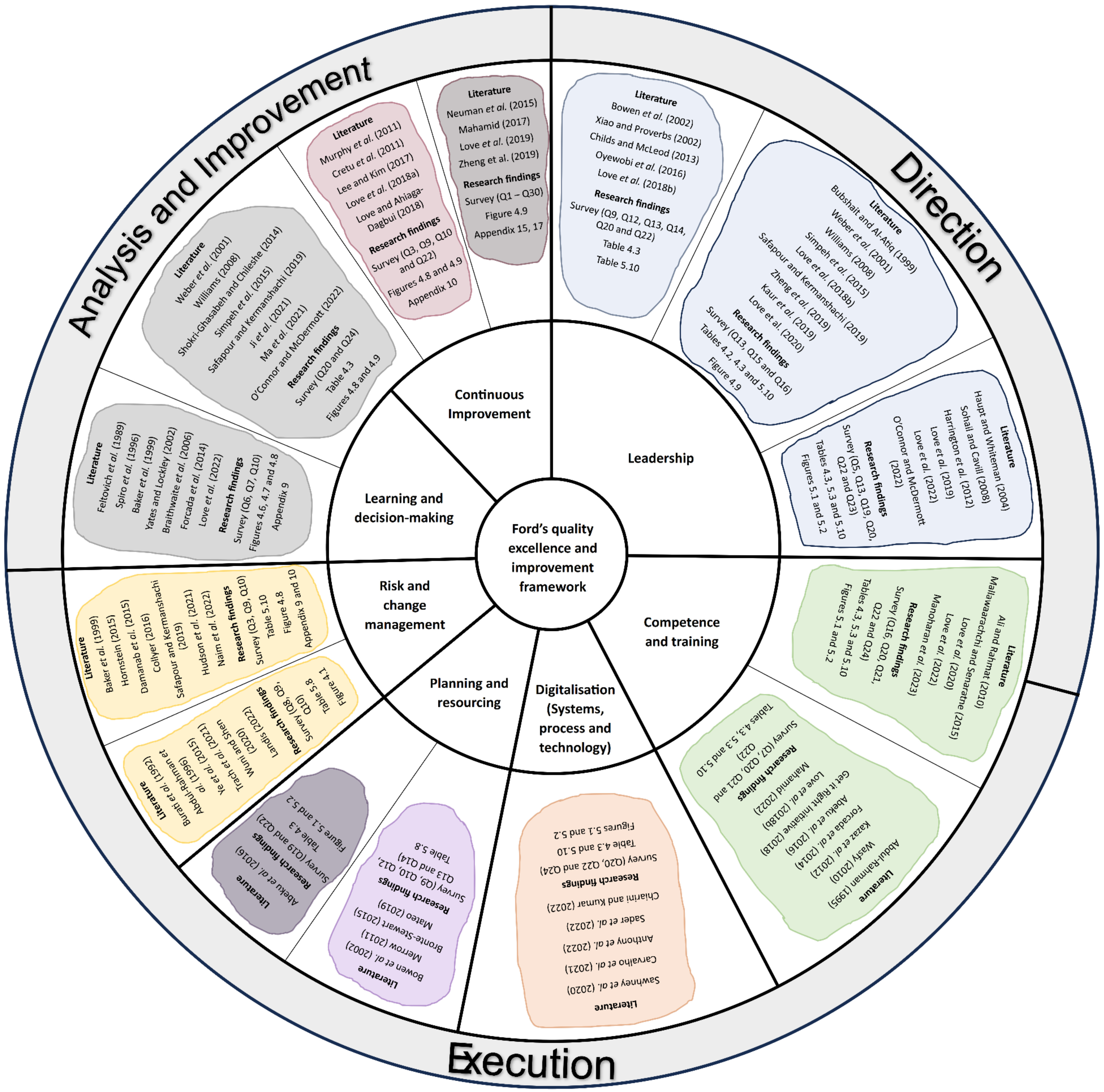


Figure 6.3 - Literature and findings overlay of Ford's quality excellence and improvement framework

The framework is built around seven major improvement pillars. These are leadership, competence and training, digitalisation (in line with Quality 4.0), planning and resourcing, risk and change management, learning and decision-making, and finally, continuous improvement. Within each pillar, the framework presents a number of improvement areas in line with findings obtained through the quantitative and qualitative phases of this research. In addition, a number of solutions are provided to offer guidance to the industry using knowledge gained through previous literature and feedback from professionals. Lastly, for leaders to take action, the author felt it appropriate to provide a 'why?' reasoning statement that justifies the need for improvement.

To demonstrate the links between literature and findings, Figure 6.3 provides a research overlay that points literature in supports of the improvement area, and draws focus to findings found within this thesis to help triangulate coherent outcomes.

6.3 An initial evaluation of the framework

As previously discussed, TQM and EFQM have provided guidance to the construction industry on how to manage quality, but from a high level perspective that lacks specific details to implement change (Fonseca *et al.,* 2021). From the authors perspective, both TQM and EFQM provide a solid foundation for quality management principles, but do not direct company leaders on why they should take interest, and ultimately, take action. Specifically, these frameworks do not present reasoning to leaders through fact based data analytics. As noted within Section 2.2.1, three limitations of EFQM were made by other scholars including confusing descriptions, unclear and subjective parts, and non-prescriptive nature with unsubstantiated links (Nenadál, 2020; Fonseca *et al.,* 2021; Murthy *et al.,* 2022).

The granularity of the authors framework to inform on pitfalls within construction, present solutions to address, and a reason why companies should action is a strength that other frameworks appear to lack.

To understand how practitioners may interpret the quality excellence and improvement framework, the author engaged with three industry quality leaders within his circle of connections that he could rely on for honest and trustworthy feedback. The first, a highly reputable construction director who oversees a number of schemes within a tier 1 contractor. This individual has decades of experience in construction, along with being a fellow of the ICE and chartered member of the CIOB. His passion for RFT and continuous improvement has been well founded within the business. The second is the head of business systems and quality within a tier 1 contractor. This individual has many years' experience, both in academia and industry practices, with a PhD in quality management, and fellowships in the CIOB, ICE and CQI. Furthermore, other non-conformance and rework scholars recommended this individual as a proactive, dedicated individual that would be extremely insightful in quality management practices. The third is the head of quality assurance within a major tier 1 contractor, with over 15 years' experience in construction, and sits on the decision-making panel for National Highways quality division. The responses from all three leaders were extremely positive, and confirmed that the target areas for improvement were well founded. A redacted version (excluding personal information) of the email transcript between the author and reviewer 2 is presented within Appendix 18, and the same for reviewer 3 within Appendix 19. This feedback provided the author with additional validation that the framework was relatable, understandable, and applicable to all sectors within construction. Each reviewer particularly liked the 'why?' reasoning statement, and thought it would prove invaluable in justifying an argument for change with company leaders.

Reflecting on the generalisability of the quality excellence and improvement framework, the authors sees much benefit for all construction companies to construct their organisational architecture around these seven pillars. Furthermore, greater investment in time and resources, supported by a leadership commitment to improve these areas will provide dividends to those wishing to eradicate error in construction.

Chapter 7: Conclusion

7.1 Summary of research findings

This final chapter gives a summary of the findings within this thesis and answers all research questions. A statement with regards to the application within the tier 1 contractor is made along with the generalisability of this study to the construction industry. Limitations of the research are discussed along with the academic contribution, implications and avenues for future research.

7.2 Research questions answered

The research questions presented in the introduction chapter are as a result of a detailed literature review and two phases research approach to uncover gaps in the body of knowledge. Each question is answered concisely below:

Research question 1a (RQ1a):

What are the most frequent and costly areas of failure from non-conformance report (NCR) data on an infrastructure construction project?

To answer this question, data analysis was performed on 1260 NCRs through RCA methods to understand most prevalent and costly areas on the UKs largest highways construction project. The findings reveal that the three most frequently occurring root causes were materials management, workmanship/quality execution and supervision (Figure 4.1). In addition, the three most costly areas of failure were workmanship/quality execution, supervision and materials management (Figure 4.4). More detailed analysis was performed on the most prevalent root cause, i.e. materials management, to understand what specific materials were causing the most problems (Figure 4.2). The results indicate that of all project materials, concrete is the most detrimental to schemes to ensure compliance with specification tolerances.

Research question 1b (RQ1b):

What are the corresponding lessons learned from NCR data that can help drive towards right-first-time delivery in construction projects?

A framework has been developed and presented in Table 4.3 to expand on the learning outcomes from the three most prevalent NCR root causes. The framework offers insight into the pitfalls of each cause and proposes solutions to address. In addition, four supporting lessons learned outcomes in Chapter 4.5.1 have been presented to assist in shaping quality management practices in construction. By enforcing a stronger leadership mandate with clearer accountability, addressing SQEP issues through rigorous vetting processes, more relevant training packages and apprenticeship programmes, deploying technology to help manage the product delivery and provide effective communication, and finally, re-evaluating how projects manage non-conformance reports through supportive predictive methods to help unburden, projects will be in a far stronger position to react more positively to quality.

These lessons learned, although from a highways scheme, should be taken forward in other sectors to ensure similar issues are not being encountered. These learning outcomes are generalised to allow cross-pollination throughout the construction industry.

Research question 2a (RQ2a):

How has the Cynefin framework been exploited and adopted within construction projects?

To answer this question, a systematic review was undertaken, and the findings from the literature review indicate that the Cynefin framework has seen limited adoption or exploitation across the construction management community. The search criteria initially yielded 305 number articles and editorials across two landmark Cynefin related papers (Kurtz and Snowden, 2003; Snowden and Boone, 2007). These were filtered to focus on a more streamlined section of citing papers. Final focus on four category β papers and five category ɣ papers. Category β papers that sought to contribute the Cynefin framework to construction brought about limited insight into the benefit that could be made to the sector. The notion of Cynefin has been embraced by some, however, from the β papers reviewed, there is a lack of evidence to suggest that the framework has been effectively considered or implemented within the construction sector to bring about a new way of thinking.

As for the ɣ category papers, which explored, exploited or challenged the framework, but did not reference construction, posed useful insights into how the knowledge management and travel of ideas can exploit the Cynefin framework. Two of the five ɣ papers express the importance of tacit and explicit knowledge transfer through various levels of complexity and decision-making. The framework has been extended further to include implicit knowledge in Figure 2.13 and developed the conceptual model shown in Figure 2.14, which amalgamates knowledge management, political influences, collaboration and the Cynefin framework.

Research question 2b (RQ2b):

How can the Cynefin framework be applied to better understand decision-making with regards to quality problems in construction projects?

Using the Cynefin framework in the context of quality problem solving, the researcher adapts the phenomenological tool to analyse the real-time and retrospective decision-making pathways of non-conformance data through cause-and-effect relationships using 5 whys analysis (Figure 3.9). In addition, FMEA was amalgamated with the Cynefin framework domains to categorise the risk profiling of each quality problem to inform on the severity and risks associated with under/oversimplification (Figure 3.11). These adaptation to the Cynefin framework can provide project professionals direction to interpret whether problem solving and decision-making is accurate or requires further action. Furthermore, linking to cause-and-effect relationships, the Cynefin framework is a useful tool in providing projects with guidance on the level of investigation required, rather than letting them struggle. In turn, it ensures improvements in quality decision-making practices, and provides those with a greater understanding of complexity and uncertainty of non-conformance in a dynamic environment to react accordingly. The researcher sees much benefit in using the

Cynefin framework with the adaptions made in other areas of construction projects including risk management, commercial decision-making and safety.

Research question 3a (RQ3a):

What are practitioner perceptions of the most critical factors that affect quality delivery in construction projects?

An industry survey within a tier 1 contractor was undertaken to understand the perceptions of quality by those delivering construction projects. The outputs of the survey reveal that, according to project practitioners, workmanship/quality execution, supervision and competence are the believed to be the most prevalent NCR root causes in construction projects (Appendix 15, Q17). Collectively both groups have called for greater investment and deployment of specific mandatory training and apprenticeships, greater allowance of engineering and quality resources through more accurate tender assumptions to delivery right-first-time quality, and more quality specific training, awareness and behavioural management practices to shape quality culture on projects (Figures 5.1 and 5.2). Of the three most frequent root causes identified within Phase 1 of this research, contract leaders and quality professionals suggest that workforce competence, quality culture and behaviours, supervision, leadership and materials management are the areas that require most urgent attention (Table 5.10). High figures in these areas indicate major weaknesses that are adversely affecting quality delivery in construction projects.

Research question 3b (RQ3b):

How can the construction industry improve quality performance, decision-making, and move closer to achieving right-first-time project delivery?

To improve how the construction industry manages quality, an excellence and improvement framework has been created that consolidates all findings obtained through this research (Figure 6.2). The framework focuses on seven pillars for improvement that will add maximum value, and help move toward a right-first-time industry. These are leadership, competence and training, digitalisation, planning and resourcing, risk and change management, learning and decision-making, and continuous improvement. Each improvement pillar has been split into specific pitfalls to focus improvement, provides a solutions to address, and informs leaders on the reasons why action is required. It is advised that construction companies evaluate their performance against each criteria within the framework to ensure there are no weaknesses within their organisations and subsequent projects.

However, it needs to be highlighted that clients have a major role to play in reducing non-conformance. As decisions from above make assumptions for costs of schemes and when they need to be delivered, more realistic expectations are needed with clearly defined requirements that do not change through the design and build phases. Hence, the framework also highlights improvement areas for clients and governing bodies to address how their influences and decision-making reduces quality and dilutes the messages of right-first-time.

With a collective improvement initiative that fixates on the failure themes within Figure 6.2, the construction industry is likely to see much improvement with project delivery, programme durations, and capital spend.

7.3 Contribution to theory

The contributions to theory are as follows:

(1) The methodological approach used to determine under/oversimplification is a novel idea. Using the Cynefin framework as a sense-making tool, coupled with RCA cause-and-effect pathways determined through the real-time and retrospective decision-making phases of quality problem solving, the author was able to confirm the suitability of the categorisation ruling in assessing how projects problem solve quality events. In addition, with the support of FMEA, risk profiling could also be attributed.

(2) A detailed literature review was conducted with regards to the Cynefin framework to understand how the sense-making tool has been received within construction industry. The review reveals limited evidence to suggest the

Cynefin frameworks has been applied within construction. In addition, the literature analysis uncovers areas where the framework has been adapted or exploited in other sectors. This exercise provides a historical timeline for the Cynefin framework along with the benefits it has offered to other sectors.

(3) The author was extremely fortunate to be given access to commercially sensitive data for research purposes. Such opportunities to exploit quality failure data are rare, particularly within construction. Furthermore, data analysis of 1260 NCRs on a current highways scheme presents new insight into the most frequent and costly avenues of failure to builds upon existing non-conformance and rework literature. This helps strengthen the overall body of knowledge and contribute to rework cost averages.

(4) Noting that there is a lack of industry feedback on the topics of nonconformance, rework and quality, the author conducted further research into the perceptions of quality from those involved in scheme delivery via an industry survey. This helped to improve the understanding of quality performance in construction projects, and contribute to the general body of knowledge on qualitative studies within construction projects.

(5) The final output of this research presents a generalisability framework for the construction industry, which provides both theoretical and practical contributions on how quality management practices should be addressed. From a theoretical perspective, this has been enhanced by previous literature and the methodological approach followed through this research. Unlike other frameworks, e.g. EFQM, which offer more high level, strategic direction, the generalisability framework developed by the author (Figure 6.2) offers deeper insights of quality management failures within construction. This provides construction companies with greater support, rather than leaving them to interpret their own pitfalls which may be subjective.

7.4 Implications for practice: three levels of influence

The implications of this research are three tiered. Firstly, at a company level, second at a highways sector level, and third, at a construction industry level, all of which can highly benefit from the excellence and improvement quality management framework presented in Figure 6.2. Further explanation for each tier is mentioned below.

7.4.1 Company level

At a company level, the implications of this study present call for quality improvements through more robust NCR processes that have sophisticated detailed root cause analysis techniques and decision-making tools to influence how projects react to problems. Furthermore, with impact analysis and risk profiling of cost and likelihood, organisations can generate more meaningful solutions to address quality problems. Capabilities to learn from data are called for through machine learning to give projects more time to manage schemes. Lastly, a lessons learned framework has been presented to give construction companies, and in particular the authors parent company, guidance on addressing workmanship, supervision and materials management issues in highways projects. At a more strategic level, there is a calling for greater quality advocacy and leadership, breeding a ‘digital by default’ mentality to manage QA records and learning outcomes, greater vetting of internal staff and supply chain to ensure acceptable levels of competence through a competency assessment matrix, and more rigorous vetting and performance measuring of supply chain to provide projects with metrics on quality delivery, rather than choosing purely on price.

7.4.2 Highways sector level

At a highways sector level, this research provides highways leaders with insights into the most prevalent and costly avenues of failure on a current construction megaproject. In addition, viewpoints from project professionals provide the sector with a complete perspective of quality delivery and attributes direction to those impacting quality performance. This includes supply chain, principal contractors, clients, local authorities, and governing bodies who all have a part to play in the success of schemes. From this research, the sector is presented with targeted areas for improvement through anonymous feedback from those less likely to speak out, along with an adaptive learning framework that encompasses learning throughout the construction industry. The framework aims to broaden the narrow fixation on lagging indicators by tracking quality performance through leading indicators similar to safety, but also encourages the need for the sector to embrace learning from different sectors, institutions, emergent literature and supply chain innovation to breed a more agile, adaptive sector that thrives on continuous improvement.

7.4.3 Construction industry level

The majority of studies into quality improvement originate from the automotive and manufacturing sectors, in which we are seeing greater uptake of these framework (e.g. TQM) within the construction sector. However, unlike the automotive and manufacturing sectors where assembly lines replicate the same product over and over again, construction projects are far more uncertain and complex, thus calling for a more robust quality management framework to cater for these types of environments. In addition, there are few frameworks that offer project led insight and initiatives for change, with the majority focusing on high level strategic change through ideologies. This is an oversight that the construction industry should address.

At the broadest level, the construction industry must rethink how to manage quality on schemes and the people that play their part in delivering them. Greater leadership direction along with technological advancements and supportive behavioural management training is fundamental to success. This research identifies seven key improvement areas through a generalised quality management framework that the construction industry should focus efforts for improvement. Building on EFQM principals, the framework offers a more detailed insight into the pitfalls of quality within the industry and informs leaders ‘why’ they should address with suggested solutions. Some sectors within construction may be in a far better position than the highways sector. Nonetheless, the framework provides real insight from data analytics and those delivering schemes with cross-sector influence, and should be used as a guiding light to avoid such pitfalls in future schemes.

7.5 Limitations and future research

Given the specific context in which the research was undertaken, the generalizability of the findings is a limitation of the work. The data used in this study is from a highways project, therefore, this exercise should be replicated in different sectors to identify any other prominent failure points and identify whether other sectors are having similar challenges.

A further limitation is that the data comes from a specific phase of the project (i.e. construction phase). The dataset supplied does not consider the preliminary design phase or project close out phase where further defects and non-conformities can manifest. Future research could consider more focus in the early design phase and handover phase to build a complete picture of non-conformance on schemes, and understand whether there are differing patterns from the construction phase of projects.

With regards to the industry survey, the questionnaire was conducted within the context of one principal contractor with a mixed range of knowledge/expertise across many sector. This is a limitation as it does not consider all major contractors within the construction sector. It would be beneficial to perform a similar exercise across many tier 1 contractors to understand whether similar challenges are observed. In addition, further consideration to compare the lessons learned streams identified within this research and cross-examining against other projects, organisations and sectors to build a more rounded picture of quality learning within construction is suggested. Lastly, much of quality problem solving is done manually through root cause analysis techniques. Future research could consider how machine learning can assist in the arduous task of interpreting NCR data to provide projects with real-time insights and allow more time to focus on quality management practices. Also, the need to explore how digitisation, change control and risk management can specifically influence quality management practices as highlighted by an industry leader (Appendix 18).

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Appendices

Appendix 1. Ethical Approval (Project Consent)

Gavin Ford

From: Information hidden @thea14.com>
Sent: 05 February 2021 18:39
To: Gavin Ford
Subject: RE: Approval to use A14 NCR dataset

Hi Gavin,

Thank you for your email,

Please take this email as approval/consent to use this data to benefit your research.

Kind Regards
Information hidden

From: Gavin Ford
Sent: 15 January 2021 13:58
To: Information hidden @thea14.com>
Subject: Approval to use A14 NCR dataset

Hi Information hidden

As you know, I am doing a PhD in Non-conformance and rework. I wish to use the A14 NCR dataset to analysis and obtain trends/patterns/correlations to prevent re-occurrence of non-conformance and rework.

Please can I have your approval/consent to use this data to benefit my research?

Kind Regards,
Gavin

Appendix 2. Cardiff University Ethics Approval (Phase 1)

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Cardiff Business School
Ysgol Busnes Caerdydd

21/05/2021

Dear Gavin Ford

Research project title: Forecast and decision making in different operational environments to prevent non-conformance and rework

SREC reference: 2021075

The School Research Ethics Committee (SREC) reviewed the above application via its proportionate review process.

Ethical Opinion

The Committee gave a favourable ethical opinion of the above application on the basis described in the application form, protocol and supporting documentation.

Additional approvals

This letter provides an ethical opinion only. You must not start your research project until any other approvals required for your research project (where relevant) are in place.

Amendments

Any substantial amendments to documents previously reviewed by the Committee must be submitted to the Committee via CARBS-ResearchEthics@cardiff.ac.ukfor consideration and cannot be implemented until the Committee has confirmed it is satisfied with the proposed amendments.

You are permitted to implement non-substantial amendments to the documents previously reviewed by the Committee but you must provide a copy of any updated documents to the Committee CARBS-ResearchEthics@cardiff.ac.uk for its records.

Monitoring requirements

The Committee must be informed of any unexpected ethical issues or unexpected adverse events that arise during the research project. The Committee must be informed when your research project has ended. This notification should be made to the Research Office within three months of research project completion.

Documents reviewed by Committee

The documents reviewed by the Committee were:

Complaints/Appeals
If you are dissatisfied with the decision made by the Committee, please contact Dr Carmela Bosangit (BosangitC@cardiff.ac.uk) in the first instance to discuss your complaint. If this discussion does not resolve the issue, you are entitled to refer the matter to the Head of School for further consideration. The Head of School may refer the matter to the University Research Integrity and Ethics Committee (URIEC), where this is appropriate. Please be advised that URIEC will not normally interfere with a decision of the Committee and is concerned only with the general principles of natural justice, reasonableness and fairness of the decision.

Please use the Committee reference number on all future correspondence.

The Committee reminds you that it is your responsibility to conduct your research project to the highest ethical standards and to keep all ethical issues arising from your research project under regular review.

You are expected to comply with Cardiff University's policies, procedures and guidance at all times, including, but not limited to, its Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data and our Research Integrity and Governance Code of Practice.

Yours sincerely,

Dr Carmela Bosangit
Chair of School Research Committee

Appendix 3. Cardiff University Ethics Approval (Phase 2)

Your ethics application has been APPROVED: ID 1556; Non-Conformance and rework within construction.

CARBS Research Office-Ethics <CARBS-ResearchEthics@cardiff.ac.uk>
Wed 19/04/2023 12:10
To: Gavin Ford <FordG9@cardiff.ac.uk>

Dear Gavin Ford,

Research project title: Non-Conformance and rework within construction.
SREC reference: 1556

The School Research Ethics Committee (SREC) reviewed the above application via its proportionate review process.

Ethical Opinion
The Committee gave a favourable ethical opinion of the above application on the basis described in the application form, protocol and supporting documentation.

Additional approvals
This letter provides an ethical opinion only. You must not start your research project until all any other approvals required for your research project (where relevant) are in place.

Amendments
Any substantial amendments to documents previously reviewed by the Committee must be submitted to the Committee via CARBS-ResearchEthics@cardiff.ac.uk for consideration and cannot be implemented until the Committee has confirmed it is satisfied with the proposed amendments.

You are permitted to implement non-substantial amendments to the documents previously reviewed by the Committee but you must provide a copy of any updated documents to the Committee via CARBS-ResearchEthics@cardiff.ac.uk for its records.

Monitoring requirements
The Committee must be informed of any unexpected ethical issues or unexpected adverse events that arise during the research project.

The programme director would include your research in end of project report. The Committee must be informed when your research project has ended. This notification should be made to CARBS-researchethics@cardiff.ac.uk within three months of research project completion.

Documents reviewed by the Committee
The documents reviewed by the Committee were:
Application ID: 1556
Link to applications list, where you can access the reviewed version.
C1974213 CARBS SREC application form (version 5).docx
C1974213 Consent Form template.docx
C1974213 Participant Information Sheet.docx
C1974213 Research integrity Training Certificate.pdf
Email Consent Form Proposal by G Ford.pdf
Nonconformance and rework in construction - What have we learnt questionnaire_.pdf
Research integrity Training Certificate.pdf

Complaints/Appeals
If you are dissatisfied with the decision made by the Committee, please contact Dr Carmela Bosangit (BosangitC@cardiff.ac.uk) in the first instance to discuss your complaint. If this discussion does not resolve the issue, you are entitled to refer the matter to the Head of School for further consideration. The Head of School may refer the matter to the University Research Integrity and Ethics Committee (URIEC), where this is appropriate. Please be advised that URIEC will not normally interfere with a decision of the Committee and is concerned only with the general principles of natural justice, reasonableness and fairness of the decision.

Please use the Committee reference number on all future correspondence.

The Committee reminds you that it is your responsibility to conduct your research project to the highest ethical standards and to keep all ethical issues arising from your research project under regular review.

You are expected to comply with Cardiff University's policies, procedures and guidance at all times, including, but not limited to, its Policy on the Ethical Conduct of Research involving Human Participants, Human Material or Human Data and our Research Integrity and Governance Code of Practice .

Yours sincerely,

Dr Carmela Bosangit
Chair of School Research Ethics Committee

Appendix 4. Root cause analysis classification table

	Primary root cause
01	Supervision - Lack of/ poor site supervision (CJV)
	Supervision - Engineering Verification/Check (CJV) including engineer site presence during works
	Supervision - Lack of/ poor site supervision (Supply chain)
02	Management - Poor Management Decision (CJV)
	Management - Poor Management Decision (Supply chain)
	Management - Poor Management of supply chain (Availability/Contract award)
03	Commercial - Poor Commercial Management Decision (CJV)
	Commercial - Poor Commercial Decision (Supply chain)
04	Competence - Lack of training / Understanding (Knowledge to complete task)
05	Poor Planning (Weather dependent)
	Poor Planning (Late/early resulting failure - Time dependent)
	Poor Planning (Testing and Documentation)
	Poor Planning (Plant movement)
	Poor Planning (Plant/Equipment/Resource to be used)
	Poor Planning (Works sequencing)
06	Design - Detailed design (Not buildable)
	Design - Survey information used in detailed design
	Design - Drawing error / Detailed Design Issue
	Design - Drawing revised post construction/fabrication (Late design submission)
	Design - Design assumptions and requirements insufficient (E.g. required drainage)
	Design - Specification, Schedule or Appendix error
	Design - Temporary works
	Design - Calculation Error (Design and/or Supplier)
	Design - Methodology / sequencing
07	Lack of Collaboration between (CJV & ACJV Designer)
	Lack of Collaboration between (CJV & Supply Chain)
	Lack of Collaboration between (CJV & HE Client)
08	Communication Breakdown (Batching plant and site team)
	Lack of communication/Knowledge sharing (Supervisor/engineer/manager to workforce)
	Lack of communication/Knowledge sharing (Supervisor/manager to supply chain)
	Lack of communication/Knowledge sharing (Between Designer and CJV)
	Lack of communication/Knowledge sharing (Between engineer and supply chain)
	Lack of communication/Knowledge sharing (Between engineer and engineer)
09	Material supplied by supplied chain
	Material supplied by IDT
	Materials stored by project (including precast facility)
	Material recycled by project
	Material failing to meet specification
	Materials Management - Planning and/or Delivery
	Materials Testing - Management and control of testing requirements/method
10	Methodology incorrect for works (CJV)
	Methodology incorrect for works (Supply Chain)
	Methodology provided by manufacturer lacking key information / detail
	Methodology (Designer)
11	Documentation - QA documentation (ITP) not adequately planned for approval ahead of works
	Documentation - Poor stocktake and inventory sign off
	Documentation - Incomplete/Incorrect/unavailable QA documentation
	Documentation - ITP Requirements not followed
12	Fabrication Error
	Fabrication Inconsistency
13	Setting out error - Precast/Prefab Works (CJV Engineer)
	Setting out error - On site (CJV Engineer)
	Setting out error - Precast/Prefab Works (Supply chain)
	Setting out error - On site (Supply chain)
	Setting out - Survey information provided to supply chain
14	Damage to permanent works (Caused by public operations)
	Damage to permanent works (Caused by CJV)
	Damage to permanent works (Cause by utilities provider)
	Damage to permanent works (Caused by Supply Chain)
	Damage to permanent works (Caused by Inclement weather - Not covered/protected)
	Damage to permanent works (Caused during transport/delivery)
15	Piling Construction - Unforeseen ground condition
	Piling Construction - Finished pile parameters / Wrong location

	Cause type
01	No/poor site supervision present during works (CJV)
	No/poor engineering verification during works (CJV)
	No/poor site supervision present during works (Supply chain)
02	Management - Implementing change without prior design acceptance (CJV)
	Management - Implementing change without prior design acceptance (Supply Chain)
	Management - Poor management of design prior to build (Incomplete design detail)
	Management - Inadequate communication (Supply chain Team)
03	Commercial Decision - Programme dictated
	Commercial Decision - Cost saving (Recycle or Re-use / Omission)
	Commercial Decision - Substandard product alternative (Substitution)
	Commercial Decision - Works sequencing
04	Competence/Training - Workforce not suitably trained for task
	Competence/Training - Engineers / Supervisors
	Competence/Training - Supply chain
05	Planning - Exposed to weather condition (Supply chain not ready / works not finished)
	Planning - Supply chain resource shortage (Management)
	Planning - Weather conditions not anticipated
	Planning - Plant operations trafficking permanent works (Using as haulage route)
	Planning - Programme delivery greater importance than quality delivery/Not finishing current works
	Planning - Incorrect sequencing of works causing nonconformity
06	Design - Design detail not buildable / Incorrect detail / Detail missed during revision
	Design - Temporary works not designed adequately
	Design - Calculation error made by Design and/or supplier resulting in error
	Design - Assumptions made during initial design are not adequate (resulting in settlement, lack of sag etc)
	Design - Survey information outdated/inaccurate causing design error
	Design - Drawing incorrect / Survey Model Incorrect / On site discrepancy
	Design - Insufficient ground investigation/survey (Rock encountered)
	Design - Design drawing revised and/or provided post completion of works (Late design submission)
	Design - Specification, schedule or appendix consisting of errors
	Design - Method/sequence dictated by design causing error
07	Collaboration - Design and Construction Teams (Shared understanding)
	Collaboration - Principal Contractor and Supply Chain
	Collaboration - Principal Contractor and Client
	Collaboration - Supply chain
08	Communication - Poor communication from supervisor/engineer/manager
	Communication - Poor communication from/with designer
	Communication - Poor communication (CJV and supply chain)
	Communication - Poor communication (Batching plant and site team)
	Communication - Poor communication (within supply chain)
09	Material – Contaminated
	Material - Wrong material delivered and used in works
	Material - Out of Specification (Earthworks formation)
	Material - Out of Specification (Sub-base)
	Material - Out of Specification (Concrete)
	Material - Lack of control of material testing methodology
	Material - Sampling not in accordance with specification
	Material - Substandard/incorrect material supplied
	Material - Inconsistent supply of concrete during pour (Different colours - Cement type)
	Material - Not stored correctly (On site/storage yard/precast yard)
	Material - Management of stockpiles (Rotation and blending) to meet testing requirements
	Materials Management - Late delivery/ Not planned correctly (Weather)
10	Methodology - Supply chain method incorrect/inadequate
	Methodology - CJV method incorrect/inadequate
	Methodology - Manufacturers installation methodology inadequate
	Methodology - Design method incorrect/inadequate
11	Documentation - QA Incomplete (Prior/during works)
	Documentation - QA and/or testing records not available
	Documentation - ITP and associated testing not followed (including tolerances)
	Documentation - ITP not approved prior to works (not fit for purpose)
	Documentation - ITP not as per specification (inadequate)
	Documentation - Engineer/supervisor not following QIR process
12	Fabrication (Steel) - Not fabricated as per design (Detail read incorrectly / Not checked prior / Fabrication drawing error)
	Fabrication (Steel) - Fabricated to previous drawing revision

	Piling Construction - Damaged caused during pile cropping activity
16	Testing not to specification and/or ITP requirements
17	Workmanship - Poor Quality Execution
18	Inadequate or defective plant/equipment/instrumentation/formwork used
	Mains power failure causing error
	Machine breakdown contingency arrangements (No alternative plant)
19	Reading Design Information - Design and/or it's detail read incorrectly (including specification)
20	UNCLASSIFIED
	DUPLICATE / EXAMPLE
21	As Built Model - Survey information supplied into model inaccurate/incorrect
	As Built Model - Model not updated accurately following works (Designers/Survey Team)
22	Design Management by project (Principal Contractor)
23	Formal system not established (E.g. MAR/NCR/TQ/RFI)
	Formal system ineffective / Not adequate in its function (E.g. Materials testing database)
24	Environmental / Ecological / Archaeological management

	Fabrication (Steel) - Human Error (Measurement)
	Fabrication (Steel) - Paintwork/protective coating not applied effectively
	Fabrication (Steel) - Equipment issue including movement (Drill / apparatus)
	Fabrication (Precast) - Casting error (Not as per design detail)
	Fabrication (Precast) - Inconsistent casting causing difference (E.g. colour due to cement)
	Fabrication (Precast) - Not achieving tolerances (Rebar cover etc)
13	Setting Out - Engineer Error (Include reading design SOP incorrectly)
	Setting Out - Supply chain Error (Include reading design SOP incorrectly)
	Setting Out - Incorrect data/information provided by project/designer
	Setting Out - Wrong drawing used
	Setting Out - Models not read correctly (Containing too much redundant information causing confusion)
14	Damage – Inadequate protection of permanent works and/or accidental(CJV)
	Damage – Inadequate protection of permanent works and/or accidental (Supply Chain)
	Damage - Caused during installation ; Site issues such as rebar congestion (CJV)
	Damage - Caused during installation ; Site issues such as rebar congestion (Supply chain)
	Damage - Caused by utilities company during diversion/maintenance
	Damage – Caused by General Public (Accidents or Vandalism)
	Damage – Caused during Transportation (Steelwork)
	Damage – Caused during Transportation (Precast works)
15	Piling - Cage construction incorrect
	Piling - Finished Concrete level (High/Low)
	Piling - Pile depth failed/refused (Part or Whole)
	Piling - Pile out of Position
	Piling - Toe level Not Reached
16	Testing - Sample testing not in accordance with spec and/or ITP requirements
	Testing - 'Push' Test failure (Series 400)
	Testing - Drainage (Mandrel) - (Series 500)
	Testing - Material Compaction (Series 600)
	Testing - MAT & Cores (Series 700 - 1000)
	Testing - Lighting and Communications (Series 1300 - 1500)
	Testing - Concrete Cube Testing (Series 1700)
17	Workmanship - Poor Quality Behaviour
	Workmanship - Works not fit for purpose / Ineffective / Defective
	Workmanship - QA process not followed including manufacturers guidelines
	Workmanship - Not listening to instructions/briefing conducted (Supply chain)
	Workmanship - Not following design detail/specification/setting out by project
	Workmanship - Fatigue
	Workmanship - Rebar and steel fixing poor/ inadequately fixed
	Workmanship - Lack of understanding
18	Plant and Equipment - Machine / Equipment breakdown
	Plant and Equipment - Mains power failure (resulting in failure of supported equipment)
	Plant and Equipment - Total Station malfunction (resulting in incorrect setting out)
	Plant and Equipment - Formwork not fit for purpose
	Plant and Equipment - Wrong plant or equipment used
19	Reading Design Information - Design/spec read incorrectly resulting in failure (inc. missing from permanent works)
20	UNCLASSIFIED
	DUPLICATE / EXAMPLE
21	As Built Model - As built survey information provided into model incorrect/inaccurate
	As-Built Information - Not captured and records during works prior to backfill
22	Design management - Drawing change not communicated effectively to relevant parties
	Design management - Inadequate review, comparison & approval of design detail
	Design management - Not using correct drawing for works
	Design management - Formal design issue process failure (Document control)
23	No formal system established causing failure in approval process
	Formal system ineffective/lacking key information to conform (E.g. Materials Testing database)
24	Environmental contamination / disturbance

Appendix 5. Nonconformance and rework in construction survey (Final Version)

COSTAIN

Nonconformance and rework in construction - What have we learnt?

Problem - Learning from our nonconformance data has proved challenging over the years along with the correct decision making protocols to prevent future recurrence. Furthermore, similar trends are being found on many other schemes which call for improvements to be made in the quality sphere.

Intent - The aims of this questionnaire is to first understand the perceptions of quality on complex construction projects, secondly to measure how we are learning from our nonconformance data through detailed analysis and Root Cause Analysis (RCA) methods, and finally where our efforts should be focused for continuous improvement.

Benefits - With the support of the participants, the questionnaire findings will divulge where our efforts are best placed in tackling quality issues to get closer to delivering right first time within Costain. The questionnaire also helps transfer knowledge from NCR analysis for the betterment of ongoing schemes.

Context - 1260 NCRs have been analysed on a major complex delivery project (*A14 Hungtingdon Improvement Scheme*) for the purposes of driving continuous improvement in quality. The questions have been tailored to generate meaningful lessons learnt for the construction consortium.

Confidentiality - Although the researcher will be supplied with details of each participant completing the questionnaire, this information will remain confidential at all times and only used to validate that persons participation. As such, all feedback will remain strictly anonymous during the qualitative research by the PhD candidate. By completing the questionnaire, you agree to participate in this research for the benefit of Costain Plc and the wider construction research community.

This questionnaire will take approximately 15 minutes and has a deadline submission date of **30 June 2022**.
(NOTE: if the questionnaire is started and left open, it will record the entire duration until it is complete)
If you have any queries, please email gavin.ford@costain.com

* Required

* This form will record your name, please fill your name.

Discussing quality within the construction sector

This section poses a number of questions pertaining to quality execution and risk within the construction sector.

1

Do you see quality execution as a problem within Costain?

- ◯ Yes
- ◯ No

2

Do you see quality execution as a problem with our supply chain?

- ◯ Yes
- ◯ No

3

Are we at risk of post project completion latent defects causing long term profitability issues for the business? *

- ◯ Yes
- ◯ No

4

According to published literature, rework is costing construction projects anywhere from 0.5% to 12.4% of total project value depending on the discipline (Ball, 1987, Burati et al., 1992, Get It Right Initiative, 2016). For a typical highway's scheme with a profit margin of 3% total project value, what do you believe the combined direct and indirect cost of nonconformance rectification was? *

- ◯ 0 – 0.2%
- ◯ 0.2 – 0.4%
- ◯ 0.4 – 0.6%
- ◯ 0.6 – 0.8%
- ◯ 0.8 – 1.0%
- ◯ In excess of 1%

5

On complex construction projects, is there an expectation that 'rework' in some form is inevitable and that 'right-first-time' from start to end of a scheme is unachievable? *

◯ Yes

◯ No

6

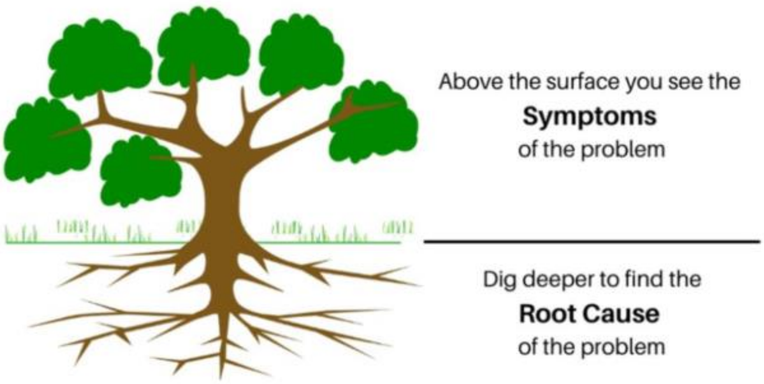
Problem solving and decision-making are vital steps to preventing future nonconformance. However, the data suggests that many NCR problems are often 'oversimplified' and that the underlying cause of the problem has not been discovered via appropriate Root Cause Analysis (RCA) methods thus providing incomplete corrective action to address and prevent repetition . Do you agree with this statement? *

◯ Yes

◯ No

7

Root Cause Analysis (RCA) is a fundamental tool for identifying underlying causes to prevent future occurrence. Do you feel our team members who manage nonconformance data are Suitably Qualified and Experienced (SQEP) with the necessary training to perform such analysis techniques as 5 whys, Pareto, Fishbone etc? *



◯ Yes - Most are suitably trained to perform RCA techniques

◯ No - Training is lacking in RCA techniques

8

Design issues have significant knock-on effects on our schemes, especially cost. Such issues as **[1]** Late/incorrect design details, **[2]** Insufficient ground investigation & surveys conducted and **[3]** Lack of designer site presence to support builds were fundamental issues that caused nonconformance. Should our contractual arrangements with designers be re-evaluated so as to apportion cost associated for nonconformance as a result of poor design? *

◯ Yes

◯ No

9

Due to stringent programme constraints, do we at times progress at risk without approved design details as a result of design delay to stay on the critical path?
Note: Approximately 68 NCRs we found to be attributable due to design related issues costing £534,600 *

◯ Yes

◯ No

10

What do you believe is the potential consequences for proceeding at risk without approved designs (*Both positive and negative*)? *

11

Please rank the following in priority order as you see it for delivery of complex construction schemes. *

Quality

Programme

Cost

Safety, Environment and Ecology

12

Our schemes appear heavily dictated by programme and cost. Of the 1260 NCRs, approximately 51 were caused as a result of continuation of the next activity before finishing the previous in order to meet the programmes critical path. This had significant impacts on the quality of the end product which resulted in rework. Do you believe cost and programme are treated as higher priority than quality delivery on our projects? *

◯ Yes

◯ No

13

If you answered 'Yes' to the previous question, do you think that cost and programme are more important than quality delivery? Please explain. *

14

Further to question 12, do you think our clients value cost and programme over quality delivery on infrastructure schemes? *

◯ Yes

◯ No

15

'Quality standard' is the level of quality to be achieved that is acceptable by our clients. However, on various schemes, this term differs in understanding between Costain and its clients. Do all parties on our project fully appreciate and understanding the level of quality to be achieved? (E.g It may be a mid-range product as opposed to high-end) *

◯ Yes

◯ No

16

If 'No', why do you believe this is the case? *

17

Of the following primary root causes, which do you believe are the <u>three</u> most likely to cause a nonconformance? (*Alphabetically ordered*)

Please choose 3 only. *

- ☐ A) As-built model (Not updated / Incorrect information supplied)
- ☐ B) Collaboration (Poor/ lack of)
- ☐ C) Commercial Issue (Decisions making / Risk taking)
- ☐ D) Communication/Knowledge Transfer (Poor/ lack of)
- ☐ E) Competency/Training (Poor/ lack of)
- ☐ F) Damage to permanent works (Caused by careless behaviour / public use)
- ☐ G) Design (Responsibilities of designer)
- ☐ H) Design Management (Principal Contractor role)
- ☐ I) Documentation Issue (QA unsuitable / not in place)
- ☐ J) Fabrication Error (Steelwork and Precast items)
- ☐ K) Formal system / Process (Not established / Late introduction)
- ☐ L) Materials Management (Storage, organisation, delivery, testing etc)
- ☐ M) Management Issue (Decisions making / Risk taking)
- ☐ N) Methodology (Incorrect / Inadequate)
- ☐ O) Piling Construction (Damage / Setting out)
- ☐ P) Planning (Including consideration of inclement weather and works sequencing)
- ☐ Q) Plant/equipment/instrumentation/formwork used (Unfit for purpose / wrong use)
- ☐ R) Quality Execution Poor /Workmanship (Not following QA procedures)
- ☐ S) Reading Design Information (Read incorrectly)
- ☐ T) Setting out (Human error / wrong info used)
- ☐ U) Supervision Poor / Lack of (Including engineering supervision)

Results Discussions

This section poses questions around the findings of the PhD analysis into 1260 non-conformities on a major highways scheme.

18

Analysis of 1260 nonconformances (NCR's) on a successful major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (**£7,739,850**). Based on a 3% profit margin, that is a potential profit loss of 17% of what could have been achieved. In reality, this figure is conservative and likely to be far higher. Is this figure of concern?

- ○ Yes
- ○ No

19

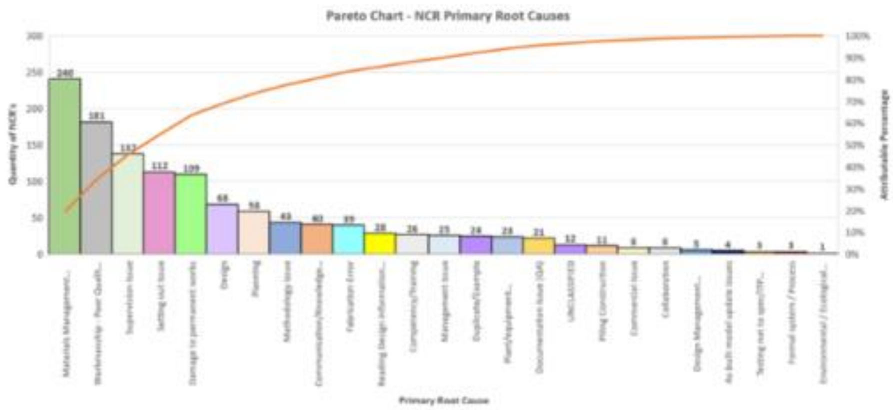
Please explain your answer to the previous question.

20

Following on from Question 18, Pareto analysis indicates that of the 1260 NCRs the three most prevalent primary root causes were:

1) Materials Management (Storage, organisation, delivery, testing etc) - **240 cases**
2) Quality Execution Poor /Workmanship (Not following QA procedures) - **181 cases**
3) Supervision Poor / Lack of (Including engineering supervision) - **137 cases**

As a business, what do you believe we should focus on within the three categories above to prevent repetition of future schemes? *Please list.*



21

The data suggests we are struggling with Suitably Qualified and Experienced Personnel (SQEP) resources in key project delivery roles (E.g engineers, supervisors). Do you agree with this statement?

◯ Yes

◯ No

22

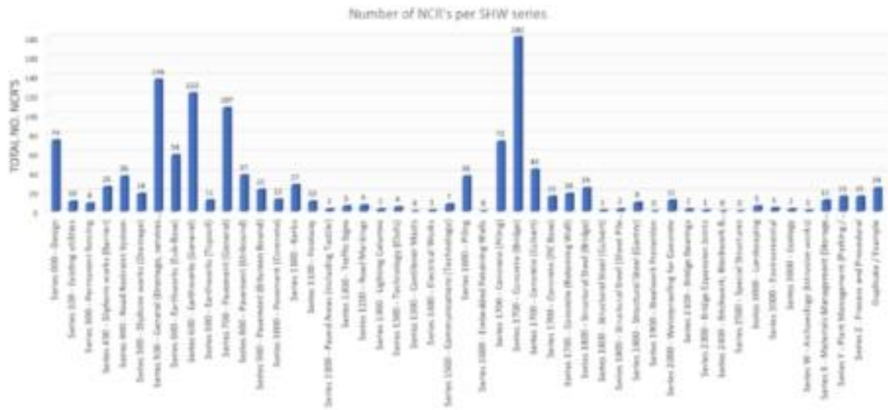
You've selected 'Yes'. Of the data, there were **137** cases of poor/lack of supervision (including engineering support and verification) and a further **26** cases of competency/training issues notified. What do you believe the solution to be?

23

You've selected 'No'. Of the data, there were **137** cases of poor/lack of supervision (including engineering support and verification) and a further **26** cases of competency/training issues notified. Why do you think such large figures are occurring?

24

Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme (30% of the overall NCR dataset). Why do you think we are continuing to make mistakes in concrete operations? *



25

Should we re-evaluate our approach to concrete operations by using more effective methods such as precast as our primary choice? These can be completed outside of other works under controlled conditions to improve quality delivery.

(Note: We must consider defects resolution and project total life cycle costs in our evaluation of appropriate options) *

- ◯ Yes
- ◯ No

26

As the principal contractor on many of our projects, we typically outsource the majority of our works to specialist supply chain. The data suggests that supply chain were responsible for 66.3% (**836 cases**) of the total NCR failures with notable commentary raised over performance that resulted in removal from the contract. Are there concerns that typically we select supply chain primarily on price and not previous performance/track record? (The saying "*You get what you pay for*".) *

- ◯ Yes
- ◯ No

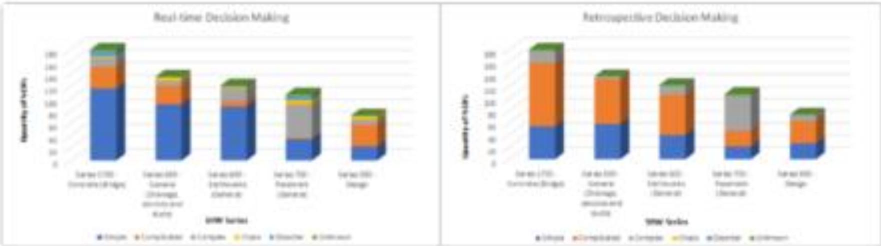
27

One of the most costly NCR's amounted from RECo panel retaining walls which cost the scheme £2,169,500 (*NOTE: Similar trends have been noted on the A465 Heads of the Valley Scheme*). Knowing this, should we continue with these types of constructions? *

- ◯ Yes - Risk is minimal and reward is high
- ◯ No - Risk is too high

28

Oversimplification of problem solving NCR's has been a common factor whilst analysing the dataset. As such, we do not always achieve the right root cause to implement sufficient corrective action (See figure). In reality, many problems are far more complex than they seem and often have more than one attributable cause. Please state your position on the following three statements: *



	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
We often look for the easiest solution to correct nonconformance	○	○	○	○	○	○
We typically focus more on addressing the remedial solution instead of eradicating the underlying cause.	○	○	○	○	○	○
We are unable to identify true root causes for many of our NCR's due to their complexity.	○	○	○	○	○	○
NCR processes are not strictly followed on our schemes (e.g NCR's are finalised long after remedial works)	○	○	○	○	○	○

29

What is your title within Costain? *

- ◯ Programme Director (Including Senior)
- ◯ Project Director (Including Senior)
- ◯ Commercial Director (Including Senior)
- ◯ Project Manager (Including Senior)
- ◯ Commercial Manager (Including Senior)
- ◯ Quantity Surveyor (Including Senior)
- ◯ Quality Director / Head of Quality / Business Improvement Manager
- ◯ Quality Manager (Including Senior)
- ◯ Quality (Engineer / Inspector / Consultant / Coordinator / Practitioner)
- ◯ Systems, Performance and/or Assurance Manager
- ◯ Handover Manager (Including Senior)
- ◯ Engineer (Including Senior, Agent etc)
- ◯ Head of Business Improvement
- ◯ Lean Manager
- ◯ Group Research and Innovation Director
- ◯ Head of Technical Assurance
- ◯ Other

30

Finally, on a scale of 1 to 10, where 1 is worst and 10 is best, how would you rate your interest of the topics being discussed? *

0	1	2	3	4	5	6	7	8	9	10

Not interested at all — Extremely interesting

Appendix 6. Critical values table for Wilcoxon signed ranks test

n	Two-Tailed Test		One-Tailed Test	
	α = .05	α = .01	α = .05	α = .01
5	--	--	0	--
6	0	--	2	--
7	2	--	3	0
8	3	0	5	1
9	5	1	8	3
10	8	3	10	5
11	10	5	13	7
12	13	7	17	9
13	17	9	21	12
14	21	12	25	15
15	25	15	30	19
16	29	19	35	23
17	34	23	41	27
18	40	27	47	32
19	46	32	53	37
20	52	37	60	43
21	58	42	67	49
22	65	48	75	55
23	73	54	83	62
24	81	61	91	69
25	89	68	100	76
26	98	75	110	84
27	107	83	119	92
28	116	91	130	101
29	126	100	140	110
30	137	109	151	120

Source:

https://users.stat.ufl.edu/~winner/tables/wilcox_signrank.pdf

Appendix 7. Pilot trial survey email

Gavin Ford

From: Gavin Ford
Sent: 11 May 2022 19:52
To: Sensitive information hidden
Subject: Pilot Testing - NCR Questionnaire

Importance: High

Hi All,

Firstly thanks to each of you for your contributions to the development of this questionnaire. Now that all comments have been addressed I would like to invite you to partake in the 'pilot trial' on MS forms to identify any remaining areas of weakness or digital issues.

Please click on the following icon to take you to the MS survey. The questionnaire should take approximately 15 mins. On the open ended questions, please bullet point your answers if possible.

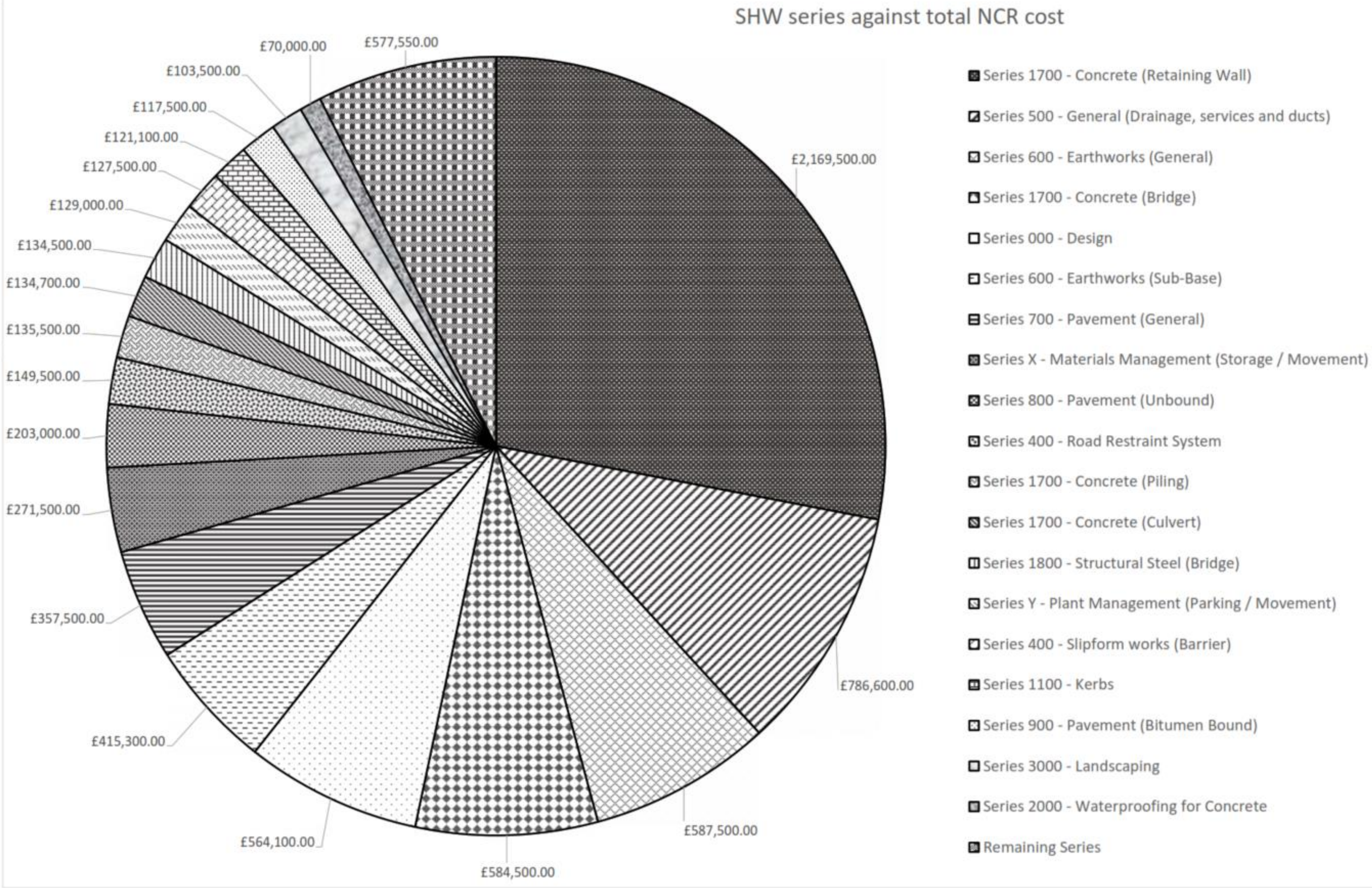
NCR Questionnaire

Thank you in advance for your support and any issues with the platform please let me know.

Regards,
Gavin

Appendix 8. NCR costs per SHW series

Cause Type Discipline (Series)	Total Cost
Series 1700 - Concrete (Retaining Wall)	£2,169,500.00
Series 500 - General (Drainage, services and ducts)	£786,600.00
Series 600 - Earthworks (General)	£587,500.00
Series 1700 - Concrete (Bridge)	£584,500.00
Series 000 - Design	£564,100.00
Series 600 - Earthworks (Sub-Base)	£415,300.00
Series 700 - Pavement (General)	£357,500.00
Series X - Materials Management (Storage / Movement)	£271,500.00
Series 800 - Pavement (Unbound)	£203,000.00
Series 400 - Road Restraint System	£149,500.00
Series 1700 - Concrete (Piling)	£135,500.00
Series 1700 - Concrete (Culvert)	£134,700.00
Series 1800 - Structural Steel (Bridge)	£134,500.00
Series Y - Plant Management (Parking / Movement)	£129,000.00
Series 400 - Slipform works (Barrier)	£127,500.00
Series 1100 - Kerbs	£121,100.00
Series 900 - Pavement (Bitumen Bound)	£117,500.00
Series 3000 - Landscaping	£103,500.00
Series 2000 - Waterproofing for Concrete	£70,000.00
Remaining Series	£577,550.00
Series 1600 - Piling	£65,000.00
Series 1800 - Structural Steel (Gantry)	£61,000.00
Series 1100 - Footway	£58,500.00
Series 600 - Earthworks (Topsoil)	£52,500.00
Series 100 - Existing utilities	£51,000.00
Series 500 - Slipform works (Drainage)	£43,100.00
Series 1700 - Concrete (RC Base)	£36,750.00
Series 1000 - Pavement (Concrete)	£34,000.00
Series Z - Process and Procedural	£29,000.00
Series 1200 - Road Markings	£28,500.00
Series 1500 - Communications (Technology)	£27,000.00
Series 3000 - Environmental	£15,500.00
Series 300 - Permanent fencing	£12,700.00
Series 1300 - Technology (Civils)	£11,500.00
Series 1300 - Lighting Columns	£10,000.00
Series 1100 - Paved Areas (including Tactile)	£8,500.00
Series 1200 - Traffic Signs	£8,500.00
Duplicate / Example	£6,000.00
Series 2300 - Bridge Expansion Joints	£5,000.00
Series W - Archaeology (Intrusive works)	£4,000.00
Series 2100 - Bridge Bearings	£3,000.00
Series 1400 - Electrical Works	£2,500.00
Series 3000 - Ecology	£2,000.00
Series 1800 - Structural Steel (Culvert)	£1,000.00
Series 1800 - Structural Steel (Sheet Pile Retaining Wall)	£1,000.00
Series 1300 - Cantilever Masts	£0.00
Series 1600 - Embedded Retaining Walls	£0.00
Series 1900 - Steelwork Protection	£0.00
Series 2400 - Brickwork, Blockwork & Stonework	£0.00
Series 2500 - Special Structures	£0.00



Appendix 9. Real-time vs retrospective decision-making categorisation of SHW series

Realtime decision making							DIFFERENCE (+/-)					Retrospective decision making						
SHW Series	Simple	Complicated	Complex	Chaos	Disorder	Unknown	Simple	Complicated	Complex	Chaos	Disorder	SHW Series	Simple	Complicated	Complex	Chaos	Disorder	Unknown
Series 000 - Design	23	35	8	6	1	0	-3	-2	-2	6	1	Series 000 - Design	26	37	10	0	0	0
Series 100 - Existing utilities	8	2	0	0	0	0	3	-3	0	0	0	Series 100 - Existing utilities	5	5	0	0	0	0
Series 300 - Permanent fencing	7	0	0	1	0	0	4	-4	-1	1	0	Series 300 - Permanent fencing	3	4	1	0	0	0
Series 400 - Slipform works (Barrier)	8	6	11	0	0	0	6	-4	-2	0	0	Series 400 - Slipform works (Barrier)	2	10	13	0	0	0
Series 400 - Road Restraint System	26	2	8	0	0	0	12	-20	8	0	0	Series 400 - Road Restraint System	14	22	0	0	0	0
Series 500 - Slipform works (Drainage)	3	6	6	0	3	0	2	-4	-1	0	3	Series 500 - Slipform works (Drainage)	1	10	7	0	0	0
Series 500 - General (Drainage, services and ducts)	91	30	8	6	1	0	33	-44	4	6	1	Series 500 - General (Drainage, services and ducts)	58	74	4	0	0	0
Series 600 - Earthworks (Sub-Base)	41	10	4	2	1	0	20	-25	2	2	1	Series 600 - Earthworks (Sub-Base)	21	35	2	0	0	0
Series 600 - Earthworks (General)	88	8	21	2	2	1	48	-58	6	2	2	Series 600 - Earthworks (General)	40	66	15	0	0	1
Series 600 - Earthworks (Topsoil)	10	1	0	0	0	0	3	-3	0	0	0	Series 600 - Earthworks (Topsoil)	7	4	0	0	0	0
Series 700 - Pavement (General)	35	2	54	7	6	3	14	-24	-3	7	6	Series 700 - Pavement (General)	21	26	57	0	0	3
Series 800 - Pavement (Unbound)	11	4	18	1	1	2	7	-27	18	1	1	Series 800 - Pavement (Unbound)	4	31	0	0	0	2
Series 900 - Pavement (Bitumen Bound)	20	1	1	0	0	0	12	-13	1	0	0	Series 900 - Pavement (Bitumen Bound)	8	14	0	0	0	0
Series 1000 - Pavement (Concrete)	2	7	2	0	1	0	2	-1	-2	0	1	Series 1000 - Pavement (Concrete)	0	8	4	0	0	0
Series 1100 - Kerbs	27	0	0	0	0	0	10	-10	0	0	0	Series 1100 - Kerbs	17	10	0	0	0	0
Series 1100 - Footway	9	0	0	0	0	1	4	-4	0	0	0	Series 1100 - Footway	5	4	0	0	0	1
Series 1100 - Paved Areas (including Tactile)	2	0	0	0	0	0	1	-1	0	0	0	Series 1100 - Paved Areas (including Tactile)	1	1	0	0	0	0
Series 1200 - Traffic Signs	4	1	0	0	0	0	2	-2	0	0	0	Series 1200 - Traffic Signs	2	3	0	0	0	0
Series 1200 - Road Markings	5	0	0	0	1	0	2	-3	0	0	1	Series 1200 - Road Markings	3	3	0	0	0	0
Series 1300 - Lighting Columns	2	0	0	0	0	0	2	-2	0	0	0	Series 1300 - Lighting Columns	0	2	0	0	0	0
Series 1300 - Technology (Civils)	4	0	0	0	0	0	2	-2	0	0	0	Series 1300 - Technology (Civils)	2	2	0	0	0	0
Series 1400 - Electrical Works	1	0	0	0	0	0	0	0	0	0	0	Series 1400 - Electrical Works	1	0	0	0	0	0
Series 1500 - Communications (Technology)	3	1	1	0	1	0	3	-5	1	0	1	Series 1500 - Communications (Technology)	0	6	0	0	0	0
Series 1600 - Piling	20	14	1	0	1	0	8	-6	-3	0	1	Series 1600 - Piling	12	20	4	0	0	0
Series 1700 - Concrete (Piling)	46	20	3	0	2	1	38	-41	1	0	2	Series 1700 - Concrete (Piling)	8	61	2	0	0	1
Series 1700 - Concrete (Bridge)	117	35	14	3	8	3	63	-69	-5	3	8	Series 1700 - Concrete (Bridge)	54	104	19	0	0	3
Series 1700 - Concrete (Culvert)	28	10	5	0	0	0	12	-14	2	0	0	Series 1700 - Concrete (Culvert)	16	24	3	0	0	0
Series 1700 - Concrete (RC Base)	9	2	2	1	1	0	5	-7	0	1	1	Series 1700 - Concrete (RC Base)	4	9	2	0	0	0
Series 1700 - Concrete (Retaining Wall)	5	1	10	2	0	0	1	-6	3	2	0	Series 1700 - Concrete (Retaining Wall)	4	7	7	0	0	0
Series 1800 - Structural Steel (Bridge)	15	8	0	0	0	1	7	-6	-1	0	0	Series 1800 - Structural Steel (Bridge)	8	14	1	0	0	1
Series 1800 - Structural Steel (Culvert)	1	0	0	0	0	0	0	0	0	0	0	Series 1800 - Structural Steel (Culvert)	1	0	0	0	0	0
Series 1800 - Structural Steel (Sheet Pile Retaining Wall)	0	0	0	2	0	0	0	-2	0	2	0	Series 1800 - Structural Steel (Sheet Pile Retaining Wall)	0	2	0	0	0	0
Series 1800 - Structural Steel (Gantry)	8	0	0	0	1	0	6	-7	0	0	1	Series 1800 - Structural Steel (Gantry)	2	7	0	0	0	0
Series 2000 - Waterproofing for Concrete	10	1	0	0	0	0	2	-2	0	0	0	Series 2000 - Waterproofing for Concrete	8	3	0	0	0	0
Series 2100 - Bridge Bearings	1	0	0	0	1	0	0	-1	0	0	1	Series 2100 - Bridge Bearings	1	1	0	0	0	0
Series 2300 - Bridge Expansion Joints	1	0	0	0	0	0	1	-1	0	0	0	Series 2300 - Bridge Expansion Joints	0	1	0	0	0	0
Series 3000 - Landscaping	1	4	0	0	0	0	0	2	-2	0	0	Series 3000 - Landscaping	1	2	2	0	0	0
Series 3000 - Environmental	2	1	0	0	0	0	1	0	-1	0	0	Series 3000 - Environmental	1	1	1	0	0	0
Series 3000 - Ecology	2	0	0	0	0	0	0	0	0	0	0	Series 3000 - Ecology	2	0	0	0	0	0
Series W - Archaeology (Intrusive works)	1	0	0	0	0	0	1	-1	0	0	0	Series W - Archaeology (Intrusive works)	0	1	0	0	0	0
Series X - Materials Management (Storage / Movement)	11	0	0	0	0	0	0	0	0	0	0	Series X - Materials Management (Storage / Movement)	11	0	0	0	0	0
Series Y - Plant Management (Parking / Movement)	9	1	0	0	5	0	1	-4	-2	0	5	Series Y - Plant Management (Parking / Movement)	8	5	2	0	0	0
Series Z - Process and Procedural	7	4	1	1	2	0	6	-10	1	1	2	Series Z - Process and Procedural	1	14	0	0	0	0
TOTAL	724	217	178	34	39	12	341	-436	22	34	39	TOTAL	383	653	156	0	0	12

Appendix 10. Failure Mode and Effects Analysis (FMEA) of SHW Series

Cause Type Discipline (SHW Series)	Probability (*P*) Total NCRs	Probability (*P*) Likelihood (Frequency)	Severity (*S*) Total Cost	Severity (*S*) %	Severity (*S*) Severity (Cost)	Real-time: Real-time Detectability (*D*)	Real-time: RPN (Real)	Retrospective: Retrospective Detectability (*D*)	Retrospective: RPN (Retro)	Diff (Decision Making)
Series 1700 - Concrete (Piling)	72	7	£135,500	1.752%	6	3.1	131.0	4.3	179.5	-48.5
Series 900 - Pavement (Bitumen Bound)	22	6	£117,500	1.519%	6	2.3	83.5	3.6	129.3	-45.8
Series 1300 - Lighting Columns	2	4	£10,000	0.129%	4	2.0	32.0	4.5	72.0	-40.0
Series 2300 - Bridge Expansion Joints	1	4	£5,000	0.065%	4	2.0	32.0	4.5	72.0	-40.0
Series W - Archaeology (Intrusive works)	1	4	£4,000	0.052%	4	2.0	32.0	4.5	72.0	-40.0
Series 600 - Earthworks (General)	122	7	£587,500	7.596%	7	3.2	156.1	3.9	192.2	-36.0
Series 1700 - Concrete (Bridge)	180	8	£584,500	7.558%	7	3.3	186.0	4.0	221.3	-35.3
Series 1100 - Kerbs	27	6	£121,100	1.566%	6	2.0	72.0	2.9	105.3	-33.3
Series 1800 - Structural Steel (Bridge)	24	6	£134,500	1.739%	6	2.9	103.3	3.7	133.8	-30.5
Series 1200 - Road Markings	6	5	£28,500	0.369%	5	3.3	83.3	4.5	112.5	-29.2
Series 1100 - Footway	10	5	£58,500	0.756%	5	2.0	50.0	3.1	77.8	-27.8
Series 400 - Slipform works (Barrier)	25	6	£127,500	1.649%	6	4.6	164.9	5.3	192.2	-27.4
Series 400 - Road Restraint System	36	6	£149,500	1.933%	6	3.1	113.0	3.9	140.0	-27.0
Series 1800 - Structural Steel (Gantry)	9	5	£61,000	0.789%	5	2.9	72.2	3.9	98.6	-26.4
Series 1300 - Technology (Civils)	4	5	£11,500	0.149%	4	2.0	40.0	3.3	65.0	-25.0
Series 3000 - Landscaping	5	5	£103,500	1.338%	6	4.0	120.0	4.8	144.0	-24.0
Series 3000 - Environmental	3	4	£15,500	0.200%	4	2.8	45.3	4.3	69.3	-24.0
Series 600 - Earthworks (Sub-Base)	58	6	£415,300	5.370%	7	3.1	130.3	3.7	153.9	-23.5
Series 1700 - Concrete (Culvert)	43	6	£134,700	1.742%	6	3.1	111.8	3.7	133.5	-21.8
Series 300 - Permanent fencing	8	5	£12,700	0.164%	4	2.8	56.3	3.8	76.3	-20.0
Series 1200 - Traffic Signs	5	5	£8,500	0.110%	4	2.5	50.0	3.5	70.0	-20.0
Series 1100 - Paved Areas (including Tactile)	2	4	£8,500	0.110%	4	2.0	32.0	3.3	52.0	-20.0
Series 100 - Existing utilities	10	5	£51,000	0.659%	5	2.5	62.5	3.3	81.3	-18.8
Series 2000 - Waterproofing for Concrete	11	5	£70,000	0.905%	5	2.2	55.7	2.9	72.7	-17.0
Series 500 - General (Drainage, services and ducts)	136	7	£786,600	10.171%	7	3.2	154.9	3.5	171.1	-16.2
Series 600 - Earthworks (Topsoil)	11	5	£52,500	0.679%	5	2.2	55.7	2.7	67.0	-11.4
Series 1000 - Pavement (Concrete)	12	5	£34,000	0.440%	5	4.9	121.9	5.2	129.2	-7.3
Series 1600 - Piling	36	6	£65,000	0.840%	5	3.3	99.6	3.5	105.8	-6.2
Series 1700 - Concrete (RC Base)	15	5	£36,750	0.475%	5	3.9	97.5	4.1	102.5	-5.0
Series X - Materials Management (Storage / Movement)	11	5	£271,500	3.511%	6	2.0	60.0	2.0	60.0	0.0
Series 3000 - Ecology	2	4	£2,000	0.026%	3	2.0	24.0	2.0	24.0	0.0
Series 1400 - Electrical Works	1	4	£2,500	0.032%	3	2.0	24.0	2.0	24.0	0.0
Series 1800 - Structural Steel (Culvert)	1	4	£1,000	0.013%	3	2.0	24.0	2.0	24.0	0.0
Series Z - Process and Procedural	15	5	£29,000	0.375%	5	4.5	111.7	4.3	108.3	3.3
Series 700 - Pavement (General)	107	7	£357,500	4.623%	6	5.3	221.9	5.1	213.8	8.1
Series 1700 - Concrete (Retaining Wall)	18	6	£2,169,500	28.052%	8	5.4	257.3	5.1	246.7	10.7
Series 000 - Design	73	7	£564,100	7.294%	7	4.3	212.4	3.9	190.3	22.2
Series 500 - Slipform works (Drainage)	18	6	£43,100	0.557%	5	5.7	170.0	4.7	141.7	28.3
Series 800 - Pavement (Unbound)	37	6	£203,000	2.625%	6	5.0	180.5	4.2	151.7	28.8
Series 1500 - Communications (Technology)	7	5	£27,000	0.349%	5	4.5	112.5	3.3	81.3	31.3
Series 2100 - Bridge Bearings	2	4	£3,000	0.039%	3	6.0	72.0	3.3	39.0	33.0
Series Y - Plant Management (Parking / Movement)	15	5	£129,000	1.668%	6	4.8	145.0	3.4	103.0	42.0
Series 1800 - Structural Steel (Sheet Pile Retaining Wall)	2	4	£1,000	0.013%	3	8.5	102.0	4.5	54.0	48.0
SUM	1205	***SUM***	£7,733,850							

Probability table (Source: Liu et al., 2013))

Possible failure rate	Rank (%)	Rank
> 1 in 2	50.000%	10
1 in 3	33.333%	9
1 in 8	12.500%	8
1 in 20	5.000%	7
1 in 80	1.250%	6
1 in 400	0.250%	5
1 in 2000	0.050%	4
1 in 15000	0.007%	3
1 in 150000	0.001%	2
1 in 1500000	0.000%	1

Appendix 11. Survey dissemination to contract leaders (group 1)

Gavin Ford

From:	Information hidden
Sent:	09 June 2022 14:00
To:	Sensitive information hidden
Cc:	
Subject:	Non-conformance and rework in construction – A qualitative questionnaire study

Dear All,

Non-conformance and rework in construction – A qualitative questionnaire study

I am reaching out to, on behalf of Gavin Ford, as valued members of our contract leaders' community to seek your thoughts and opinions of nonconformance and rework in construction.

Your support and participation will greatly help Gavin's research into the challenges we face with quality execution within Costain, it's supply chain and the wider construction industry.

Participation in this study is entirely voluntary and you can withdraw any time without giving reason.

The information provided by you will be processed and analysed for the purposes of ascertaining correlations and trends that can positively influence the business (Costain group plc). The data will be held confidentially, securely and will only be used for the purpose of this research. Furthermore, all participant names will <u>not</u> be disclosed and will remain confidential following the research outcome.

You can take part is this survey by following the instruction in *italics* below.

You hereby confirm that you agree with the above and that only the researcher himself can trace the information provided back to you individually. The storage and analysis of this research related data is in accordance with the legal requirements.
By clicking on the "I Agree" button below you will gain access to the questionnaire which will take approximately 15 minutes to complete. Deadline is 30th June 2022.

I Agree

If you have any queries or difficulties accessing the study, you can contact the responsible researcher under: Sensitive information hidden

Many thanks in anticipation of your cooperation.

Regards,

& Gavin

Appendix 12. Survey dissemination to quality community (group 2)

Gavin Ford

From: Gavin Ford
Sent: 09 June 2022 13:54
To: Sensitive information hidden
Subject: Nonconformance and Rework in Construction - A Qualitative Questionnaire Study
Importance: High

Non-conformance and rework in construction – A qualitative questionnaire study

Dear quality professionals,

We are reaching out to our quality community within Costain to seek their thoughts and opinions of nonconformance and rework in construction. You have been hand selected to participate in the study as a member of said community due to your active roles within quality. Your support and participation will greatly help the challenges we face with quality execution within Costain, it's supply chain and the wider construction consortium.

Participation in this study is entirely voluntary and you can withdraw any time without giving reason. The information provided by you will be processed and analysed for the purposes of ascertaining correlations and trends that can positively influence the business (Costain group plc). The data will be held confidentially, securely and will only be used for the purpose of this research. Furthermore, all participant names will not be disclosed and will remain confidential following the research outcome.
You hereby confirm that you agree with the above and that only the researcher himself can trace the information provided back to you individually. The storage and analysis of this research related data is in accordance with the legal requirements.
By clicking on the "I Agree" button below you will gain access to the questionnaire which will take approximately 15 minutes to complete. ***Deadline is 30th June 2022.***

If you have any queries or difficulties accessing the study, you can contact the responsible researcher under Sensitive information *NOTE: It is requested you use your Costain email addresses to access the link as outside email addresses have proved problematic.*

I Agree

Thank you again in advance for your participation.

Regards,
Gavin

Appendix 13. Contract leader survey results export

Nonconformance and rework in construction - What have we learnt?

21	106:48	Active
Responses	Average time to complete	Status

1. Do you see quality execution as a problem within Costain?

Yes	17
No	4

2. Do you see quality execution as a problem with our supply chain?

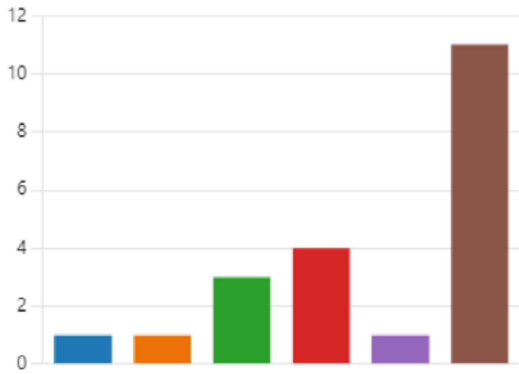
Yes	20
No	1

3. Are we at risk of post project completion latent defects causing long term profitability issues for the business?

Yes	19
No	2

4. According to published literature, rework is costing construction projects anywhere from 0.5% to 12.4% of total project value depending on the discipline (Ball, 1987, Burati et al., 1992, Get It Right Initiative, 2016). For a typical highway's scheme with a profit margin of 3% total project value, what do you believe the combined direct and indirect cost of nonconformance rectification was?

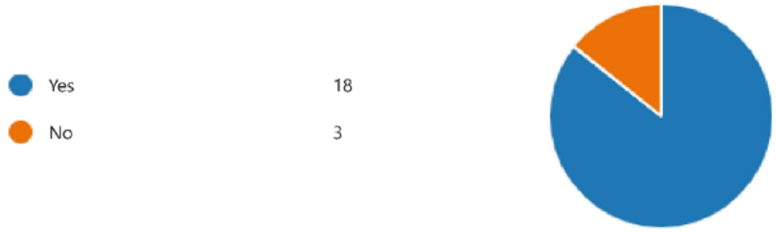
0 – 0.2%	1
0.2 – 0.4%	1
0.4 – 0.6%	3
0.6 – 0.8%	4
0.8 – 1.0%	1
In excess of 1%	11



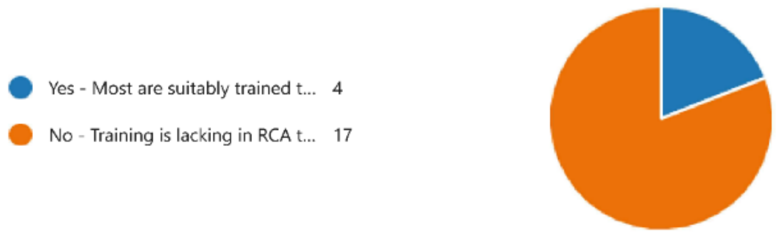
5. On complex construction projects, is there an expectation that 'rework' in some form is inevitable and that 'right-first-time' from start to end of a scheme is unachievable?

Yes	18
No	3

6. Problem solving and decision-making are vital steps to preventing future nonconformance. However, the data suggests that many NCR problems are often 'oversimplified' and that the underlying cause of the problem has not been discovered via appropriate Root Cause Analysis (RCA) methods thus providing incomplete corrective action to address and prevent repetition . Do you agree with this statement?



7. Root Cause Analysis (RCA) is a fundamental tool for identifying underlying causes to prevent future occurrence. Do you feel our team members who manage nonconformance data are Suitably Qualified and Experienced (SQEP) with the necessary training to perform such analysis techniques as 5 whys, Pareto, Fishbone etc?



8. Design issues have significant knock-on effects on our schemes, especially cost. Such issues as **[1]** Late/incorrect design details, **[2]** Insufficient ground investigation & surveys conducted and **[3]** Lack of designer site presence to support builds were fundamental issues that caused nonconformance. Should our contractual arrangements with designers be re-evaluated so as to apportion cost associated for nonconformance as a result of poor design?

9. Due to stringent programme constraints, do we at times progress at risk without approved design details as a result of design delay to stay on the critical path?
Note: Approximately 68 NCRs we found to be attributable due to design related issues costing £534,600

10. What do you believe is the potential consequences for proceeding at risk without approved designs (*Both positive and negative*)?

21
Responses

Latest Responses

"Possible benefits are time related in minimising prelim costs....

"Programme progression which is at huge risk of later rework...

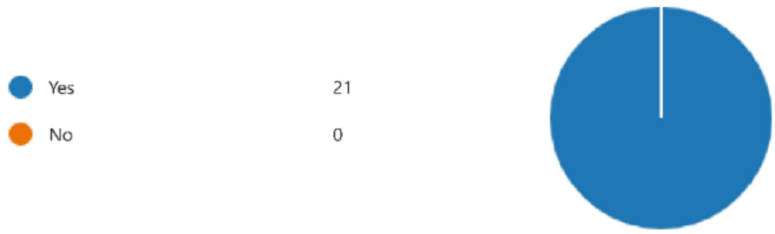
"it's a risk mgmt exercise - how likely are the designs to chan...

Update

11 respondents (**50**%) answered **costs** for this question.

11. Please rank the following in priority order as you see it for delivery of complex construction schemes.

12. Our schemes appear heavily dictated by programme and cost. Of the 1260 NCRs, approximately 51 were caused as a result of continuation of the next activity before finishing the previous in order to meet the programmes critical path. This had significant impacts on the quality of the end product which resulted in rework. Do you believe cost and programme are treated as higher priority than quality delivery on our projects?



13. If you answered 'Yes' to the previous question, do you think that cost and programme are more important than quality delivery? Please explain.

21
Responses

Latest Responses

"Cost and programme are under much more focus by our clie...

"Personally, no. And not on my current project; the value of 'ri...

"No - the three are interrelated. However as a business Costa...

Update

14 respondents (**64**%) answered **Quality** for this question.

14. Further to question 12, do you think our clients value cost and programme over quality delivery on infrastructure schemes?

Yes	15
No	6

15. 'Quality standard' is the level of quality to be achieved that is acceptable by our clients. However, on various schemes, this term differs in understanding between Costain and its clients. Do all parties on our project fully appreciate and understanding the level of quality to be achieved? (E.g It may be a mid-range product as opposed to high-end)

16. If 'No', why do you believe this is the case?

13
Responses

Latest Responses

"It is important to clarify requirements and understand from ...

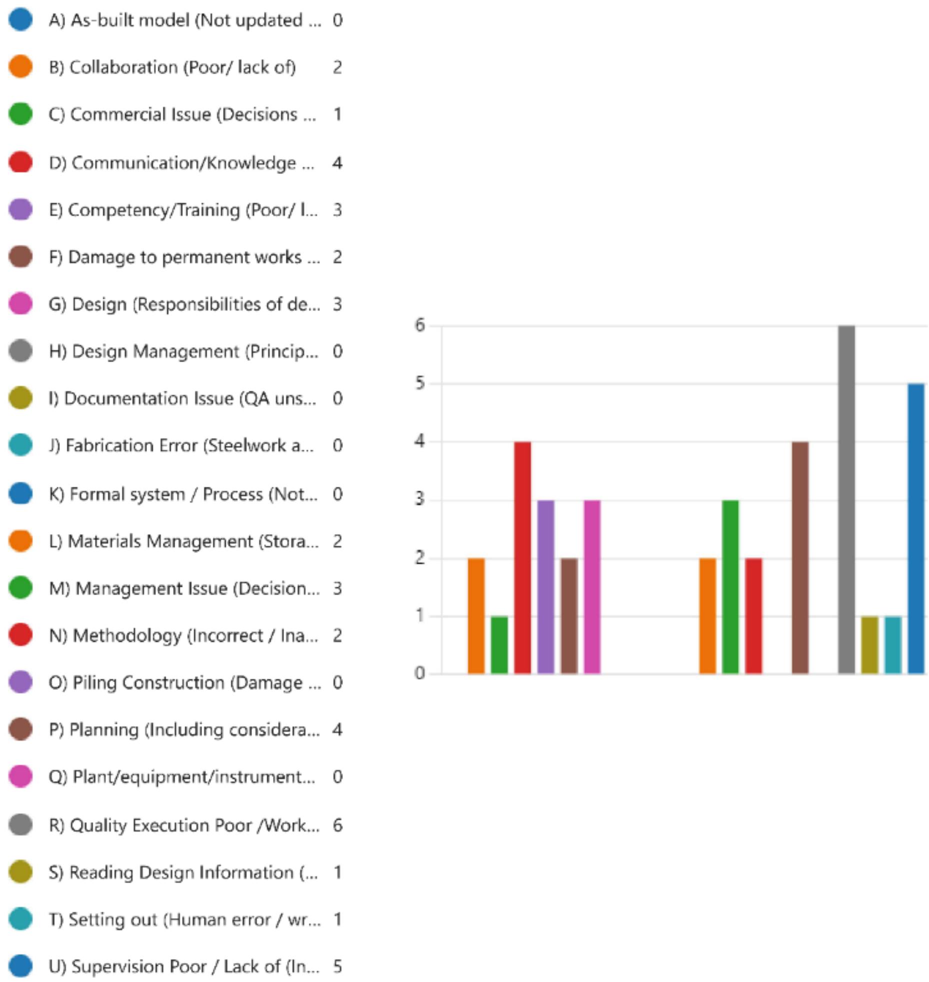
"Client business silos with different and competing objectives...

Update

7 respondents (**50**%) answered **Clients** for this question.

17. Of the following primary root causes, which do you believe are the <u>three</u> most likely to cause a nonconformance? (*Alphabetically ordered*)

Please choose 3 only.



18. Analysis of 1260 nonconformances (NCR's) on a successful major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (**£7,739,850**). Based on a 3% profit margin, that is a potential profit loss of 17% of what could have been achieved. In reality, this figure is conservative and likely to be far higher. Is this figure of concern?

Yes	20
No	1

19. Please explain your answer to the previous question.

21
Responses

Latest Responses

"If we look at the energy expended in delivering these levels ...

"£7m is a huge amount of rework!! The cost of the actual wo...

"At first glance 0.5% looks excessive - I assume the £7.7m is t...

Update

10 respondents (**45**%) answered **cost** for this question.

20. Following on from Question 18, Pareto analysis indicates that of the 1260 NCRs the three most prevalent primary root causes were:

1) Materials Management (Storage, organisation, delivery, testing etc) - **240 cases**
2) Quality Execution Poor /Workmanship (Not following QA procedures) - **181 cases**
3) Supervision Poor / Lack of (Including engineering supervision) - **137 cases**

As a business, what do you believe we should focus on within the three categories above to prevent repetition of future schemes? *Please list.*

21
Responses

Latest Responses

"A consistent approach to site set up and facilities. A return t...

"Storemen and materials acceptance by suitably qualified per...

"Suggest checking the total costs associated with the root cau...

Update

9 respondents (**41**%) answered **quality** for this question.

21. The data suggests we are struggling with Suitably Qualified and Experienced Personnel (SQEP) resources in key project delivery roles (E.g engineers, supervisors). Do you agree with this statement?

22. You've selected 'Yes'. Of the data, there were **137** cases of poor/lack of supervision (including engineering support and verification) and a further **26** cases of competency/training issues notified. What do you believe the solution to be?

19
Responses

Latest Responses

"Reinstating engineering basic site training."

"Training of Engineers between roles. Costain to provide 'trad...

"1) A centrally maintained set of standard ITP & process chec...

Update

9 respondents (**45**%) answered **quality** for this question.

23. You've selected 'No'. Of the data, there were **137** cases of poor/lack of supervision (including engineering support and verification) and a further **26** cases of competency/training issues notified. Why do you think such large figures are occurring?

2
Responses

Latest Responses

24. Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme (30% of the overall NCR dataset). Why do you think we are continuing to make mistakes in concrete operations?

21
Responses

Latest Responses

"Lack of on site training from suitably experienced materials ...

"This is not my experience, but potentially complacency in re...

"With no data other than my own experience i'd suggest relia...

Update

6 respondents (**27**%) answered **quality** for this question.

25. Should we re-evaluate our approach to concrete operations by using more effective methods such as precast as our primary choice? These can be completed outside of other works under controlled conditions to improve quality delivery.

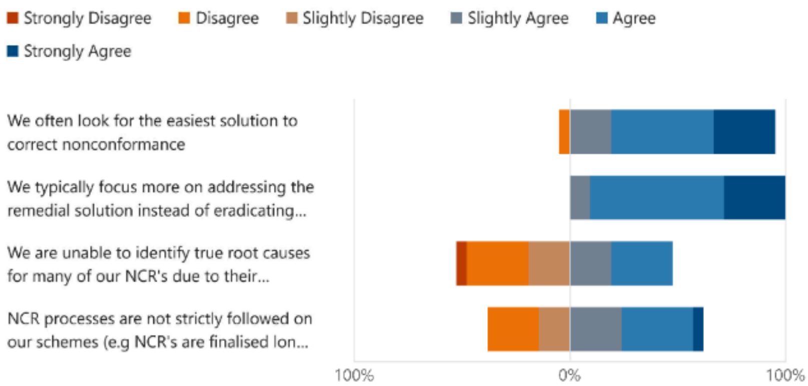
(Note: We must consider defects resolution and project total life cycle costs in our evaluation of appropriate options)

Yes	16
No	5

26. As the principal contractor on many of our projects, we typically outsource the majority of our works to specialist supply chain. The data suggests that supply chain were responsible for 66.3% (**836 cases**) of the total NCR failures with notable commentary raised over performance that resulted in removal from the contract. Are there concerns that typically we select supply chain primarily on price and not previous performance/track record? (The saying "*You get what you pay for*".)

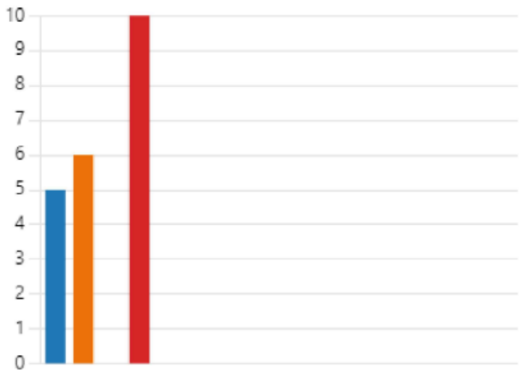
27. One of the most costly NCR's amounted from RECo panel retaining walls which cost the scheme £2,169,500 (*NOTE: Similar trends have been noted on the A465 Heads of the Valley Scheme*). Knowing this, should we continue with these types of constructions?

28. Oversimplification of problem solving NCR's has been a common factor whilst analysing the dataset. As such, we do not always achieve the right root cause to implement sufficient corrective action (See figure). In reality, many problems are far more complex than they seem and often have more than one attributable cause. Please state your position on the following three statements:



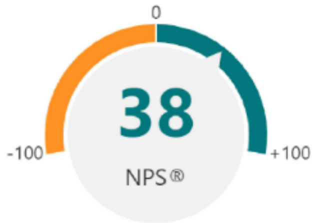
29. What is your title within Costain?

Programme Director (Including ...	5
Project Director (Including Senior)	6
Commercial Director (Including ...	0
Project Manager (Including Seni...	10
Commercial Manager (Including...	0
Quantity Surveyor (Including Se...	0
Quality Director / Head of Quali...	0
Quality Manager (Including Seni...	0
Quality (Engineer / Inspector / C...	0
Systems, Performance and/or As...	0
Handover Manager (Including S...	0
Engineer (Including Senior, Age...	0
Head of Business Improvement	0
Lean Manager	0
Group Research and Innovation ...	0
Head of Technical Assurance	0
Other	0



30. Finally, on a scale of 1 to 10, where 1 is worst and 10 is best, how would you rate your interest of the topics being discussed?

Promoters	8
Passives	13
Detractors	0



Appendix 14. Quality community survey results export

Nonconformance and rework in construction - What have we learnt? (2)

38	31:43	Active
Responses	Average time to complete	Status

1. Do you see quality execution as a problem within Costain?

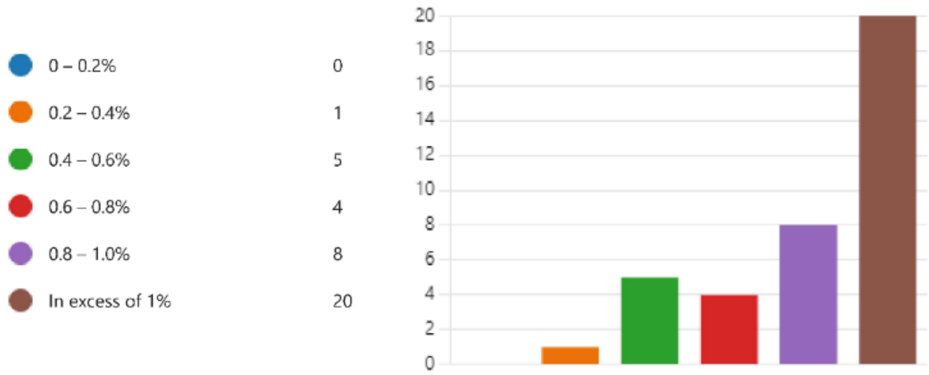
Yes	22
No	16

2. Do you see quality execution as a problem with our supply chain?

Yes	32
No	6

3. Are we at risk of post project completion latent defects causing long term profitability issues for the business?

4. According to published literature, rework is costing construction projects anywhere from 0.5% to 12.4% of total project value depending on the discipline (Ball, 1987, Burati et al., 1992, Get It Right Initiative, 2016). For a typical highway's scheme with a profit margin of 3% total project value, what do you believe the combined direct and indirect cost of nonconformance rectification was?



5. On complex construction projects, is there an expectation that 'rework' in some form is inevitable and that 'right-first-time' from start to end of a scheme is unachievable?

6. Problem solving and decision-making are vital steps to preventing future nonconformance. However, the data suggests that many NCR problems are often 'oversimplified' and that the underlying cause of the problem has not been discovered via appropriate Root Cause Analysis (RCA) methods thus providing incomplete corrective action to address and prevent repetition . Do you agree with this statement?

7. Root Cause Analysis (RCA) is a fundamental tool for identifying underlying causes to prevent future occurrence. Do you feel our team members who manage nonconformance data are Suitably Qualified and Experienced (SQEP) with the necessary training to perform such analysis techniques as 5 whys, Pareto, Fishbone etc?

8. Design issues have significant knock-on effects on our schemes, especially cost. Such issues as **[1]** Late/incorrect design details, **[2]** Insufficient ground investigation & surveys conducted and **[3]** Lack of designer site presence to support builds were fundamental issues that caused nonconformance. Should our contractual arrangements with designers be re-evaluated so as to apportion cost associated for nonconformance as a result of poor design?

9. Due to stringent programme constraints, do we at times progress at risk without approved design details as a result of design delay to stay on the critical path?
Note: Approximately 68 NCRs we found to be attributable due to design related issues costing £534,600

10. What do you believe is the potential consequences for proceeding at risk without approved designs (*Both positive and negative*)?

38
Responses

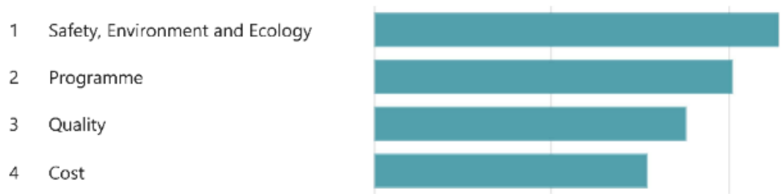
Latest Responses

"Positive - allows you to keep within the project programme ...

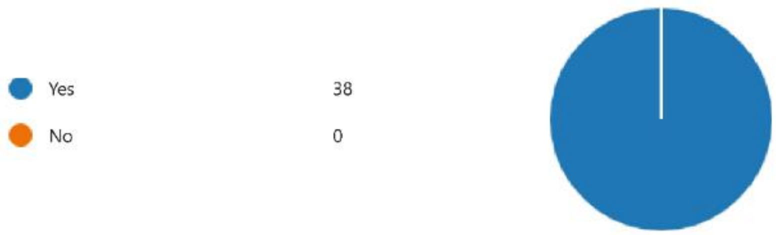
"Positive - Programme Negative - Building something that d...

"Design always are late, therefore RAMS are not clear, MCRs ...

11. Please rank the following in priority order as you see it for delivery of complex construction schemes.



12. Our schemes appear heavily dictated by programme and cost. Of the 1260 NCRs, approximately 51 were caused as a result of continuation of the next activity before finishing the previous in order to meet the programmes critical path. This had significant impacts on the quality of the end product which resulted in rework. Do you believe cost and programme are treated as higher priority than quality delivery on our projects?



13. If you answered 'Yes' to the previous question, do you think that cost and programme are more important than quality delivery? Please explain.

38
Responses

Latest Responses

"As a minimum Quality must have equal focus as cost and pr...

"."

"It is more important for the Construction Team"

23 respondents (**61**%) answered **quality** for this question.

14. Further to question 12, do you think our clients value cost and programme over quality delivery on infrastructure schemes?

Yes	25
No	13

15. 'Quality standard' is the level of quality to be achieved that is acceptable by our clients. However, on various schemes, this term differs in understanding between Costain and its clients. Do all parties on our project fully appreciate and understanding the level of quality to be achieved? (E.g It may be a mid-range product as opposed to high-end)

Yes	14
No	24

16. If 'No', why do you believe this is the case?

24

Responses

Latest Responses

"Depends on the Customer- Why deliver a Rolls Royce when ...

"."

"Cost and after Program are more important for the Constru...

13 respondents (**54**%) answered **Clients** for this question.

17. Of the following primary root causes, which do you believe are the <u>three</u> most likely to cause a nonconformance? (*Alphabetically ordered*)

Please choose 3 only.

18. Analysis of 1260 nonconformances (NCR's) on a successful major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (**£7,739,850**). Based on a 3% profit margin, that is a potential profit loss of 17% of what could have been achieved. In reality, this figure is conservative and likely to be far higher. Is this figure of concern?

19. Please explain your answer to the previous question.

36
Responses

Latest Responses

"To be able to fully appreciate the true cost of rework/ rectific...

"."

"It is more than the percentaje that should be expected. Also, ...

20 respondents (**56**%) answered **cost** for this question.

20. Following on from Question 18, Pareto analysis indicates that of the 1260 NCRs the three most prevalent primary root causes were:

1) Materials Management (Storage, organisation, delivery, testing etc) - **240 cases**
2) Quality Execution Poor /Workmanship (Not following QA procedures) - **181 cases**
3) Supervision Poor / Lack of (Including engineering supervision) - **137 cases**

As a business, what do you believe we should focus on within the three categories above to prevent repetition of future schemes? *Please list.*

37
Responses

Latest Responses

"1. Materials Management (Storage, organisation, delivery, te...

"."

"Procurement - How the supply chain is choosen (A quality a...

18 respondents (**49**%) answered **Quality** for this question.

21. The data suggests we are struggling with Suitably Qualified and Experienced Personnel (SQEP) resources in key project delivery roles (E.g engineers, supervisors). Do you agree with this statement?

22. You've selected 'Yes'. Of the data, there were **137** cases of poor/lack of supervision (including engineering support and verification) and a further **26** cases of competency/training issues notified. What do you believe the solution to be?

36
Responses

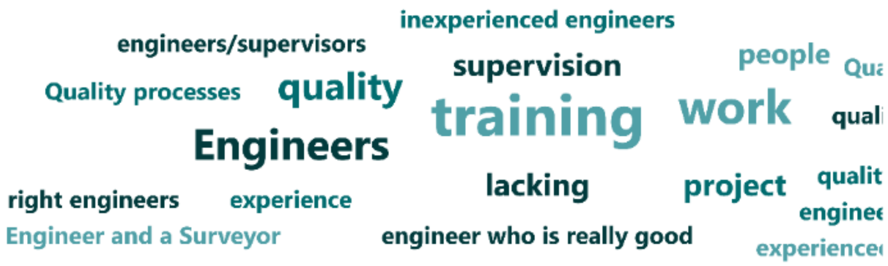
Latest Responses

"From a Quality perspective the biggest issue I have come acr...

"."

"Choose better the construction people involve with the work...

12 respondents (**33**%) answered **training** for this question.



23. You've selected 'No'. Of the data, there were **137** cases of poor/lack of supervision (including engineering support and verification) and a further **26** cases of competency/training issues notified. Why do you think such large figures are occurring?

2
Responses

Latest Responses

24. Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme (30% of the overall NCR dataset). Why do you think we are continuing to make mistakes in concrete operations?

38

Responses

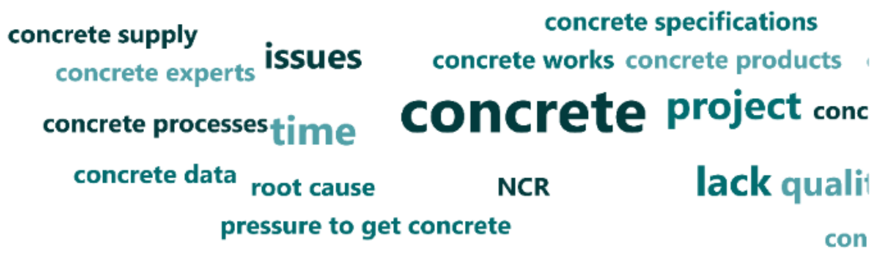
Latest Responses

"Concrete is a poplar material and forms a large percentage ...

"Not learning from previous mistakes, most lessons learnt are...

"The root-cause analysis of the non-conformity wasn't proper...

10 respondents (**26**%) answered **concrete** for this question.



25. Should we re-evaluate our approach to concrete operations by using more effective methods such as precast as our primary choice? These can be completed outside of other works under controlled conditions to improve quality delivery.

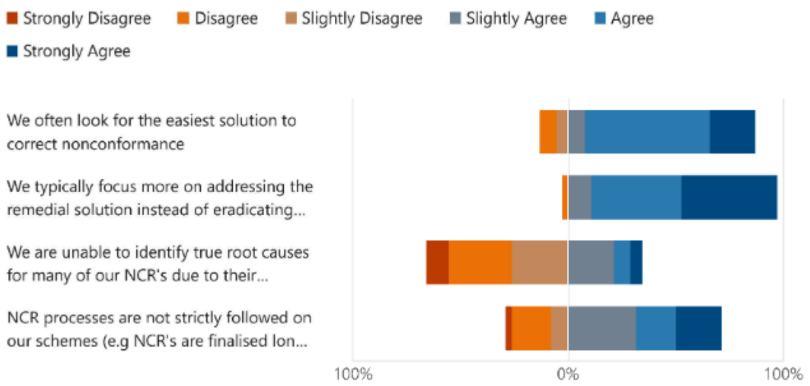
(Note: We must consider defects resolution and project total life cycle costs in our evaluation of appropriate options)

Yes	33
No	5

26. As the principal contractor on many of our projects, we typically outsource the majority of our works to specialist supply chain. The data suggests that supply chain were responsible for 66.3% (**836 cases**) of the total NCR failures with notable commentary raised over performance that resulted in removal from the contract. Are there concerns that typically we select supply chain primarily on price and not previous performance/track record? (The saying "*You get what you pay for*".)

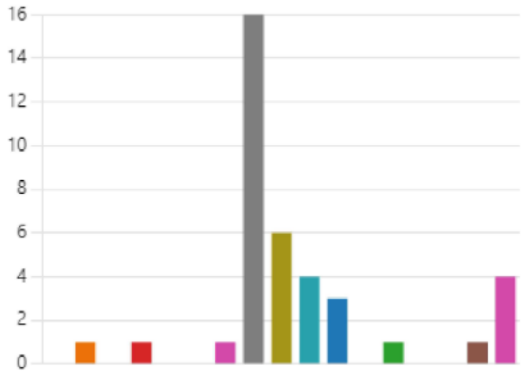
27. One of the most costly NCR's amounted from RECo panel retaining walls which cost the scheme £2,169,500 (*NOTE: Similar trends have been noted on the A465 Heads of the Valley Scheme*). Knowing this, should we continue with these types of constructions?

28. Oversimplification of problem solving NCR's has been a common factor whilst analysing the dataset. As such, we do not always achieve the right root cause to implement sufficient corrective action (See figure). In reality, many problems are far more complex than they seem and often have more than one attributable cause. Please state your position on the following three statements:



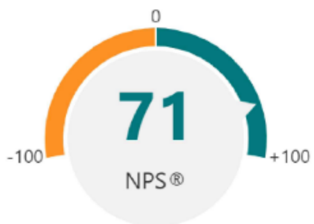
29. What is your title within Costain?

Programme Director (Including ...	0
Project Director (Including Senior)	1
Commercial Director (Including ...	0
Project Manager (Including Seni...	1
Commercial Manager (Including...	0
Quantity Surveyor (Including Se...	0
Quality Director / Head of Quali...	1
Quality Manager (Including Seni...	16
Quality (Engineer / Inspector / C...	6
Systems, Performance and/or As...	4
Handover Manager (Including S...	3
Engineer (Including Senior, Age...	0
Head of Business Improvement	1
Lean Manager	0
Group Research and Innovation ...	0
Head of Technical Assurance	1
Other	4

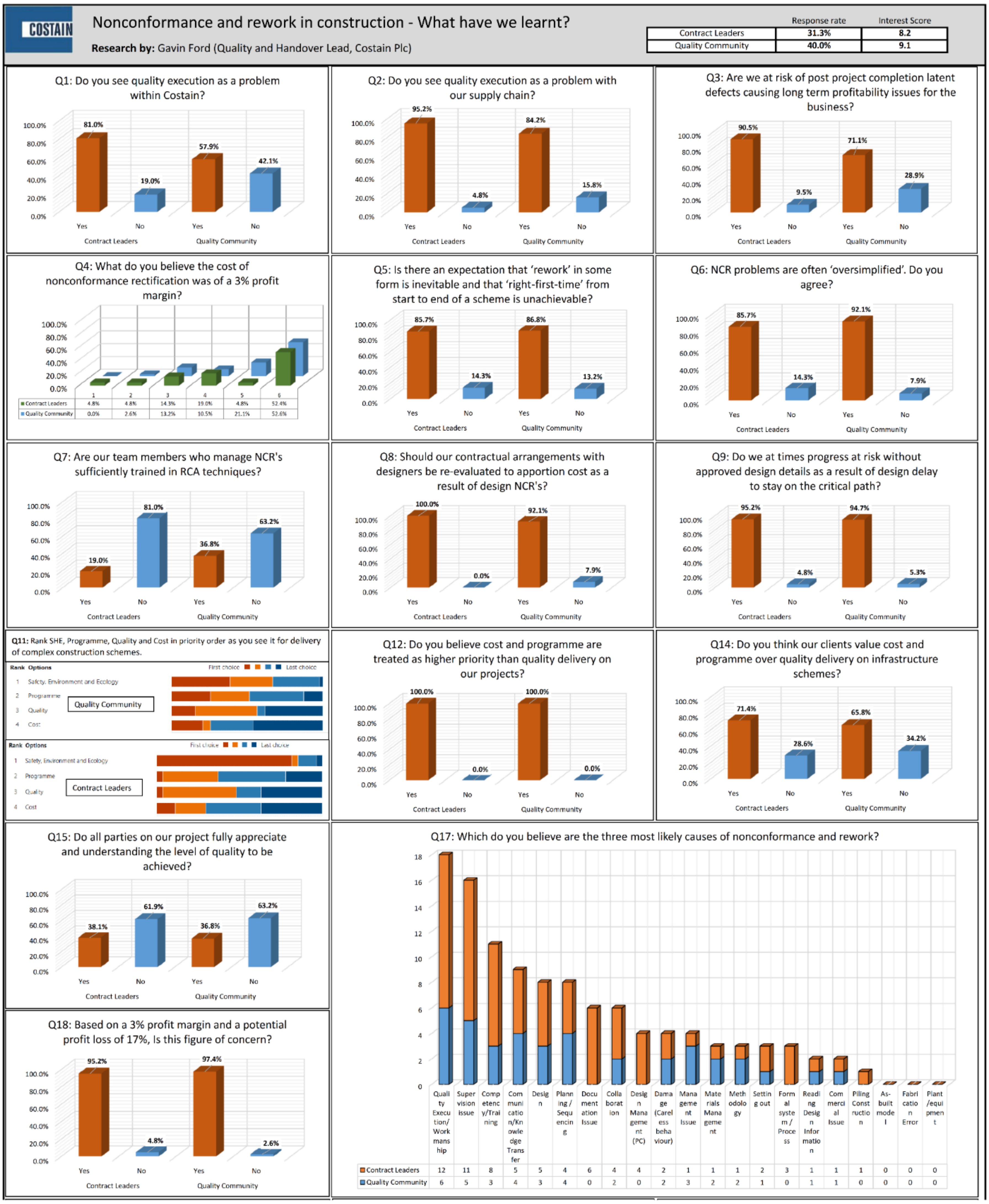


30. Finally, on a scale of 1 to 10, where 1 is worst and 10 is best, how would you rate your interest of the topics being discussed?

Promoters	28
Passives	9
Detractors	1



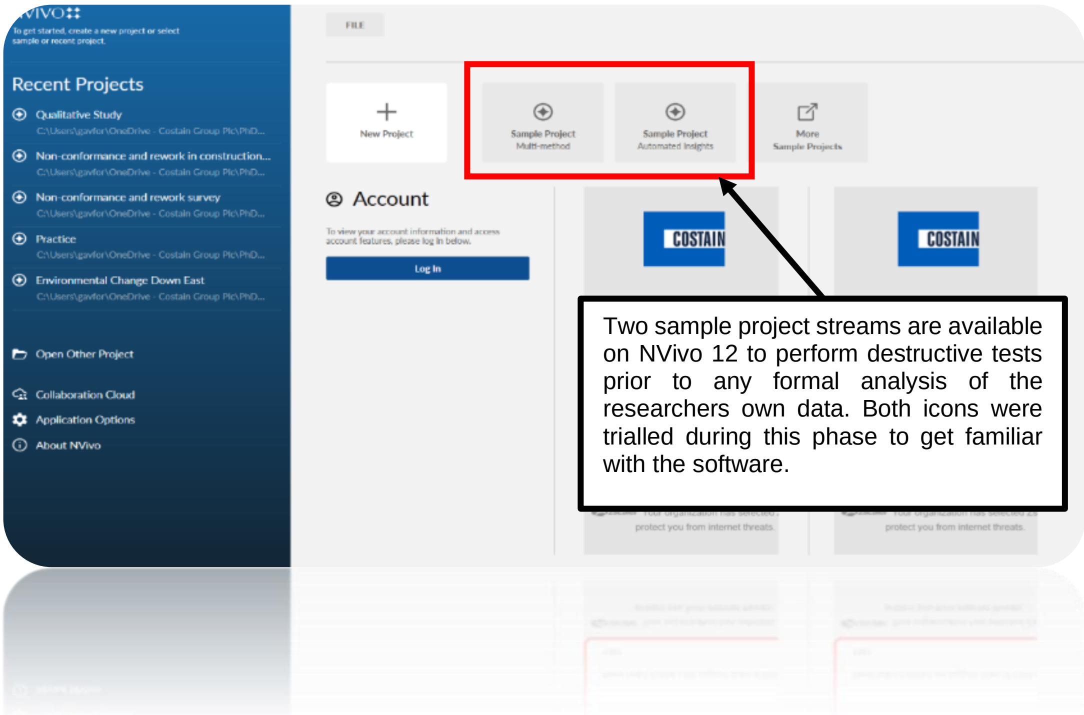
Appendix 15. Closed-ended survey question responses from group 1 and 2



Q21: We are struggling with SQEP resource (E.g engineers, supervisors). Do you agree with this statement?
90.5%
9.5%
94.7%
5.3%
Yes
No
Contract Leaders
Quality Community
Q25: Should we re-evaluate our approach to insitu concrete operations? (e.g. precast)
76.2%
23.8%
86.8%
13.2%
Q26: Are there concerns that typically we select supply chain primarily on price and not previous performance/track record?
76.2%
23.8%
84.2%
15.8%
Q27: RECo panel walls. Due to expensive failings, should we continue with these types of builds?
57.1%
42.9%
52.6%
47.4%
Q28a) We often look for the easiest solution to correct nonconformance
Q28b) We typically focus more on addressing the remedial solution instead of eradicating the underlying cause
Q28c) We are unable to identify true root causes of many of our NCR's due to their complexity
Q28d) NCR processes are not strictly followed on a scheme
Slightly Agree
Agree
Strongly agree
Slightly Disagree
Disagree
Strongly Disagree
What is your role within Costain? (Contract Leaders)
Programme Director (Including Senior)
Project Director (Including Senior)
Project Manager (Including Senior)
What is your role within Costain? (Quality Community)
Head of Business Improvement
Head of Technical Assurance
Head of RDP(N) Integrated...
Quality Director / Head of Quality /...
Project Director (Including Senior)
Project Manager (Including Senior)
Quality Manager (Including Senior)
Handover Manager (Including Senior)
Systems, Performance and/or...
Quality Delivery Manager
Quality (Engineer / Inspector /...
Completions Manager
Product Quality Manager/Materials...

Step 1 – Training of new software

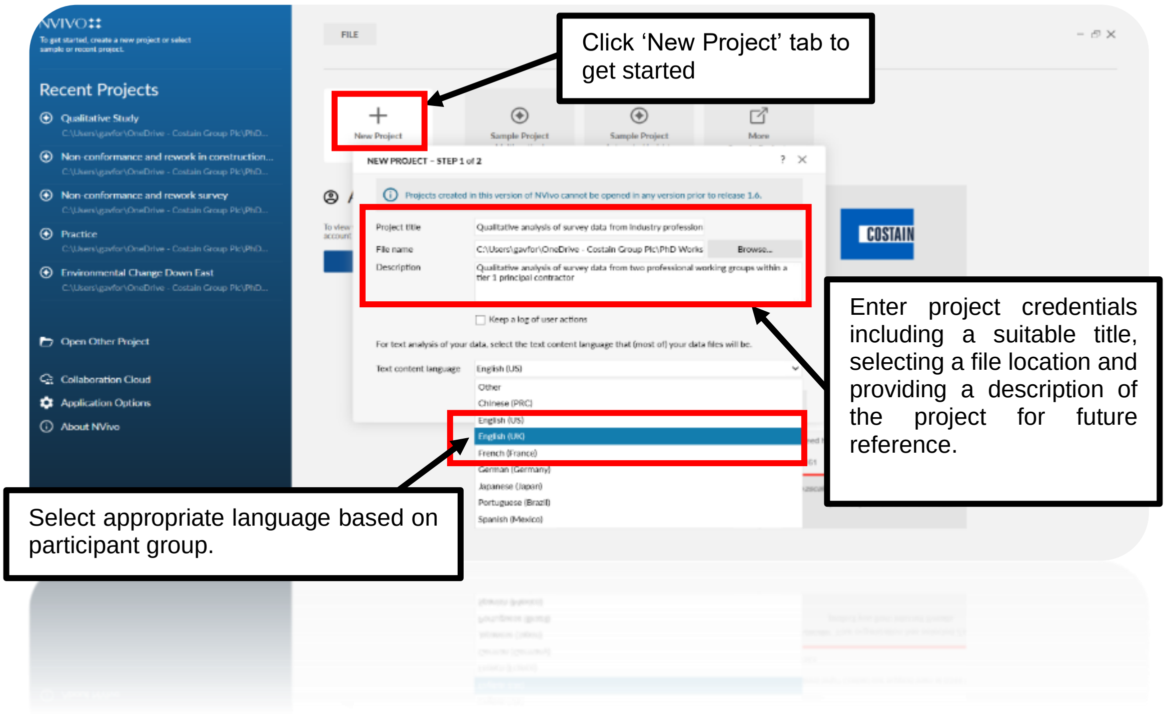
- Specific training provided by Cardiff University is described in main body of thesis (chapter 5.4)
- Additional insights gained from YouTube and literature. A particular useful video presentation created by NVivo was used: https://www.youtube.com/watch?v=Mo6sdP02xIE&t=1326s
- Destructive testing of example test cases was performed by the 'Sample Project' tabs as shown in screenshot X below.



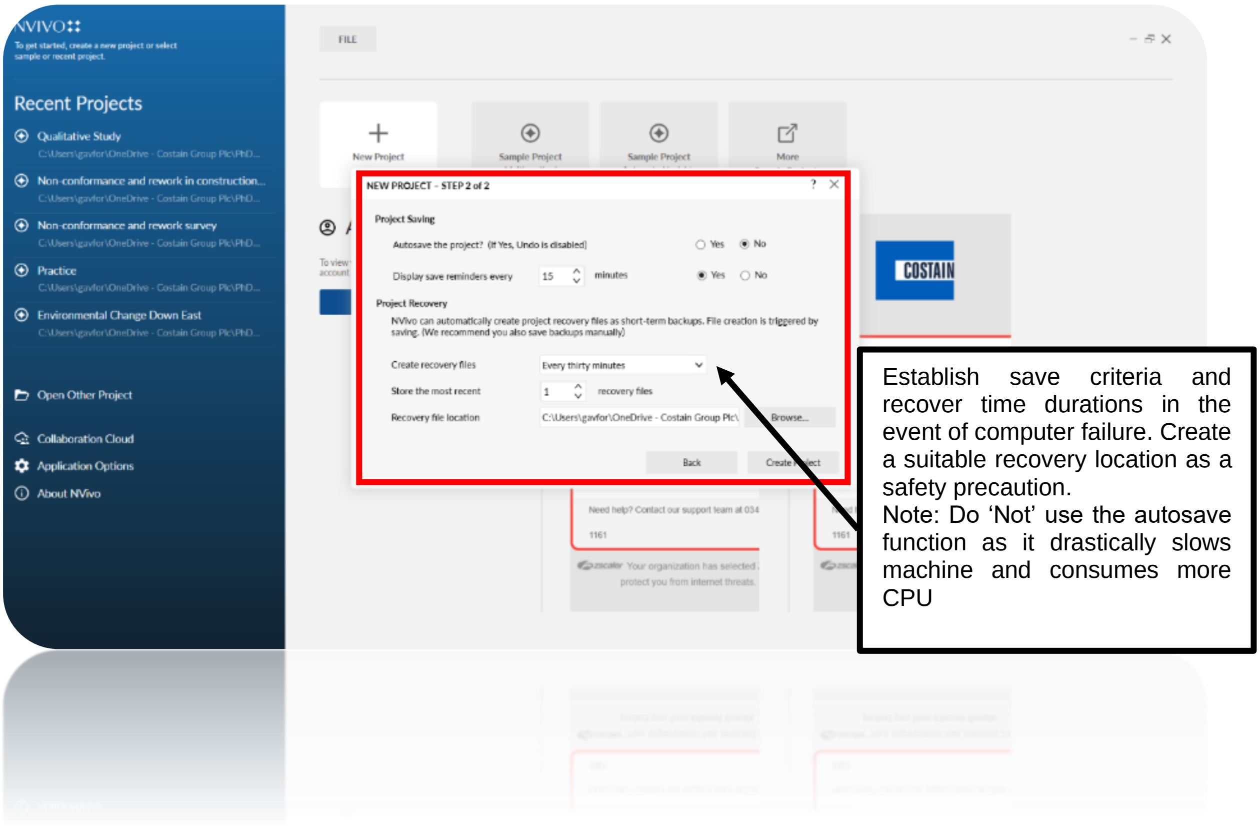
Screenshot 1

Step 2 – Starting a new project

- Click the 'New Project' tab on the main screen and input project information including title, specifying a file location and description for the project (screenshot 2).
- Prior to clicking next, select a suitable language for conducting the software analysis. In this example, 'English (UK)' is selected (screenshot 2).
- Protect data by creating backup durations and save reminders to ensure data is not lost in the event of computer failure (screenshot 3).



Screenshot 2

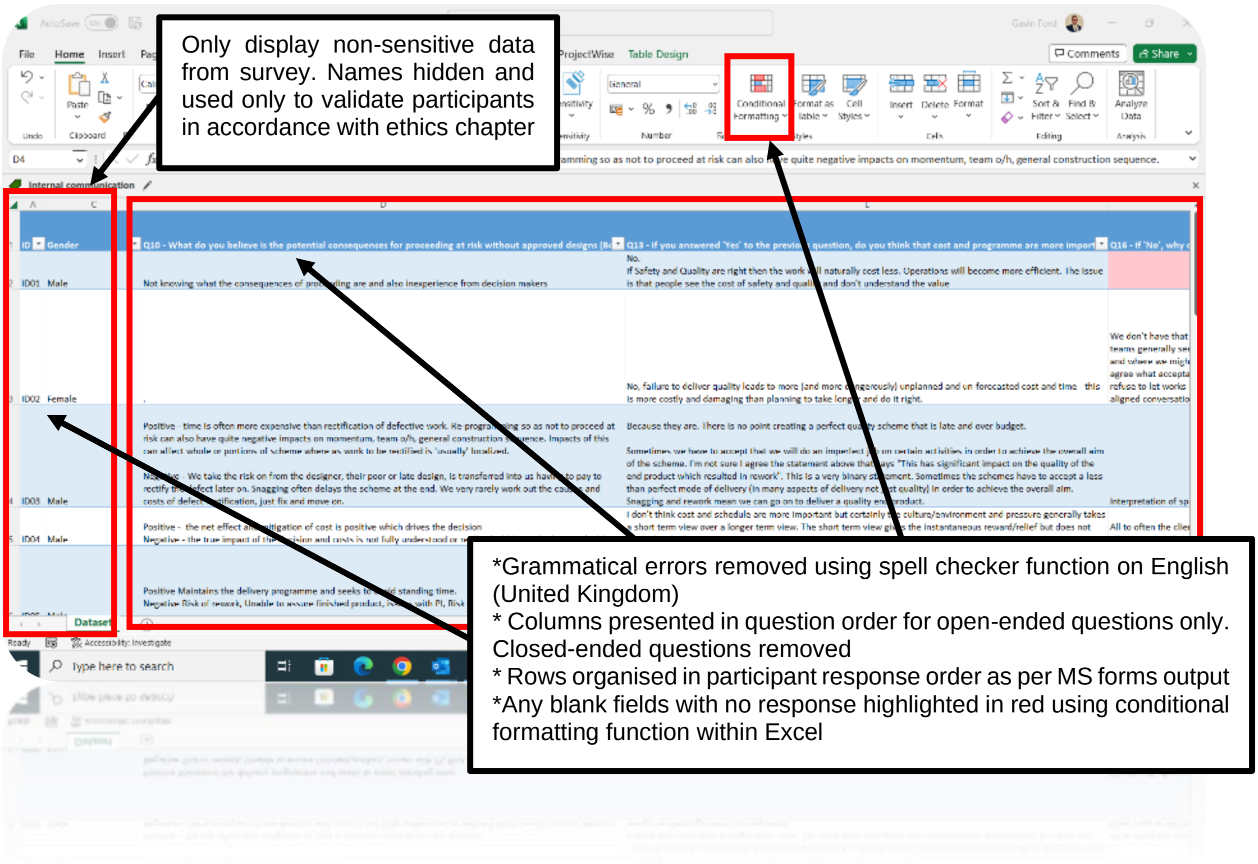


Screenshot 3

Step 3 – Prepare data files and import

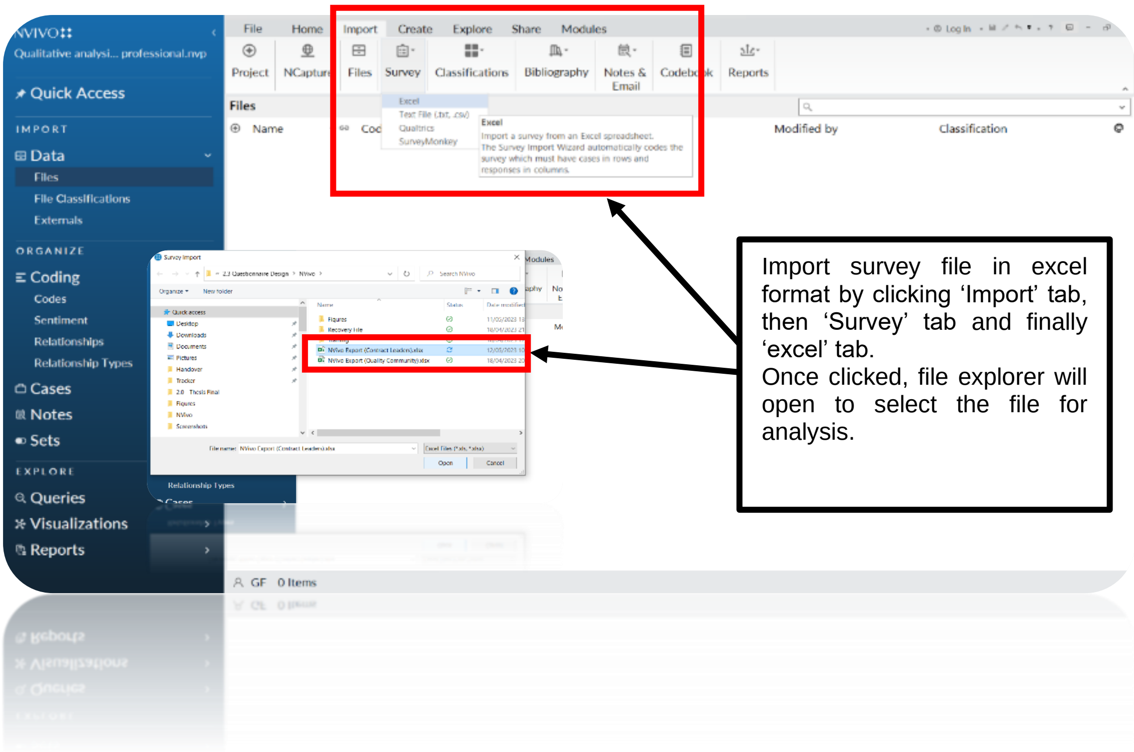
Data export for each response group from MS forms was prepared in a way that presented well in NVivo 12. The following exercises were conducted as per screenshot 4:

- Remove grammatical errors using 'Spelling' checker function under 'Review' tab (F7 Windows shortcut)
- Remove sensitive columns containing names of participants in accordance with ethical considerations chapter
- Remove closed-ended questions from dataset
- Perform conditional formatting on blank cells to identify missing information
- Re-organise columns and rows to present questions along top and participants down the side

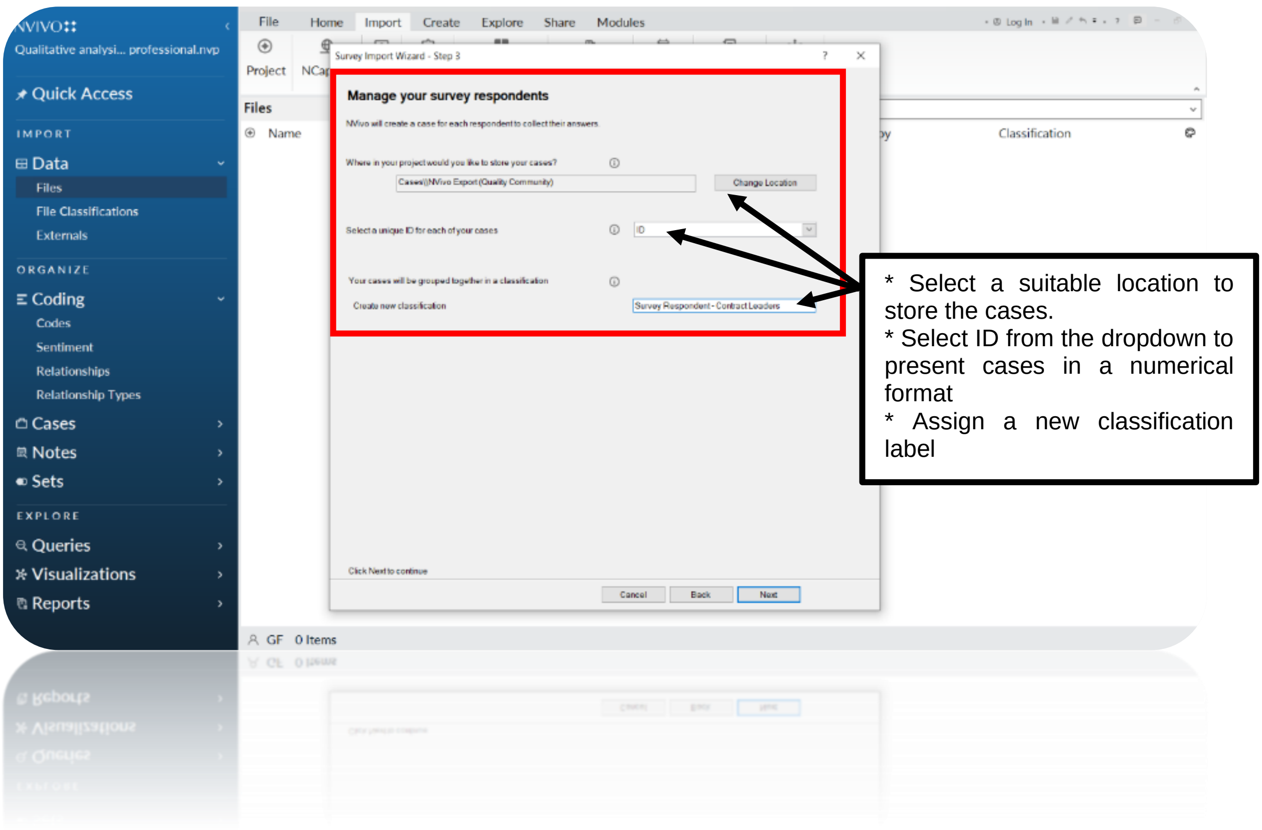


Screenshot 4

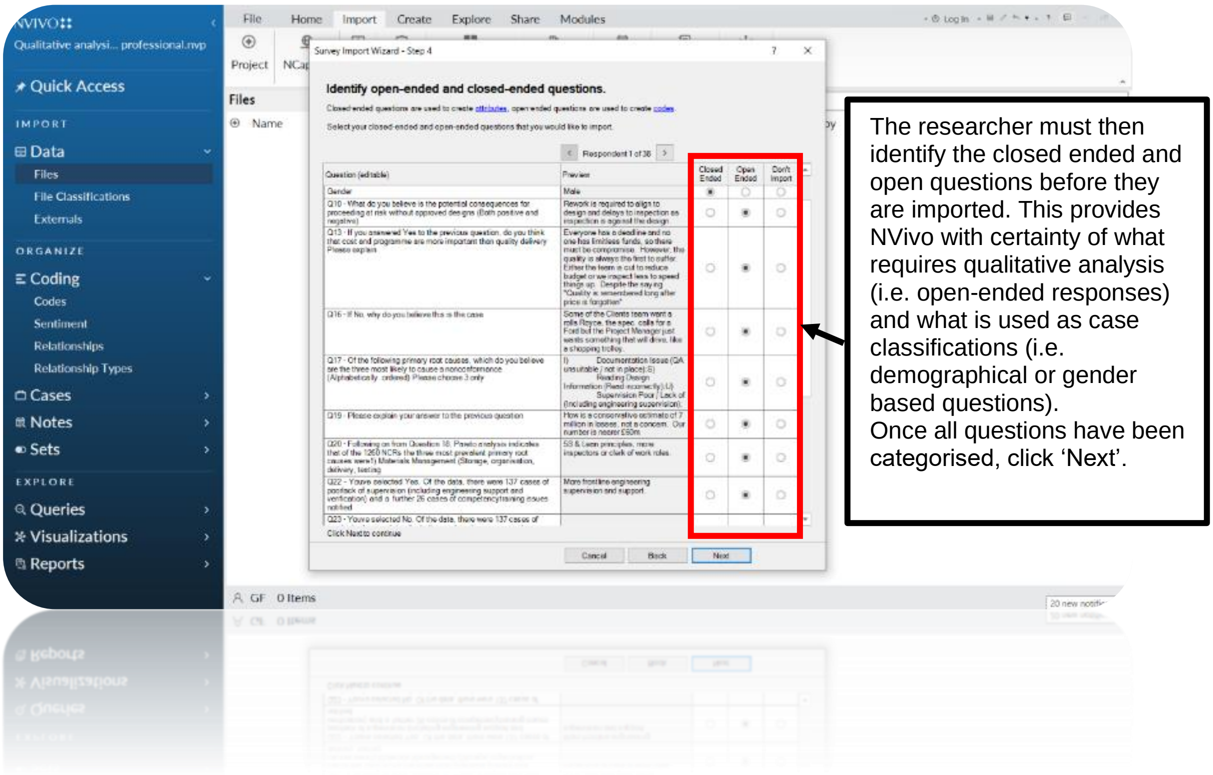
- Once the data is in a format that can be easily digested by NVivo, the files are then to be imported for analysis (screenshot 5).
- Select an appropriate location to store the cases, select a unique I.D referencing format and label the new classification (screenshot 6)
- Finally, the research must identify open-ended and closed-ended questions before they are imported (screenshot 7). Once satisfied, click 'Next' to import.



Screenshot 5



Screenshot 6

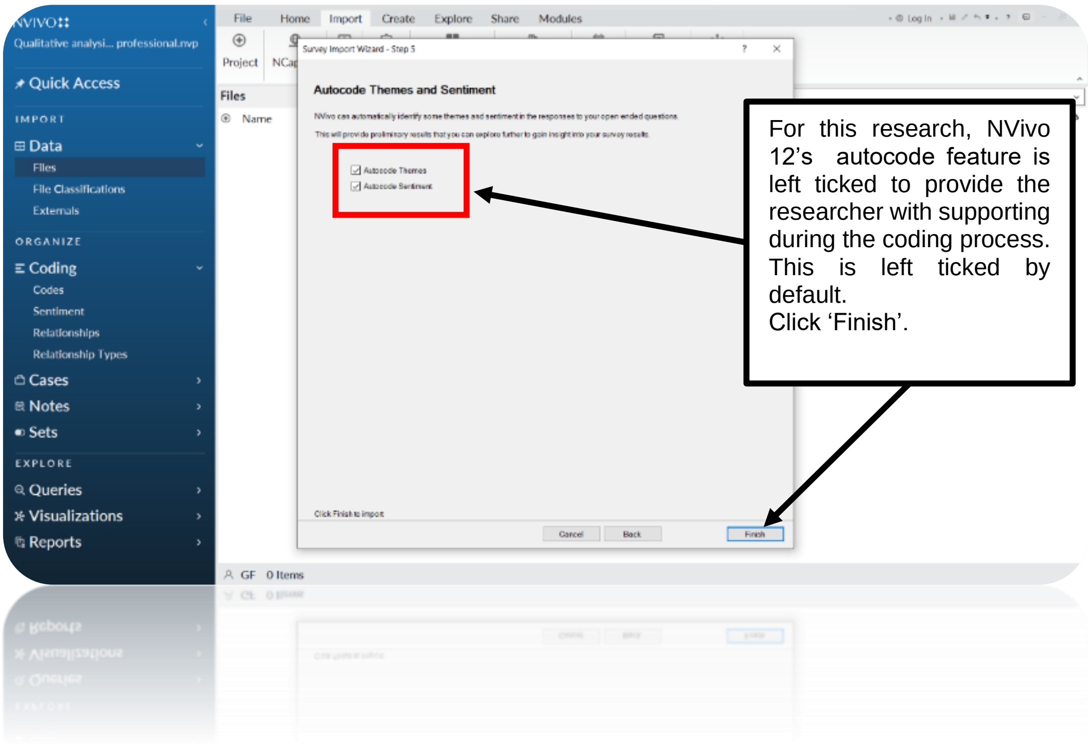


Screenshot 7

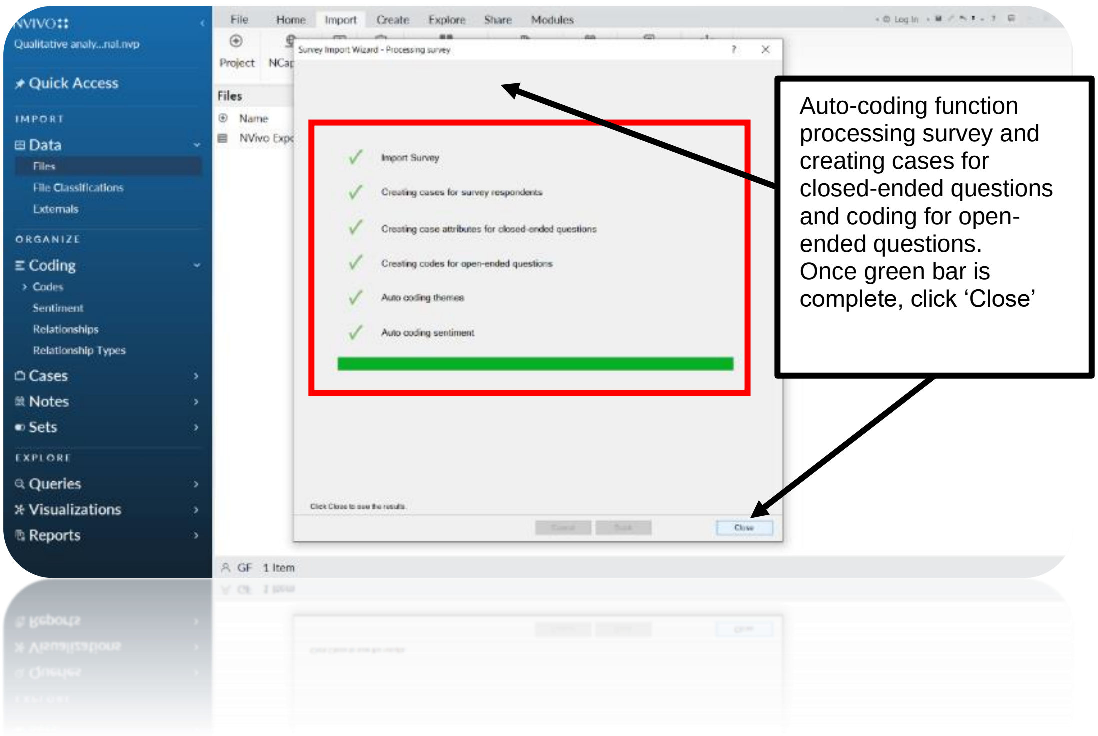
Step 4 – Code data entries

A new feature exists on the latest NVivo software whereby the software can auto-code the document by interrogating the data and select most frequent words and phrases as nodes.

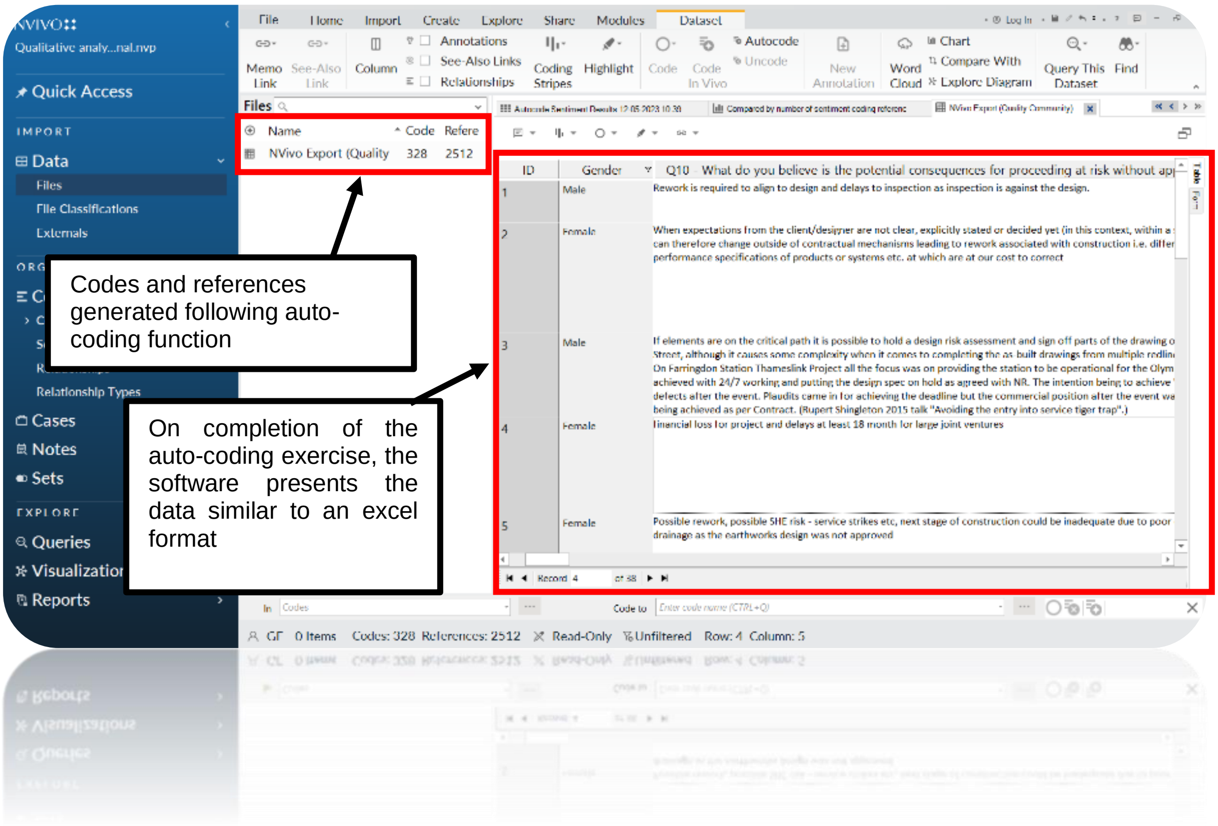
- ❖ Once ‘Next’ has been clicked (screenshot 7), the researcher is presented with a choice whether to use the auto-code function or undertake the task manually. For this research, the auto-code option is used (screenshot 8). Both ticks are left as default and ‘Finish’ is clicked.
- ❖ The software then performs the auto-coding exercise and creates cases for closed-ended questions and coding (i.e. nodes) for open-ended questions to allow the research to cross examine different characteristics. Once complete, click ‘Close’ (screenshot 9).
- ❖ Once auto-coding is complete, a display is presented showing the number of codes and references assigned to the survey file along with the dataset (screenshot 10).



Screenshot 8



Screenshot 9



Screenshot 10

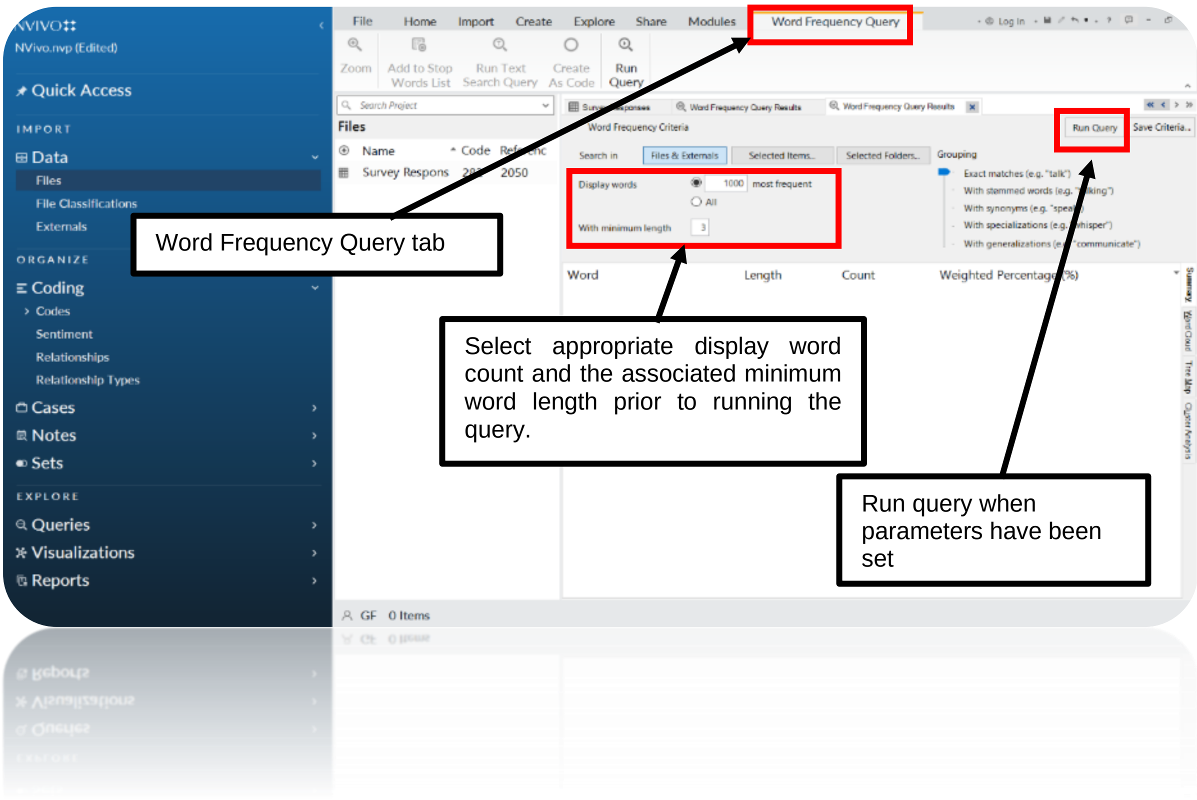
Step 5 – Visualisation and Analysis techniques

There are many visualisation techniques and query searches that can be used to analyse the data. A few are mentioned below but not limited to:

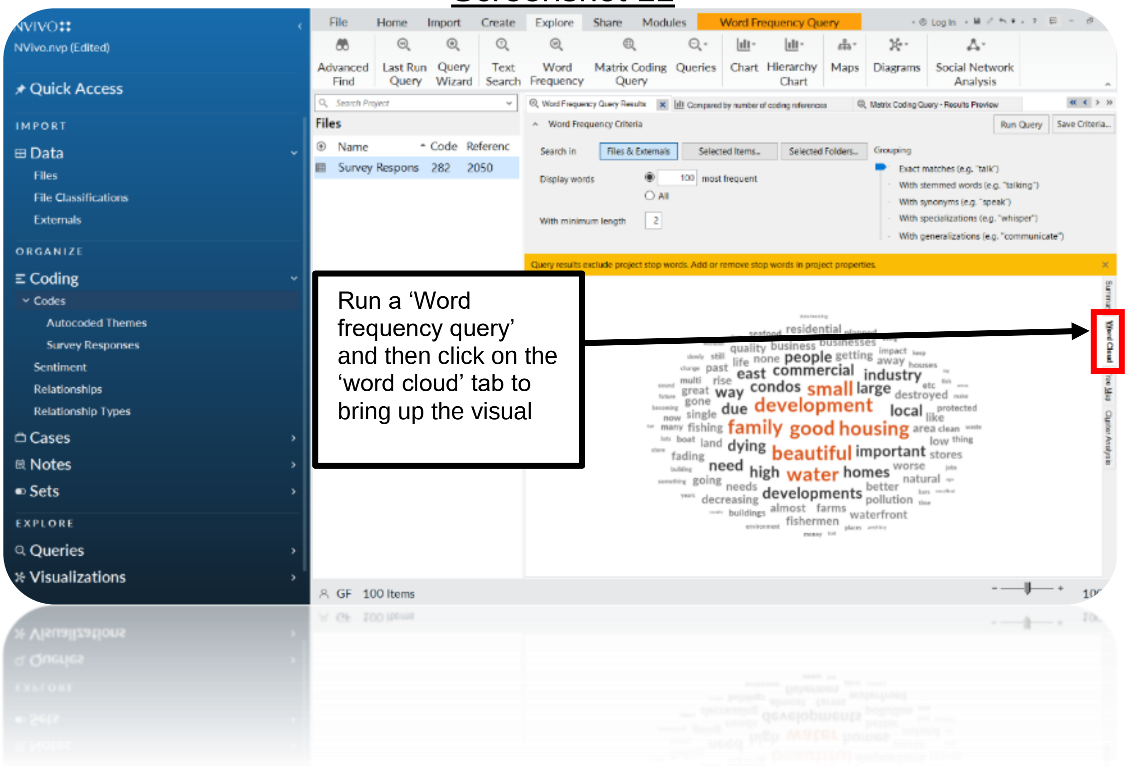
(1) ***Word frequency query*** – Identifies the most prominent and frequently used words within the dataset. Click on 'Explore' tab then 'Word Frequency' tab to bring up the word frequency query. The researcher can use the pre-coded words and select the number of words to display. Typically 100 words with a minimum word length of three is suitable (screenshot 11)

   a. ***Word Cloud*** – Provides a visual of the most frequent words within the dataset. When a word frequency query has been run, click on the 'word cloud' tab to display the visual (screenshot 12).

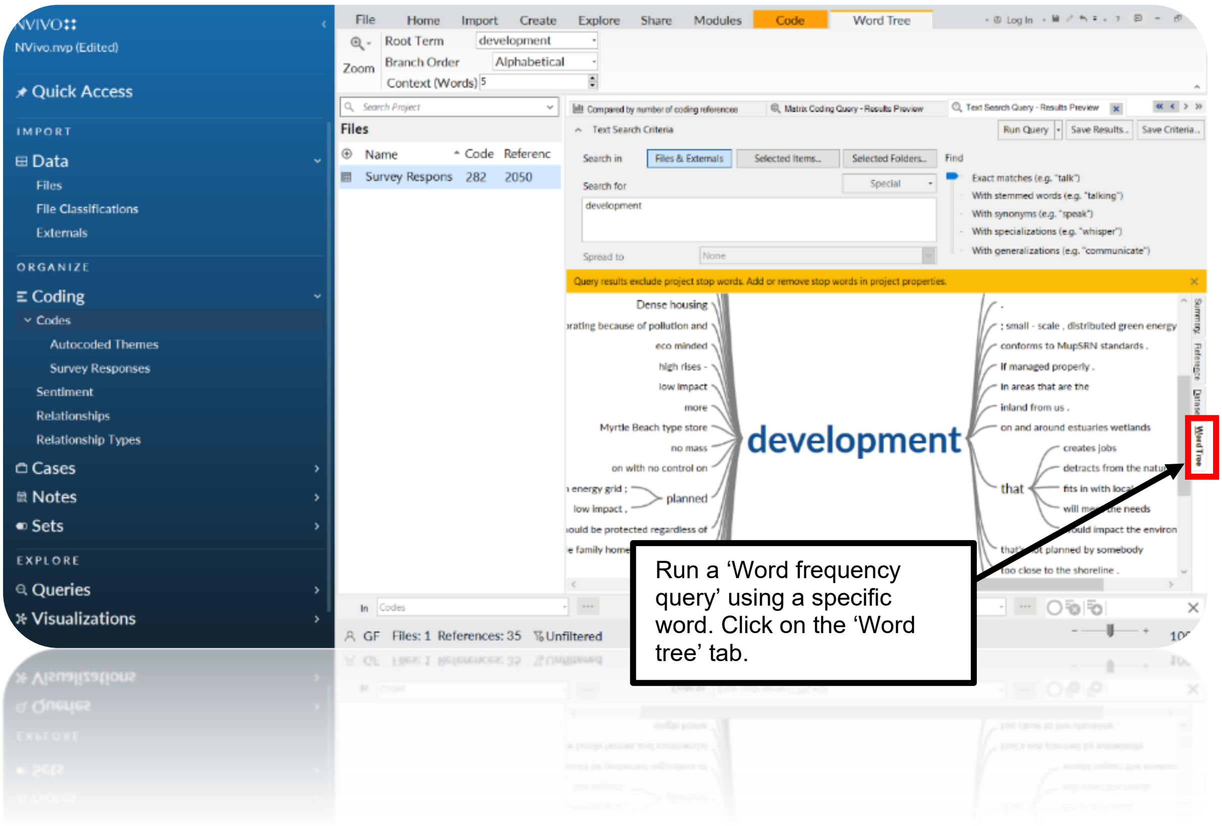
   b. ***Word tree*** – Another visual to interrogate specific words and link the before and after wording (screenshot 13).



Screenshot 11



Screenshot 12



Screenshot 13

Appendix 17. NVivo 12 word frequency tables, clouds and trees for open ended questions

QUESTION 10: What do you believe is the potential consequences for proceeding at risk without approved designs (*Both positive and negative*)?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
design	6	19	3.79	design, designer, designers, designs
costs	5	17	3.39	cost, costs
programme	9	14	2.79	programme
risk	4	12	2.40	risk
work	4	11	2.20	work, works
positive	8	9	1.80	positive, positives
change	6	8	1.60	change, changed, changes
impact	6	8	1.60	impact, impacts
time	4	7	1.40	time
proceeding	10	7	1.40	proceed, proceeding
negative	8	6	1.20	negative
project	7	6	1.20	project
rework	6	6	1.20	rework
approval	8	5	1.00	approval, 'approval, approved
decision	8	5	1.00	decision

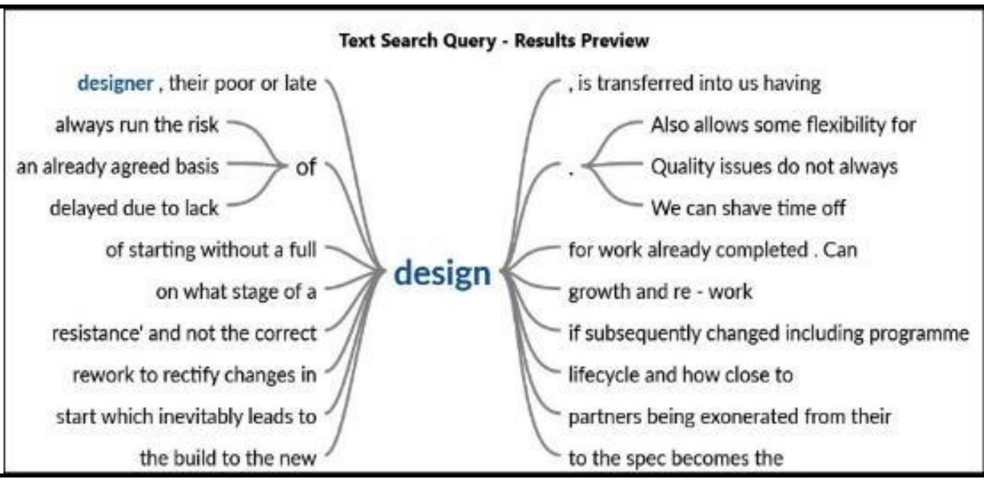
Quality Community

Word	Length	Count	Weighted Percentage (%)	Similar Words
design	6	41	4.43	design, designer
works	5	28	3.03	work, working, works
rework	6	21	2.27	rework, reworks
risk	4	17	1.84	risk, risks
costs	5	15	1.62	cost, costs
programme	9	15	1.62	programme
delays	6	13	1.41	delay, delayed, delays
changes	7	12	1.30	change, changes, changing
positives	9	11	1.19	position, positive, positives
approved	8	10	1.08	approval, approved
time	4	10	1.08	time
increased	9	9	0.97	increase, increased, increasing
drawings	8	8	0.86	drawing, drawings
issues	6	8	0.86	issue, issues
negative	8	8	0.86	negative, negatives

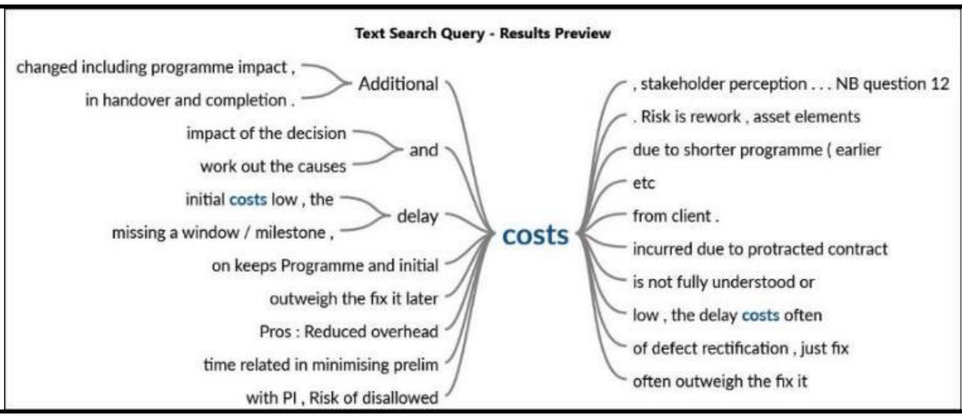
QUESTION 10: What do you believe is the potential consequences for proceeding at risk without approved designs (*Both positive and negative*)?

Contract Leaders

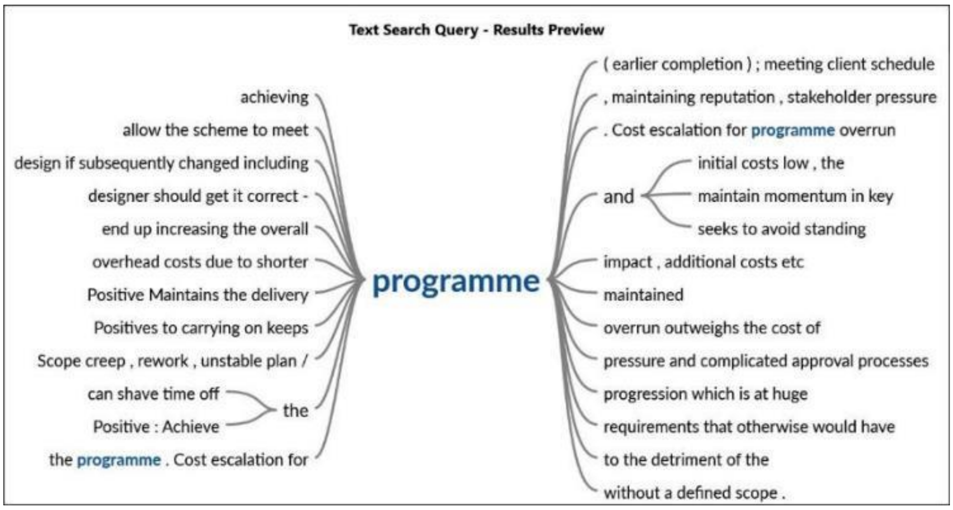
(1) Design



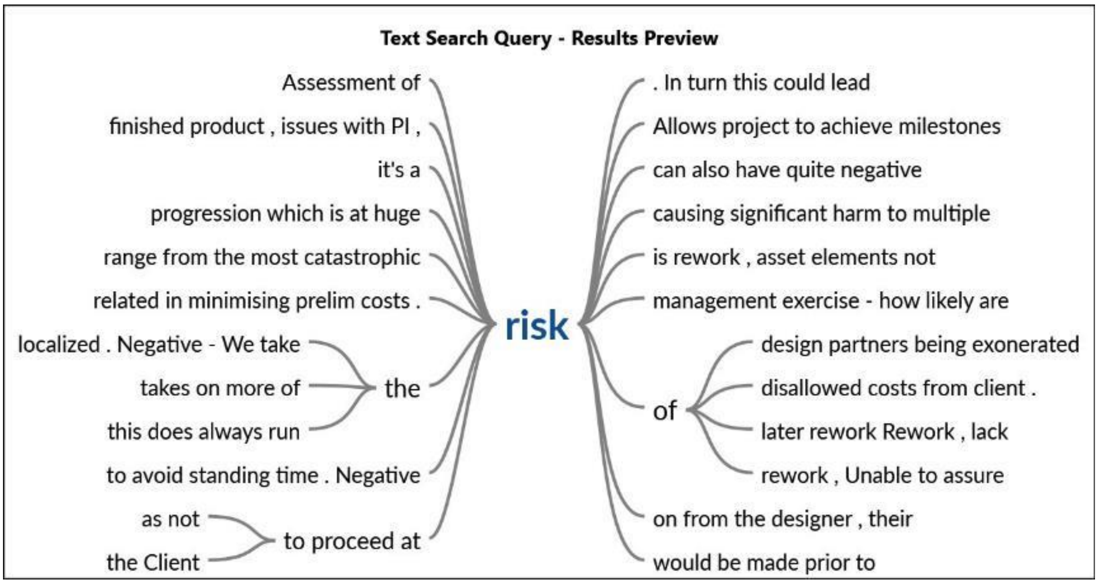
(2) Cost



(3) Programme

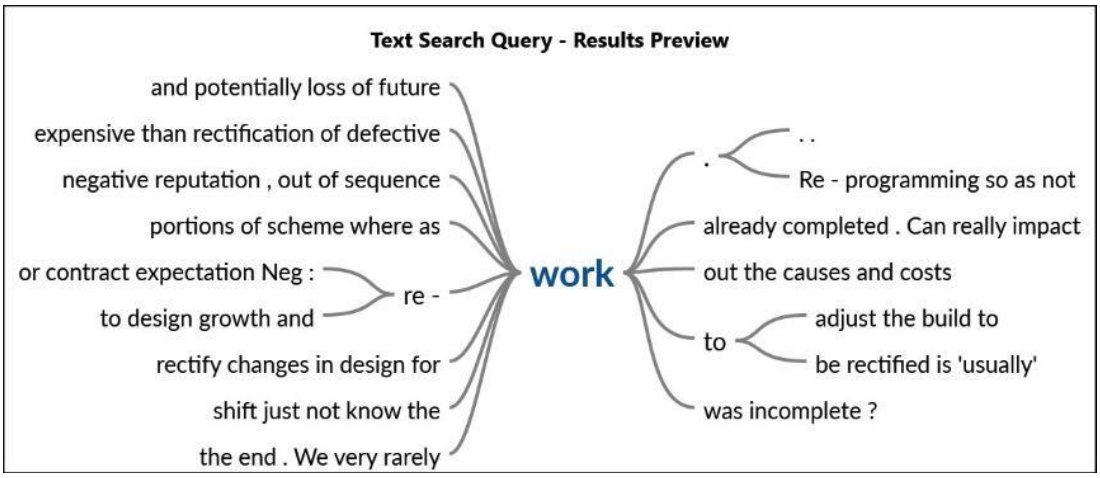


(4) Risk



Text Search Query - Results Preview
Assessment of
finished product , issues with PI ,
it's a
progression which is at huge
range from the most catastrophic
related in minimising prelim costs .
localized . Negative - We take
takes on more of
this does always run
the
to avoid standing time . Negative
as not
the Client
to proceed at
risk
. In turn this could lead
Allows project to achieve milestones
can also have quite negative
causing significant harm to multiple
is rework , asset elements not
management exercise - how likely are
of
design partners being exonerated
disallowed costs from client .
later rework Rework , lack
rework , Unable to assure
on from the designer , their
would be made prior to

(5) Work

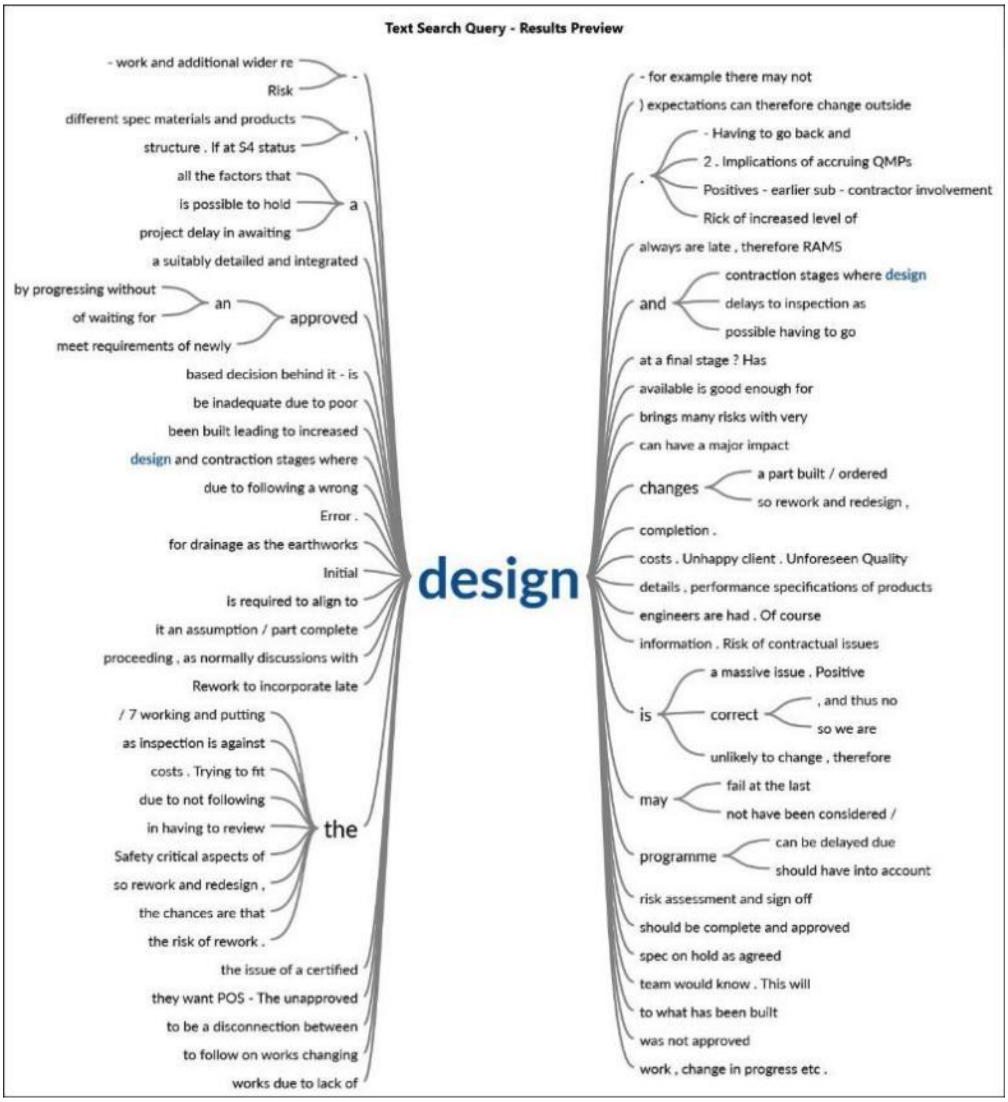


Text Search Query - Results Preview
and potentially loss of future
expensive than rectification of defective
negative reputation , out of sequence
portions of scheme where as
or contract expectation Neg :
to design growth and
re -
rectify changes in design for
shift just not know the
the end . We very rarely
work
.
. .
Re - programming so as not
already completed . Can really impact
out the causes and costs
to
adjust the build to
be rectified is 'usually'
was incomplete ?

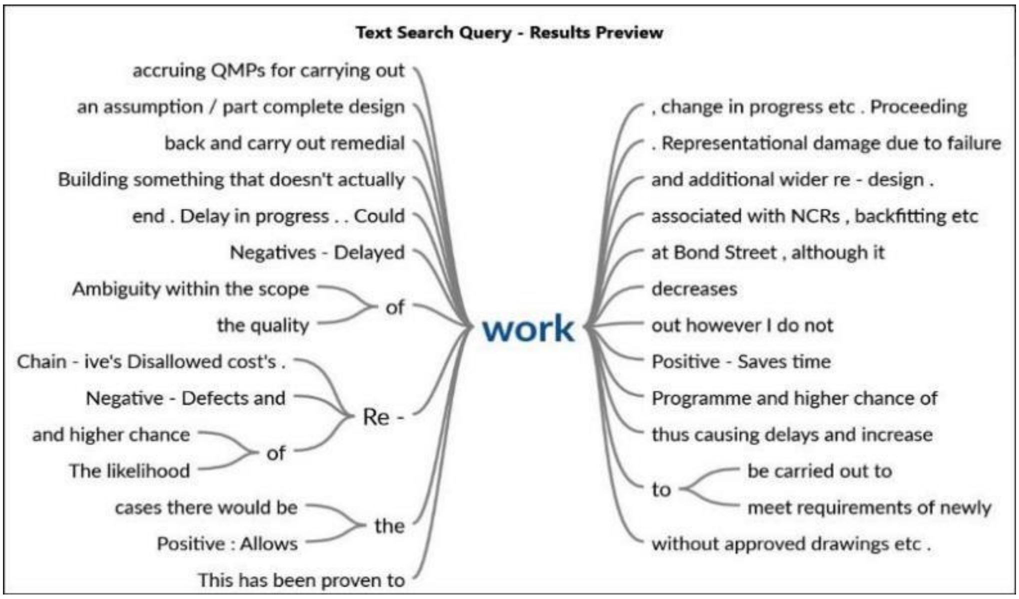
QUESTION 10: What do you believe is the potential consequences for proceeding at risk without approved designs (*Both positive and negative*)?

Quality Community

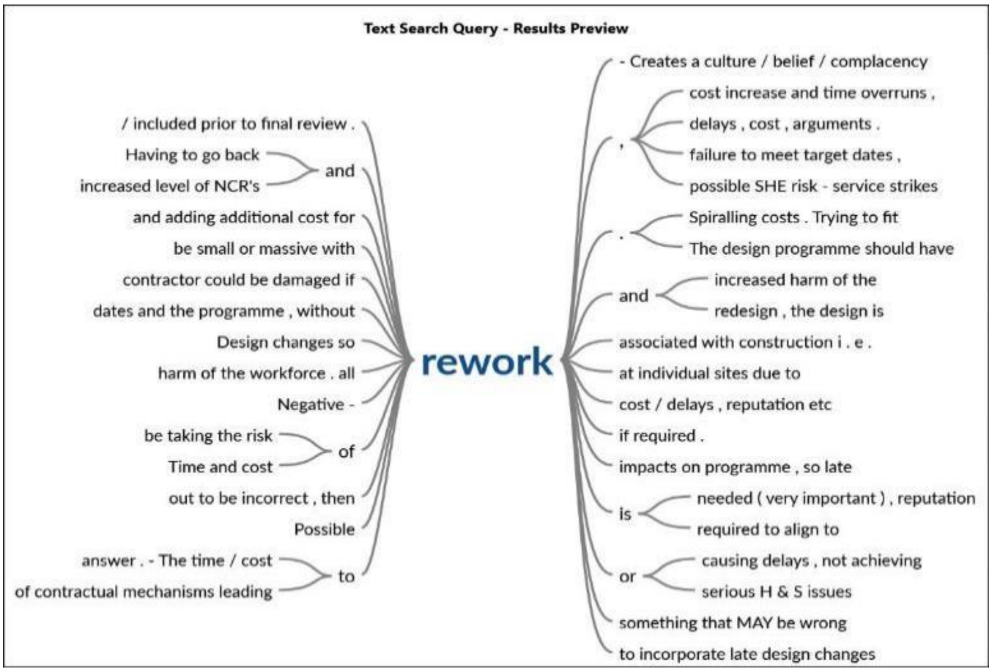
(1) Design



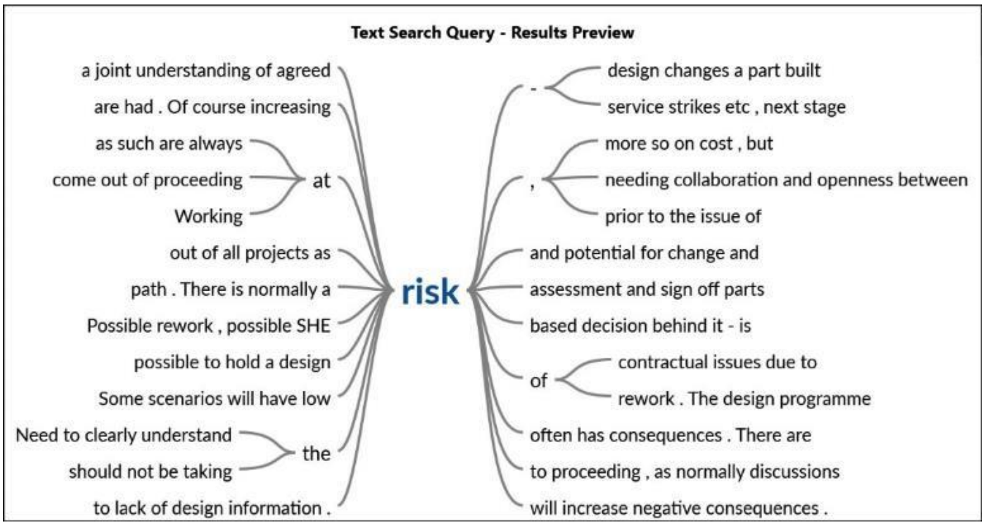
(2) Work



(3) Rework

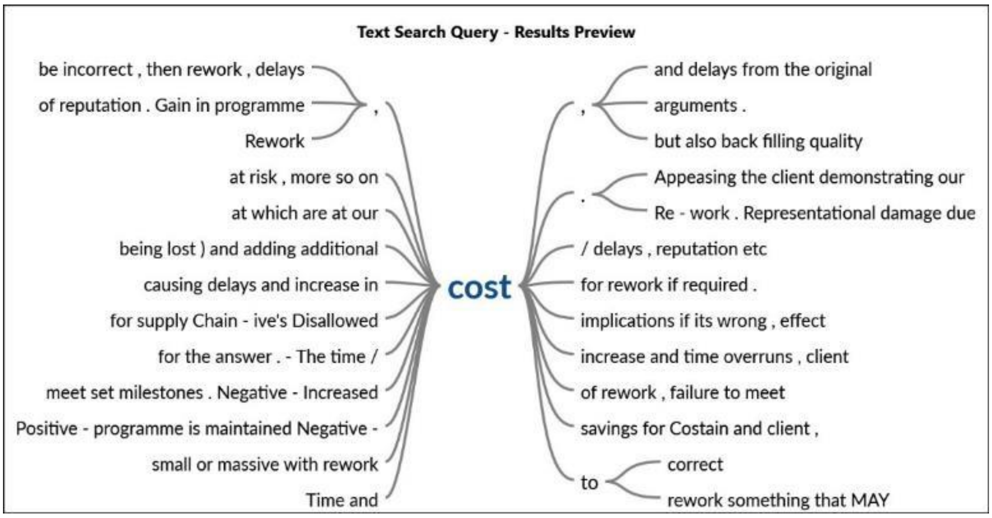


(4) Risk



Text Search Query - Results Preview
a joint understanding of agreed
are had . Of course increasing
as such are always
come out of proceeding
Working
at
out of all projects as
path . There is normally a
Possible rework , possible SHE
possible to hold a design
Some scenarios will have low
Need to clearly understand
should not be taking
the
to lack of design information .
risk
-
design changes a part built
service strikes etc , next stage
,
more so on cost , but
needing collaboration and openness between
prior to the issue of
and potential for change and
assessment and sign off parts
based decision behind it - is
of
contractual issues due to
rework . The design programme
often has consequences . There are
to proceeding , as normally discussions
will increase negative consequences .

(5) Cost



Text Search Query - Results Preview
be incorrect , then rework , delays
of reputation . Gain in programme
Rework
,
at risk , more so on
at which are at our
being lost) and adding additional
causing delays and increase in
for supply Chain - ive's Disallowed
for the answer . - The time /
meet set milestones . Negative - Increased
Positive - programme is maintained Negative -
small or massive with rework
Time and
cost
,
and delays from the original
arguments .
but also back filling quality
.
Appeasing the client demonstrating our
Re - work . Representational damage due
/ delays , reputation etc
for rework if required .
implications if its wrong , effect
increase and time overruns , client
of rework , failure to meet
savings for Costain and client ,
to
correct
rework something that MAY

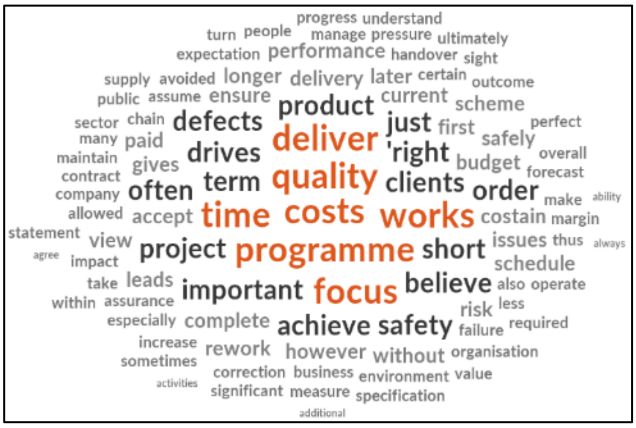
QUESTION 13: Do you think that cost and programme are more important than quality delivery? Please explain.

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
costs	5	27	5.13	cost, costly, costs
quality	7	26	4.94	quality
programme	9	15	2.85	programme
works	5	10	1.90	work, working, works
time	4	9	1.71	time, time', timing
deliver	7	8	1.52	deliver, delivered
focus	5	8	1.52	focus
clients	7	7	1.33	client, clients
term	4	6	1.14	term
'right	6	5	0.95	right, 'right
drives	6	5	0.95	drive, drives
important	9	5	0.95	important
product	7	5	0.95	product, product'
project	7	5	0.95	project
short	5	5	0.95	short

Quality Community

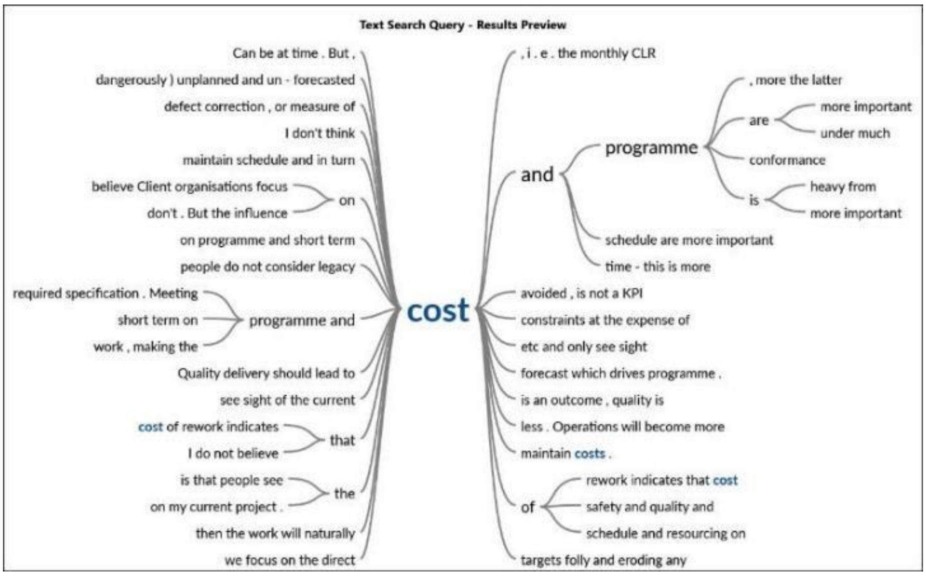
Word	Length	Count	Weighted Percentage (%)	Similar Words
quality	7	44	5.58	quality
cost	4	35	4.44	cost, costs
programme	9	29	3.68	programme, programmes
time	4	19	2.41	time, time'
project	7	16	2.03	project, projects
first	5	11	1.40	first
client	6	10	1.27	client, clients
right	5	10	1.27	right, right'
team	4	10	1.27	team, teams
delivery	8	6	0.76	delivery
important	9	6	0.76	importance, important
issue	5	6	0.76	issue, issues
meet	4	6	0.76	meet, meeting, meets
people	6	6	0.76	people, peoples
rework	6	6	0.76	rework



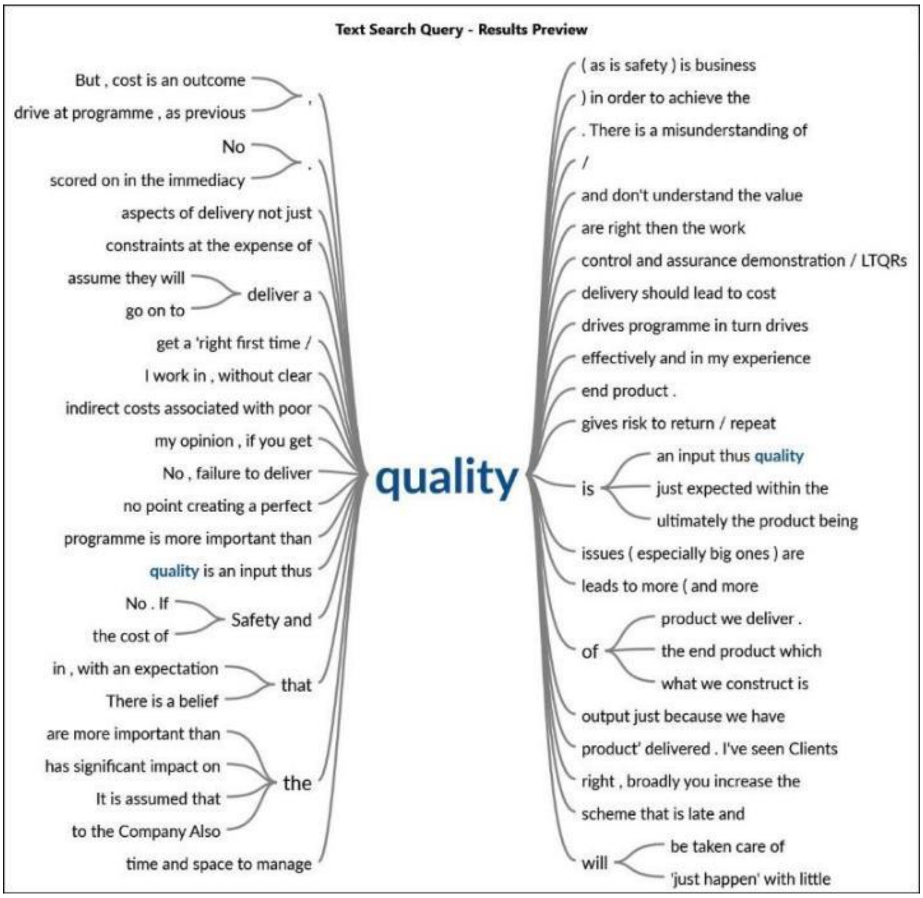
QUESTION 13: Do you think that cost and programme are more important than quality delivery? Please explain.

Contract Leaders

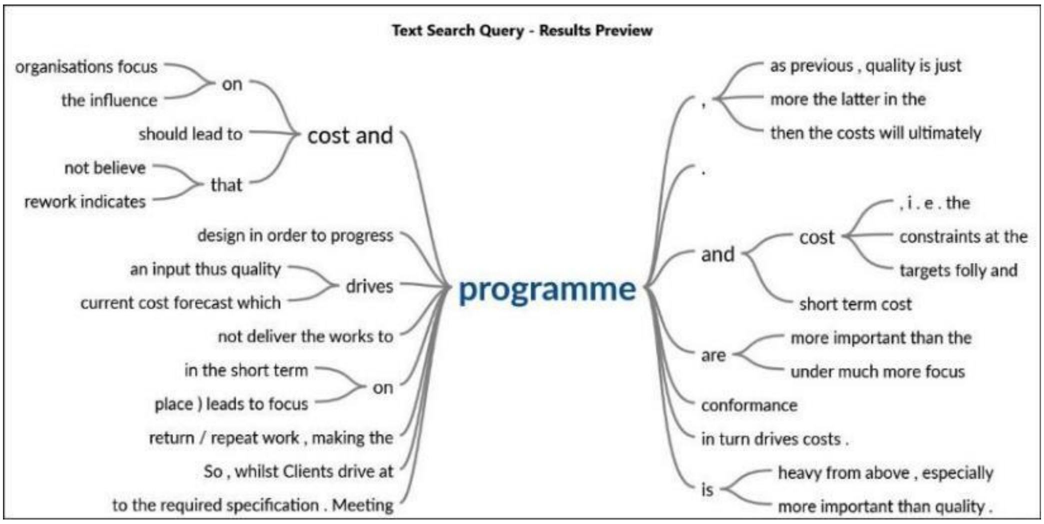
(1) Cost



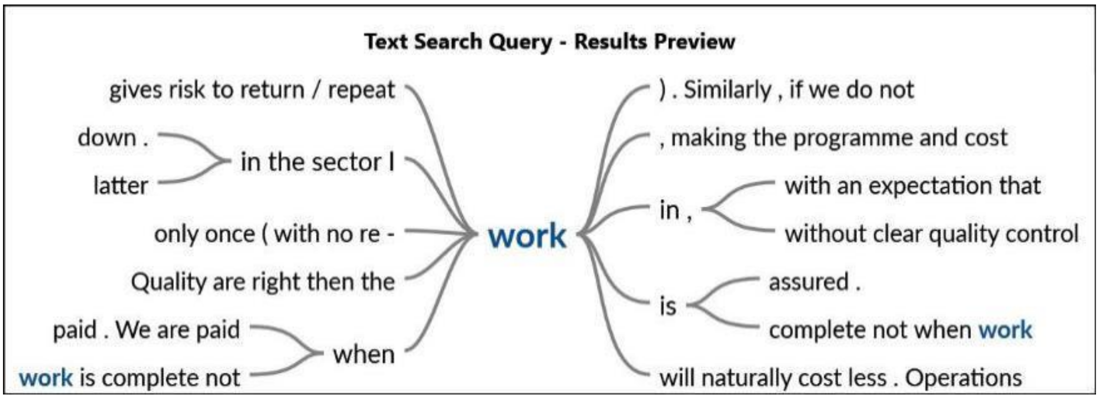
(2) Quality



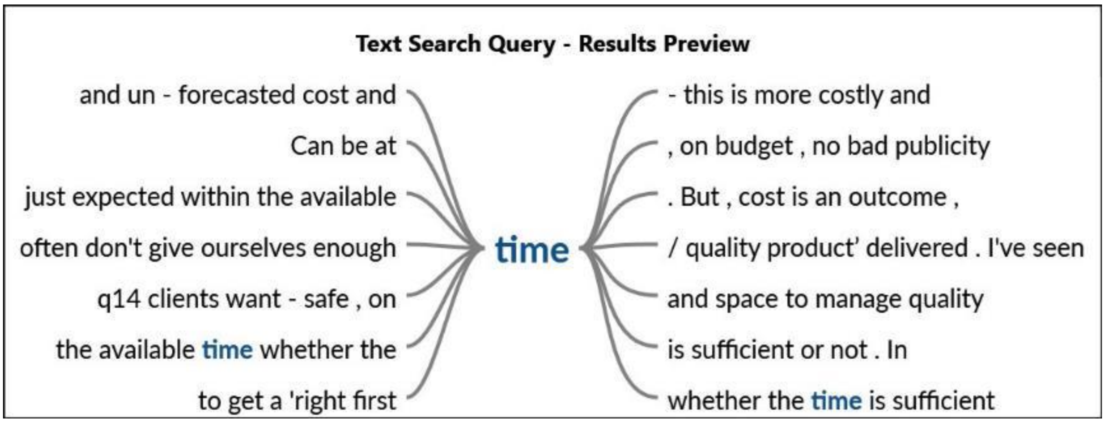
(3) Programme



(4) Work



(5) Time

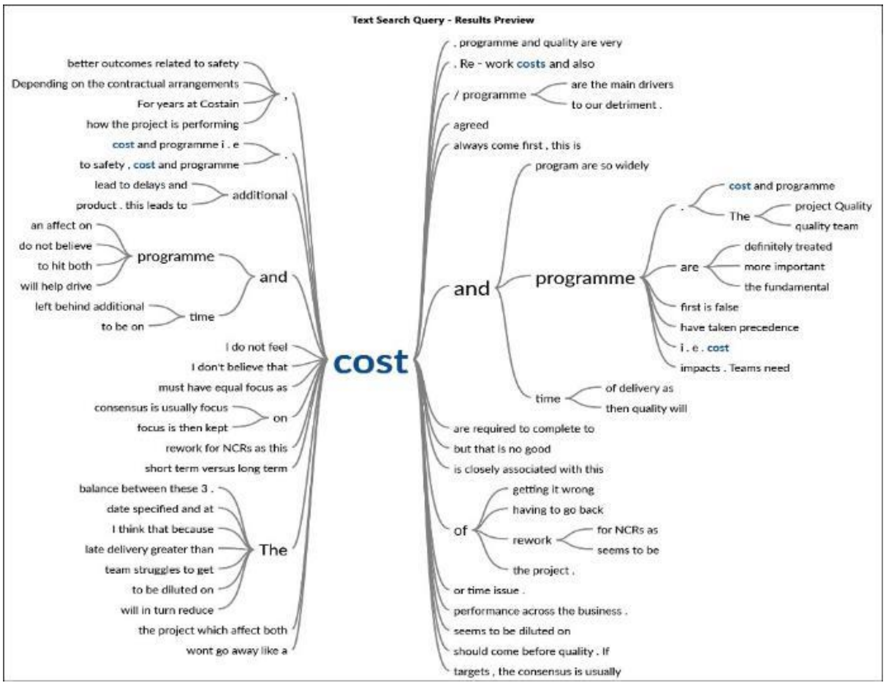


QUESTION 13: Do you think that cost and programme are more important than quality delivery? Please explain.

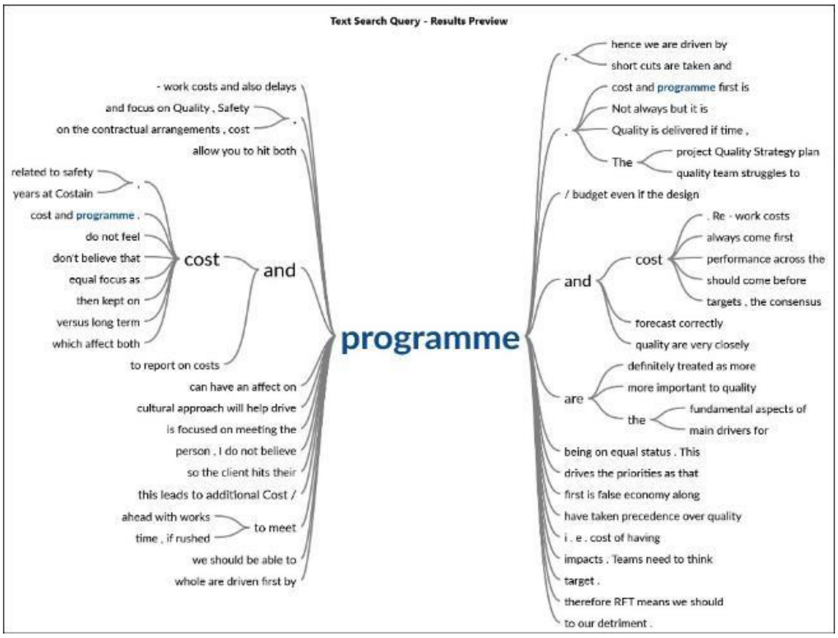
Quality Community

(1) Quality

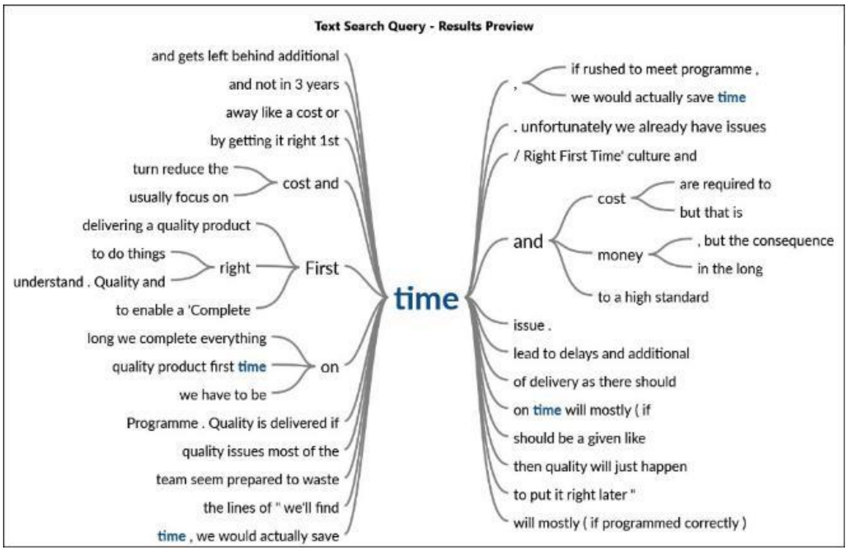
(2) Cost



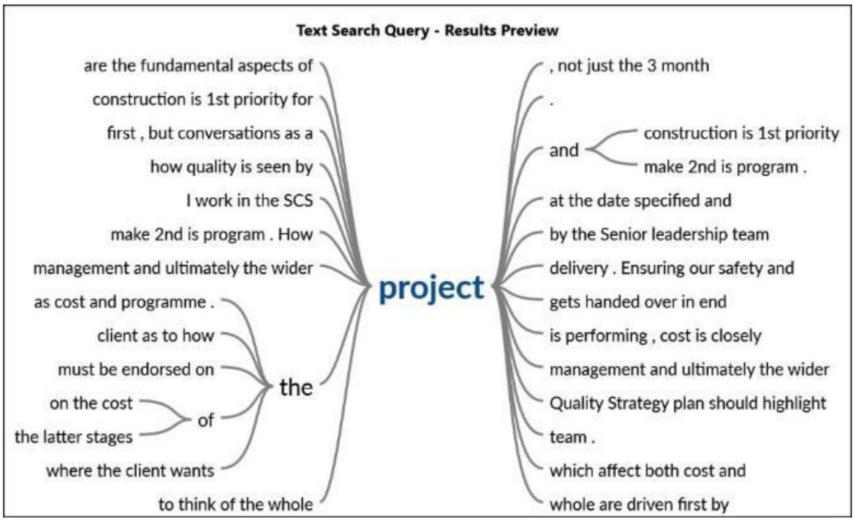
(3) Programme



(4) Time


Text Search Query - Results Preview
and gets left behind additional
and not in 3 years
away like a cost or
by getting it right 1st
turn reduce the
usually focus on
cost and
delivering a quality product
to do things
understand . Quality and
right
First
to enable a 'Complete
long we complete everything
quality product first time
on
we have to be
Programme . Quality is delivered if
quality issues most of the
team seem prepared to waste
the lines of " we'll find
time , we would actually save
time
,
if rushed to meet programme ,
we would actually save time
. unfortunately we already have issues
/ Right First Time' culture and
and
cost
are required to
but that is
money
, but the consequence
in the long
to a high standard
issue .
lead to delays and additional
of delivery as there should
on time will mostly (if
should be a given like
then quality will just happen
to put it right later "
will mostly (if programmed correctly)

(5) Project


Text Search Query - Results Preview
are the fundamental aspects of
construction is 1st priority for
first , but conversations as a
how quality is seen by
I work in the SCS
make 2nd is program . How
management and ultimately the wider
as cost and programme .
client as to how
must be endorsed on
the
on the cost
of
the latter stages
where the client wants
to think of the whole
project
, not just the 3 month
.
and
construction is 1st priority
make 2nd is program .
at the date specified and
by the Senior leadership team
delivery . Ensuring our safety and
gets handed over in end
is performing , cost is closely
management and ultimately the wider
Quality Strategy plan should highlight
team .
which affect both cost and
whole are driven first by

QUESTION 16: Do all parties on our project fully appreciate and understanding the level of quality to be achieved? If 'No', why do you believe this is the case?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
client	6	7	3.06	client, clients
quality	7	6	2.62	quality
standard	8	6	2.62	standard, standards
different	9	5	2.18	different
often	5	5	2.18	often
requirements	12	5	2.18	required, requirements
wants	5	5	2.18	want, wants
acceptable	10	4	1.75	accept, acceptable, accepted
project	7	4	1.75	project
team	4	4	1.75	team, teams
agreed	6	3	1.31	agree, agreed
commercial	10	3	1.31	commercial, commercially
conversation	12	3	1.31	conversation
designers	9	3	1.31	design, designers
management	10	3	1.31	management, manager, managers

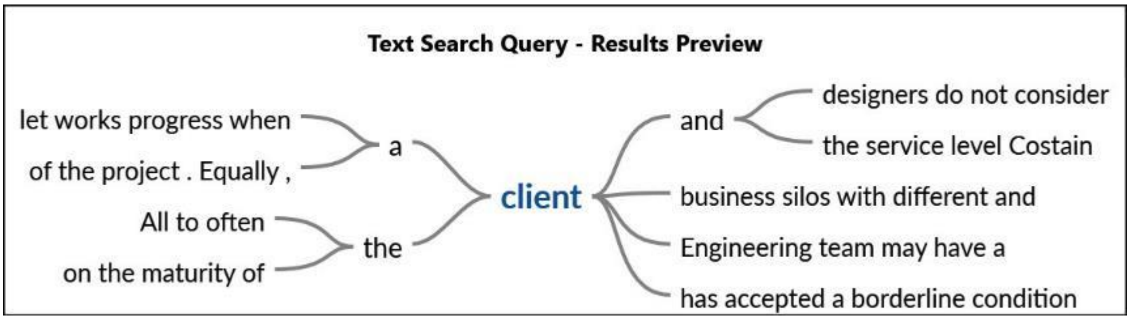
Quality Community

Word	Length	Count	Weighted Percentage (%)	Similar Words
client	6	17	3.73	client, clients
expects	7	14	3.07	expect, expectations, expected, expects
quality	7	13	2.85	quality
project	7	10	2.19	project, projects
time	4	10	2.19	time, times
work	4	9	1.97	work, working, works
team	4	8	1.75	team, teams
often	5	7	1.54	often
required	8	7	1.54	required, requirement, requirements
standards	9	7	1.54	standard, standardize, standards
understanding	13	7	1.54	understand, understanding
meetings	8	6	1.32	meet, meeting, meetings, meets
specification	13	6	1.32	specification, specifications
different	9	5	1.10	differ, different, differently
enough	6	5	1.10	enough

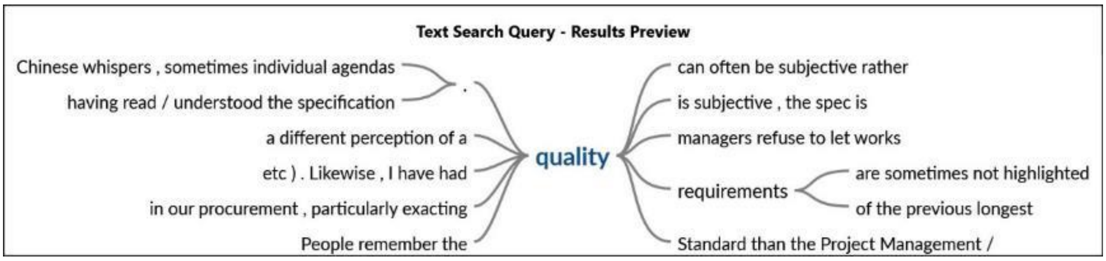
QUESTION 16: Do all parties on our project fully appreciate and understanding the level of quality to be achieved? If 'No', why do you believe this is the case?

Contract Leaders

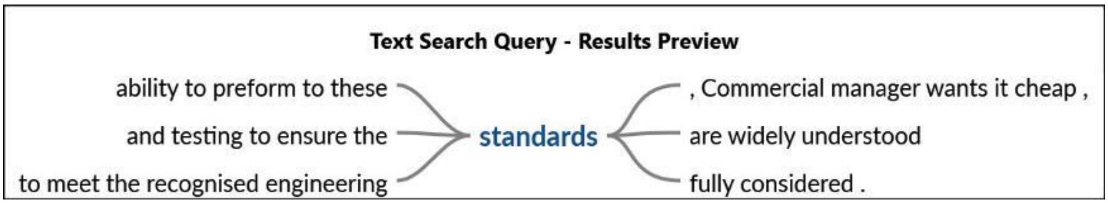
(1) Client



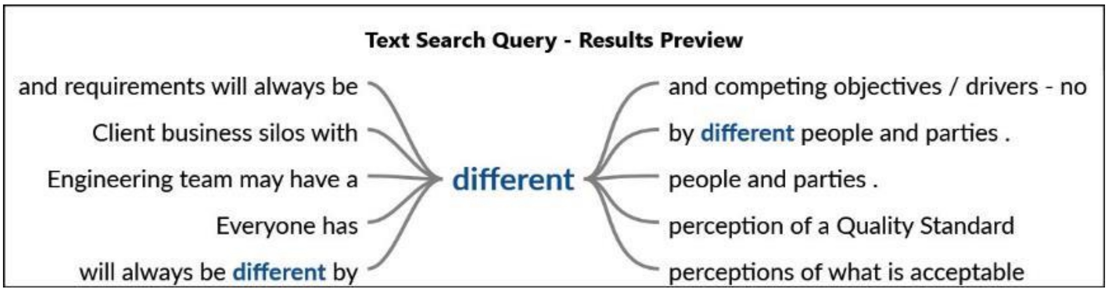
(2) Quality



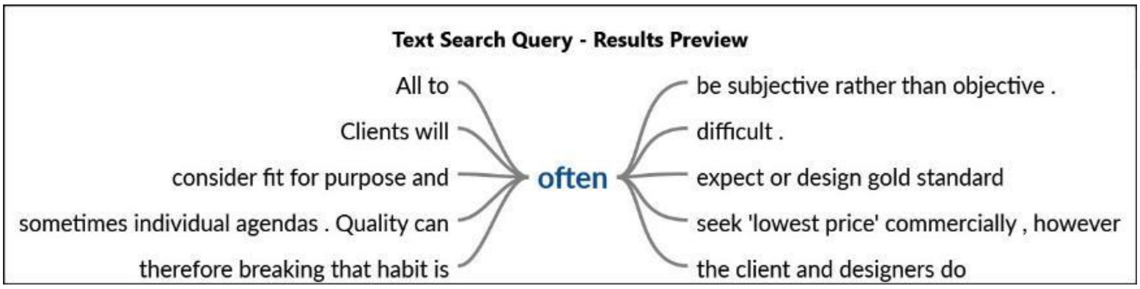
(3) Standard



(4) Different



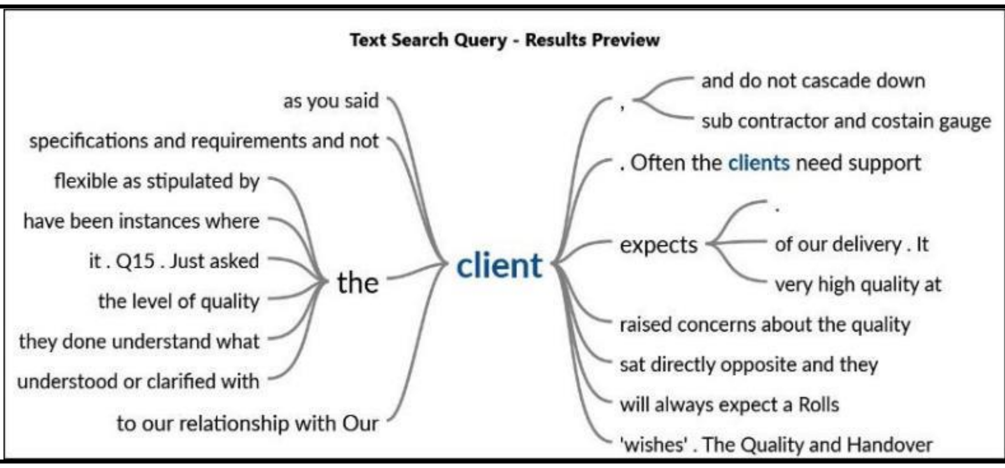
(5) Often


Text Search Query - Results Preview
All to
Clients will
consider fit for purpose and
sometimes individual agendas . Quality can
therefore breaking that habit is
often
be subjective rather than objective .
difficult .
expect or design gold standard
seek 'lowest price' commercially , however
the client and designers do

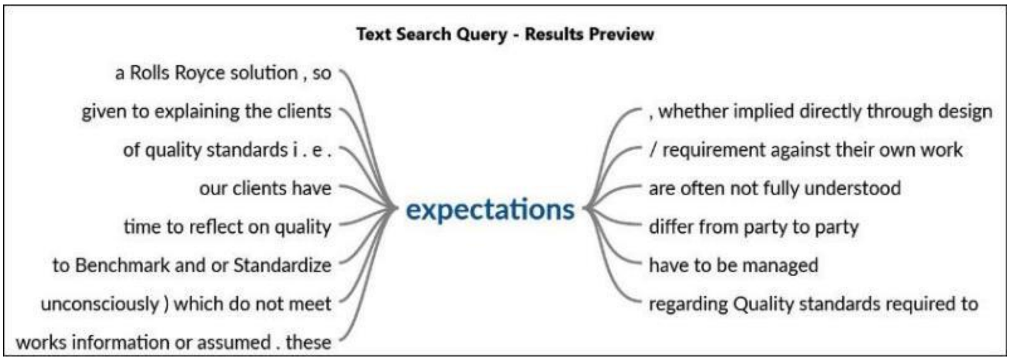
QUESTION 16: Do all parties on our project fully appreciate and understanding the level of quality to be achieved? If 'No', why do you believe this is the case?

Quality Community

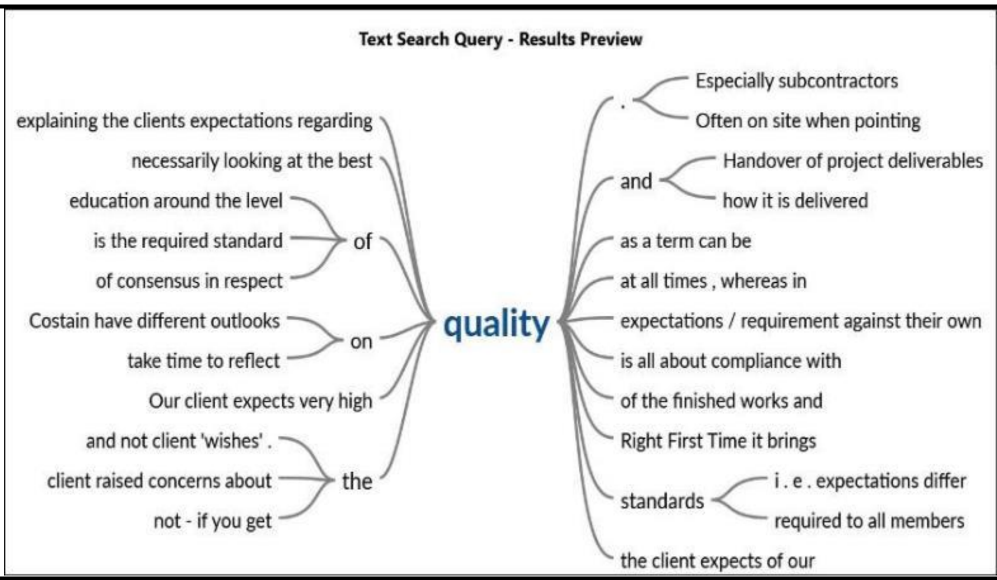
(1) Client



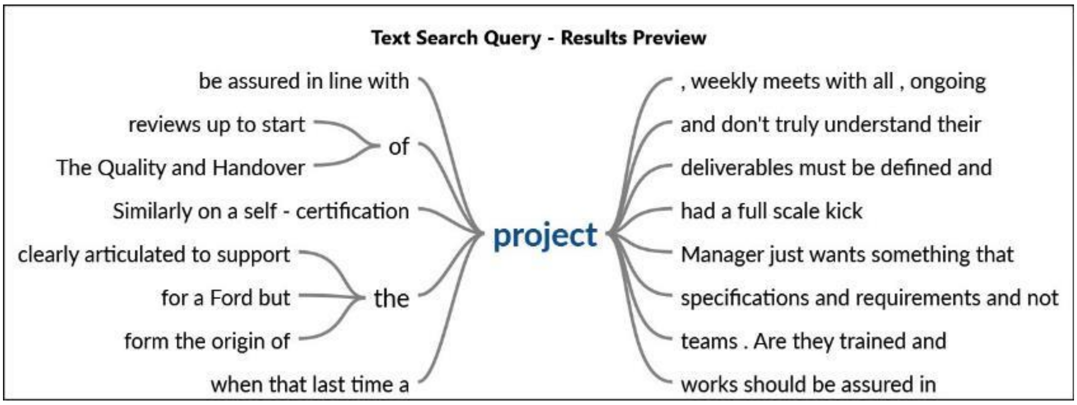
(2) Expectations



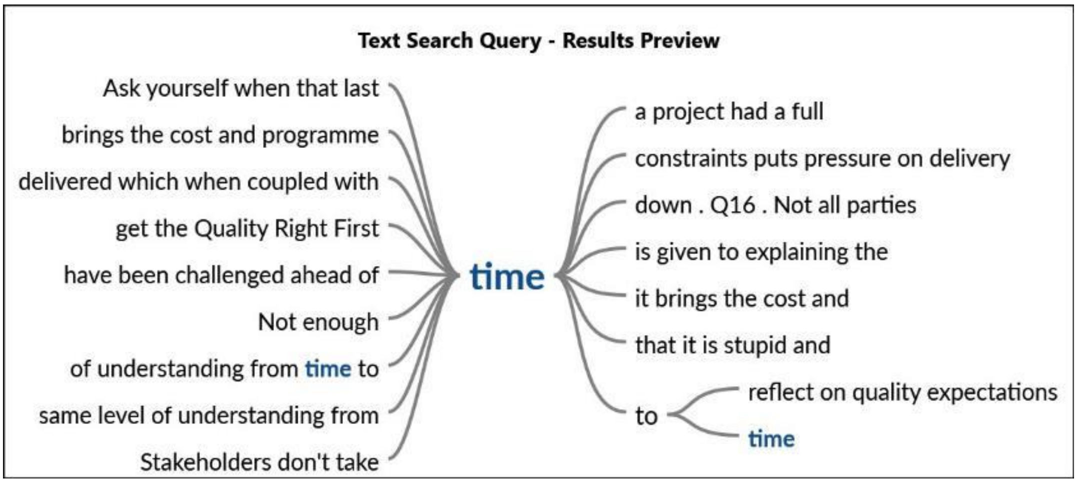
(3) Quality



(4) Project



(5) Time



QUESTION 19: Analysis of 1260 nonconformances on a major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (£7,739,850). Based on a 3% profit margin, that is a potential profit loss of 17%. Is this of concern?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
cost	5	16	3.90	cost, costs
profit	6	11	2.68	profit, profitability
margin	6	7	1.71	margin, margins
quality	7	7	1.71	quality
work	4	7	1.71	work, working, works
defects	7	6	1.46	defect, defects
significant	11	6	1.46	significant, significantly
amount	6	5	1.22	amount
rework	6	5	1.22	rework
time	4	5	1.22	time, times
associated	10	4	0.98	associated
business	8	4	0.98	business
level	5	4	0.98	level, levels
loss	4	4	0.98	loss
need	4	4	0.98	need

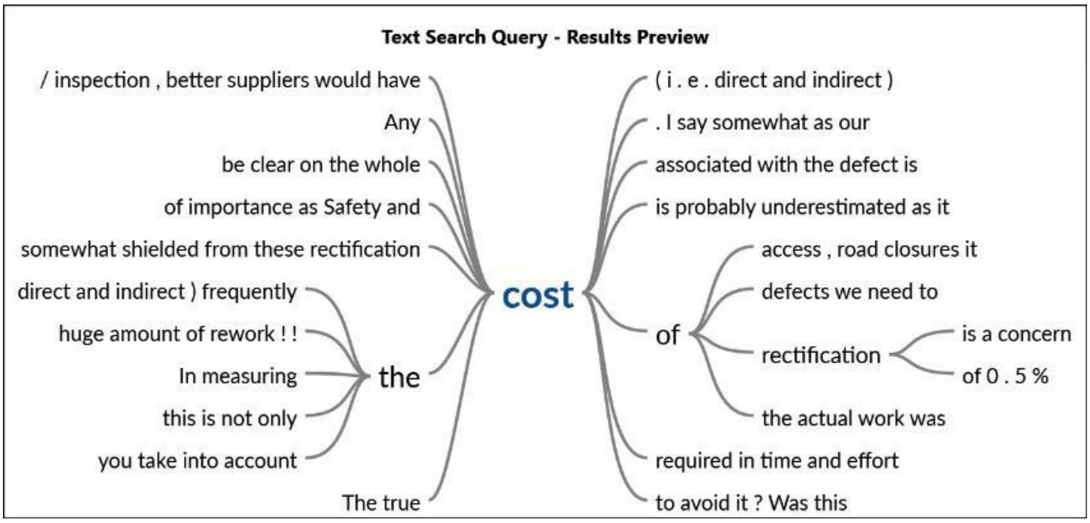
Quality Community

Word	Length	Count	Weighted Percentage (%)	Similar Words
cost	5	31	4.82	cost, costs
project	7	16	2.49	project, projects
profit	6	14	2.18	profit, profits
rework	6	13	2.02	rework, reworks
loss	4	11	1.71	loss, losses
quality	7	11	1.71	quality
margin	6	7	1.09	margin, margins
company	7	6	0.93	companies, company
concern	7	6	0.93	concern, concerned, concerns
higher	6	6	0.93	higher
like	4	6	0.93	like, likely
work	4	6	0.93	work, works
business	8	5	0.78	business
number	6	5	0.78	number
significant	11	5	0.78	significant, significantly

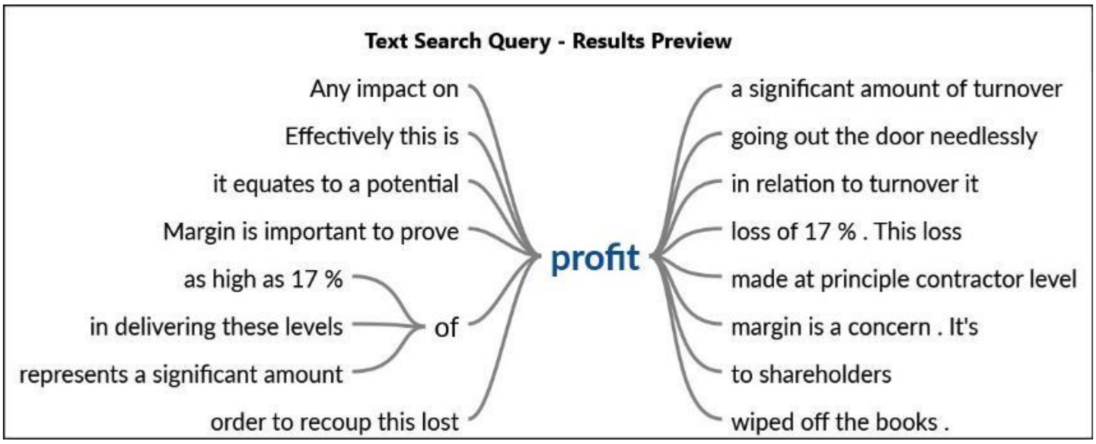
QUESTION 19: Analysis of 1260 nonconformances on a major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (£7,739,850). Based on a 3% profit margin, that is a potential profit loss of 17%. Is this of concern?

Contract Leaders

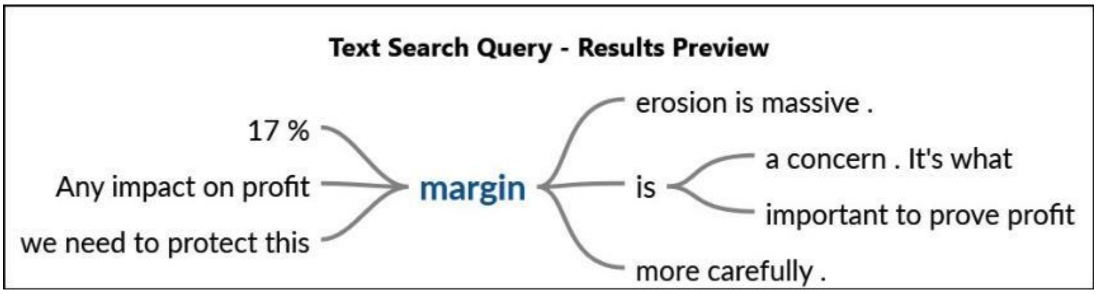
(1) Cost



(2) Profit

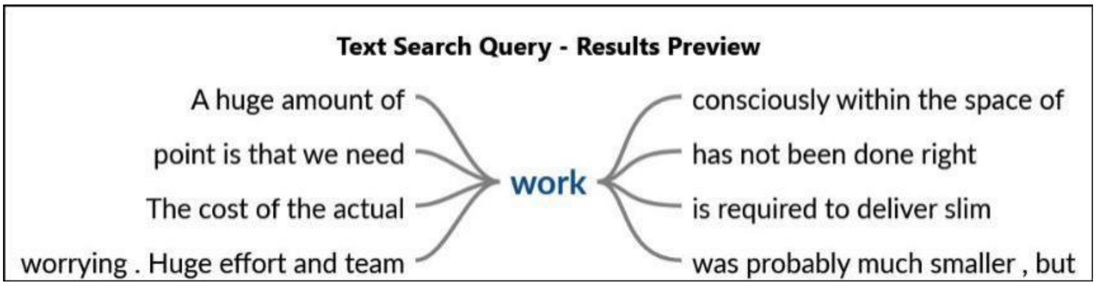


(3) Margin



(4) Quality

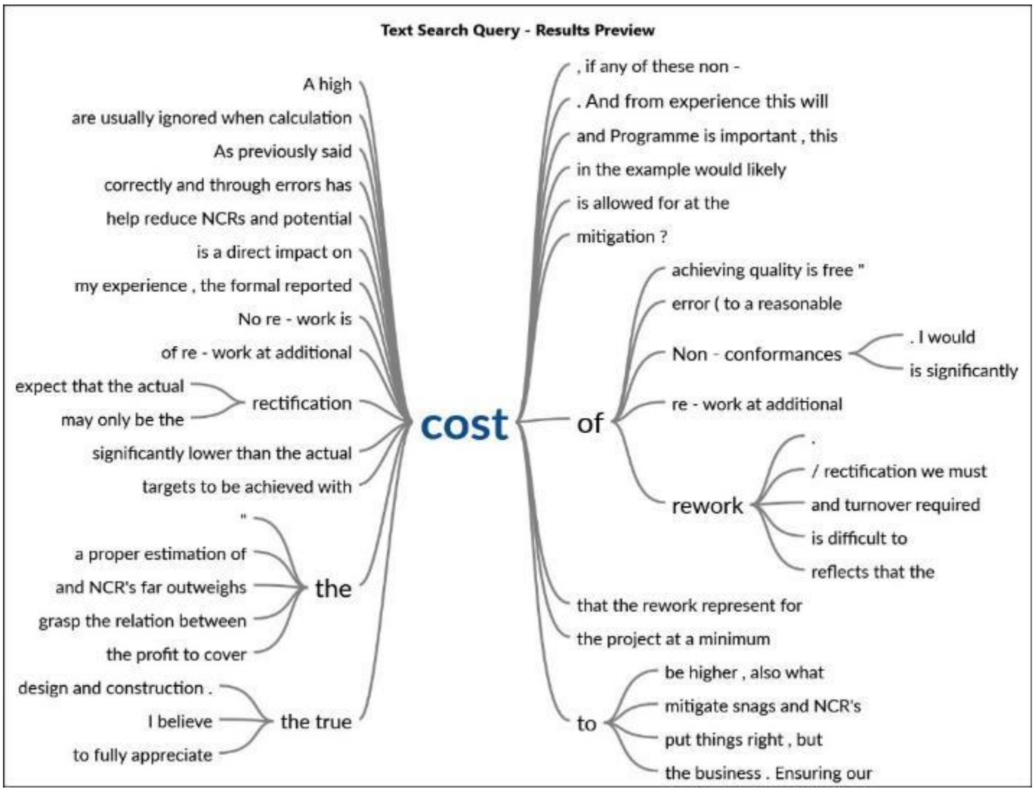
(5) Work



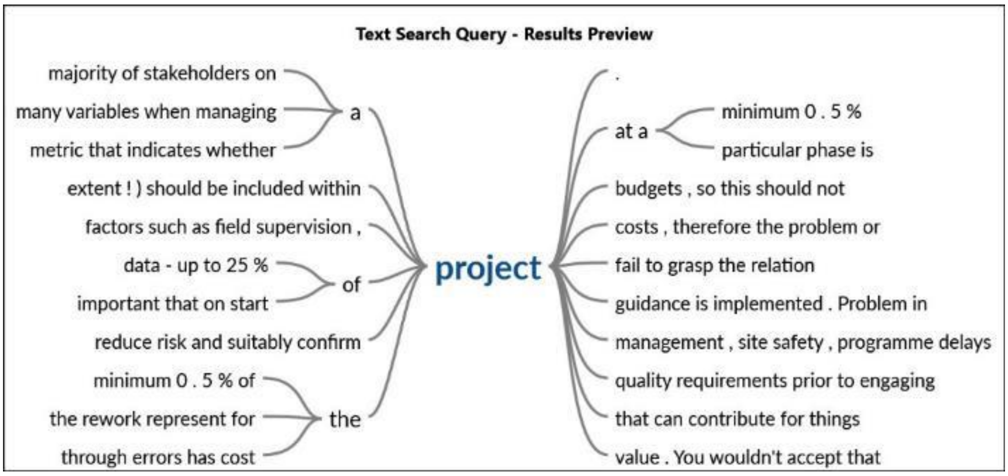
QUESTION 19: Analysis of 1260 nonconformances on a major complex highways delivery project yielded a total cost of rectification at 0.5% of the total project value (£7,739,850). Based on a 3% profit margin, that is a potential profit loss of 17%. Is this of concern?

Quality Community

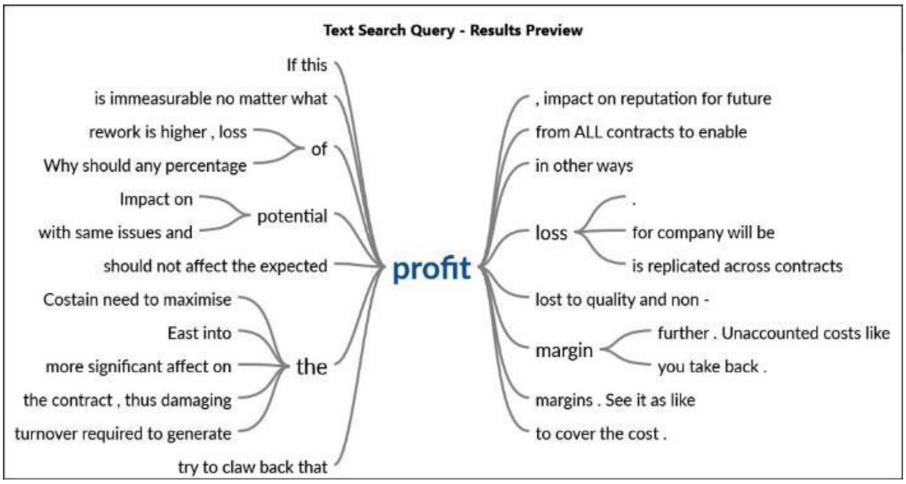
(1) Cost



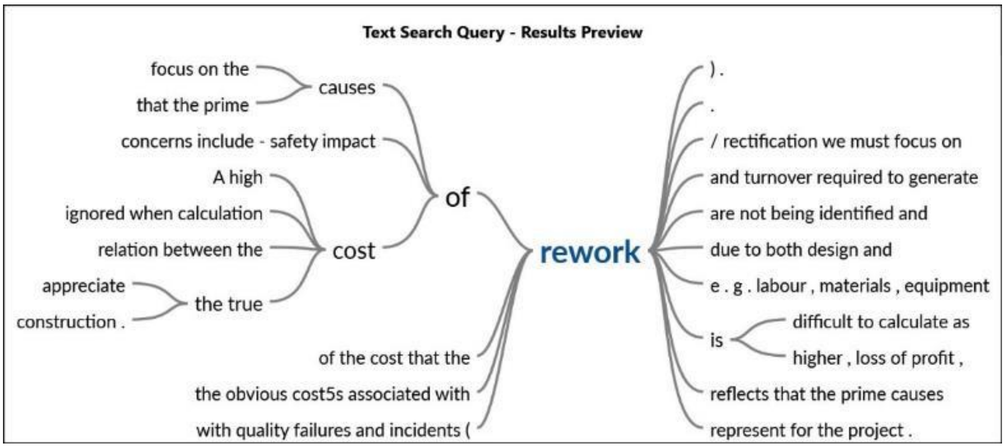
(2) Project



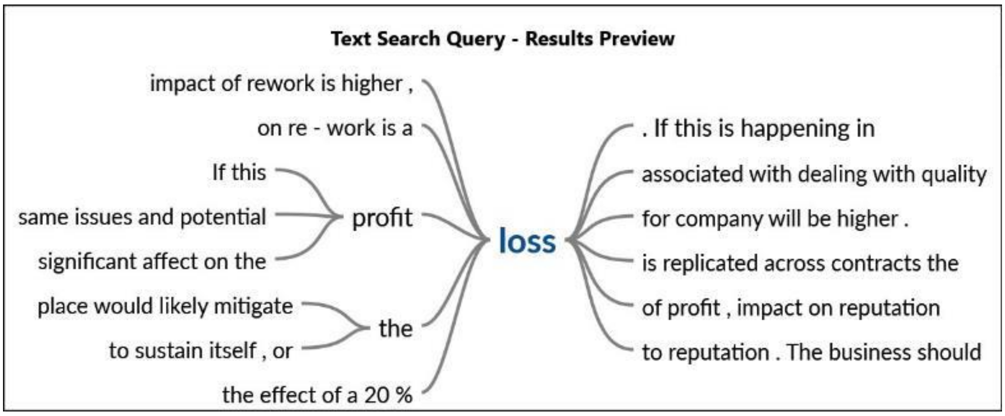
(3) Profit



(4) Rework



(5) Loss



QUESTION 20: The most frequent NCR root causes were found to be materials management, Poor workmanship and Supervision. What do you believe we should focus on to prevent repetition of future schemes?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
quality	7	15	3.01	quality
management	10	10	2.01	manage, managed, management, managers, managing
engineering	11	8	1.61	engineering, engineers
materials	9	8	1.61	material, materials
right	5	8	1.61	right
training	8	8	1.61	training
supervision	11	7	1.41	supervision
works	5	7	1.41	work, works
correct	7	6	1.20	correct
ensure	6	6	1.20	ensure, ensured, ensuring
need	4	5	1.00	need, needs
root	4	5	1.00	root, roots
causes	6	4	0.80	causes
communication	13	4	0.80	communicated, communication
foremen	7	4	0.80	foremen

Quality Community

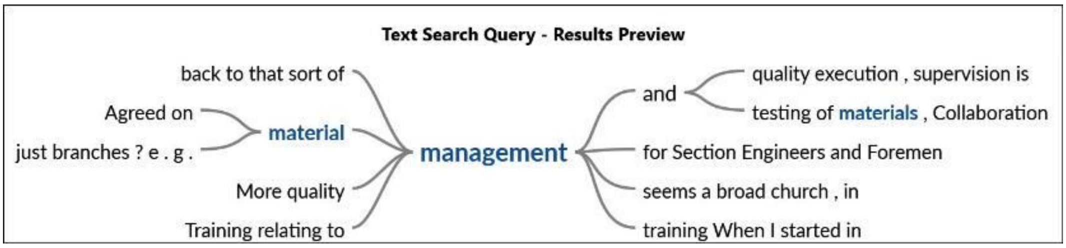
Word	Length	Count	Weighted Percentage (%)	Similar Words
quality	7	35	3.18	quality
materials	9	24	2.18	material, materials
work	4	20	1.82	work, working, works
supervision	11	19	1.73	supervise, supervising, supervision
management	10	16	1.45	manage, management, managers, managing
site	4	13	1.18	site
process	7	12	1.09	process, processes
workmanship	11	12	1.09	workmanship, workmanships
change	6	11	1.00	change, changes, changing
training	8	11	1.00	train, training
better	6	10	0.91	better
issues	6	10	0.91	issues
need	4	10	0.91	need, needs
focus	5	9	0.82	focus
check	5	8	0.73	check, checked, checking, checks

QUESTION 20: The most frequent NCR root causes were found to be materials management, Poor workmanship and Supervision. What do you believe we should focus on to prevent repetition of future schemes?

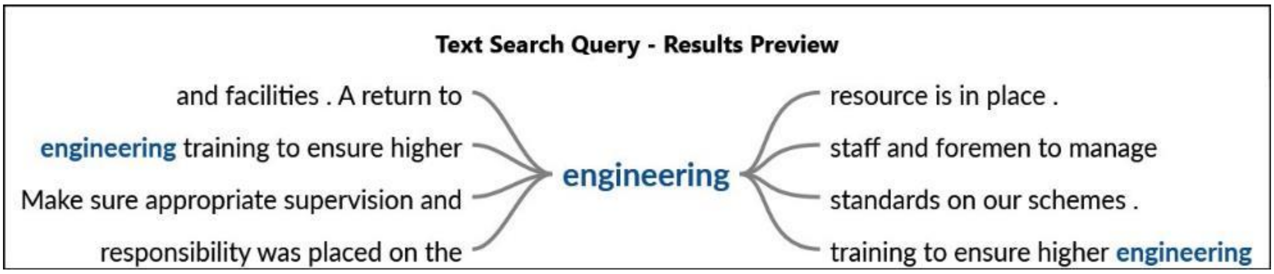
Contract Leaders

(1) Quality

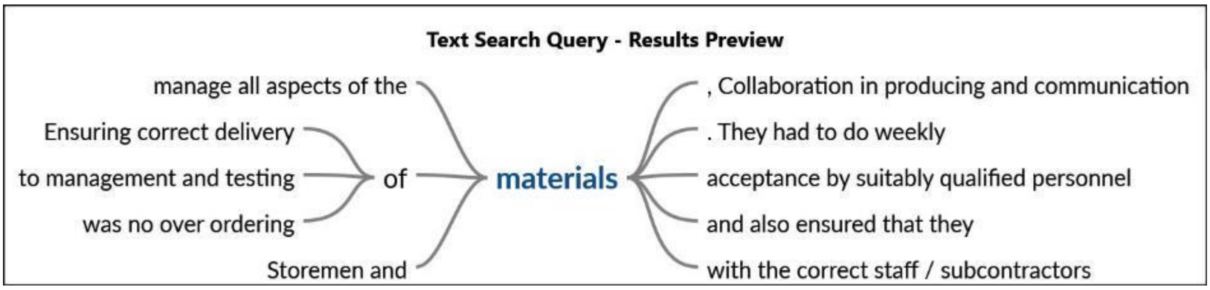
(2) Management



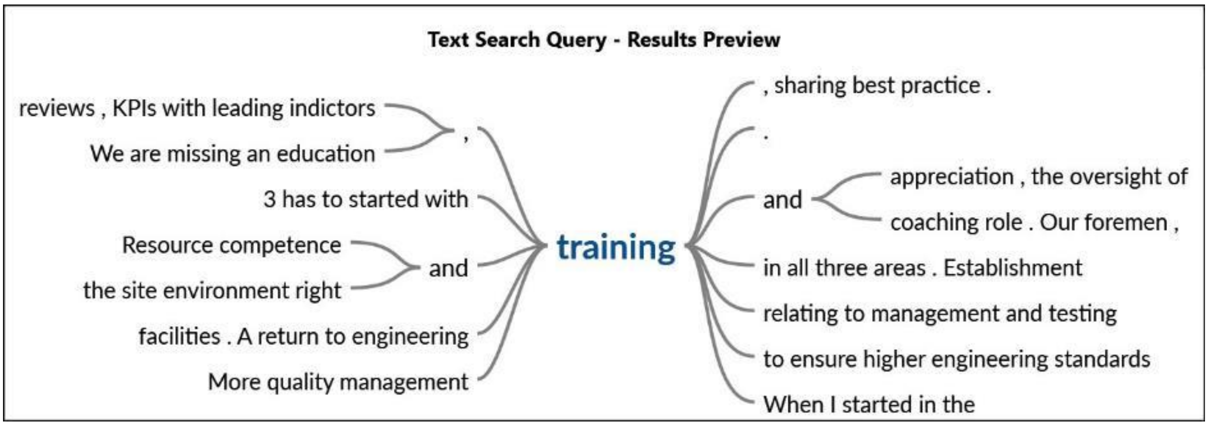
(3) Engineering



(4) Materials



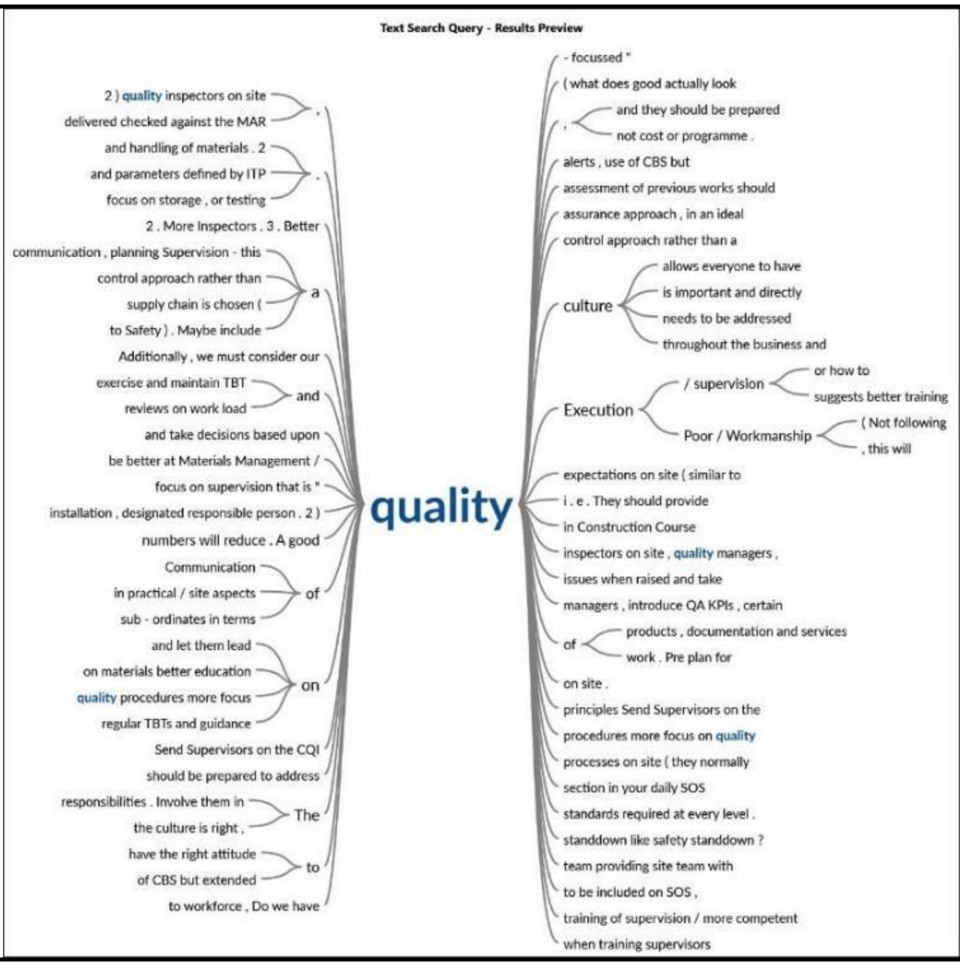
(5) Training



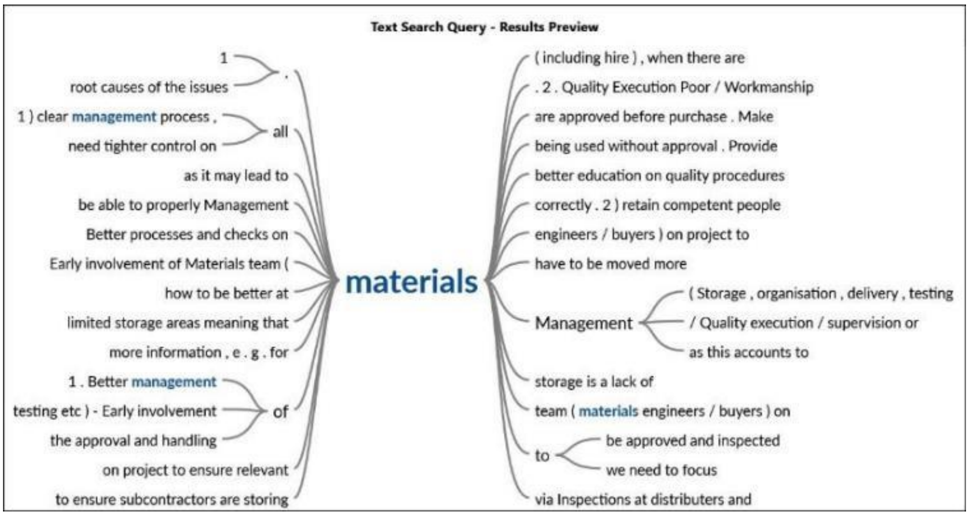
QUESTION 20: The most frequent NCR root causes were found to be materials management, Poor workmanship and Supervision. What do you believe we should focus on to prevent repetition of future schemes?

Quality Community

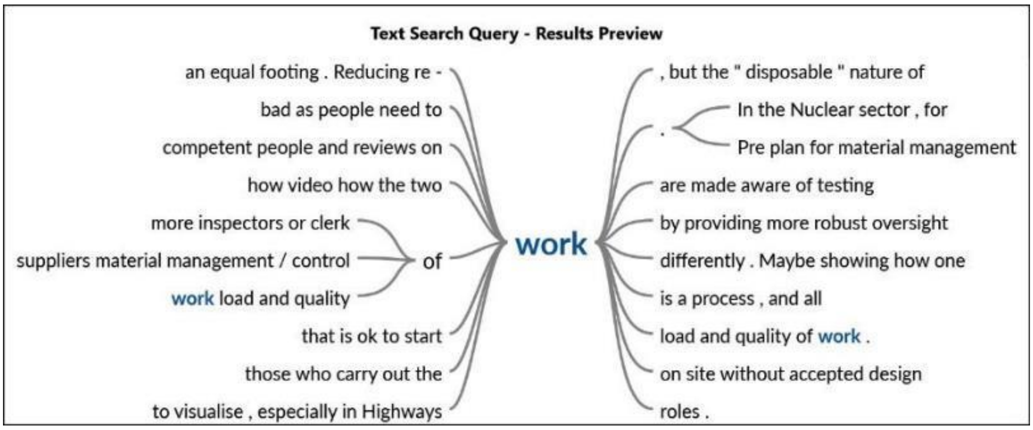
(1) Quality



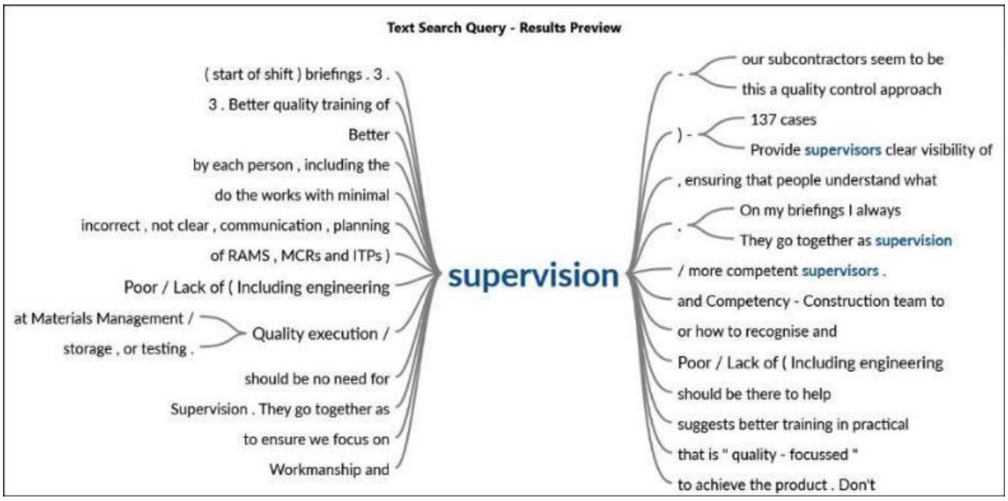
(2) Materials



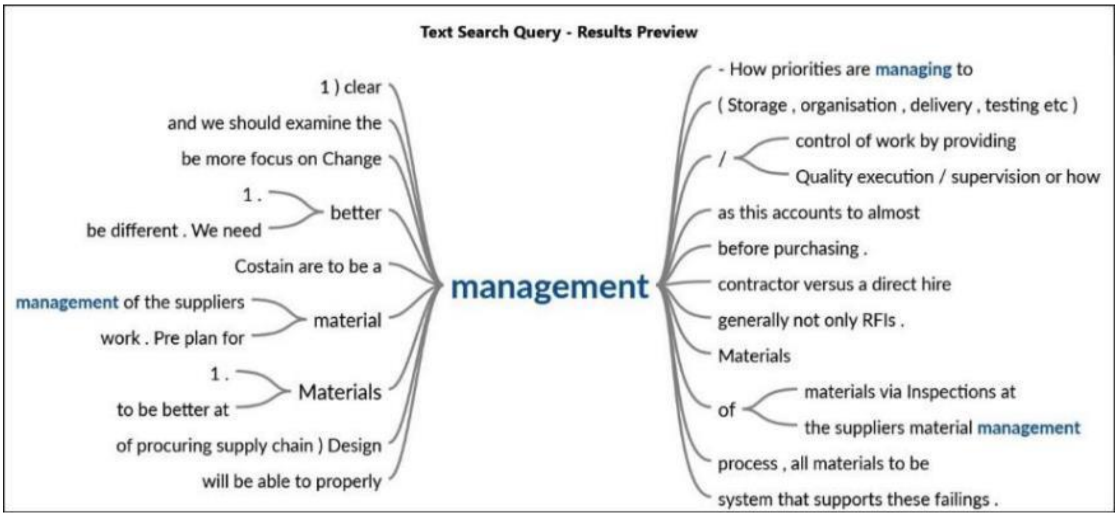
(3) Work



(4) Supervision



(5) Management



QUESTION 22: You've selected 'Yes' to the previous question. Of the data, there were 137 cases of poor/lack of supervision (including engineering support and verification) and a further 26 cases of competency/training issues notified. What do you believe the solution to be?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
quality	7	17	3.59	quality
engineers	9	15	3.17	engineer, engineering, 'engineering', engineers
training	8	11	2.33	train, training
managers	8	7	1.48	management, managers
work	4	7	1.48	work, worked, working, works
need	4	7	1.48	need, needed
project	7	6	1.27	project
time	4	6	1.27	time
defects	7	5	1.06	defect, defects
make	4	5	1.06	make, making
roles	5	5	1.06	role, roles
ensure	6	4	0.85	ensure
everyone	8	4	0.85	everyone
people	6	4	0.85	people
provide	7	4	0.85	provide

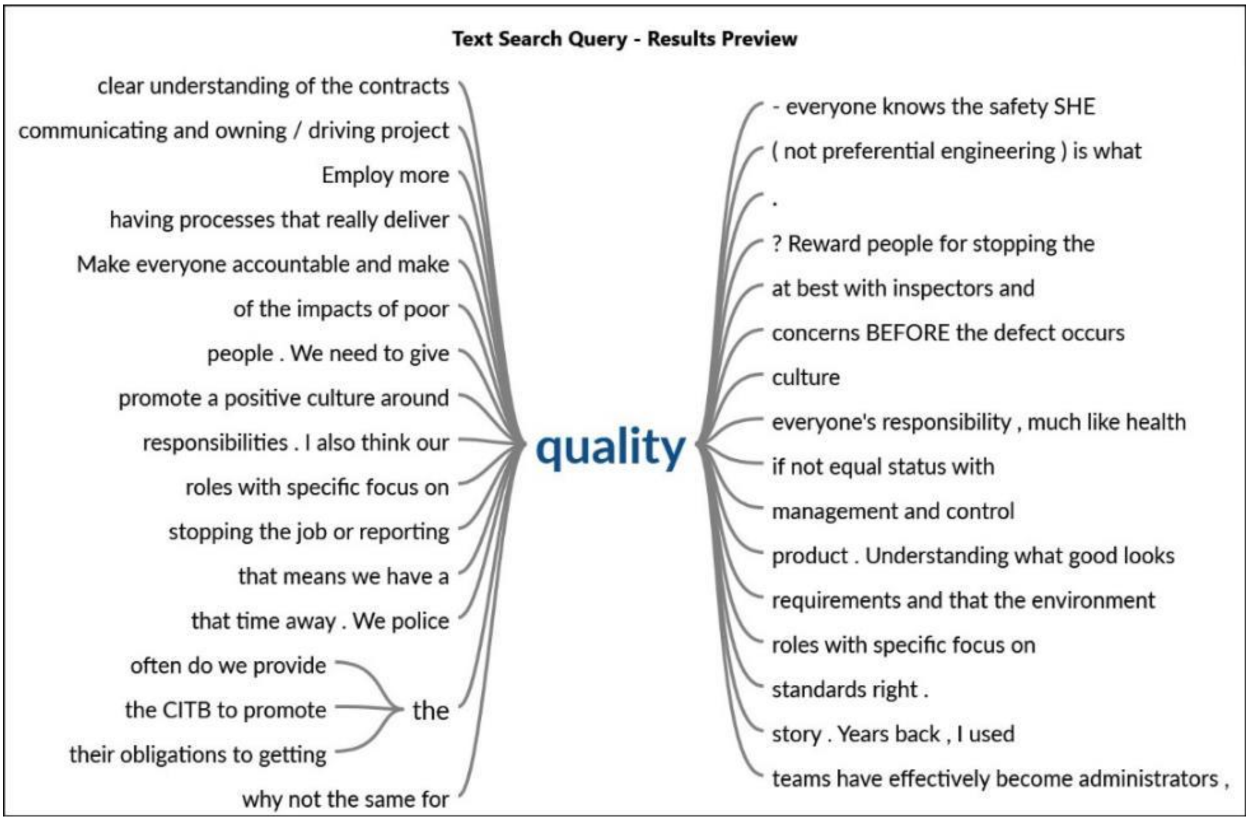
Quality Community

Word	Length	Count	Weighted Percentage (%)	Similar Words
engineers	9	26	3.78	engineer, engineering, engineers
quality	7	17	2.47	quality
works	5	16	2.33	work, worked, working, works
training	8	13	1.89	train, training
project	7	12	1.75	project, projects
lack	4	9	1.31	lack, lacking
people	6	9	1.31	people
requirements	12	9	1.31	require, required, requirements
supervision	11	7	1.02	supervision
supervisors	11	7	1.02	supervisors
ensure	6	6	0.87	ensure
experience	10	6	0.87	experience
need	4	6	0.87	need, needed
setting	7	6	0.87	setting
allow	5	5	0.73	allow, allowed, allowing

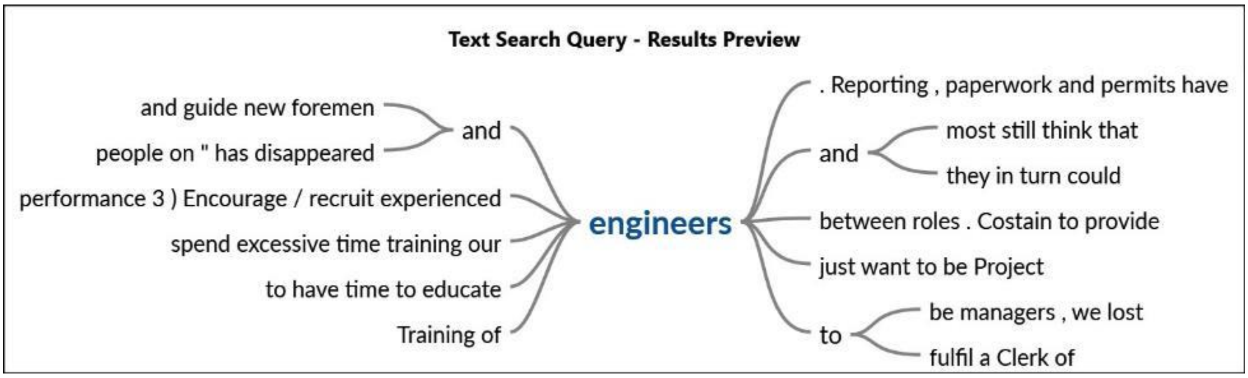
QUESTION 22: You've selected 'Yes' to the previous question. Of the data, there were 137 cases of poor/lack of supervision (including engineering support and verification) and a further 26 cases of competency/training issues notified. What do you believe the solution to be?

Contract Leaders

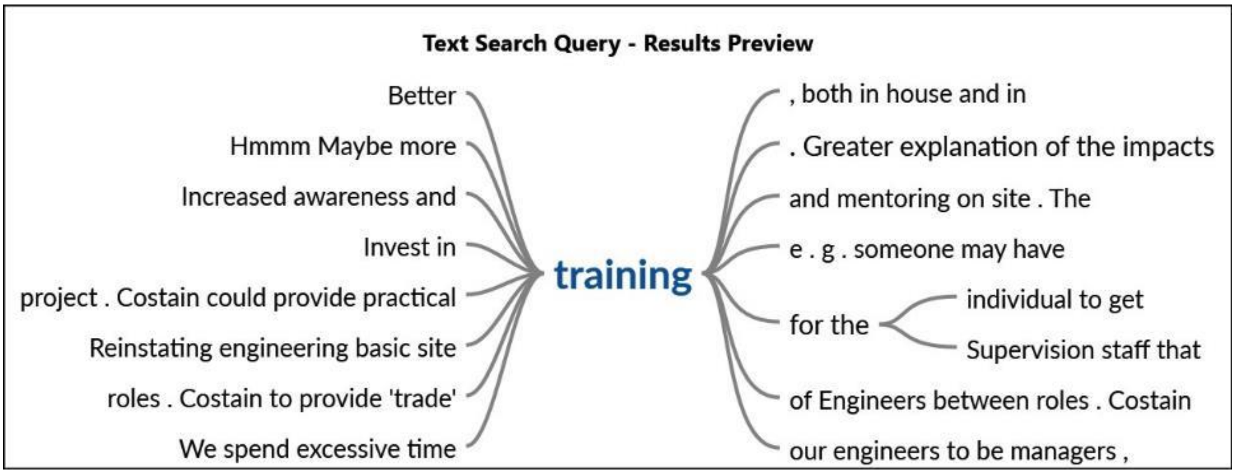
(1) Quality



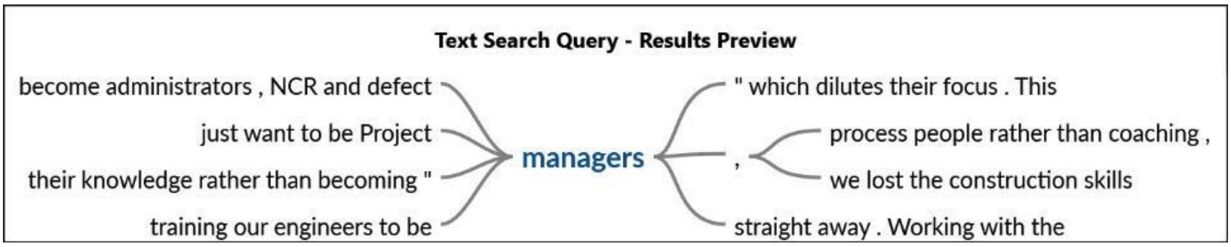
(2) Engineers



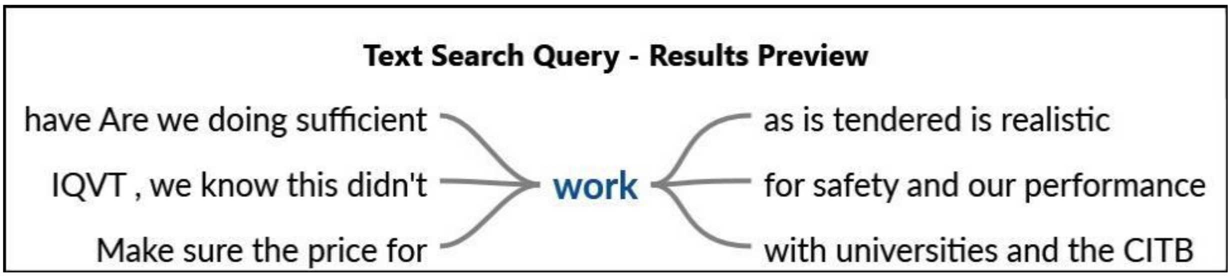
(3) Training



(4) Managers



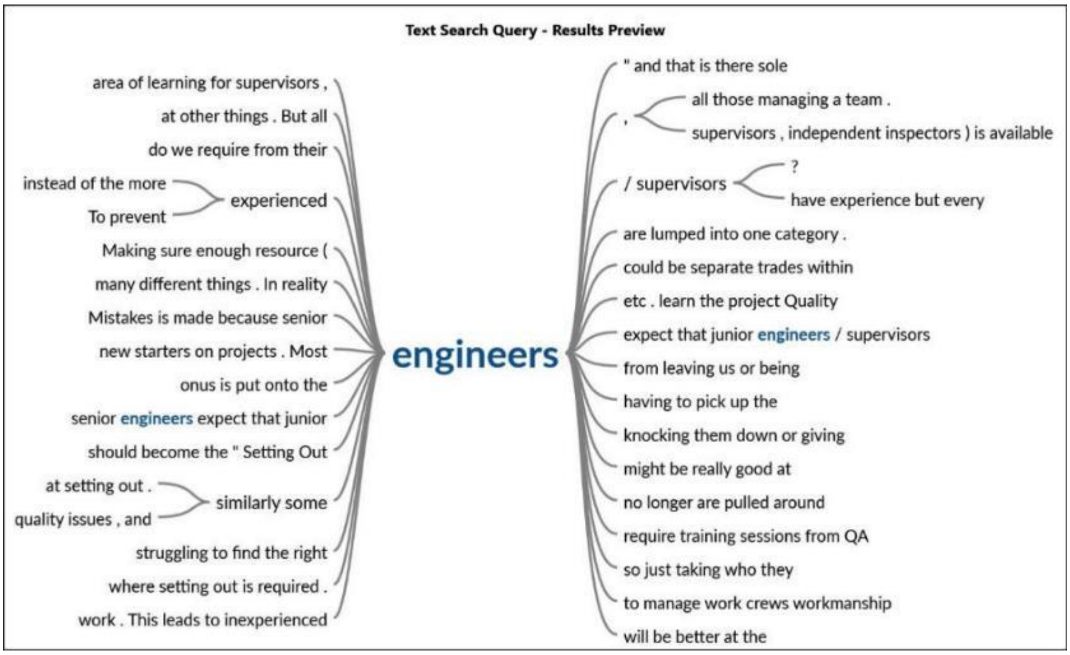
(5) Work



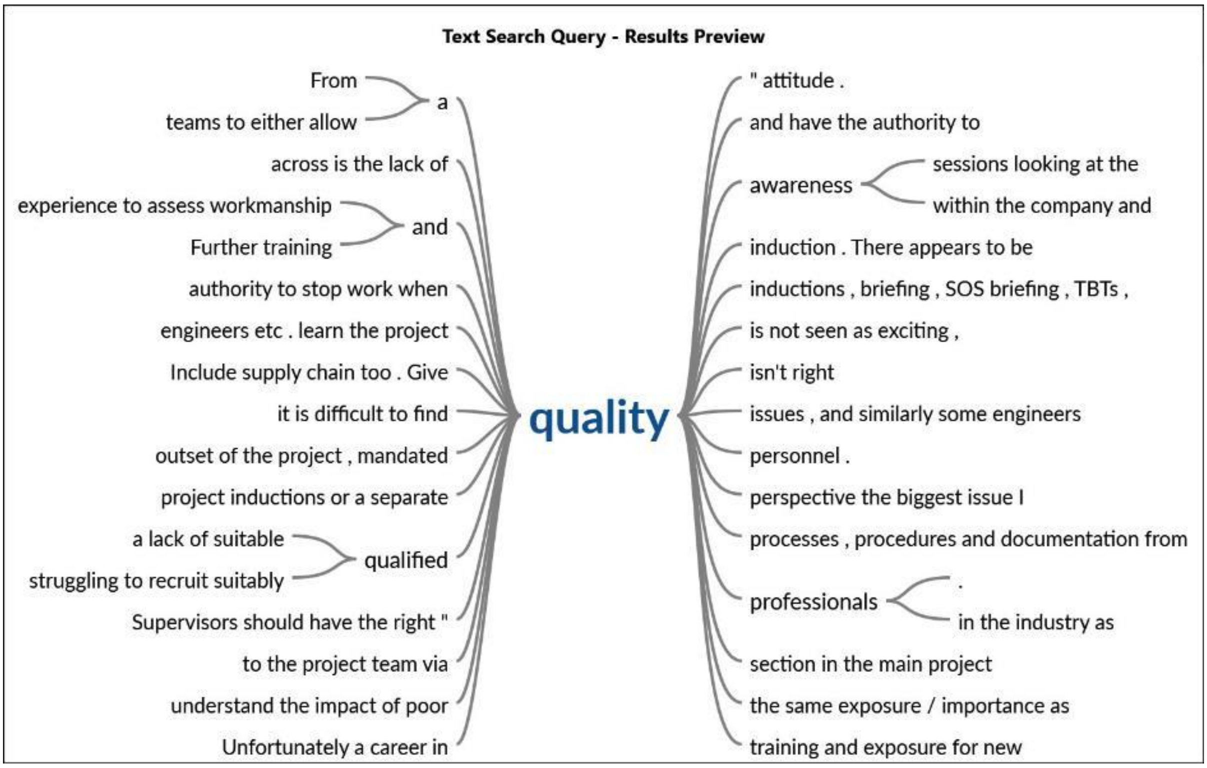
QUESTION 22: You've selected 'Yes' to the previous question. Of the data, there were 137 cases of poor/lack of supervision (including engineering support and verification) and a further 26 cases of competency/training issues notified. What do you believe the solution to be?

Quality Community

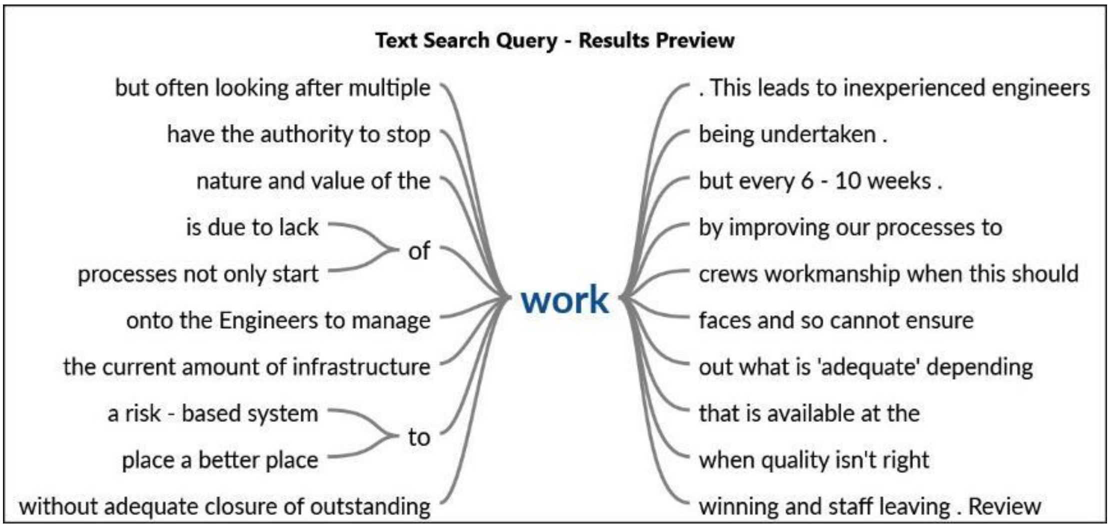
(1) Engineers



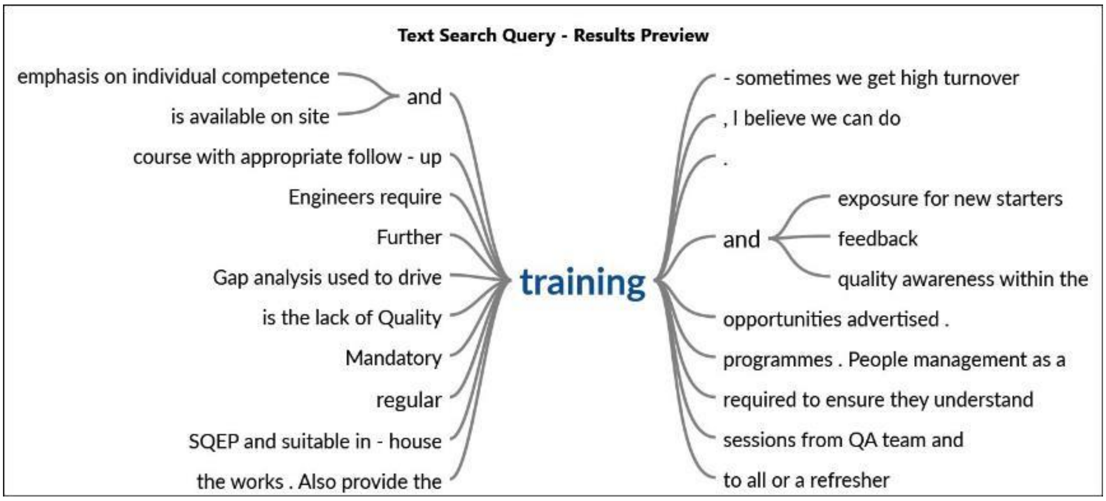
(2) Quality



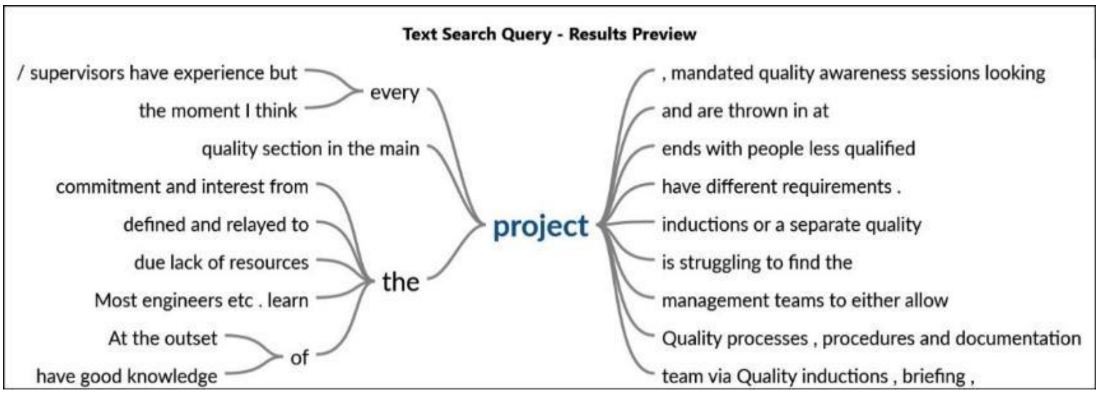
(3) Works



(4) Training



(5) Project



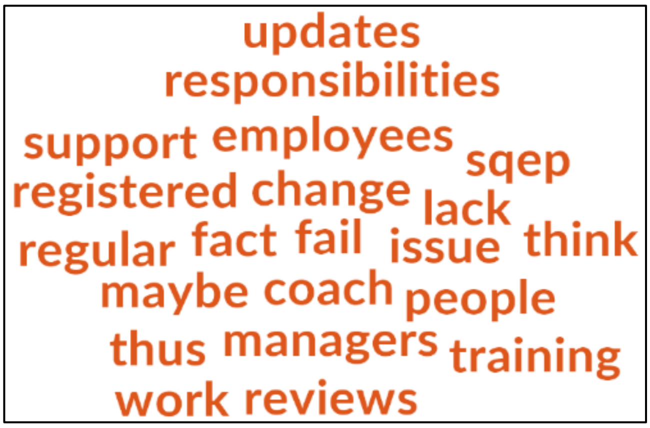
QUESTION 23: You've selected 'No' to the previous question. Of the data, there were 137 cases of poor/lack of supervision and a further 26 cases of competency/training issues notified. Why do you think such large figures are occurring?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
believe	7	2	7.69	believe
accountability	14	1	3.85	accountability
approach	8	1	3.85	approach
bring	5	1	3.85	bring
capable	7	1	3.85	capable
chain	5	1	3.85	chain
create	6	1	3.85	create
driven	6	1	3.85	driven
engineers	9	1	3.85	engineers
environment	11	1	3.85	environment
function	8	1	3.85	function
hands	5	1	3.85	hands
house	5	1	3.85	house
much	4	1	3.85	much
often	5	1	3.85	often

Quality Community

Word	Length	Count	Weighted Percentage (%)	Similar Words
fail	4	2	8.70	fail
change	6	1	4.35	change
coach	5	1	4.35	coach
employees	9	1	4.35	employees
fact	4	1	4.35	fact
issue	5	1	4.35	issue
lack	4	1	4.35	lack
managers	8	1	4.35	managers
maybe	5	1	4.35	maybe
people	6	1	4.35	people
registered	10	1	4.35	registered
regular	7	1	4.35	regular
responsibilities	16	1	4.35	responsibilities
reviews	7	1	4.35	reviews
sqep	4	1	4.35	sqep



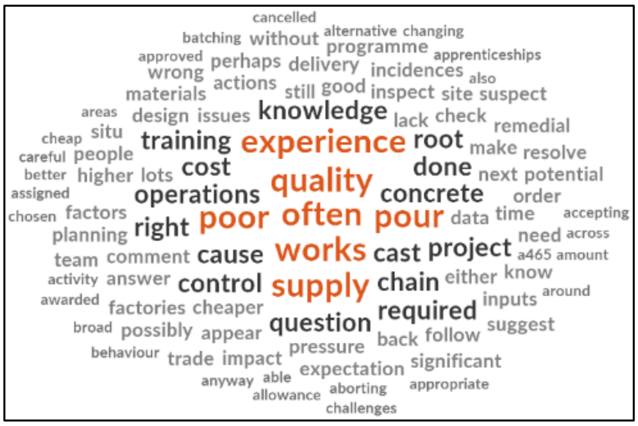
QUESTION 24: Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme. Why do you think we are continuing to make mistakes in concrete operations?

Contract Leaders

Word	Length	Count	Weighted Percentage (%)	Similar Words
often	5	7	1.61	Often
quality	7	7	1.61	Quality
works	5	7	1.61	work, worked, works
poor	4	6	1.38	Poor
pour	4	6	1.38	pour, pouring, pours
experience	10	5	1.15	Experience
supply	6	5	1.15	Supply
concrete	8	5	1.15	concrete, concrete', concreting
operations	10	5	1.15	operation, operations, operatives
cast	4	4	0.92	cast, casting
cause	5	4	0.92	cause, causes
chain	5	4	0.92	Chain
control	7	4	0.92	control, controllers, controls
cost	4	4	0.92	Cost
done	4	4	0.92	Done

Quality Community

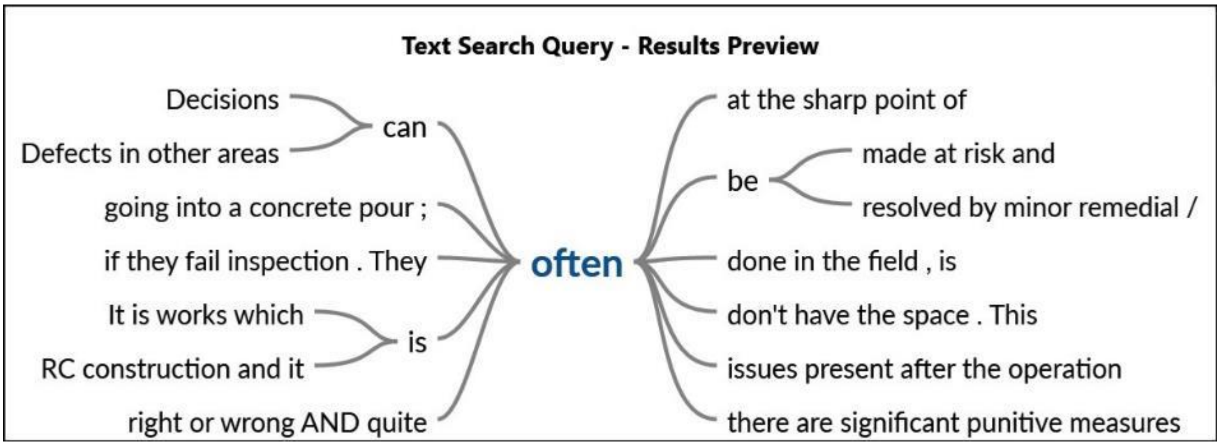
Word	Length	Count	Weighted Percentage (%)	Similar Words
concrete	8	24	4.21	concrete
works	5	16	2.81	work, working, works
time	4	10	1.75	time, timely, times
issues	6	9	1.58	issue, issues
lack	4	9	1.58	lack
quality	7	8	1.40	quality
product	7	7	1.23	product, products
project	7	7	1.23	project, projects
ncrs	4	6	1.05	ncrs
poor	4	6	1.05	poor
processes	9	6	1.05	process, processes
lessons	7	5	0.88	lessons
programme	9	5	0.88	programme
also	4	4	0.70	also
cause	5	4	0.70	cause, causes



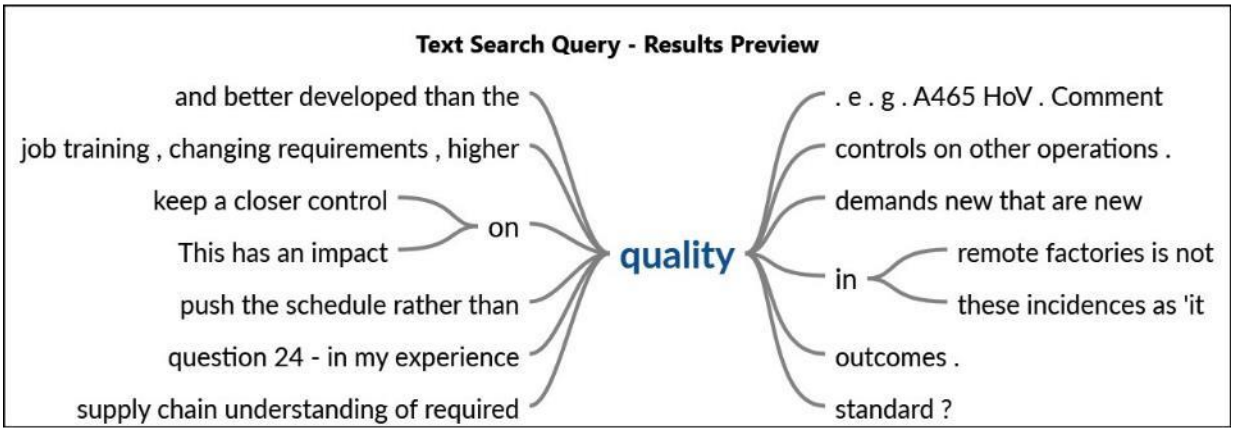
QUESTION 24: Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme. Why do you think we are continuing to make mistakes in concrete operations?

Contract Leaders

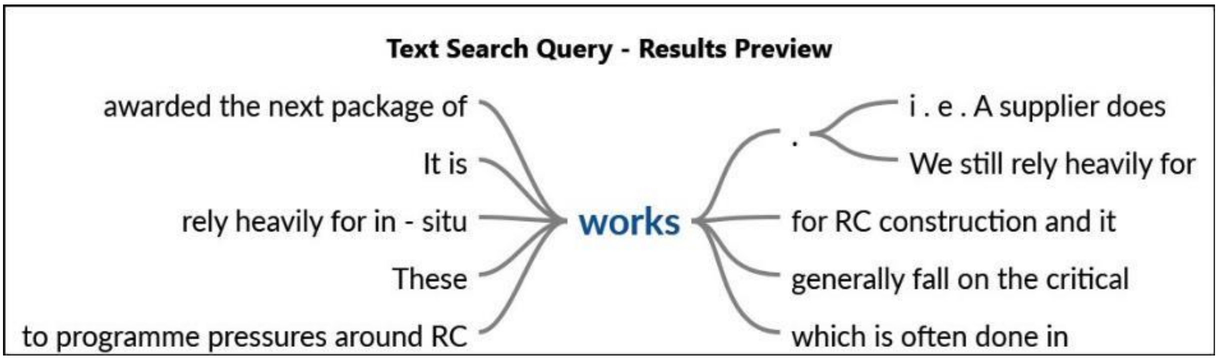
(1) Often



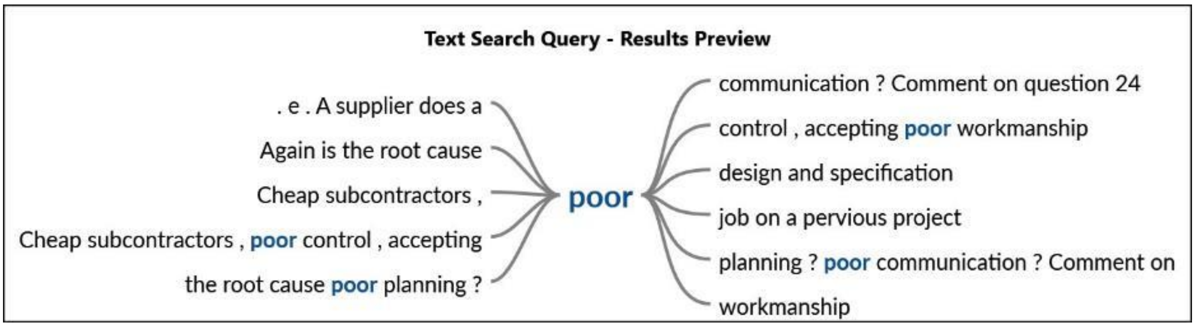
(2) Quality



(3) Works

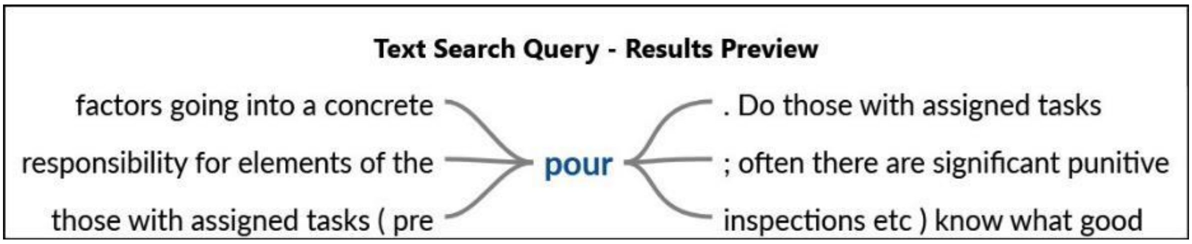


(4) Poor



Text Search Query - Results Preview
. e . A supplier does a
Again is the root cause
Cheap subcontractors ,
Cheap subcontractors , poor control , accepting
the root cause poor planning ?
poor
communication ? Comment on question 24
control , accepting poor workmanship
design and specification
job on a pervious project
planning ? poor communication ? Comment on
workmanship

(5) Pour

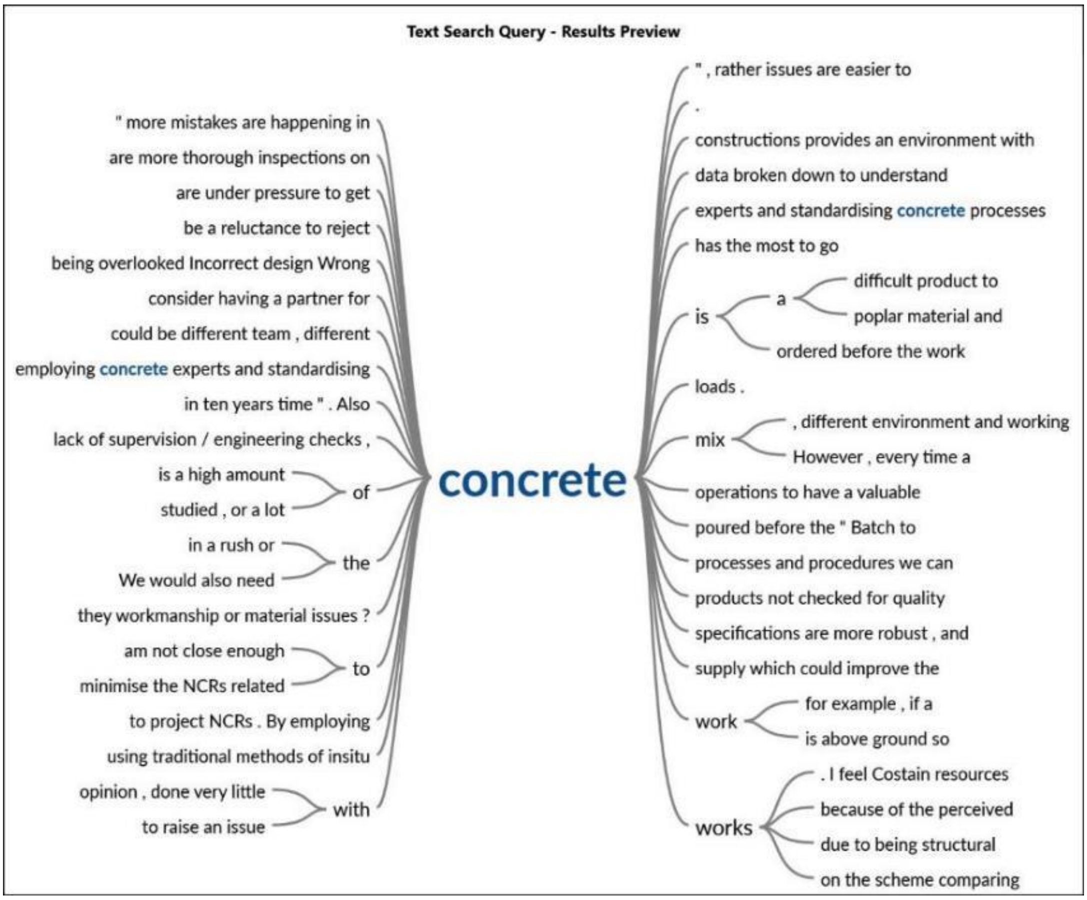


Text Search Query - Results Preview
factors going into a concrete
responsibility for elements of the
those with assigned tasks (pre
pour
. Do those with assigned tasks
; often there are significant punitive
inspections etc) know what good

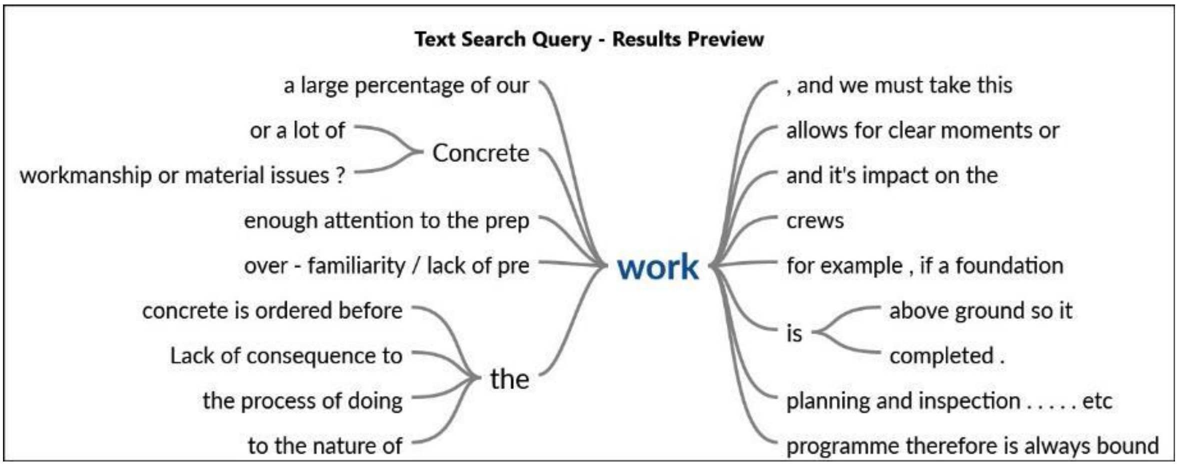
QUESTION 24: Of the concrete related activities (including series 400 (slip form), 500 (slip form), 1000 and 1700), this equated to 383 NCRs raised on the scheme. Why do you think we are continuing to make mistakes in concrete operations?

Quality Community

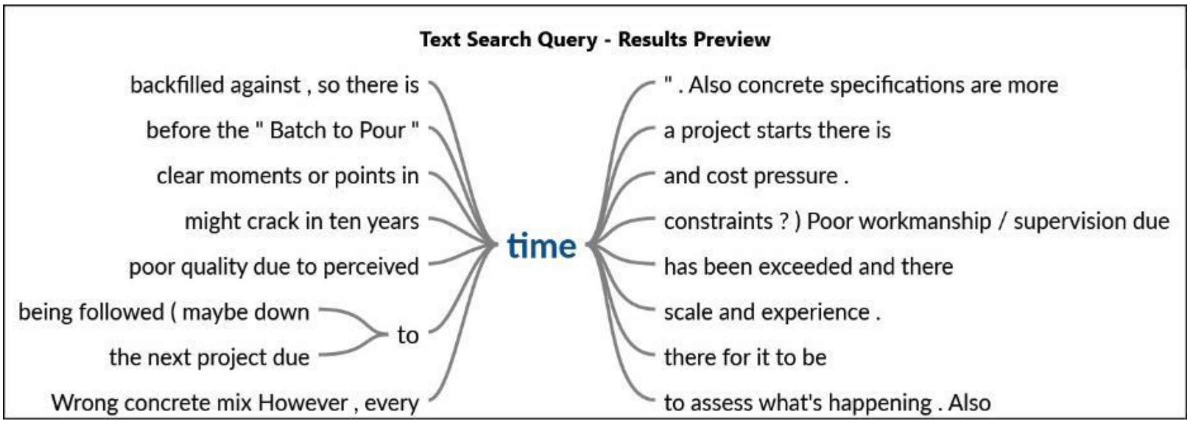
(1) Concrete



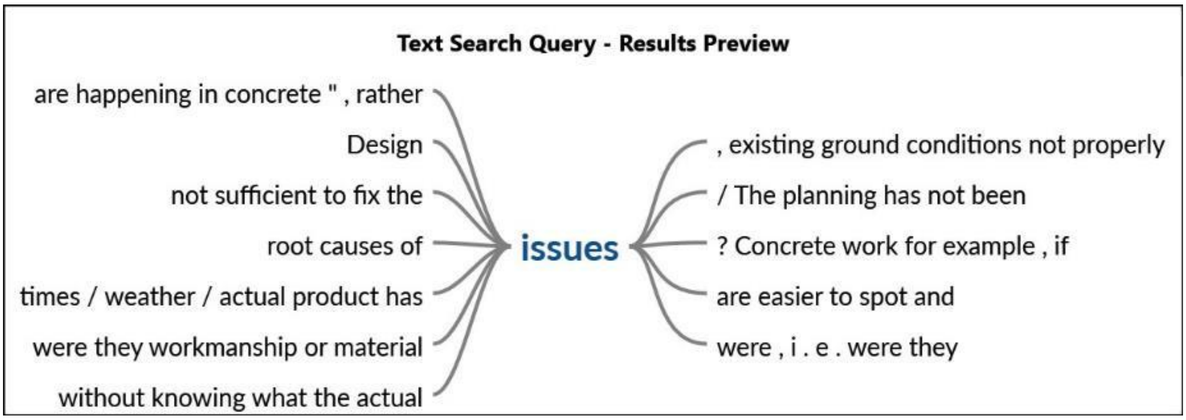
(2) Work



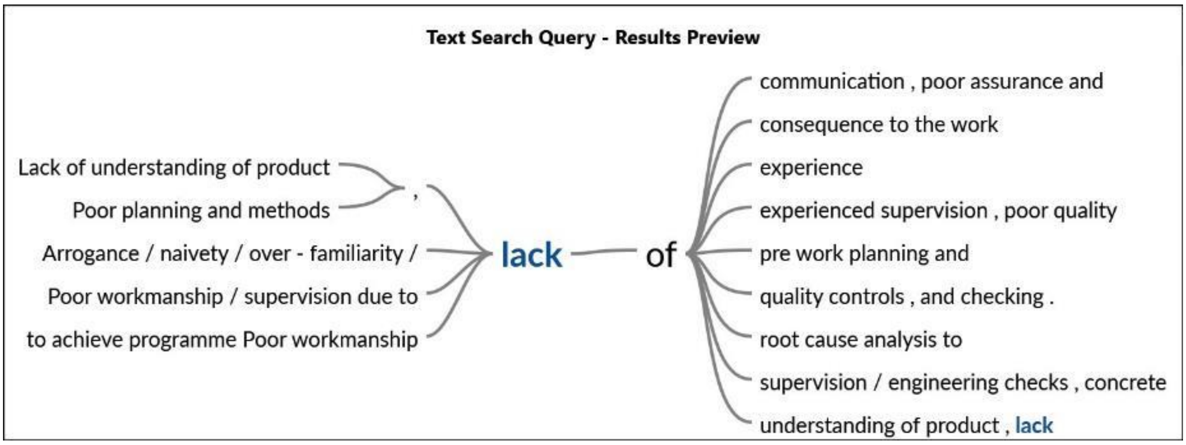
(3) Time



(4) Issues



(5) Lack



Appendix 18. Email transcript of feedback on Ford's quality excellence and improvement framework (Reviewer 2)

Gavin Ford

From: Sensitive information
Sent: 14 November 2023 15:18
To: Gavin Ford
Subject: RE: Quality Management Improvement Wheel - G Ford thesis

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments, unless you recognise the sender and know the content is safe. Always verify with the source if unsure.

Hi Gavin
Just some feedback on the Wheel
I think you are onto a winner here.
I like all of the whys you list !!!!!
I also see real value in other aspects listed on the wheel ie digitized (seeing a problem internally here where people think if digitized then change control and version control isn't needed!)
You also list risk, hugely important
I also really like competence (links to hacket report for example) and also lessons learned.
So I think that the wheel resonates strongly with me!
Finally, a last acid test, when you publish this I'd share this with our board and CEO.
I can see the whys you list as a key 'way in' for me in a discussion, I think this could be a powerful tool.

Regards

Sensitive information
Head of Integrated Management Systems

Sensitive information

Sensitive information

From: Gavin Ford Sensitive information
Sent: Friday, November 10, 2023 1:55 PM
To: Denis Leonard <Denis.Leonard@graham.co.uk>
Subject: Quality Management Improvement Wheel - G Ford thesis

[WARNING] - External email, exercise caution.

Hi Sensitive information

Great chatting with you this morning and look forward to our next encounter. Please see the framework (wheel) I've devised for the final portion of my thesis.

I warmly welcome your feedback and hope you agree with the general principles of the model.

Kind Regards,
Gavin

Sensitive information

Appendix 19. Email transcript of feedback on Ford's quality excellence and improvement framework (Reviewer 3)

Gavin Ford

From: Sensitive information
Sent: 13 December 2023 08:33
To: Gavin Ford
Subject: RE: NCR outputs from PhD thesis and Industry survey
Attachments: Self-Determination Theory and Work Motivation - Gagne Deci 2005.pdf; The behaviour change wheel.pdf

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments, unless you recognise the sender and know the content is safe. Always verify with the source if unsure.

Morning Gavin

Firstly, excellent paper – coherent and persuasive points which I support. Your findings are relatable and comparable to our internal review of our Quality data collection; specifically the attributing of "workmanship" as an RCA - this isn't a *root* cause but an immediate one, with contributory causes lying far deeper in an organisational failing that the person "doing it wrong" - I actually vote to remove it from a root cause list all together. We could learn a lot from the likes of Richard Roff and the investigative methods applied in the HSW world in this.

The reliance on "people as the problem" demonstrates a lack of critical thinking on the part of the organisation, something we share in Skanska; we don't spend anywhere near enough time in critically reviewing the environmental conditions we set as an employer and controller of the working world we create.

There is a significant lack of demonstrable Quality performance measures throughout our supply chain and industry; this is a great point and we are able to influence National Highways in this space, I am keen to develop some Quality performance metrics in.

You make a point about consequence and reward which I support in the near future, however, check out Self-Determination Theory research, originally carried out by Deci and Ryan in the 80's; their model puts external regulation i.e., reward and punishment, at the first stage of motivation; we may be better placed exploring their levers of autonomy competence (which you pick up well), and relatedness to the subject of Quality.

Really interesting point around material management - specifically the disjointed nature of the end-to-end management of materials; I am keen to explore this in Skanska and beyond and the impact of the construction process on material performance i.e., what do we do to a material with expected performance outcomes, to reduce that performance….

Framework
Your framework tool is comprehensive and looks useful. I will have a go at working through some of those segments to understand how useful this can be for an organisation like ours; I think there are really good parallels with the behaviour change wheel (Mitchie 2016) you may have come across too.

Kind Regards

Sensitive information
Head of Quality Assurance

Sensitive information

From: Gavin Ford Sensitive information
Sent: Tuesday, December 5, 2023 11:04 PM
To: Sensitive information
Subject: RE: NCR outputs from PhD thesis and Industry survey

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Hi Sensitive information

Hope all is well.

Any feedback on my quality excellence and improvement framework please? Would be good to get some feedback to add to my thesis.

Kind Regards,
Gavin

Gavin Ford Sensitive information