A strategic approach to failure mitigation: A study of project and quality management in five projects

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A thesis submitted in partial fulfilment of the requirements of University College London for the degree of Doctor of Philosophy

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I, Diyana Syafiqah Binti Abd Razak confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis

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Abstract

The causes of operational failure remain unclear to those tasked with both delivering projects and managing operational assets. Greater awareness of the owner and their supply network capabilities to mitigate failure could reduce significant quality costs that can amount to many millions of pounds. This thesis investigates why assets handed over to the owner have failed during operation, and proposes new ways that capabilities can be integrated to reduce and prevent potential operational failure from arising. An abductive reasoning with a grounded theory approach was used over a three-year period, and involved quarterly expert research steering group meetings to validate the iteration between literature and empirical observation to obtain new insights. The first workshop and questionnaire phase of the study created a Cost of Quality (COQ) framework; this was then tested on five multi-case study and subsequently developed within a single expert owner organisation using semi-structured interviews, card sorting and a Delphi review. The results show that the owner and the multi-organisational supply network capabilities are fragmented in addressing operational failure. By identifying and measuring quality cost failure, owners and their supply network will learn and be able to procure more integrated capabilities in failure mitigation for reducing quality cost failure. This will be achieved with better understanding of the relationship between owner's strategic requirement, technical project delivery and functional operations management capabilities, which is summarised in a capabilities cycle model. The model illustrates the need for a strategic project and quality management approach to integrate capabilities within each phase of a project's lifecycle. An integrated capabilities approach is proposed for the owner and its multi-organisational supply and operator network to integrate and collaborate in relation to the capabilities required to equally share project risk and quality cost in mitigating the failures.

Keywords: Failure, failure mitigation, integrated capabilities, quality cost

Impact statement

Not many people are aware of the impact of operational failure in construction projects. This multi-case study describes how research in Construction and Project Management at University College London has contributed to innovative new project and quality management; this includes a new process and a new organisation and network structure to improve the operational delivery of a project. The new strategic approach has directly contributed to the project and quality management approach in failure mitigation. The research has shown that there is a need to integrate owner's strategic requirement, technical project delivery and functional operations management capabilities in failure mitigation. Using the measurement of cost of quality measure, owners and their multi-organisational supply network can address the problem of capabilities distribution in a project's lifecycle. The research supports the construction industry in the development of a new strategic approach to better understand the operational failures in reducing quality cost failure. Research contributions to project-based organisation delivery include a cost of quality framework that is suitable for construction scope to support the understanding of failure mitigation. The research ascertains what could be done to share knowledge of failure throughout the supply network, and to create a shared culture of quality between all partners. This research provides greater transparency of where costs lie within the owner and its multi-organisational supply network.

Wider dissemination routes have been through conventional publications and presentations (conferences, seminars) as well as a steering meeting to promote benefits of the cost of quality measure (workshops). Through the very close collaboration with industry partners (the Chartered Quality Institution working group), research outputs have provided practical implications for the organisational impact. The work has been published in Quality World Magazine to address the failure and cost of poor quality in construction. The collaboration work with the cost of quality working group has increased the interest in the research area, attracting new staff, students and researchers to contribute to the new integration model in supporting the reduction of operational failure in construction. This research benefited from the working group and has been directly supported by one of the UK's leading construction owner organisations in providing significant data. Wider benefits of this impact have led to the owner organisation forming new capability to focus on and highlight changes in the organisational structure and the development of a new Knowledge Transfer Partnership application.

Acknowledgements

Firstly, I would like to express my deepest gratitude to my first supervisor, Dr. Grant Mills, for introducing me to this exciting field of project management and for his dedicated help, advice, inspiration, encouragement and continuous support, throughout my Ph.D. Your enthusiasm, integral view on research and mission to provide high-quality work have made a deep impression on me. You have given me a lot of opportunity, for which I will be forever in your debt. I would also like to thank my second supervisor, Dr. Aeli Roberts, for her encouragement and direction in my research. Your support has enabled me to focus on my efforts for this research. This thesis has been an adventure, to say the least, but both my supervisors made it that much easier and more enjoyable. Their continual support and persuasiveness conveyed a spirit of enthusiasm. Without their intellectual knowledge, out-of-hours supervisions and advice, this thesis would not have been possible.

Secondly, I would like to express my deepest gratitude and appreciation to all the industry participants – especially the Chartered Quality Institution (CQI ConSIG group) and Helen Soulou – that have given me the opportunity to gather all the data needed to build this thesis. Their time and enthusiasm have kept me going.

Thirdly, my husband, Ahmad Syafiq Afzal, for always being there for me and giving me unconditional love and faithful support. Thank you to you who made me believe I was capable of this thesis. Your understanding, patience, sacrifice and love have always restored my faith.

Fourthly, to my dear parents, thank you for showing faith in me and giving me liberty to choose what I desired. Your prayers and love have always been my pillars of strength. I owe you huge gratitude. To my family and friends, thank you for all the advice, help and support throughout the incredible journey.

Lastly, to my three-year-old daughter, Sofea Alysa, you are my inspiration to achieve greatness. Because of you, I gathered my strength to finally finish this thesis. Thank you for continually providing the requisite breaks from philosophy and for being such a good girl who always cheered me up.

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Glossary

Applying capability: Capability that is applied during project execution to fit operational needs and requirements. It is the capabilities that are applied during the execution, establishment and coordination to meet the operational environment. This capability is shaped according to the earlier transferred capability by the project team to shape the later development of operational capabilities. This capability will allow a development for the operations ability to operate the assets or projects.

Capability: The distinctive managerial knowledge, experience and skills located within a single organisation (a firm) of either it is an individual experience or as an organisation ability to provide the desire knowledge and skills. In which are required to establish, coordinate and execute a project. This includes a distinct behavioural pattern, which is complex in nature, involving both formal and informal processes.

Cost of quality: This is an approach that allows an organisation to determine the extent to which its tools and resources are used for activities that prevent poor quality, that appraise the quality of the organisation's products or services, and that result from internal and operational failures. The information will allow an organisation to determine the potential savings to be gained by implementing process improvements.

Failure: Failure is defined as the condition or fact of not achieving the desired end or ends. Failure is an unacceptable difference between expected and observed performance; also the termination of the ability of an item or system to perform an intended or required function. Failure usually results from a combination of conditions, mistakes, oversights, misunderstandings, ignorance and incompetence, or even dishonest performance.

Functional operations management: A proactive system of business function responsible for managing the operations of an asset through a collaborative process of the creation of the goods and services. The management is concerned with designing and controlling the management of the production and redesigning the business operation to control and ensure the deliverability of its capability to meet the functional need.

Multi-organisational supply and operator network: An extension of supply chains with the operational team, it involves different capabilities that is seeks to accommodate and construct the commercial complexity associated with the creation and delivery of the goods and services. This involved different organisations from the delivery of raw materials to the completions of project that meet end-user satisfaction and towards the operations of the asset.

Operating (Operational) costs: These are the expenses related to the operation of a business, or to the operation of a system or asset. These are the cost incurred due to the day-today operating works such as fixed cost (e.g.: rent or mortgage) or variable cost (e.g.: maintenance or insurance).

Operational capabilities: The ability to align critical processes, resources and technologies according to the overall guiding vision and owner-focused value propositions coupled with the ability to deliver these processes effectively and efficiently. It is the capability to fully employ and maintain the asset/system to meet an operational need.

Operational failure: This is the inability of a system to meet a specified performance standard. A complete loss of function is clearly one type of operational failure. However, the term also includes the lack of capability and inability to function at the level of performance that has been specified as satisfactory during project operations. Operational failure can lead to corrosion and catastrophic damage to the system that will have a cost in relation to quality.

Owner capabilities: This is a complete set of capabilities that an organisation requires to executes its business model or fulfil its mission. It is an organisational level of skills imbedded in people, process and/or technology.

Owner strategy and requirement: Owner's initial planning in initiating a new project, a structure for defining, approving and implementing the project scope within an organisation or funding programme. It provides a strategic requirement for procuring capabilities.

Owner: Entity that initiates a project, finances it, contracts it out and benefits from its output(s).

Project capabilities: These are the knowledge, tasks and structures that organisations require to design and produce complex products and systems as one-off units or in small, tailored batches to address the requirements of large businesses, governments and institutional owners. The capability includes different sources of skill and knowledge in delivering a project. This includes the activities and structures required to manage the project through its life, from the front-end engagement with owner and sponsors, through tendering and project delivery, to the back-end handover to the owner and provision of on-going support.

Project failure: Any project that fails to meet time, budget and quality targets is considered a failure. Project failure is when a project cannot attain its aims and causes a negative impact for the owners, contractors and others. This includes insufficient capabilities to deliver the desired function of a project and further resulted in quality cost of failure.

Quality cost failure: This is costs arising from failure to achieve specified quality within the organisation or the quality specified for the project. It deals with identification of problem areas and analysis of quality costs. Quality cost failure includes all the cost incurred due to the occurrences of the failure be it either before the project is complete or after its handover.

Quality failure: A lack or deficiency of a desirable quality or a nonfulfillment of the agreed specifications or requirements.

Quality management: The act of overseeing all activities and tasks needed to maintain a desired level of excellence.

Recognising capability: Capability that is recognised and captured for the owner's future project(s). It entails ability to capture the operational capability that consists of the set of new routines to be combined with the existing operating environment or to add to the owner's operating environment. This is further developed as an improvement to the owner's capability for existing and future business. It is recognised as a new set of capability for owner and multi-organisation based on the learning that is obtained from the previous failure.

Stakeholder: A person or group of people who own a share in a business or project that has an interest in a company and can either affect or be affected by the business.

Technical project delivery: A temporary organisation that undertakes a design process to deliver the desired outcome that meets the business needs. The organisation provides the initiative from a concept through to a concrete deliverable as a project with specialist technical knowledge by utilising the allocated resources within a pre-defined timescale.

Total quality management: A management approach to long-term success that views continuous improvement in all aspects of an organisation as a process and not as a short-term goal.

Transferring capability: Capability that is transferred from owner's strategic planning towards the project execution. This was later developed by the project team as a project capabilities to execute the intended business goal. It consists of different sets of capabilities to suit the project scopes and aims. This capability is own by the owner and its multi-organisational supply and operator network that need to be integrated throughout the project life-cycle.

1 Introduction

1.1 Overview of the thesis

This thesis presents knowledge on appraising the cost of quality (COQ) allowing an understanding of the causes of operational failure in project management (PM). It seeks to understand the key elements that contribute to the growth of operational failure and to provide an integrated model that can help owners to better manage their multi-organisational supply and operator network in reducing the COQ. This chapter addresses the research scope and problem, research question, research aim and objectives, significant contribution to knowledge, research design, research structure and chapters, and, finally, the significance of this study. It explains how the research was carried out based on the root problems to achieve the underlying aim and objectives.

1.2 The research problem and need

The complexity of construction today and the sophisticated demands contribute to the pressurised environment that makes it difficult to obtain a successful Total Quality Management (TQM). Industries are now seeking a better resolution in regards to the failure costs (Krishnan, 2006; Ahsen, 2008; Love & Li, 2000). The exact nature of these costs and their root cause are not understood (Miguel & Pontel, 2004). As such, there is limited control and management of these costs. The introduction of Cost of Quality (COQ) in TQM was first propounded to help many organisations in various sectors to better understand the distribution of quality cost in regards to the reduced failure costs (Figure 1.1). However, despite the general classification of COQ that is widely used in various industries, studies have shown many difficulties in applying COQ (Abdul-Rahman, 1993; Low & Yeo, 1998; Love & Li, 2000; Hall & Tomkins, 2000; Aoieong et al., 2002; Rosenfeld, 2009; Love & Irani, 2002; Jafari & Rodchua; 2014).

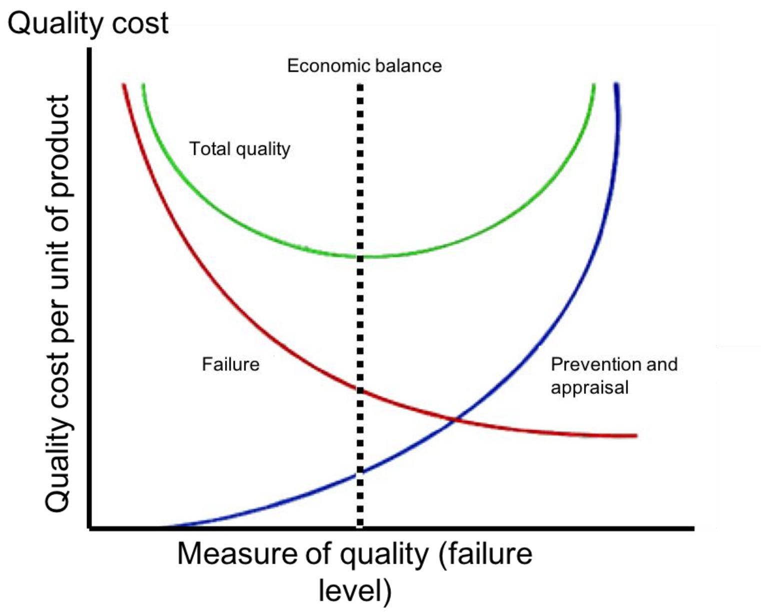


Figure 1.1: Traditional cost of quality (Adapted from Juran, 1951)

The innovation of TQM today has become a challenge to the above traditional view of COQ (Basu, 2015). A more dynamic model needs to be integrated (Snieska et al., 2013) to support the reduction of failure costs. Although there is no doubt various applications of the COQ in the construction industry have demonstrated tangible savings (Abdul-Rahman et al., 1996; Love & Irani, 2002; Love & Li, 2000) failure cost is still highly recurrent (Taggart et al., 2014). COQ is now highly prioritised and is a key part in managing business strategy (Tye et al., 2011). Studies show COQ can average 10% - 12.4% of the total project cost (Rosenfeld, 2009). It is believed that the use of COQ can increase profitability by reducing the operating costs incurred from poor-quality processes and project failures. Operational failures (failure cost during operational performance) are considered as the most significant (Snieska et al., 2013) but were mostly found to be hidden in the process (Love et al., 2002). In ISO9000, quality is described as a managerial issue that must be embedded in the production process. In this sense, there is an increasing necessity to understand the implementation of COQ and to resolve the misalignment of incentives that work against the achievement of quality.

Given the difficulties in quantifying the COQ in construction projects, studies show that the implication of quality failure does not only occur at project handover; it has further implications throughout the lifecycle of a building (Josephson & Saukkoriipi 2005; Josephson & Saukkuriipi 2007). The difficulty of quantifying the COQ in a construction project may be a challenge but emphasises that the opportunity for saving a substantial part of construction quality cost is extremely beneficial. However, this has not been well articulated in how COQ could improve the project performance. Hence, sophisticatedly capturing and balancing project quality cost could be more of an imperative (Rosenfeld, 2009) with a new integrated and dynamic model (Snieska et al., 2013) that combines both the project and operation management (Pena-Mora et al., 2008) in reducing the quality failure costs. The main importance of appraising COQ is thus to see beyond what its capability is in improving quality performance. Organisations must see beyond normative tools and techniques, which includes soft-systems approaches. The complexity of the multi-organisational supply and operator network in the operational environment is seen as the core in supporting the Quality Management System (QMS) of measuring COQ and thus reducing failure.

An organisation must first synchronise its internal departments, if it is to implement a successful QMS (Jafari & Rodchua, 2014). There is a need to promote quality costing systems in improving the operational performance (Shah, 1999) as a quantification to reduce failures (Omar & Murgan, 2014). Currently, the successful completion of a construction project is no longer judged simply according to its meeting the targeted time and budget; it includes the quality performance after its post-completion. However, there is little evidence from the literature showing how construction projects manage quality within their processes (Delgado-Hernandez & Aspinwall, 2008) while many studies have shown the increasing numbers of projects with quality failure (Willis and Willis, 1996; Barber et al., 2000; Hwang and Aspinwall, 1996; Teo and Love, 2017), and cost overrun and delays (Adam et al., 2017; Invernizzi et al., 2018). Industries are now seeking a better resolution in regards to failure (Krishanan, 2006; Ahsen, 2008), specifically in responding to its impact on project operations (Slack, 2005). The link between cost incurred after the project completion with overall project performance in general has not been well understood; with an interchange of understanding the causes of failure with defect or rework (Jingmon & Agren, 2015 ; Josephson, 1998; Miguel & Pontel, 2004). As such, there is limited control and management of these costs of failure.

Despite the enormous amount of cost in delivering infrastructure development projects, surprisingly little systematic and reliable knowledge exists regarding the performance of these investments in terms of the actual cost and its operational performance. Existing studies of cost, benefit and uncertainty in infrastructure developments are few, especially in looking at the operational side of complex infrastructure projects. Most large capital projects have failed to live up to expectations, with the majority being abandoned after a few years (Flyvbjerg et al., 2002). Some examples of well-known projects that experienced operational failures are Heathrow terminal 5 (Caldwell et al., 2009), Berlin Brandenburg airport (Nieto-Rodriguez, 2017) and the 'Millennium Dome' in London that had to be closed only a year after opening due to the failure to sustain the operations (Bourn, 1999). Recently, the industry was alerted by the Grenfell tower incident which resulted in many fatalities. An independent report by Hackitt (2017) revealed the use of a regulatory fire system does not fit the operational purpose. The report stated:

> *The primary motivation is to do things as cheaply as possible rather than to deliver quality homes which are safe for people... there is a cultural issue across the sector which can be described as a race to the bottom caused with through ignorance, indifference or because the system does not facilitate good practice. There is insufficient focus on delivering the best quality* (Hackitt, 2017; p.6)

All too frequently projects deliver failures in critical operational outcomes, put operations at risk, constrain future investments and jeopardise innovation. Without knowledge and incentive to change, a project can be expected to have poor-quality outcomes (Brookes, 2013); projects are seen as lacking in identifying functional requirements, which needs more emphasis in project management. Although construction organisations acknowledge that it is essential to deliver high-quality products and services, the consequences of failure are growing even more significant in today's world of increasing customer and stakeholder expectations. There are still many quality failures that cause damage to reputation (Love et al., 2018) and waste money (Miguel, 2015) in construction projects.

Quality failures at any scale are becoming increasingly unacceptable and there are many construction professional membership bodies, such as the Chartered Quality Institute (CQI) and Institution of Civil Engineers (ICE); the latter recently formed the Infrastructure Client Group (ICG), which is working actively in sharing experts' experience to support and highlight the opportunity for improving the delivery of major infrastructure projects. The organisations are strongly promoting optimisation of operational effectiveness to avoid the potential catastrophic consequences of getting things wrong. Their aims are to articulate a clear vision for quality to sustain the delivery of high-quality products and improve the commissioning and delivery of projects. Those procuring construction projects are mostly aware of the need to improve. At every level of the construction supply network, the prices tendered by companies include allowances for the management, overheads and corrective cost of failures, all of which are avoidable. Delivery to time, cost and quality has perhaps remained the mantra of the construction industry, although failures post-completion are still highly recurrent (Razak et al., 2016), and few studies are focusing on the failure implications (Hall & Tomkins, 2000; Barber et al., 2000).

The construction profession needs to ensure it is capable of avoiding the consequences of poor governance, ineffective quality assurance, inertia to change and subsequent quality failure. There is an increasing need for improvement and transformation in how quality is delivered (Olawale & Sun, 2015); and particularly in understanding the magnitude of different factors that cause quality failures (Josephson, 1998) and of how cost has impacted the delivery of the project based on retrospective views (Adam et al., 2017). Studies suggest top management support is the most critical success factor for project success (Pinto & Selvin, 1983), and literature highlights the need to call for improvement from capable public owners (Adam et al., 2015) and owner project capabilities (Winch & Leiringer, 2016) that would help top management to support the mitigation of potential failure. This shows that the owner may play a significant role in developing a new strategic approach to project and quality management to integrate the capabilities in mitigating failures. However, it is neither practical nor desirable for top managers to be overly active at the project level in ensuring the quality is delivered. Projects may need to get the right input at the right time to prevent quality failures but the industry's commonly understood view of quality is frequently defined by the owner and is set at the beginning of the project; thus, projects do not always deliver the right quality.

Capable owners assume projects will integrate with operations. Some place significant weight on the capabilities of contractors and suppliers in understanding how this is done, but research perhaps shows that the owner's projects and operational capabilities are the key (Davies et al., 2016). Although these capabilities are frequently held by their supply network and distributed across an inter-organisational network, they need to be simultaneously managed (Davies & Brady, 2016). Recent project studies acknowledge that project capabilities are either embedded or unique in an organisation, but can be transferred through the project lifecycle of actors participating in delivery of the project across the domain of projects and programmes, project-based firms, and owner-operator organisations (Winch, 2014). It is agreed that owners can enact project and operational capabilities through different cycles of a project to achieve a balance between confirmation of establishing delivery expectations and the negative expectation of service outcomes upon project handover (Zerjav et al., 2018). However, although there is a great deal of project and operational management literature on capabilities, there is currently no research looking at how these capabilities that are distributed within the project lifecycle influence the 'operational delivery' in reducing quality failure.

The diversity of capabilities involved within the multi-organisational supply network may be another challenge for the owner to undertake effective project-operational management. Management actions need greater examination at the strategic and operational level (Pena-Mora et al., 2008), where the multi-organisational project's operational capability will be embedded through the transmission of resources and people (Davies & Brady, 2016). Although the importance of the operation's strategy and capability has been conveyed (Slack, 2005; Hobday et al., 2005), the nature and scope of how the owner could mitigate failure have not been widely addressed, whilst capabilities theory suggests a strong relationship between project process and operational management (Davies & Brady, 2016) and the importance of owning the operational capability throughout the project supply network (Thoo et al., 2015). It has been explained how knowledge embedded within different projects should provide competitive capabilities as part of an organisation's assets to capture lessons learned (Flynn et al., 1990; Brady & Davies, 2004) and which are useful for the owner to reduce the failures.

These forms of capabilities must be advanced if projects are going to deliver operational outcomes that do not fail. The application of these capabilities in failure mitigation needs further clarification. Therefore, this research seeks to fill the gap in quantifying the COQ within complex construction projects to provide a better understanding of how the owner could reduce failures. By appraising and understanding quality cost failure, owners will learn lessons and be more able to distribute operational capabilities across the project supply network.

1.3 Research questions

Based on the research problems identified, this section makes explicit the research purpose and defines the core aim, objectives and research questions.

1.3.1 Aim

The aim of the research is to investigate why assets handed over to owners have failed during operation and how the **complex interrelationship of an owner and its multi-organisational supply network** members may influence the existence of **operational**

failure and its quality cost, to further develop a new strategic project and quality management approach in mitigating failures.

1.3.2 Objectives and research questions

In achieving the research aim, the following objectives and research questions (Table 1.1) are addressed through this thesis.

Table 1.1: Research objectives and questions

Research Objectives	**Research Questions**	**Supporting Evidence/ Chapters**
To explore the existing COQ and investigate its empirical application within an overarching TQM system.	•What is COQ and it's significant in supporting the mitigation of operational failure?	Literature review (chapter 2)
To investigate the status of quality cost and the occurrence of COQ within the construction supply network.	•What are the quality cost elements of operational failure in the construction industry?	Literature review, data collection (workshop, questionnaire and survey) (chapters 2, 4 & 5)
To investigate the causes of operational failure within the owner and its multi-organisational supply network capabilities.	•What are the causes of operational failure and how does the diversity of capability influence the occurrences of quality cost at operation?	Literature review, data collection (interviews, case study and workshop) (chapters 3, 5 & 6)
To develop a new strategic project and quality management approach in failure mitigation to integrate capabilities between the owner, multi-organisational supply and operator network.	• How can COQ be integrated with project management as a new approach to mitigate operational failure and reduce quality cost?	Discussion and recommendation (chapters 7, 8 & 9)

1.4 The scope and field of study

1.4.1 The field of contribution

As described earlier, there are only limited studies that quantify the COQ within construction projects, although many have agreed on the challenges of applying a quality cost system to the dynamic nature of the construction project. Research therefore focuses on exploring the COQ within the construction industry at the initial stage. The research is intent on understanding the empirical application of quality within the complex and emerging construction process as a way to reduce failure. However, understanding this concept in isolation and within the quality management perspective would not help to develop an integrated measure for reducing the failures. The research further investigates the causes behind operational failure within a multi-organisational supply network capabilities perspective to better understand the relationship of cost incurred and operational failure. Although the project management field has defined a lot of sub-fields and approaches, none have helped owners, multi-organisational supply and operator network to mitigate failure and reduce quality costs. The outcomes of this thesis address this gap and contributes to a strategic project and quality management approach to address problems in Project-based Organisations (PBOs), project capability and operational capability to directly build integrated capabilities in failure mitigation (Figure 1.2).

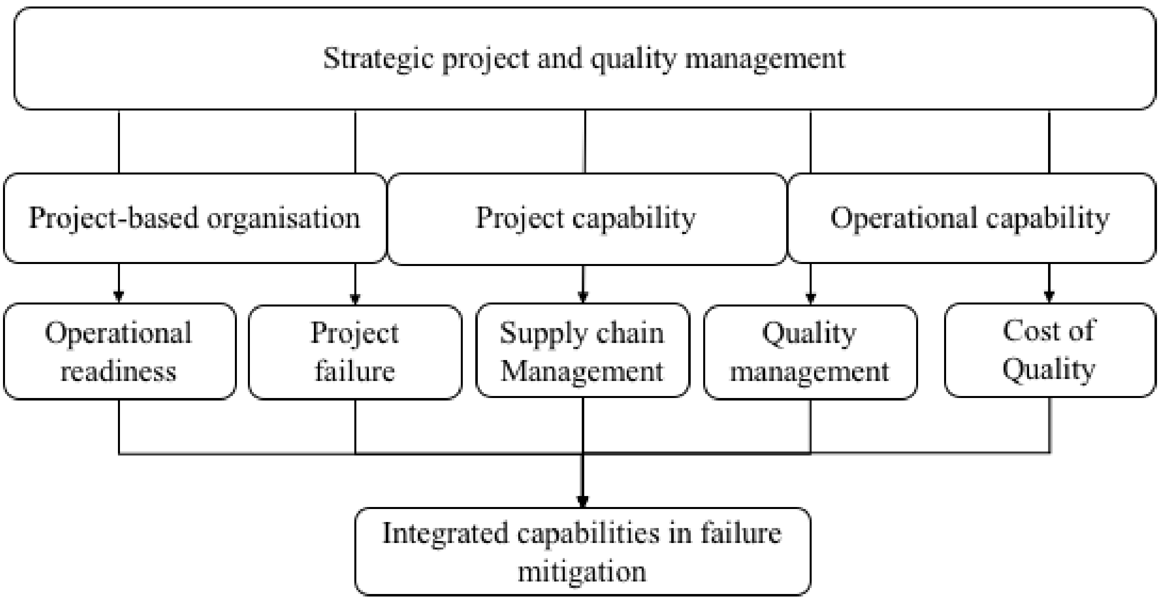


Figure 1.2: Thesis field, domains and contribution areas

1.4.2 Making a contribution to practice

The initial consulting phase of this research was supported entirely by the industrial research parties who are experiencing operational failure (this includes owner, contractor and consultants). The organisations involved in this work are doing so because, *primarily*, they want to understand why COQ is highly recurrent and the reason behind operational failure in order to mitigate this failure. The research does not identify exactly the technical details behind every operational issue, but focuses on the situations where they happen, that are known and to what extent they are influencing the occurrences, and this is what helps the author to understand the cause of operational failure. The final output is to better understand the root cause of failure within the owner and complex multi-organisational supply network as the way to improve the distribution of capabilities in mitigating operational failures. The research provides a new perspective that combines the principles of organisational structure, project quality process and quality performance outcomes in developing a strategic project and quality management approach to integrate the diversity of capabilities in the complex supply network that will help to mitigate failures.

1.4.3 Complexity inherent in researching failure

An interpretive approach to project failure helps to reveal the nature of what constitutes project performance (Sage et al., 2013) and research shows many interdependencies in complex projects have long been associated with failure (Holgeid & Thompson, 2013). However, in investigating operational failure, an important issue in the present study is the quality culture (Barber et al., 2000), and how the construction environment can be adapted to deliver optimal quality (Ethiraj et al., 2005; Castillo et al., 2010; Snieska et al., 2013) to reduce failure cost. This is because cost is one of the success criteria by which the success or failure of a project is judged (Cooke-Davies, 2001) and is also known to be an effective tool to help management to visualise and understand the different technical languages used in projects (Hwang & Aspinwall 1996). This is why the measurement of COQ in the manufacturing industry is well advanced and effective (Tang et al., 2004) but the use of COQ in the complex construction environment is still limited (Castillo et al., 2010). This may be due to many factors, such as ineffective decision-making (Love & Irani, 2002), design errors, poor communication, construction deficiencies and uncertainty about ground conditions (Love & Li, 2000; Krishnan, 2006; Castilo et al., 2010, Hwang & Aspinwall, 1996); most of all, it is because each construction project is unique.

1.4.4 Moving from failure quantification to failure capability qualification

A vital challenge is the insular way relating to how quality is to be quantified (Love & Irani, 2002) that leads to uncoordinated project management (Dale & Plunkett, 1995) in a complex environment. Hwang and Aspinwall (1996) stress that the difficulty is due to difficulties in collecting time-indexed data during a practical process. Others mention that service industries are difficult to define and collect quality cost from, as such industries involve human-related interaction that is diverse in nature (Asher, 1990; Asher, 1988) but the management of people needs a combination of the ability to manage people capability and project and operational capabilities (Bredin, 2008). Consequently, capabilities are embedded in an idiosyncratic social structure that is frequently presumed to be organisational resource allocation (Schreyögg & Kliesch-Eberl, 2007), but it is still difficult to explain the use of heterogeneity in resources and capabilities (Helfat & Peteraf, 2003) in mitigating failure. Thus, the identification of social and behavioural features of resources and capabilities in relation to failure and quality cost implication may be beneficial, as most organisations do not realise that costs of poor quality are included in many of construction activities (Josephson & Saukkoriipi, 2003) including the resources and capabilities (Helfat & Peteraf, 2003) that are encapsulated within the capabilities cycle of a project.

1.4.5 Operational failure in a broader management of projects environment

While in project management failure is often assumed to be due to the deficiencies in management (Sage et al., 2014), a different theoretical position is required to gain better understanding of its causes (Pinto & Mantel, 1990). In the main, construction project owners tend to choose the procurement route with which they are familiar, and yet many projects suffer with variations in cost affecting one or another actor (Osipova & Eriksson, 2011). However, the combination of methods in procurement seems to be another problem in addressing the quality cost (Al-Tmeemy et al., 2012) that needs managerial awareness (Jafari & Rodchua, 2014; Olawale & Sun, 2015). Many have suggested that a well-established standard procedure is an important attribute in the cost control system (Jafari & Rodcua, 2014; Olawale & Sun, 2015) to overcome the challenge, while others believe that a comprehensive model is a necessity in judging the causes of its occurrence (Porter & Rayner, 1992, Abdul-Rahman et al., 1996, Low & Yeo, 1998; Yang, 2008; Hwang & Aspinwall, 1996), which will help in improving project performance.

Research on project and project performance management has a long history, but there is still a gap within the many project management approaches in understanding project failure, especially as it relates to operations. The interest in the concept of project capability development is relatively recent (Ahern et al., 2015). Above all, it is important to see how the assembly of project capabilities towards the project's operational need will help owners to better understand the diversity of capabilities in mitigating operational failures. Therefore, it is then imperative to advocate a comprehensive study with regard to these challenges to establish a new integrated capability model that includes a more routinely collaborative environment for COQ as a way to mitigate failures. This thesis is thus based on the concept of COQ, appraising the existence of operational failure and its quality cost to further understand the causes of operational failure. This concept is then further mapped with the emergent findings upon wider project management literature and, finally, through understanding the concept of capabilities, the research explores how the capabilities concept in the PBO was developed. The outcome of this thesis will address this gap and contribute to directly build the strategic project and quality management approach in failure mitigation. An integrated approach will be developed focusing on how integration of capabilities across owner and multi-organisational supply network could be developed to mitigate the occurrence of failure and thus reduce the quality failure costs.

1.5 Thesis structure and research phases

To begin with, this research aims to understand: (i) how COQ occurs and is absorbed in the construction industry; (ii) the causes of operational failures; and (iii) how failures can be congenially described and generalised across the complex supply network. To achieve these aims and objectives, three research phases will be applied. These are framework development, workshop and questionnaire (Phase 1); five project multi-case study using interviews, card sorting and a Delphi review with a single expert owner organisation, its multi-organisational supply and operator network (Phase 2); and, finally, analysis of data and theory building (Phase 3).

1.5.1 Thesis structure

The study comprises nine chapters; the chapter structure is shown in Figure 1.3.

Chapter 1 Introduction	
Chapter 2 Quality management, COQ and failure literature	Chapter 3 Project-based, project failure and capability literature
Chapter 4 Research Design and Methodology	
Chapter 5 Understanding COQ (Phase 1 – framework development)	Chapter 6 Exploring the operational failures (Phase 2 – framework developed)
Chapter 7 The capabilities cycle (Phase 3 – theory building)	
Chapter 8 Conclusion and contribution to knowledge	
Chapter 9 Recommendations	

Figure 1.3: Research structure

1.5.2 Research Phases

The three research phases of framework development, developed framework and theory building are described in a Research Map (Figure 1.4) and reflect the methodology. They are summarised as follows:

Phase 1 – Literature review, workshop and questionnaire

The first phase used the COQ literature and empirical analysis to develop a primary framework that expands the theory and language of the complex supply network in understanding operational failures. This framework development is described in chapters 1-5 and addresses objectives 1 and 2, which combine the following research questions: What is COQ? What are the categories of COQ? How is COQ being applied? Does the TQM system support COQ? What is operational failure quality cost? What are the quality cost elements of operational failure in the construction industry? What is the perceptions of the project supply and operator network in relation to operational failure and its quality costs?

A literature review was conducted to build up this knowledge and to understand the problems. The review begins first with the COQ in the construction industry, focusing on the operational failure and its quality cost, then moves on to the area of project management, examining collaborative working with practical practices. At this stage, the COQ literature is extensive while that on the complex supply network is more modest. The first stage involved a critical review in these two fields; workshops and a questionnaire were used to support the development of the new COQ framework. The COQ model (Chapter 5) developed from the literature and steering group discussion shows quality cost elements in each category of Prevention, Appraisal and Failure. This model is further defined and categorised in each phase of this study.

Workshops were conducted within the steering group. This helped to further classify the categories, maturity and ownership of each cost element. The result of the workshop shows the complexity and interrelation of the supply network with most of the cost elements. The insight of this relationship may be dependent on organisation type, roles, contract and project-related factors. It highlighted the multi-organisational complexity that shows why measurement is hard, understanding is often lost and that such costs are today expected overheads. The opportunity for these costs to be the basis for supporting long-term relationship building in construction projects is becoming apparent. The alternate view – that operational failure quality cost is only born by owners – is therefore challenged.

The questionnaire was constructed to generally understand the maturity of each failure quality cost element. It helps to characterises and define the wider industry context for comparison with the responses from the case study. Data was collected from a range of construction industry stakeholders and experts. The population of this study is comprised of professionals working in construction projects in the United Kingdom, ranging from operations and asset managers, owner quality directors and managers, contractor and consultant project/commercial managers to designers and technical/specialist supply network members. Data from the questionnaire will provide statistical evidence of relationships (Fellows & Liu, 2012) to determine the direction of operational failure and its quality cost element causalities when combined with theory and literature.

Phase 2 – Five project multi-case study from a single owner

During this second stage of the study, the author worked closely with a Quality Manager to acquire and participate (e.g. through action research) in project data collection. All multi-case study was undertaken within the owner organisation's projects. The retrospective research on selected multi-case study helped to investigate the COQ nature in the construction industry and to give an insight into the project-specific nature of the complexity of the supply network in relation to failure elements (to build an in-depth qualitative examination). This provides a comprehensive analysis of how COQ is implemented. Thus, the case study included note-taking activities (Taggart, 2014), semi-structured interviews and workshop discussion. Data was collected from a cross-section of project participants to gain understanding and opinions (Fellows & Liu, 2008). All activities including informal conversations were summarised and recorded in field notes and a research diary.

The multi-case study provides relevant information in constructing a theory for reducing the operational failure quality cost. All samples have been selected based on the author's assumption that they will provide a rich source of information (Gay et al., 2009). Taking into consideration the viability of the case, earlier informal interviews (through pilot studies) that were conducted with key participants in the owner organisation demonstrated participants' willingness to share experience and knowledge of the COQ phenomenon. This supports full understanding and commitment. In qualitative research, the case study data will be collected to answer 'how' and 'why' questions (Gay et al., 2009) where qualitative data can be difficult and laborious to analyse and must be systematically handled (Fellows & Liu, 2008). Therefore, during this stage, definition and selection of cases and units of analysis will be fully justified (Yin, 2003). However, the concept and content including level of analysis will emerge during the last phase of the research.

Phase 3 – Analysis of data and theory building

Further qualitative data analysis took into consideration the complex nature of the case study interviews. A flexible design approach has been selected to manage the data. The author rigorously examined both the qualitative and quantitative data and adhered it to the grounded theory methodology. The method involves 'assessment from experiences' and 'the use of calculations' (Olawale & Sun, 2015). In analysing multi-case study, cross-site analysis will be used (Gay et al., 2009). Through the thematic analysis method, a series of coding is used to analyse and interpret interview transcripts for all participants. The importance in conducting this kind of cross-case synthesis is that it relies strongly on argumentative interpretations (Boblin et al., 2013). The quantitative medium of the case study strengthened the breadth of the data and analysis.

The contribution to knowledge is stated in this final phase. The distribution of capabilities influence on operational failure within the capabilities cycle is addressed to develop a strategic project and quality management approach in failure mitigation. Integration across the owner's strategic requirement, technical project delivery and functional operations management capabilities is proposed for the owner, its multi-organisational supply and operator network to mitigate failure and reduce quality cost. Figure 1.4 shows the research map of the study and thesis, which is used at the beginning of each chapter as a signpost to guide the reader.

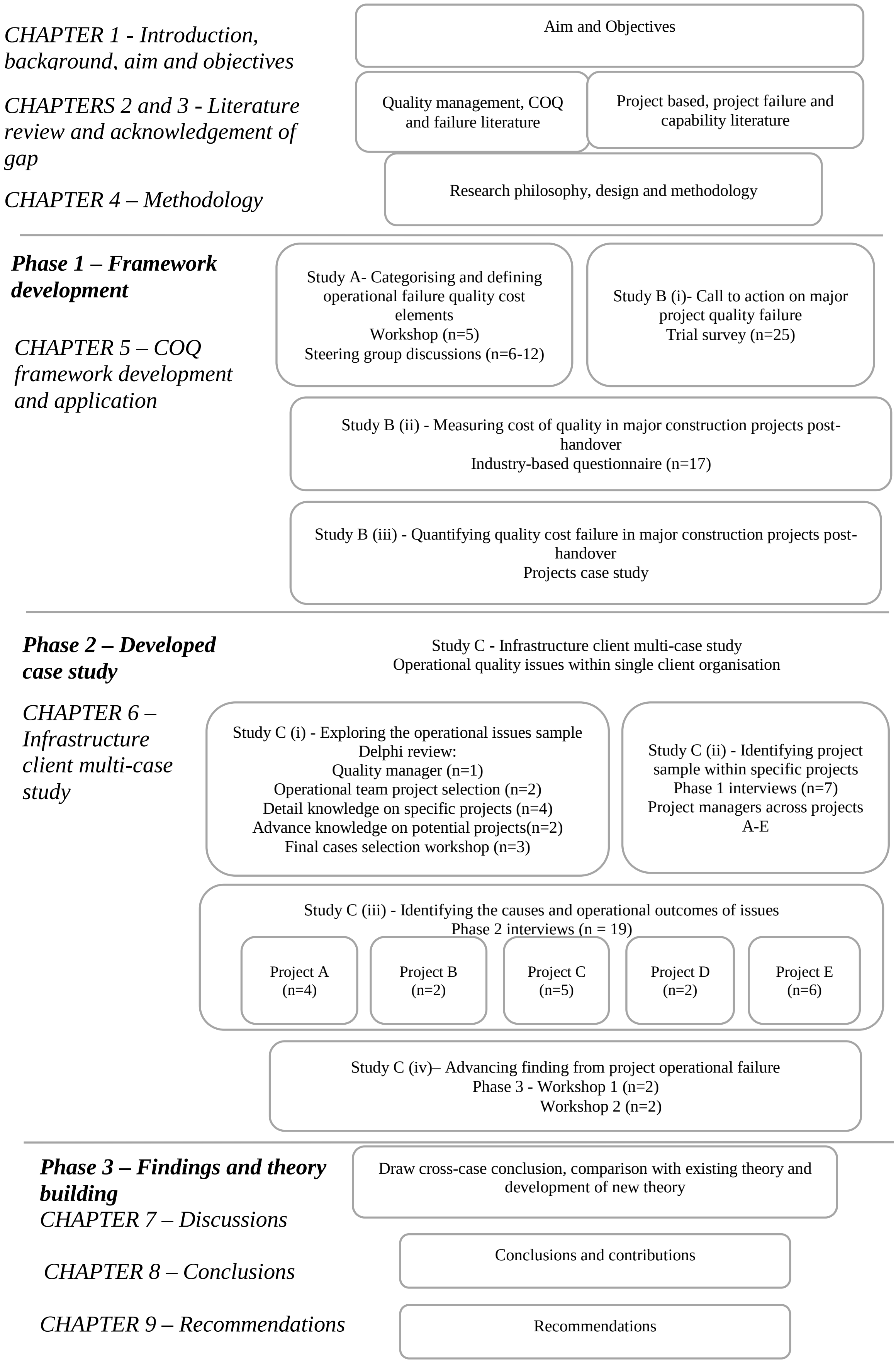


Figure 1.4: Research Map

1.6 Academic significance and value

1.6.1 Project management and the application of COQ

This study searches for capabilities held by owners, tier 1 contractors and suppliers on how to mitigate failure. While the measurement of COQ has been explored in the construction sector, its application within complex project environments and across supply and project management capabilities has not. The importance of quantifying COQ is known (Juran, 1951), but the required sophistication in measurement (Branca & Lopes, 2011) has often created drawbacks that have led to criticism (Schiffauerova & Thomson, 2006), and questions on the applicability of COQ to the construction industry (Abdul-Rahman et al., 1996; Barber et al, 2000; Love & Li, 2000; Love & Irani, 2002; Yang, 2008; Schiffauerova & Thomson, 2006; Jafari & Rodchua, 2014). COQ failure has yet to be quantified in the construction industry. Schiffauerova and Thomson (2006) stressed the importance of an improved model for a project management context. Currently, no empirical work exists that focus on operation. Previous studies show only partial work in addressing COQ without transmitting its causes and the influence of a complex project supply network on operational failure. Many have considered a single project, but none have looked at the capabilities employed by an owner across a number of projects.

Measurement by way of an organisational performance excellence model has been the current focus (Miguel, 2015), but this has not defined the complex array of owner capability for failure mitigation needed in managing the supply network of a multi-project network. Some have identified the need for a robust quality management system, management structures and tools (Barlow, 2009), but these need elaborating to ensure quality in a project-based context (e.g. contractor quality performance) and beyond that to ensure the delivery of operational quality and thus owner satisfaction (Yasamis et al., 2002; Basu, 2015). This study will show how owner organisations deploy COQ measurement capabilities alongside traditional project management approaches to better ensure that they can prevent and mitigate the operational failure. In so doing, it will explore new and inventive ways of promoting COQ quantification (Barlow, 2009) and provide better understanding of its concept, system, tools and culture to suit the construction environment (Rosenfeld, 2009), and, more specifically, a single capable owner with a complex multi-project environment. Thus, the academic significance of this study is in defining and characterising the capabilities for failure mitigation typified by a large-scale project-supporting organisation and its project-based supply network.

1.6.2 The existing COQ and its relationship to operational failure quality cost

In the current absence of a comprehensive COQ framework in the construction industry (Hall & Tomkins, 2000; Schiffauerova & Thomson, 2006; Jafari & Rodchua, 2014), the development of a reflective framework of an improved COQ approach is believed to be a basis in further appraising the occurrences of failures in construction projects. It combines principles, process, a framework and structured methods, as suggested by Schiffauerova and Thomson (2006), and uses a focus on failure cost as the test case to understand the implementing of COQ (as operational failure is the highest contributor when ignored, according to Ahsen (2008) and Lari and Asllani (2013) and to see the causes of the occurrences of quality failures; and so provides the greatest opportunity for efficiency improvement, according to Miguel and Pontel (2004). At the beginning of the research, this COQ framework is used to understand the relationship of the costs incurred within the project organisation and will be extended into the values, systems and culture of the business environment that link COQ elements and multi-organisational supply network in PBO and the occurrences of operational failures (Figure 1.5). The use of the COQ framework is then further developed during the research process in further developing the understanding in a project management context. The future COQ framework (resulting from this work) will then support dynamic decision-making towards the integrated capabilities by the owner, multi-organisational supply and operator network in mitigating failures.

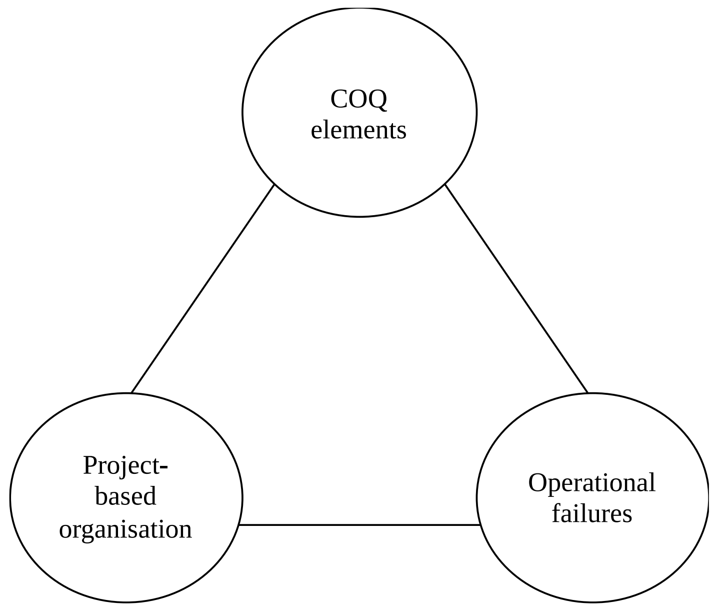


Figure 1.5: COQ links towards project-based organisations and operational failure
(Source: Author's own)

The COQ incurred within each operational failure is believed to be linked with how project-based organisations are managed. Dahlgaard et al. (1992) have highlighted the importance of quality measurement, as a continuous improvement to diminish failures (Taggart, 2014). Quality costs exist in any type of organisation, regardless of function (Özkan & Karaibrahimoğlu, 2013), although ineffective and unsystematic capture throughout the whole construction process is seen as problematic (Miguel & Pontel, 2004). Each failure may be quite different from one to another, and so the causes of project failure may be contingent on the project lifecycle (Pinto & Mantel, 1990). Therefore, project management literature has suggested the need for a better understanding of the organisational structure and project-based management in managing capabilities (Söderlund & Tell, 2011) and the quantification of quality cost (Hall & Tomkins, 2000).

Currently, quality management systems (BS EN ISO 9000: 2000) mostly corresponded to the processes of creating the product (Lari & Asllani, 2013). However, today the complexity of the construction industry is creating deviation, and highlighting the inadequacy of this partial view. Quality in product and services, after delivery to owner (Feigenbaum, 1956), has had little attention; neither has the complexity of the multiple supply network capabilities involved in complex infrastructure projects. Focusing on failure through quantifying its cost could demonstrate the root cause of its occurrence and create solutions to the intangibility of its high occurrences. Taggart (2014) indicates that supply network participants can help identify the root causes and could suggest possible cost-effective solutions. It is believed that operational failure quality costs are incurred during and after the operational process that is shared within the supply network. This is, however, yet to be explored and explained. In most cases, a quality standard (British Standards Institution ISO 9001, 2000) helps in determining the improvement effort but little attention is paid to its impact on failure costs (Dror, 2010).

No mechanism has been found to be effective (Miguel & Pontel, 2004), while most studies only indicate that basic guidelines are needed for control over failure cost (Dror, 2010; Snieska et al., 2013) and none have explored the supply network relationship in achieving cost reduction in existing COQ. This complexity further generates uncertainty and ambiguity. It is therefore necessary that an evaluation of these quality costs should be initiated with the identification of potential failure and causes embedded within the organisational capabilities of the project lifecycle. By far, it is acknowledged that the quantification of failure cost is frequently used to transfer the effects of poor quality into monetary terms (Hwang & Aspinwall, 1996); this should be used to assist owner management in preventing future potential failure. The result of this study could have a considerable impact on mitigating failure in complex projects.

1.7 Significance and relevance of this study (the practicability of the research)

1.7.1 Why quantifying COQ failure is important to mitigate failure in project management enterprises

There are strong relationships in the organisational supply network, the culture, the operations process and the failure cost. Therefore, these relationships will be sought to enrich the boundary of existing knowledge to achieve a fair distribution of capabilities that includes quality culture in mitigating failure and thus reducing failure cost. Understanding the project management enterprises may be important in explaining the uniqueness of project failure, project environments, project supply network and form of contract, but it is also important to understand the existing application of COQ in order to create improvement as a way to mitigate failure. The lack of an integrated approach in understanding COQ is perceived as a challenge for reducing the failure costs. As suggested by Love and Josephson (2004), knowledge about the causes is needed to reduce construction errors, and this can only be achieved by examining the chain of events and its relation to costs. However, project management practice is still lacking when it comes to using costing to support wider decision making (Ludvig & Gluch, 2010) that will support the change and willingness of construction participants to take comprehensive responsibility.

Measuring COQ shows the financial consequences of adopting a quality improvement programme (Omar & Murgan, 2014), and creates a healthy business environment (Jaju et al., 2009) that leads to lower costs, less failure, and better use of time and material resources. Some suggest that a traditional accounting system approach may no longer be adequate (Omar & Murgan, 2014). This research will provide valuable insights into the behaviour of the different components that constitute the existing approach to COQ in mitigating failures. The occurrences of operational failure quality cost will be explored through understanding the maturity and awareness of the construction supply network in dealing with the quality cost elements. This study will further elaborate on the causality of COQ application within the organisation's managerial and project team by looking into their projects.

Quantifying COQ will help organisations to quantify and minimise internal losses (Snieska et al., 2013) that contribute to unsustainable performance (Isaksson, 2006), and indicate where high COQ measure might show low quality and profitability (Zairi, 2002). Systematic visualisation through this study will help the attainment of sustainable quality programme implementation (Krishnan, 2006; Jaju et al., 2009), and provide a reliable process by which to portray intangible and complex data that can respond to rapid technological and market change (Jafari & Rodchua, 2014, Al-Tmeemy et al., 2012). Dynamic measurement will support cycles of change in quality, which are never-ending (Juran & De Feo, 2010), and provide a balance between efficiency, economy and quality of the product and production (Borri & Boccaletti, 2006). From a philosophical perspective, COQ categories of prevention, appraisal and failure are intimately connected and a full understanding of one category cannot be achieved without taking the other category into account. As explained by Love and Li (2000), processes improve over time; prevention cost is expected to rise at the beginning of the project and thus reduce the appraisal and failure cost during construction.

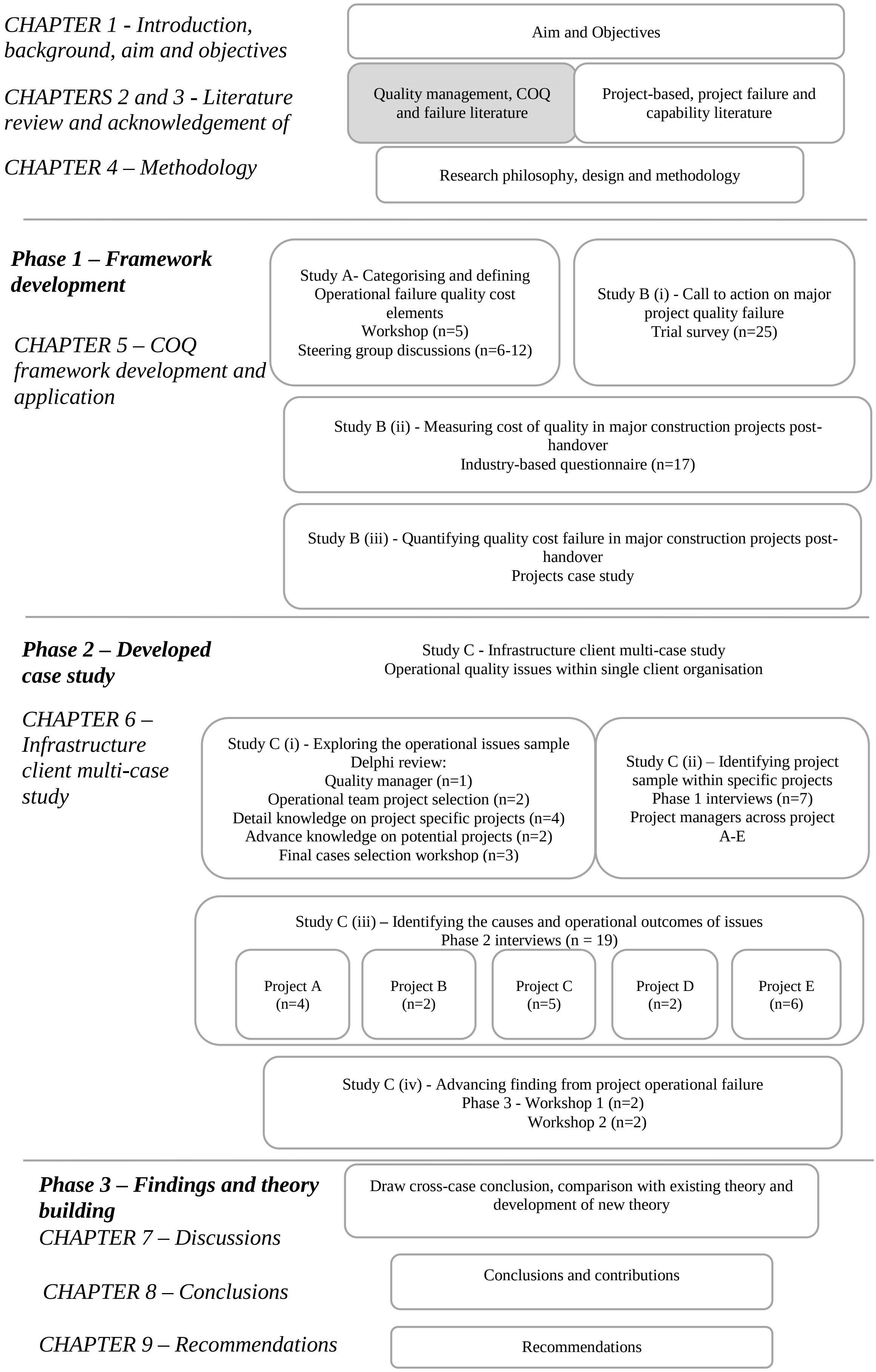
For a wider adoption of an advanced project management approach, this research looks at the operational side of construction projects. It is suggested that there is an advantage in linking the financial performance to show the direction for action and results (Ludvig & Gluch, 2010). By looking at the adaptation, coordination and alignment that emerge around the operational side of a construction project, this will help to accrue the value for the project user and operator (Zerjav et al., 2018). Continuous investment is needed to build new resource configurations, and to respond and adapt capabilities to the external environment. Comparatively little attention has been devoted to how distribution of capabilities will impact project operational failure in managing complex projects. A study by Davies and Brady (2016) acknowledged the importance of owner requirements and capabilities integration role. This is because project participants are often focused on their own interests and on managing their own project risks, rather than on the operational realisation of the owner's objectives (Hughes & Murdoch, 2001). This can lead to the misalignment of project capabilities that increases the risk of operational quality failures.

In achieving an innovative project, capabilities need a continuous routine that is shaped and adapted differently by different organisations (Flynn et al., 2010) to response to the operational advantage. Currently, the owner's capability role is unclear, particularly as suppliers move to operate and maintain facilities (Davies et al., 2016); thus, the balance between owner and supplier operational capabilities needs further investigation.

First understanding the quantification of COQ failure could help provide a greater understanding of the linkage of cost incurred, responsible parties and the chain that constitute the event. In this way, operational failure can be better understood, to enable stronger project management to provide a high-quality performance in developing the integrated capabilities for failure mitigation.

1.8 Chapter summary

This chapter has introduced the aim, objectives, research questions and significance of the research. The following chapters first review the COQ literature before generating a new COQ framework as a base to further clarify its relation to operational failures, which in later chapters is applied within the context of project management.


CHAPTER 1 - Introduction, background, aim and objectives
Aim and Objectives
CHAPTERS 2 and 3 - Literature review and acknowledgement of
Quality management, COQ and failure literature
Project-based, project failure and capability literature
CHAPTER 4 – Methodology
Research philosophy, design and methodology
Phase 1 – Framework development
CHAPTER 5 – COQ framework development and application
Study A- Categorising and defining Operational failure quality cost elements
Workshop (n=5)
Steering group discussions (n=6-12)
Study B (i) - Call to action on major project quality failure
Trial survey (n=25)
Study B (ii) - Measuring cost of quality in major construction projects post-handover
Industry-based questionnaire (n=17)
Study B (iii) - Quantifying quality cost failure in major construction projects post-handover
Projects case study
Phase 2 – Developed case study
CHAPTER 6 – Infrastructure client multi-case study
Study C - Infrastructure client multi-case study
Operational quality issues within single client organisation
Study C (i) - Exploring the operational issues sample
Delphi review:
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on project specific projects (n=4)
Advance knowledge on potential projects (n=2)
Final cases selection workshop (n=3)
Study C (ii) – Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across project A-E
Study C (iii) – Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) - Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

2 Cost of Quality (COQ)

2.1 Introduction

This chapter discusses how COQ is being developed as a quality management tool and how it contributes to an organisation's overall performance. It also looks at many other imperative elements of COQ, the history, the different categorisations, the fundamental of its application and finally its relation to failures. The range of COQ is also explained to provide an overview of how COQ has impacted construction projects. This chapter also focuses on the COQ failure in construction projects, and the impact as well as the causes of failures in construction.

2.2 The COQ background

During the past few decades, the poor performance and lack of productivity of the construction industry have been heavily criticised (Love & Irani, 2002). Many of the management practices in supporting construction organisations have been challenged. Owners in the industry are moving forwards with the increased demand for improving service quality, faster building and innovations in technology (Hoonakker et al., 2010). Many organisations have started to fully implement quality management to achieve continuous improvement and owner satisfaction. In the United Kingdom (UK), all government suppliers are mandated to perform quality management in the form of ISO9000 (Thorpe et al., 2004), with more than 20,000 companies certified (McGeorge & Palmer, 2002). However, although the application of quality management is now acknowledged, the capital expenditure of poor-quality projects or savings from good-quality ones have been ignored by the industry. Advanced quality management has now increased the need to achieve the balance between the level of end-product quality and its concomitant expenses (Jafari & Rodchua, 2014). A lack of appreciation for a different perspective on quality may be the most limiting factor in improving the quality, but there is also a lack of attention paid to the unknown and unquantifiable COQ in construction projects. Aoieong et al. (2002) stated that, to quantify the benefits of quality management, quality must be measureable.

Many studies have looked to improve quality in construction, but there are remarkably few that have quantified the COQ. This is surprising when the quality-related cost is substantial and cannot be ignored (Jafari & Rodchua, 2014; Yang, 2008). According to Aoieong et al. (2002), various tools for measuring COQ have been introduced since its introduction by Crosby (1984) and Juran (1989), but most of the implications of measuring the real COQ within construction organisations are doubtful.

Due to the success of implementing COQ in the manufacturing industry, some authors have emphasised the need for it to be applied in the construction industry (Aoieong et al., 2002). However, most of the literature concludes that construction is different and that it is difficult to translate the principles, practice and techniques of COQ to make them specific to the construction industry (Jafari & Rodchua, 2014). There is no comprehensive system in the construction industry in defining, collecting and analysing COQ. Subsequently, most construction companies measure quality costs based on their own quality costing programme (Hwang & Aspinwall, 1996).

Despite the benefits and substantial amount of research found in addressing COQ, construction quality failures are still a concern, with no methodology allowing calculation of all failure costs that are incurred post-project (Snieska et al., 2013). Currently, failure costs are highly recurrent, with limited studies addressing failure costs in relations to quality of the process (Castillo et al., 2010). It is agreed that failure cost may arise due to many factors along the project lifecycle that need advanced understanding. These are mainly addressed as a management problem by Castillo et al. (2010), but further exploration of the links is required, particularly on COQ application, measurement and the causality behind its existence. In doing so, this chapter will first theoretically explore the development of quality management and the role of COQ in supporting the quality systems that further led to the focus on failures.

2.3 Understanding quality

2.3.1 What is quality?

Simply defined in the *Oxford Dictionary*, quality is *"the standard of something measured against other things of similar kind; the degree of excellence of something"*. It is often used to signify '*excellence'* of products or services, but quality may also include human factors. From the management perspective, quality is simply defined as '*meeting the customer requirement'* – the need and the expectations (Oakland, 2003). Thus, in construction projects, 'quality' has been expressed differently by different parties depending on one's perspective. Consequently, the construction industry has continually struggled with the term quality, with many organisations devising their own definition. Accordingly, in construction, quality should be defined as the *"degree to which a set of inherent characteristics fulfils requirements"* (ISO 9000:2000 Quality Management Systems in Hoyle & Thompson, 2002), which is set differently in every element on a project. With this definition, there is a need to integrate different quality meanings by different organisations in different projects.

2.4 Quality management (QM) and total quality management (TQM)

2.4.1 From QM to TQM in construction

The adoption of QM in construction projects is important for an organisation in determining the standards needed for a project. Oakland and Marosszeky (2006) describe QM as a strategic decision where the objectives set out in the implementation of the quality policy are to be accomplished by the organisation. QM is thus to understand and organise all the suppliers of products or services according to the quality need of the owner. It is frequently adopted by construction companies as an initiative to solve quality problems in meeting the required needs (Kanji & Wong, 1999) and also to maintain or improve the quality of an organisation's products and services (Dahlgaard et al., 1992).

In QM, International Organisation for Standardisation (ISO) standards and control procedures are essential in meeting the quality requirements, which includes environmental and safety management (Hoonakker et al., 2010). The overall investments in QM in an organisation should increase the performance of the overall organisation rather than – as is traditional – focusing only on the project level (Landin & Nilsson, 2001). Deming (1986) long ago introduced the concept of continuous quality improvement known as 'The Deming Cycle' Plan-Do-Check- Act (PDCA) to help focus the company's attention and resources on continually meeting the owner's needs. Deming's main concept is to reduce variability in achieving conformance to specifications, which requires higher quality and productivity in reducing cost, as a result of competitive advantage.

Conversely, in construction projects, the supply network procures materials and services from different professions which are brought together at various points of a project to fulfil the customer's requirements. This raises different problems where every decision affects the other (Delgado-Hernandez & Aspinwall, 2008). In addition, the nature of construction projects (Walker, 2000) can adversely impact the quality and customer satisfaction; such as site conditions, weather and project time, different teams and organisations, and different arrangements for each project. Due to this variability, as Vrijhoef and Koskela (2000) explained, apart from quality problems, the industry faces many performance difficulties. In responses to this, the use of TQM has been suggested by numerous literatures as a method of management that responds to competitive advantage not only in reducing the cost but also as a comprehensive way to improve total organisation performance and quality performance (Yasamis et al., 2002). It is believed the application of TQM can only thrive through strong support from the top management with commitment and understanding (Arditi & Gunaydin, 1997) as it may be affected by different elements, as shown in Figure 2.1.

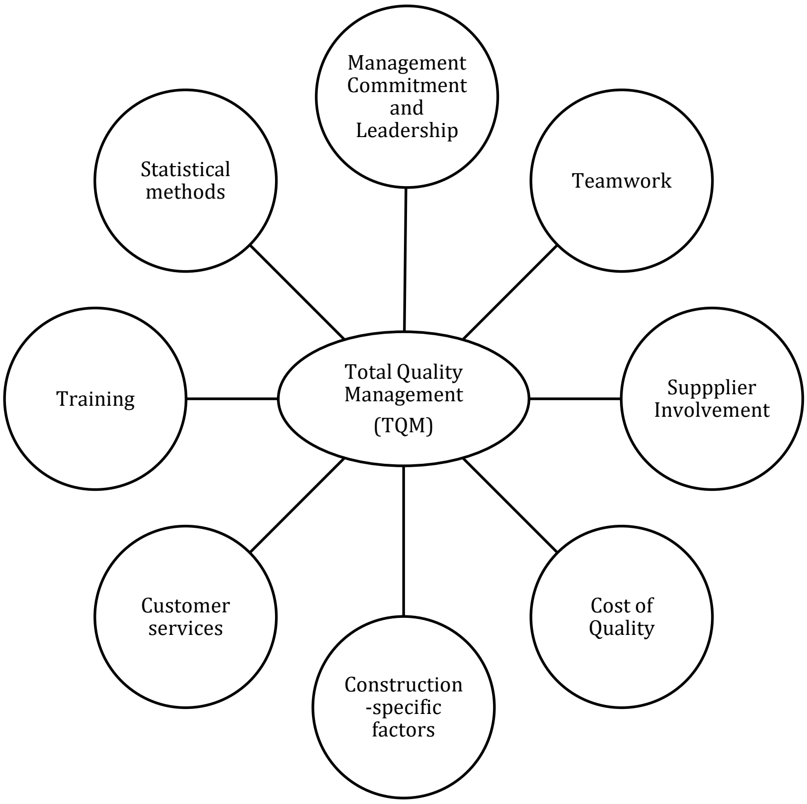


Figure 2.1: Elements of TQM in the construction scope (Adapted from: Arditi & Gunaydin, 1997)

Therefore, the TQM approach has been increasingly introduced into construction organisations as an improvement strategy for both achieving owner satisfaction and improving performance (Delgado-Hernandez & Aspinwall, 2008). The core values of TQM are assumed to penetrate the project performance and behaviours towards the realisation of higher quality in its undertakings that should not be treated in isolation (Svensson, 2006). Commonly, core values of TQM include *'customer focus'*, *'continuous improvement'*, *'focus on processes'*, *'focus on facts'*, *'participation of everybody'* and *'committed leadership*' (Roden & Dale, 2001; Eskildsen & Dahlgaard, 2000). Ishikawa (1985) and Juran (1989) have described continuous improvements as '*the fact that tolerance levels are rejected*'; which requires constant questions to be asked about the level of quality required by the corporate business operations in order to challenge what the owner's want as their benchmark of quality. Metrics are also stressed in the TQM literature (Juran 1989), but it is not enough to rely solely on quantitative measures (Deming, 1986) to benchmark quality.

Clearly, applying ‘quality’ in construction is extremely difficult and potentially needs multiple meanings for terms that can be applied to various aspects of the construction process. Yasamis et al. (2002) stated that quality-conscious companies normally have a strong quality culture, which is helpful for achieving owner satisfaction, while Hoonakker et al. (2010) showed that the overall motivation for implementing TQM has remained static over recent years. The classic TQM literature in Eskildsen and Dahlgaard (2000) stated that, according to Deming (1986) and Juran (1989), employee involvement and satisfaction are stressed as the most important drivers of continuous improvement and owner satisfaction. With this, construction organisations have now moved from a closed system of looking at what QM is within their own organisation to a more open system of linking QM to the practicality of quality in project management. This includes a careful balance between the owner’s requirements of project costs and schedule, desire operating characteristics and construction materials, and the designer’s need for adequate time and budget to meet those requirements during the design process (Stewart & Waddell, 2008).

This perspective has led to the need of a wider management approach in looking at ‘quality’ as central to the owner’s value, contributing to loyalty, profitability and differentiation (Branca & Catalão-Lopes, 2011). Therefore, an organisation should be concerned about the level of quality provided to the market, which would probably be the ‘project’ in the construction perspective. As quality is known to carry benefits, involved costs and any other influence on management decision, the TQM practice is believed to have a strong and positive relationship with quality performance (Hassan et al., 2012). The quality literature has shown that quality must be measured and evaluated (Love et al., 2018). Based on this, researchers have argued that, in a complex and broad environment, there is a need for more competitive tools to enhance TQM application in the construction industry (Aoieong et al., 2002; Thorpe & Sumner, 2004). The complexity of the interplay between the nature of the construction project and its lifecycle needs further understanding as to how quality could be successfully embedded in managing projects.

2.5 Cost of quality (COQ) as a quality management system

2.5.1 What is COQ?

The concept of COQ was first introduced in Juran’s quality control handbook as “*gold in the mine*” (Juran, 1951, p.34) as a part of the fundamental quality management process. COQ was implied as the cost resulting from defects and was a ‘gold mine’ in which profits could be made. COQ then was well known as the price of not creating a quality product or service. According to Krishnan et al. (2000), quality costs are the costs incurred to prevent a shortfall in quality and failure to meet customer requirements. COQ is simply a cost absorbed due to the work require in achieving targeted quality in a project; it is either the cost to achieve the quality or a cost due to quality failure (Hwang & Aspinwall, 1996). Many authors have attempted to define COQ, with one definition being the 'cost of poor quality' (Ali et al., 2010). It is said to be the cost associated with preventing, finding and correcting defective works (Mukhopadhyay, 2004). It has also been summarised as a classification of cost collected in quantifying a quality in a project (Barber et al., 2000; Ali et al., 2010; Love & Irani, 2002)

2.5.2 The early classification of COQ

As mentioned earlier, the term quality cost was first propounded by Juran (1951) and later developed by Crosby (1979, 1984), where quality was first known as the conformance with the requirements, but it was Crosby (1979) who elaborated on quality cost to see it as both the price of conformance (cost invested to comply with requirements) and the price of non-conformance (cost of poor quality). Feigenbaum (1991) later redefined these categorisations as the cost of control (cost of conformance) and cost of failure of controls (cost of non-conformance) (see Figure 2.2). According to Schiffauerova and Thomson (2006), the cost of conformance includes cost invested in the process of preventing and appraising the quality, while cost of non-conformance is additionally a cost due to failure in achieving customer requirements (such as correcting, reworking or scrapping). All costs are simply costs that are avoidable, if quality costs are effectively managed (Al-Tmeemy et al., 2012). Further, Ali et al. (2010) differentiated between internal failure quality cost (cost incurred before delivery to owner) and operational failure quality cost (after delivery to owner).

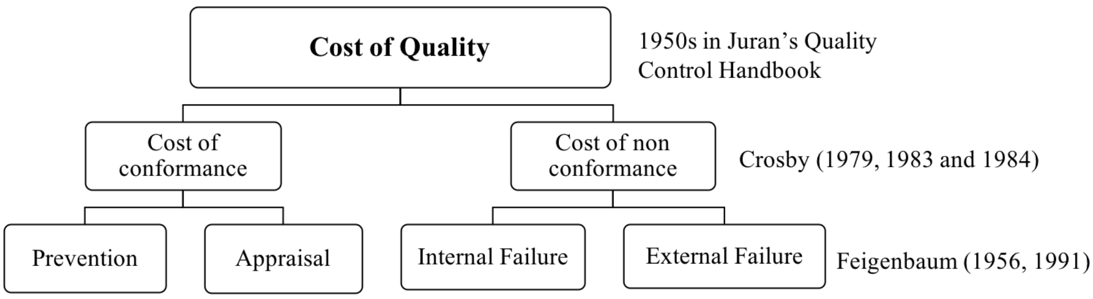


Figure 2.2: The early classification of COQ (Source: Author's own)

Consequently, COQ has previously been consistently classified into three main categories: prevention, appraisal and failure (Feigenbaum, 1956), according to the timing of its occurrence. This categorisation is better known as the 'Prevention-Appraisal-Failure' (PAF) model by most of the quality-related cost researchers (Abdul-Rahman et al., 1996; Low & Yeo, 1998; Love & Li, 2000; Hall & Tomkins, 2000; Aoieong et al., 2002; Rosenfeld, 2009; Love & Irani, 2002; Jafari & Rodchua; 2014). As explained in Ali et al. (2010), prevention costs are associated with the costs expended in provision of the process of gaining quality; appraisal costs, on the other hand, are the costs expended in measuring the level of quality attained by the process; while failure cost is the cost incurred to correct quality issues either before or after delivery. Further, internal failure costs are costs resulting from products or services not conforming to requirements or need which occurred prior to delivery to the owner, while operational failure quality costs are costs resulting from products or services not conforming to requirements or need after delivery to the owner, and during or after furnishing of a service to the owner (Kiani et al., 2014). Operational failure quality cost can also include loss of failure through customer dissatisfaction (Tsai, 1998; Kazaz et al., 2005), in which is recognised as operational failure quality cost in this thesis.

Despite the implementation of a general classifications model of COQ, some authors have expressed scepticism as to the overall coverage of this traditional categorisation (Yang, 2008; Dahlgaard et al., 1992), with those such as Yang (2008) and Krishnan (2006) referring to failure category as the 'hidden' nature of failure costs that frequently difficult to identify. Although there are sceptics in confirming these classifications, no better alternatives have yet been found. While the quantification of COQ will almost certainly help to benchmark and show the causality between costs incurred, it is believed that the increased and controlled cost of prevention and appraisal will lead to a decrease in internal and operational failure quality costs (Kiani et al., 2014). Thus, the central tenant of the P-A-F model is an investment in prevention and appraisal activities which will reduce failure costs, and further investments in prevention activities thus resulting in a reduction of appraisal cost (Roden & Dale, 2001). However, this needs better confirmation on how different costs are classified, defined and measured according to the nature of complex projects that involve multi-organisational networks to reduce the failure costs.

2.5.3 The different earliest COQ models

From the initial classification of COQ, several models were developed by some of the earliest research on COQ; and it was initially developed widely in five categories, which are: prevention-appraisal-failure (PAF), process cost, cost-benefit, Taguchi loss function and activity-based costing (ABC). COQ models are frequently initiated to deliver the quality dimensions in dealing with deficiencies of production processes (Freiesleben & Freiesleben, 2005) and to depict the development of the total COQ for a change in quality level. These models were developed as part of an initiative to establish quality and to capture the range of quality costs. Table 2.1 below shows different classifications of COQ.

Table 2.1: Generic earliest cost of quality models

COQ models	Concepts	Authors
PAF	Capturing prevention, appraisal and failure costs	Juran (1952), Feigenbaum (1956) and Masser (1975)
Process cost	Price of conformance and non-conformance	Crosby (1979, 1984)
Cost-benefit	Dynamic system based on individual quality product	Porter and Rayner (1992)
Taguchi loss function	External quality losses into a loss function base	Taguchi (1987)
ABC	Value added + non-value added with a two-stage methodology: assigns activity resources and different cost driver for each activity.	Cooper and Kaplan (1988)

Accordingly, the first concept of quality costing as described in section 2.5.2, the economics of quality and the graphical form of the COQ model developed by Joseph Juran (1951), was well accepted by many. This was later classified as the PAF model (Feigenbaum, 1956) as an approach to quality costing that was almost universally accepted (Plunkett & Dale, 1987), in which all the categories are linked. The second model is a process cost model which was originally developed by Crosby (1979, 1984) and has a similar classification to the PAF model (Schiffauerova & Thomson, 2006). The process cost model groups quality cost into price of conformance (POC) and price of non-conformance to quality (PONC). Crosby (1984) described POC as necessary spending to make things right; this includes professional quality functions (e.g. prevention efforts, quality education and training, and procedure or product confirmations), while PONC is described as all the expenses involved in doing things inaccurately, which includes all costs incurred due to not getting the quality right the first time (e.g., rework, warranties and other claims). Despite the existence of these two models, Taguchi (1987) developed the Taguchi loss function method model, which was based on his own industrial experiences (Hwang & Aspinwall, 1996). This model combines the experimental design techniques with quality loss considerations, which is the conventional approach in off-line quality control (Tang et al., 2004). However, this model has not been widely used in the construction industry. Not much research was found clarifying the success of this model; only a few studies have been conducted testing the model in manufacturing industries and none have been performed in the construction industry.

Further to this, Porter and Rayner (1992) suggested a simple cost-benefit model to monitor the effect of Total Quality Management (TQM) without reflecting the dynamics of the quality activities. A simulation model has been developed over time with system dynamics in specifying different costs and benefits relating to prevented activities. The dynamic flow system has been developed with the inclusion of complaints and managerial pressure in measuring quality costs (Hwang & Aspinwall, 1996). Additionally, an activity-based costing (ABC) model was initially developed by Cooper and Kaplan (1992) and may be a better solution in providing an accurate way of calculating product costs. However, Schiffauerova and Thomson (2006) mentioned that an activity-based costing model is not a cost of quality model; it is an alternative approach that can be used in identifying, quantifying and allocating the quality cost throughout the product, in which it helps to manage quality more effectively by collecting accurate data on various cost objects. The activity-based costing traces both individual cost activities and the total cost of activities in producing the object, which is the process (Schiffauerova & Thomson, 2006).

Specific model has not been recognised and developed as a successful model for the COQ specifically in the construction industry. Some models may have focused on quality-related activities fundamentality as a part of quality cost, but not all have considered the interrelated activities within the construction process. A review by Jafari and Rodchua (2014) showed that variations of quality systems have also been developed in recent years, but they are neither popular nor widely used. An organisation may develop and adopt its own classifications of quality costing due to limitations in existing systems or for practical reasons. The different sets of models as elaborated above are seen as the complexity in manging and capturing COQ, which comprises different individual or professional groups' perceptions in defining their 'compliance or conformance' to quality. This may be more difficult in construction projects that involve different units of organisation, in which construction projects may well include other institutional influences that will form the whole project climate. It is worth highlighting the different methodologies for classifying and capturing quality cost, as it shows the non-existence of a single reliable model to quantify the total COQ in construction. However, in referring to the most sustainable concept in the COQ literature, the concept of PAF will be used to facilitate the flexibility of quantifying the diversity of quality elements in construction as well as representing the most suitable model in appraising the COQ within this research.

2.5.4 The fundamental nature of cost of quality

Today's competitive market is driving the necessity to understand COQ to achieve a balance between quality and costs in construction projects (Yang, 2008). Traditional literature shows that quality may affect an industrial organisation's economy in two ways: the effect on costs (quality is used mainly in the sense of conformance to specification) and the effect on incomes (quality is used mainly in the sense of fitness for use) (Juran, 1951). Given this, the fundamental nature of quality may not be achievable without the consequences of cost in managing projects. Fundamentally, the concepts of COQ and total cost of quality have become the most powerful management tools for the measurement of quality performance (Tye et al., 2011). A COQ measure is used not only to acquire the highest quality but to provide cost diminution in achieving quality performance. COQ has now been widely accepted in many organisations and has largely become a priority for top management in managing business strategy (Tye et al., 2011).

COQ is frequently used to transfer the effects of poor quality into a monetary term that can be visualised and assist the management and employees to have an awareness of how costs are incurred (Hwang & Aspinwall, 1996). This could help in monitoring project flow together with the cost monitor as an assessment of project management. Porter and Rayner (1992) described the application of COQ as providing information for continual improvement and eliminating waste. They described that quality costing analysis information in an organisation's management quantified the non-value adding activities and ascertained the activities that needed to be improved, in order to reduce or eliminate reworking. Additionally, the use of COQ measures by the quality professionals in an organisation provides data upon completion of their quality assessment and cost quantification (Roden & Dale, 2001). By focusing on poor performance areas, corrective action can be taken to prevent failure costs emerging (Jafari & Rodchua, 2014).

Love and Li (2000) showed that a lack of quality focus during construction affects the project performance and results in operational failures during production. Ineffective and unsystematic capture of quality cost also leads to time and costs overruns in construction projects (Love et al., 2002). Therefore, quality costing is essential in gaining management commitment to prepare for quality management initiatives that will act as a tool to highlight areas for improvement and to provide an estimate of the potential benefits to be gained through quality improvement (Porter & Rayner, 1992). This recognises the dynamic development of quality improvement plans in guiding the elements that make up the process of institutional construction organisation projects. In this sense, capturing and understanding COQ based on the project cycle is believed to better suit and complement the argument about difficulties and non-standardisation of the evolutionary dynamic nature of construction projects.

Substantially, every segment of the construction industry could benefit from quantitative analysis of quality-related efforts that is moreover vital in determining the overall COQ in design and construction. Jafari and Rodchua (2014) listed the benefits of the implementation of quality costing as derived from various authors, as shown in Table 2.2 below.

Table 2.2: The benefits of implementing quality cost

Benefits	Authors
It could be used as a means for providing estimates of the potential benefits to be gained through quality improvement.	Porter and Rayner (1992)
It could also help project the monetary benefits and ramifications of the proposed changes.	Sirvastava (2008)
It helps evaluate quality programme success and points to the strengths and weaknesses of a quality system.	Johnson(1995); Sirvastava (2008)
It alerts management about the potential impact of poor quality on the financial performance of the company.	Aoieong et al. (2002)
It helps organisations to determine where quality costs have been incurred and where problems exist, and serves as well as a tool for focusing on areas of poor performance in need of improvement.	Johnson (1995); Yang (2008)
It provides corrective action to prevent the occurrence of non-conformances.	Aoieong et al., (2002); Johnson (1995); Love and Li (2000)
It helps identify and eliminate organisational activities that do not provide or enhance quality, and helps management to determine the types of activities that are more beneficial for reducing quality costs.	Abdelsalam & Gad (2009); Tye et al. (2011); Aoieong et al. (2002)
It transfers lessons learned to other areas.	Love and Li (2000)
It focuses attention on the origin of failures and their costs, making those responsible aware of and accountable for incurring such costs, thus helping them to become more efficient in their jobs.	Johnson (1995); Plunkett and Dale (1998)
It helps to reduce reworks and thus reduces claims.	Hoonakker et al. (2010)
It motivates employees to work towards pursuing quality goals	Tye et al. (2011)

Thus, the absence of such COQ systems may cause many organisations to develop insular ways to gain control over their own area of improvements, as a result of time and cost overruns in construction projects (Love & Irani, 2002). COQ is considered to be a process of activity that includes information gathering, reporting, and coordinating design and key information, which is to manage the transformation of inputs to outputs (Aoieong et al., 2002). This ultimately assists an organisation to function effectively, either within its individual process or with its interaction with other processes. Thus, it clearly shows that QM efforts, if expended by construction organisations, will have a significant effect in reducing COQ in all aspects of the construction process (Barlow, 2009).

2.5.5 The development of quality costing systems in construction environments

The development of an adequate quality cost collection and measurement system is central to the establishment of a quality cost system. Many previous studies have been centred on the manufacturing industries rather than the construction industry; however, the application of COQ in the construction industry has recently received much attention (Tang et al., 2004). Quality costing management systems have also been developed and implemented to determine quality costs (Love & Irani, 2002) that are transferable within the same industry (Hwang & Aspinwall, 1996), but organisations should create a unique quality cost of projects for a project that could also be useful for future projects. However, although some agree that common structures and measures almost certainly exist within construction organisations (Barlow, 2009), the application of COQ is still unclear, with many organisations set in their individuality, rather than integrating the quality system within their projects.

Previously, the Construction Industry Institute (CII) Quality Management Task Force developed a Quality Performance Management System (QPMS) to track quality cost in design and construction (Jafari & Rodchua, 2014). It was used by Willis and Willis (1996) and showed less than 2% of deviation on correction costs. This confirms that the application of quality costing systems may result in the reduction of COQ, which suggests that an improved system needs to be developed to achieve better results. Davis (1987) extended the system, creating a Quality Performance Tracking System (QPTS) (Jafari & Rodchua, 2014) as an extensive costs coding system that classifies the various items used to ensure that the cost data captured is compatible with the works breakdown of a project. This system showed better capture of quality costs during the different cycles of a project. Abdul-Rahman et al. (1996) also developed the Quality Cost Matrix (QCM), due to some challenges faced in capturing the cost of non-conformance during construction by other systems. However, despite all the different methods in capturing COQ, quality management systems are still in their infancy.

Regardless of the different approaches, Low and Yeo (1998) proposed the Construction Quality Cost Quantifying System (CQCQS) to collect data. It uses a coding system to categorise and represent various components of the system (Low & Yeo, 1998) that shows a detailed analysis of COQ. Aoieong et al. (2002) developed a quality cost tracking system in the process cost method (QCPCM) to capture the quality cost for a process instead of the quality costs of the total project. This system is used to trace each component of the quality coding system and its deviations to quantify costs. However, it is said to be incomprehensive, as projects require longer periods and involve many processes at a time. Dale and Plunkett (1995) developed a quality costing method that focuses on identifying non-conformance elements in specific departments, and it was reported by Roden and Dale (2001) that departmental quality costing was the most suitable method.

The American Society of Quality Control (ASQC, 1987) showed good coverage of quality costing but offers no mechanism for building and maintaining the relevance of these costs. Despite all of the systems that have been developed for quality costing in the construction industry, no comprehensive system has been found for defining, capturing and analysing the quality-related cost; since the standard structure for quality costing depends on each organisation's unique environment. In most cases, a quality standard (ISO 9001, 2000) has helped to determine the efforts of quality improvement, but this pays limited attention to the impact of failure costs. Thus, only a few construction companies use a COQ system in measuring and capturing quality cost. It is apparent there is limited knowledge in understanding COQ in construction organisations.

Table 2.3 shows studies conducted using the developed quality cost system in capturing the quality cost of construction projects. None have tried to capture the operational failure quality cost. Consequently, a limited number of studies have been found that look at construction projects, as researchers only show a few construction companies that use a COQ system in measuring and capturing quality cost due to the sensitivity and effort needed to identify every cost detail (Low & Yeo, 1998; Snieka et al., 2013). It is thus clear that there is limited knowledge in understanding COQ within construction organisations. A broad development of quality costing systems is needed to provide better understanding and to achieve an effective model for quality in construction (Delgado-Hernandez & Aspinwall, 2008) that should be considered in order to achieve quality. A framework should not only present such quality elements but also present ways of how the framework could be used in construction practice.

Table 2.3: Summary of developed quality cost systems in construction projects

Authors/ References	Aims	Methodology	Model Developed	Types of projects tested	Findings
Abdul-Rahman et al. (1996)	The use of a quality cost matrix to capture cost of non-conformance.	Case study, interviews	(QCM) Quality Cost Matrix	Water treatment plant and a bridge	The case study found costs of non-conformance incurred 5-6% of the tender value. The study stated that the costs of preventing failure are significantly low compared with the cost of rectification.
Love and Li (2000); Love and Irani (2002)	The paper quantifies causes, magnitude and costs of rework experience in two projects that were procured using different contractual arrangements in Australia.	Interviews, observations, documentary sources	(PROMQACS) Project management quality cost information system	Construction projects including apartments and industrial buildings	Finding reveals that the cost of rework for the case project was 3.15% and 2.40% of their projects' contract value. The primary cause of rework was due to change initiated by owner and end-user together with errors and omissions in contract documentation.
Hall and Tomkins (2000)	The paper presents a methodology for assessing the 'complete' cost of quality for construction projects.	Case study	-	New construction office building in the UK	The finding shows quality failures are small where prevention and appraisal costs are much higher. Failures are 5.84% and prevention and appraisal cost only 12.68% of contract sum.
Tang et al. (2004)	The paper's objective is to report the finding on two case studies using PCM to capture costs on two construction projects.	Two case studies – by recording numbers of defects	(PCM) Process Cost Model	One 38-storey building project and one civil engineering project in Hong Kong.	The case study on the 1st project shows a reduction in non-conformance cost from 0.48% of the total process costs to 0.43%, while the 2nd project shows the cost of non-conformance fell dramatically

					from 3.55% to 0.03% upon the last cycle. The case study illustrates that the process shows continual improvement as the improvement of a process within a project.
Low and Yeo (1998)	The paper explains the proposed quality costs system developed in helping to capture quality costs for construction projects.	Proposed documentation matrix for site staff to code quality costs.	(CQCQS) Construction Quality Costs Quantifying System	Not tested	Proposes that future works related to construction quality costs should focus on testing the costs system in a further study.
Aeoing et al. (2002)	The paper aims to investigate the suitability of the PAF model in capturing quality cost and propose an alternative approach to facilitate the fundamentals of TQM.	Interview has been held with professional involve in construction industry.	(QCPCM) Quality cost tracking system based on PAF	Not tested	Alternative process cost model is more feasible than the traditional PAF model because the resource level of quality cost measurement will be more flexible. The performance indicates that straight implementation of the PAF model might not be possible due to the complexity of the structure of the construction industry.

2.5.6 The need to measure COQ

Özkan and Karaibrahimoğlu (2013) give two steps in reporting COQ: classification and measurement. They further clarify that it is necessary for each organisation to determine its definition of COQ in providing the right model and categorisation to quantify the quality costs, but this does not help in quantifying the COQ for a project. Despite the general classifications model of COQ being implemented in the industry, many researchers have expressed scepticism regarding the overall coverage of the traditional categorisations towards quality-related cost (Yang, 2008; Dahlgaard et al., 1992) in understanding the quality failure cost for a project. It seems that, with a lack of evidence for the flourishing impact of traditional approaches on the existing concepts of COQ, many researchers have developed new methods of combining and exploring innovations towards measuring the COQ in the construction industry. Thus, no standard COQ documentation could be found that was applicable and replicable within the construction scope.

Measuring COQ assures its benefits in providing financial information about the financial consequences of adopting quality improvement programmes (Omar & Murgan, 2014), because measuring COQ requires precision in all cost information records. Although some say this may be an easy matter, several costs have been incorrectly reported (Yang, 2008). The traditional cost accounting systems have failed to provide accurate cost information to management and hence there is failure in measuring COQ (Ozkan & Karaibrahimoglu, 2013; Yang, 2008; Tsai, 1998). Table 2.4 illustrates some of the works looking at COQ in the construction industry, where only two pieces of research were found that focus on failure costs.

Table 2.4: Summary of COQ literature in the construction industry

Developed methods and systems for capturing and controlling quality costs	**Quantifying poor quality cost and identifying their associated causes**	**To increase awareness and consciousness about the poor-quality issues**	**Definition and implementation of COQ**	**Focusing on failure costs**
Construction Industry Institute (CII) (1989); Davis et al. (1989); Abdul-Rahman (1993); Willis and Willis (1996); Low and Yeo (1998)	Construction Industry Institute (CII) (1989); Buriati et al. (1992)	Abdul-Rahman (1993); Josephson and Hammarlund (1999)	Construction Industry Institute (CII) (1989); Abdul-Rahman (1997)	
Barber et al. (2000); Hall and Tomkins, (2000); Aoieong et al. (2002); Tang et al. (2004); Kazaz et al. (2005)	Love and Li (2000); Barber et al. (2000); Josephson and Saukkoriipi (2003); Rosenfeld (2009)	Barber et al. (2000)	Ali et al. (2010); Al-Tamey et al. (2011); Jafari and Rodchua (2014)	Barber et al. (2000); Castillo et al. (2010)

Consequently, there is still a lack of proof in explaining the quantification of COQ in its measurement in relation to the operational failure quality cost and the mitigation of failure cost. Many organisations have urged for and struggled in reducing the COQ to achieve better quality with less loss but none has successfully shown the cost relationship to the management of the project. Due to this, firms may have attempted to develop their own methods to capture the quality costing, but there is a huge variability in the standards and guidelines for quality costing (Jafari & Rodchua, 2014). Barber et al. (2000) stated that investments in recruiting and providing training in knowledge and skills are needed for a successful COQ measure that requires circumstantial consideration in different project stages of the construction process. Some go so far as to say measuring COQ is dynamic and constantly changing over time (Srivastava, 2008). Thus, construction organisations need an integrated measure where standardisation in measurement may be the key in quantifying COQ.

Nevertheless, to be effective, an organisation's controllable efforts have to be considered in conjunction with its quantification of failure cost (Dror, 2010) where basic guidelines are needed for an individual company. Previous research shows there is a link to how failure is a consequence of the 'quality' that is executed during the front end of the project (Josephson & Hammarlund, 1999). Equally, the core concepts and focus area of a company's business environment should be understood to successfully measure COQ (Hall and Tomkins, 2000) in reducing failure cost. The foundations of quantifying quality failure cost should therefore be defined first at an organisational level rather than at a project level. As described by Pursglove and Dale (1996), existing quality management is complex and cumbersome, with much documentation frequently overlapping with procedure and work instructions, which may be the reason for the failure to address the overall direction in quantifying quality.

2.6 The focus on failure

2.6.1 What is failure?

Generally, failure is a lack of success, a neglect or omission of expected or required action and the action or state of not functioning (Oxford Dictionary). It is a state or condition of not meeting the desirable and intended objective. Failure can be interpreted differently in different fields (Pretorius, 2009), but is usually measured through predictions on a financial basis. Most research that focuses on failure appears to be problematic, with many struggling to define the failure and the ways in which failures have been measured in the past (Castro et al., 1997). In construction projects, Pinto and Mantel (1990) have agreed that the concept of project failure is nebulous and that only a few people agree on how to define failure. However, a mutual understanding of failure is still needed in mitigating the occurrences of failure to improve the quality delivery and to reduce the quality costs. Castillo et al. (2010) described failure as either product or process failure, or a combination of both, that will consequently result in the additional usage of resources. Product failure can be an error, defect or non-conformance which leads to reworking, repairing, retesting, replacing or rejecting the product, while process failure is derived from inefficient processes that require additional resources.

Based on this definition, some researchers only consider specific elements in construction projects to better understand change and rework (Love & Irani, 2002; Barber et al., 2000; Love & Edward, 2004) or defects and non-conformance of products (Josephson & Hammarlund, 1999; Josephson, 1998; Atkinson, 1999; Love & Josephson, 2004; Jingmond & Agren, 2015; Love et al., 2018) as a classification of failure. Janney (1986) defined construction failure as failure that occurs during construction, either the collapse or distress of a structural system to such a degree that it does not achieve the level of safety required to serve its intended purpose. However, Atkinson (1999) differentiated failure as a departure from good practice that is either corrected or not corrected before the asset is handed over; while defect is described as a shortfall in performance once the building is operational. Either way, this definition shows that failure is distributed between the construction process and the finished product (Hall & Tomkins, 2000), whether the process is interrupted or the product goes awry in some way. A failure, for instance, can also be described as if and when the firm's quality of design does not contain the necessary qualities to maintain or improve customer satisfaction, or quality of production that fails to live up to the design quality as specified (Barber et al., 2000).

From the project management perspective, projects are considered a failure when completion time exceeds the due date, if there are budget overruns and the outcomes do not satisfy the performance criteria or stakeholders' expectations (El-sokhn & Othman, 2014). However, there is an uncertainty with regard to how project management processes may cause problems in construction (Atkinson et al., 2006), either towards the process or the system. Some have tried to describe failure as mismanagement in business that affects the operation (Assaf et al., 2015), poor performance management (Miguel, 2015), or by looking at quality performance (Willis & Willis, 1996) and non-conformance to owner needs and requirements (Sower et al., 2007). This has prompted a reflection on how construction projects with problematic sources might be characterised and defined as failures. Thus, failure is a lack of success, a falling short, omission or inability to operate any further, either during the process or in the final product of a construction project.

2.6.2 What is the range of failure cost in construction?

Failure is highly recurrent in construction projects (Castillo et al., 2010), but there has been limited empirical investigation. The Standish Group report (2014) shows that 31.3% of projects are cancelled before completion, while 52.7% of project costs are 189% of the original cost estimates. In the United States, it was reported that 20 civil infrastructure projects in 17 states experienced significant cost increases with poor construction performance ranging from 40%-400% (GAO, 2002), while, in Europe and Asia, cost escalation is no longer a new phenomenon, but has persisted over 70 years with 90% of all mega projects facing cost overruns (Flyvbjerg et al., 2003), for example, among major problems in construction projects, cost overruns and delay with cost overruns commonly range from 25%-33% (Marshall, 2007; Flyvbjerg et al., 2002) Morris and Hough (1987) found that 63% out of 1778 projects had experienced significant cost overruns. Substantially, many projects end with either dispute or litigation (Levin, 1998).

Therefore, the construction business is recognised as having the second highest failure rate of any business (Clough et al., 2000), with many projects often failing to meet the end user's expectations in operation (Basu, 2015). According to Love and Irani (2002), it is believed that failure costs could be 25% of the total construction process, while Taggart et al. (2014) suggested that failure costs range from 2% to 6% during construction, and additionally 3% to 6% during the maintenance period. A study from Hall and Tomkins (2000) showed that the COQ in construction projects was an average of 18.52% of the project contract sum, while Josephson and Hammarlund (1999) estimated post-project quality failure to be as high as 4% of actual project production cost. Conversely, another study found that 50-90% of total COQ was failure cost after the project was operational (Snieska et al., 2013). Thus, operational failure costs are determined as one of the most significant quality costs (Snieska et al., 2013), and have been said to be the most difficult to evaluate among all quality costs in construction projects (Sower et al., 2007), as operational failure costs was classified by Feigenbaum (1991) as a cost of failure control (Figure 2.3). Many have now questioned how to calculate and estimate the failure cost to maximise benefits from COQ to reduce the failures. However, cost development matters may be held back by the project owners, as failure cost is often considered as reputation elements towards the owners (Flyvbjerg et al., 2003) but establishing reliable cost data is often highly time-consuming or even impossible. Thus, many projects may not quantify and clarify failure costs; as a result, failure costs are still highly recurrent (Taggart et al., 2014), not understand and are not learnt from one project to another.

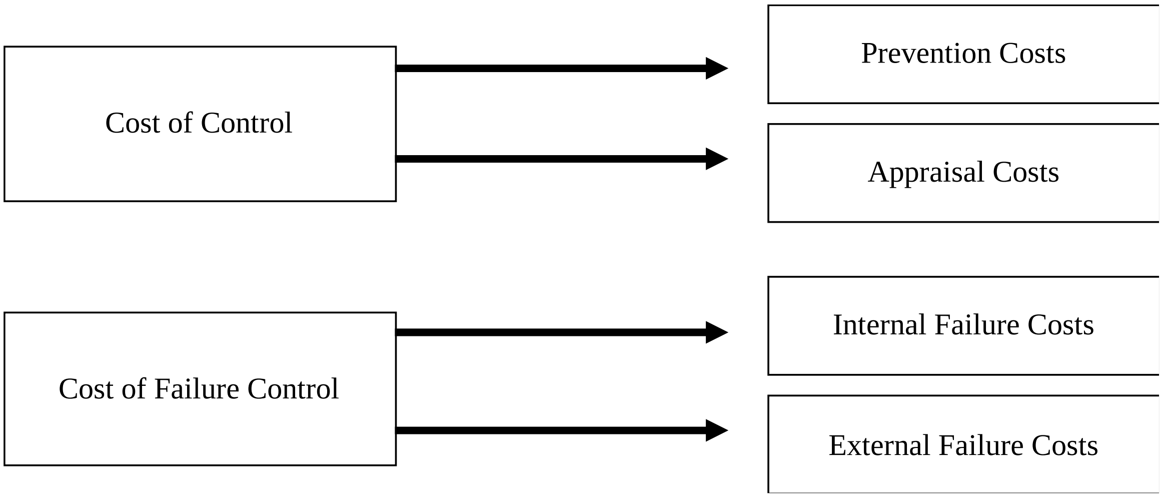


Figure 2.3: Quality costs: cost of control and failure (Source: Feigenbaum, 1991)

Nonetheless, examples of post-project failure are still widespread. In the United Kingdom (UK) an air traffic control centre was 10 years over schedule and still required reworking a year after opening (BBC, 2002). Berlin's Brandenburg airport was not functionally fit for its intended purpose, resulting in significant cost overruns and time delays from its 2011 opening. Heathrow terminal 5 had a disrupted opening, costing British Airlines (BA) $31 million in the first five days (Davies et al., 2009). Seventeen schools in Edinburgh were closed after 10 years of operation with a £870,000 cost of failure, found an independent report undertaken by Edinburgh city council (Hackitt, 2017). Within these examples, many projects are still continuously being built despite the numerous records of poor performance (Flyvbjerg et al., 2003); this shows the significant need for greater quantification and understanding as a way of improvement.

2.6.3 How failures have impacted the industry

The construction industry is unique and this relates to the fragmentation of the project economic cycle and political environment. Thus, failure impacts the construction industry differently in different aspects according to the nature of the project. Osmani et al.'s (2008) research shows that construction, demolition and excavation is impacting the wider environment, such as through waste production, with an estimated 91 million tonnes being produced in 2003. Typically, the consequences of failure could come in several forms, such as construction fatalities, injuries, structural damage, damage to contents, loss of functionality or environmental damage, which should be defined clearly at the time of the consequence was notify. In some cases, failure in construction also relates to occupational health and safety (Yates & Lockey, 2002) or design for construction safety (Behm, 2005) that involves the labour as well as all professional stakeholders. In 2006, the UK and US construction sectors showed a 3.7 and 4.1% fatality rate respectively, while Singapore had 39% of the total of 62 workplace fatalities which contributed to problems in construction (Ling et al., 2009). The study further highlights worker safety as a contributor to construction failures that impact on the construction safety. Therefore, failures in construction may affect a project throughout its lifecycle (Josephson & Saukkoriipi, 2007), which negatively impacts the effectiveness of many construction projects and causes financial losses (Weinstein et al., 2009).

Further to that, failure in construction projects, as mentioned by Assaf et al. (2015), will impact the growth rate of the sector, with rework being identified as the most significant factor that contributes to project cost increases and schedule delays (Love at al., 2002; Hwang & Aspinwall, 1996; Love & Sing, 2012). The changes that occur during project development may have significant and often unpredictable impacts on an organisation and its management which have not been clearly identified. It is difficult to determine the nature or cause of some failure (Love & Sing, 2013) that predominantly involves human errors (Love & Jospehson, 2004). Frequently, reworks are associated with defects that include a lack of quality workmanship, poor design, manufacturing, fabrication or construction that may have impacted the operations and maintenance (Love et al., 2018).

In some cases, failures involve bankruptcy of construction companies (Kangari, 1988), and impact on an organisation’s reputation (Baloi & Price, 2003; Teo & Love, 2017) and management performance (Miguel, 2015). Thus, construction participants are still unaware of the appropriate action they need to take; the construction industry needs further understanding to influence the behaviour of project systems (Love et al., 2002). Without good management, owners suffer compensation liabilities (Abdul-Rahman et al., 1996), which could be lessened if more details of project performance could be monitored and forecasted to better obtain quality and efficiency. Findings from Mir and Pinnington (2014) showed that the management of employees is directly related to the project environment and has a greater impact on achieving project success; thus, failure in construction also impacts low motivation in an organisation’s learning, which then prevents the retention of learnt knowledge (Cooper et al., 2002) to be incorporated into the next project (Kotnour, 2000). Project organisations may lose knowledge when key persons leave the organisation (Aert et al., 2016). The project processes stop while the new person learns about the project, and this prevents the establishment of trains of thought. Hence, the failure in construction will impede project innovations to increase business competitiveness (Holt, 2013), which needs further managerial rigour in an approach that has more of a practitioner-oriented focus rather than only looking at technical tools (Davies et al., 2016) to reduce project failure rates. The impact of failure in construction management may be acknowledged by construction stakeholders but to what extent failure may impact a project's owner and its multi-organisational network needs grater clarifications in terms of its cost and implications to project management.

2.6.4 What causes failures in construction project management?

Failure in the construction business is among the highest in business. Although the precise cause of construction business failures is hard to define, most are related to financial management problems (Kangari, 1988). Rework usually arises out of incomplete and erroneous information (Love & Li, 2010) which later became failures. Thus, failure can be the result of missing activities, lack of product analysis or inadequate control of the development function. Additionally, Josephson and Hammarlund (1999) suggested that most failure are attributed to the poor skills of site management which are caused by defective workmanship, defects in products, insufficient work separation, inadequate construction planning, disturbances in personnel planning, delays, alterations, failures in setting out and coordination failure. The study quantified these failures as either design related, poor installation of material or material failure. Additionally, in other studies, managerial factors were identified as the predominant cause leading to defect, with communication issues as the most significant cause (Atkinson, 1999). Two case studies by Andi and Minato (2003) agree that information and low motivation are the predominant causes of defect. Lack of information about the project causes sub-optimisation and results in a lack of understanding of how specific tasks could be incorporated into the project and their relevance to the end-product (Love & Josephson, 2004).

Generally, the causes of quality failure and defect in construction projects are manifold. As mentioned earlier, failure can be associated with the internal production of a product, or construction of a building (Jingmond & Ågren, 2015), or they can be external causes related to the work of different actors, environmental changes or organisational issues (Newton, 2003). Tam et al. (2000) found that cultural factors or global factors were the major cause of quality issues, while Fyvbjerg et al. (2003) identified that mega projects fail due to underestimated costs, overestimated revenues, unvalued environmental impacts and overvalued economic development effect. In construction projects, non-integration of different organisation quality-focused may correspondingly result in quality deviations (Love et al., 2002). Similarly, Love and Li (2000) concluded that a lack of quality focus by design consultants significantly affected project performance, with no prevention of poor quality, which that resulted in operational failures during production. Dahlgaard et al. (1992) explained that many quality failures can be found in all departments and functions, and that some potential failures post-production are due to failures originating in the service departments.

Consequently, quality-related issues are frequently ascribed to organisational conditions (Josephson, 1998) including changing the key person, which leads to project organisations losing important knowledge. Several studies have indicated that many failures are influenced by various types of human errors, which include knowledge not being currently available, delayed communication in acquiring knowledge, ignorance of recently acquired knowledge, misunderstanding of accepted knowledge, and outright ignorance or incorrect procedures (Levy & Salvadori, 1992). However, human errors are always caused by the actions of individuals; thus it is individuals who are acting wrongly that may cause the failure. Thus, failure may occur when the worker is forgetful or careless (Styhre et al., 2004), but individual action is usually influenced by how the organisation is designed, so that many causes are found to be within organisational aspects.

Due to this, with regard to the causes of failure, many researchers are highly idiosyncratic, either specifically to one organisation or project (Morris & Hough, 1987), only focusing on reworks or defect (Barber et al., 2000; Love et al., 2018), on complex projects (Ivory & Alderman, 2005; Robertson & Williams, 2006) or generally on poor performance (Wakchaure & Kumar, 2011). Others have developed an operation system to identify companies' failure (Kangari, 1988; Russell & Jaselskis, 1992) and look at managerial problems (Pinto & Mantel, 1990). Some factors are intrinsically related to the construction organisations that are solely responsible for managing them, whereas others are somehow closely related to how the organisation operates in terms of the socio-cultural, economic, technological or political environment (Baloi & Prince, 2003). It is understood that there is a common link between failure to produce and failure during process in how they will affect both cost and management.

Edward Deming has long suggested that most quality failure in a Western firm is attributable to management paying little or no attention. The UK industrial society showed that companies whose projects failed had no project management infrastructure (Amyas, 2015). Typically, the construction industry depends on successful project management to manage project success (Munns & Bjeirmi, 1996) as the success of project management has often been associated with the final outcome of the project. Yet, failure occurs as a consequence of multiple interactions, internal coordination and complex system of the nature of projects (Ivory & Alderman, 2005). Ika et al., (2012) demonstrated that completing a project within cost, scope and time is still not enough and the project can still fail, thus suggesting the necessity to investigate failure beyond the above-mentioned criteria.

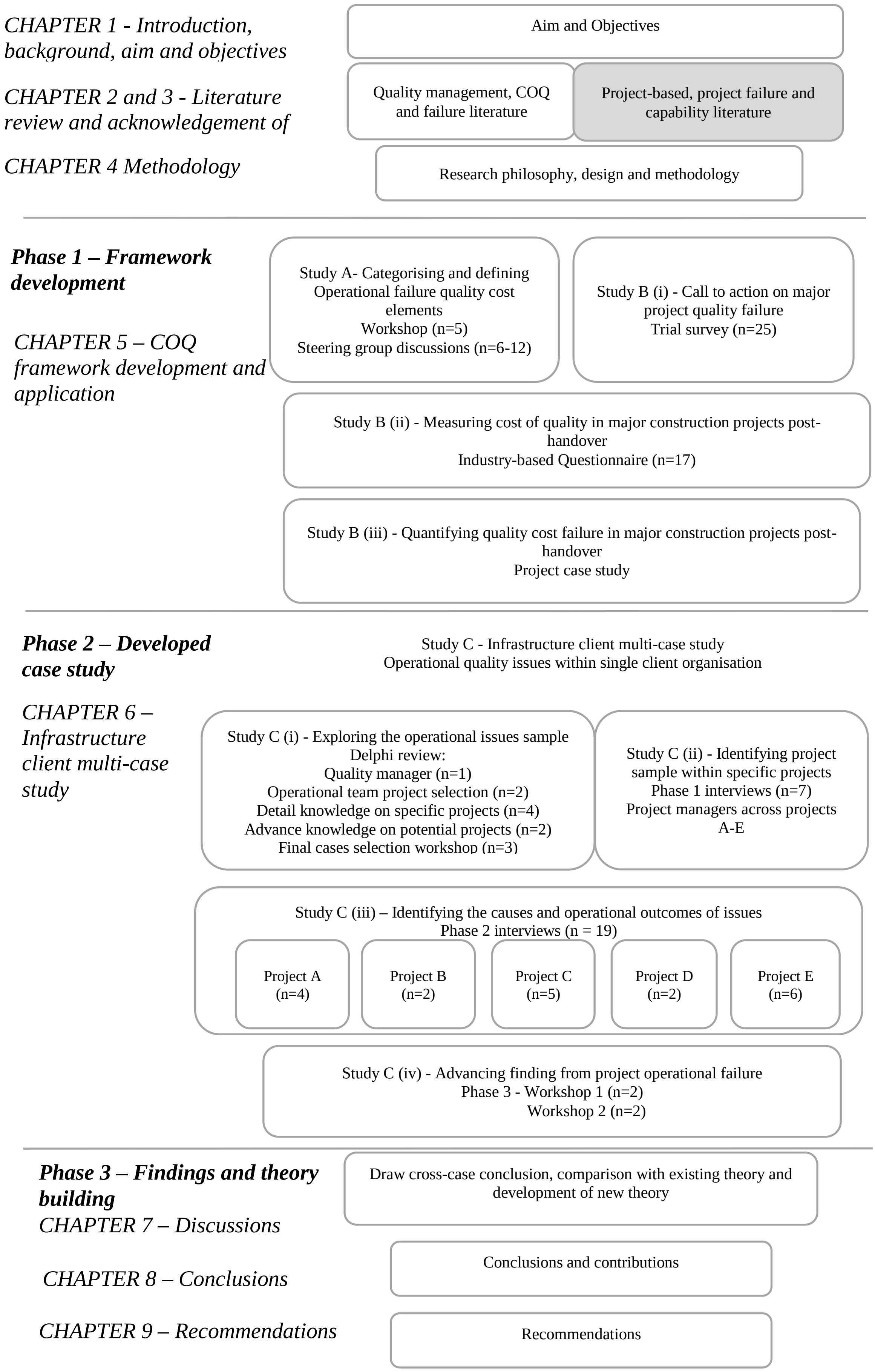
Stakeholders' interest, project functionality, learning potential and value added to the organisation all need to be accounted for as standards for understanding project failure (Nelson, 2005). Research by Davies et al. (2016) shows that many complex projects fail because of unsuccessful transition from project to operations when organisations involved fail to adapt to plans and provide innovations during execution when facing an unexpected change or new opportunity. Although Sun et al., (2017) showed team diversity is the most important enabler of innovation performance in gaining process success, many professions in construction remain trapped in their functional discipline (Munns & Bjeirmi, 1996), which prohibits the integrative multi-disciplinary process. However, the interrelationship of these causes with failure is yet to be studied and quantified, which would be helpful in providing a better understanding of the operational interaction of the causes and in providing better learning, design, construction and functionality of a project (Wakchaure & Kumar, 2011).

The industry's problem in developing its economy was categorised by Ogunlana et al., (1996) as problems of shortages or inadequacies in industry infrastructure, problems by contractor's incompetence, or inadequacies or problems caused by owners and consultants. Olomolaiye and Ogunlana (1989) indicated that major problems faced by contractors in developing countries have been classified as problems imposed by the industry's infrastructure, inaccurate information and frequent changes in instructions and failure to meet obligations. This indicates that a strong relationship is required between the contractor and the owner which requires the owner to have a stronger management role Although construction failure can never be completely eliminated, the construction environment could always be improved (Yates & Lockley, 2002). Lessons learned from multi-case study of failures can obviate the occurrence and reduce the risk of future failure. Much literature shows the fundamental problem with identification of cause and effect of project failure but does not examine the relationship between process activities (Love et al., 2002), thus failure is not learned from.

While much of the project management literature defines critical success factors and even identifies the causes of project success or failure, most research does not satisfactorily explain the reasons behind the causes (Davies et al., 2016). Typically, projects find difficulty in visualising all problems that are involved until the business concept is turned into a specific project brief; failure is only realised when there is a mismatch between budget expectations and proposed project costs. In which case, most projects continue to completion with resulting failure during operation, but most studies on quality failure tend not to differentiate among those parties responsible for the cost incurred (Love et al., 2002). Many failures, in this viewpoint, are the management's responsibility. Therefore, improving the failure investigation process would produce results to provide insight into the behaviour of organisation structure in construction. Although research by Love et al. (2018) shows that contractors are reluctant to share quality failure costs because of issues of commercial confidentiality and the potential impact on their reputation, Morris (2013) emphasised the importance of understanding cost besides scope, schedule and stakeholder management in achieving successful management but there are currently few references available in the pertinent literature. By knowing more about the causes of failures, or performance, and quality problems, with its relationship to cost incurred, it will provide management with information about process failure and how to prevent any future occurrences.

2.7 Chapter summary

It is clear that COQ has not been widely applied in the construction industry and has some limitations. The emphasis must be on the application and capabilities of the owner to mitigate the occurrence of quality failures, which requires an understanding of the skills beyond mere COQ measurement. Chapter 3 focuses on the capabilities for failure mitigating literature, including the introduction of project-based organisation (PBO) in managing the different capabilities within the multi-organisational construction supply network. It also introduces the dynamic nature of failure in complex infrastructure projects.


CHAPTER 1 - Introduction, background, aim and objectives
Aim and Objectives
CHAPTER 2 and 3 - Literature review and acknowledgement of
Quality management, COQ and failure literature
Project-based, project failure and capability literature
CHAPTER 4 Methodology
Research philosophy, design and methodology
Phase 1 – Framework development
CHAPTER 5 – COQ framework development and application
Study A- Categorising and defining Operational failure quality cost elements
Workshop (n=5)
Steering group discussions (n=6-12)
Study B (i) - Call to action on major project quality failure
Trial survey (n=25)
Study B (ii) - Measuring cost of quality in major construction projects post-handover
Industry-based Questionnaire (n=17)
Study B (iii) - Quantifying quality cost failure in major construction projects post-handover
Project case study
Phase 2 – Developed case study
Study C - Infrastructure client multi-case study
Operational quality issues within single client organisation
CHAPTER 6 – Infrastructure client multi-case study
Study C (i) - Exploring the operational issues sample
Delphi review:
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on specific projects (n=4)
Advance knowledge on potential projects (n=2)
Final cases selection workshop (n=3)
Study C (ii) - Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) – Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) - Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

3 Capabilities in complex projects

3.1 Introduction

This chapter focuses on the literature pertaining to complex infrastructure projects, particularly the development of the project-based organisation (PBO) as an advance in project management development. This includes further exploration and explanation of the diversity of capabilities of a PBO to generate the understanding of failure-related capabilities. Also, literature that is relevant to knowledge on capabilities for failure mitigation is also described. This includes the definition of capabilities, how it can be developed, and the potential problems that can arise in doing it.

3.2 Failure in the dynamic nature of construction projects

Given the view of the previous published and limited literature in understanding COQ in construction, specifically looking at operational failure and its quality cost, whether within the construction project management or general organisational context, it is important to review the functions and operations of complex organisations to further map the context of the study. As emphasised by Morris (2013; p.6), "*Understanding history is a sign of maturity. Where today history is rarely view as objective, disinterested enquiry but rather social constructed*". He took a view of how every project may follow the same generic development cycle: from feasibility to operations, but the development lifecycle of each project is what distinguishes it from all the others. Recently, the research of Zerjav et al. (2018) looked into the assembly of project capabilities in the temporal inter-organisational setting of project delivery, and has recognised the relation of failure with poor management of capabilities.

Generally, the nature of a construction project has been long known to be a complex and a dynamic process. Frequently changing technology has often required a bespoke design, to address rapidly changing market needs (Turner & Keegan, 2000). Mulholland et al. (2016) described technological obsolescence within the operating system as a high risk to systems failure, and will lead to unforeseen and unplanned operational costs. A successful project management, as recognised by Davis (2017), is dependent on the recognition of both internal and external factors that will influence the final outcome; thus, any discrepancy between project expectations may influence the successful delivery of a project's operations. Project managers in the construction industry have recognised the importance of operational performance, beyond delivery to project time, budget and compliance, to technical and quality specifications (Aubry et al., 2007). From this viewpoint, project managers must create value for the benefit of the business, which requires human, budgetary and technical capabilities beyond those required by the projects themselves (Pinto & Prescott, 1988).

The fragmentation and inefficiency of creating value within the complex connections amongst multi-organisationals needs collaboration between owner, contractor and supplier alliances to align the diversity of capabilities in managing projects. Literature acknowledges that construction participants are also known as construction project firms who are unique entities that are created through a complex integration of capabilities, with interdisciplinary information and knowledge, responsibilities and objectives (Hu, 2008). However, little is known about how they mitigate failure and the capabilities that are needed for construction participant to mitigate the failures.

While all projects are acknowledged to be different from one to another, construction project management is also a multi-phase process that is frequently divided into decision and concept, design, construction and implementation, as well as maintenance and demolishment phases (Hu, 2008), so that each project experiences a unique process on its own. Winch and Merrow (2012) argued that failure to achieve an efficient and effective construction lifecycle will lead to heavier and long-term implications for other assets in the economy and for society; thus, preventing the value of project's capability to be recognised. Most projects frequently deliver failures in critical operational outcomes, creating risky operational readiness, thus constraining future investments. In this sense, the characteristic of the industry's activities are distinct in that every project should be treated as separate with its individual settings, where each construction project is discrete and temporary (Rosenfeld, 2009). By distinguishing these characteristics, Jaafari (1984) suggested that performance and failure issues are more effectively addressed in understanding the functioning of the project itself as well as its benefits to the broader economy. Therefore, capabilities to mitigate failure are clearly a significant concern.

Project management studies have now moved from the classic view of the project management structure towards how organisations are managing projects. The term project-oriented is well acknowledged as project-based organisations responding to organisations whose strategic business objectives rely on the results of projects or programmes (Gareis, 2007). However, within the project-based organisation (PBO) literature, distribution of capabilities needs further understanding in relation to how temporary project organisations can create a lasting performance that collates and integrates different knowledge and skills (Brady & Davies, 2004; Pryke & Smyth, 2006; Winch, 2010). The meaning of organisation, management and construction project management within PBOs in general is significant to further understand how this process is influencing operational failure in construction projects. As the operational failure is the focus of this research, both project process and management are viewed as dynamic, operating from the view of the processes embedded in both project management and organisational levels. As such, the research agrees with the need for a stronger owner management view of the multi-organisational project environment and the need for the owner and multi-organisational supply network to advance their capabilities (Winch, 2014; Winch & Leiringer, 2016), both strategic and operational capabilities (Helfat & Peteraf, 2003; Pena-Mora et al., 2003), to achieve project quality (Bubshait, 1994) and, more importantly, to mitigate operational failures.

Thus, this chapter defines the PBO and capabilities in complex projects. This includes how complex construction projects are managed in PBO and how capabilities are defined within the owner and multi-organisational supply network. There is a clear articulated theory of capabilities in this chapter. This is to initiate some underpinnings and intricacies of the concept and context that are compared and discussed to address the benefits of understanding the concept in the construction industry and the lack of attention to it in responding to operational failure.

3.3 The project-based organisation (PBO)

3.3.1 What are they?

Project-based management is used in adapting to the changing environment (Lundin & Soderholm, 1995; Hobday, 2000; Turner & Müller, 2004) such as new products, processes, technological or market changes (Teece & Pisano, 1994). According to Melkonian and Picq (2011), the complexity in current construction projects has increased the level of uncertainty as well as risk, thus promoting the introduction of PBO. This is understood to be ideally suited in dealing with the dynamic, unstable and discontinuous environment of construction projects (Huemann, 2015). However, failure in many project still regularly occurs. The complexity of a project can be explained as a ‘temporary coalition’ which extends beyond the boundary of the single firm (Hobday et al., 2005) that is no longer sufficient for a firm to create a long-term and sustainable performance. Firms are forced to advance from single to multiple project management (Söderlund et al., 2008). As a result, failure mitigation must be understood beyond a single firm and project.

Some studies have suggested the PBO is a natural organisational form of a CoPS (Complex Product System) producer, typically when several supplier partners are engaged with the owner through various stages of innovation and production (Hobday, 2000; Gann & Salter, 2000). Consequently, the PBO (Figure 3.1) is an alternative to the matrix-based organisation (Aubry et al. 2007) (Figure 3.2); it is an organisation that may stand alone or be a subsidiary of a larger firm, in which the majority of the products (or services) are developed against a bespoke design for either internal or external customers (Turner & Keegan 2001). According to Turner and Keegan (2001), if the end product is bespoke, the intermediate product is also bespoke, and thus the processes required to produce the project will be novel on every project. This requires integrated capabilities (Davies, 2004) in responding to the bespoke intermediates to mitigate failure; this is different to the matrix-based structure, which may require one-off failure mitigation within each stable process, although this has not been explored within the context of project management in failure mitigation. Customer requirements frequently change with different competencies and technology required. As a result, the nature of the project is unpredictable and complex (Turner & Keegan, 2000; Morris, 1994; Winch & Merrow, 2012) and perhaps increases the risk of failure during operations.

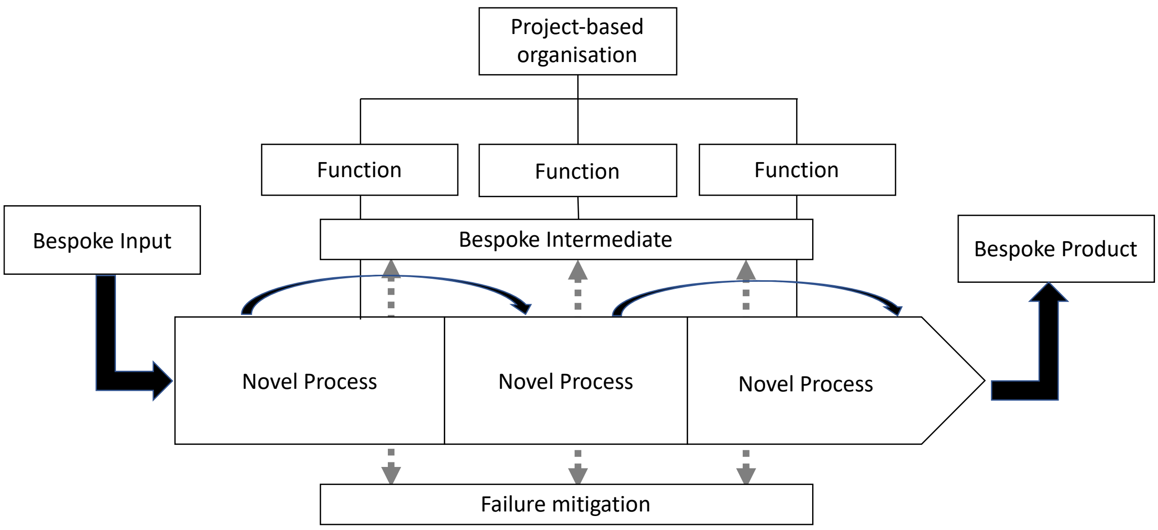


Figure 3.1: Project-based organisation structure (Adapted and developed from: Turner and Keegan 2001)

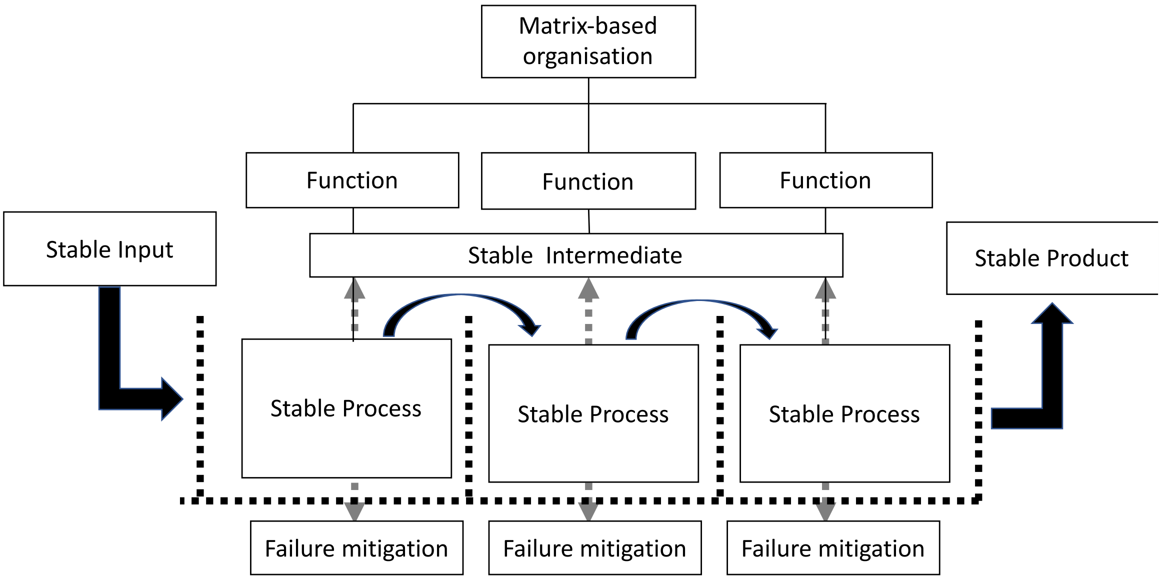


Figure 3.2: Matrix-based organisation structure (Adapted and developed from: Turner and Keegan, 2001)

The PBO is inherently flexible and reconfigurable and enables the combination and transfer of different knowledge through multi-organisational and stakeholders in a complex product-solving process (Soderlund & Tell, 2011), and quasi-permanent intra-organisational coordination (Sydow et al., 2004; Bredin, 2008a). The PBO must develop project capabilities to create lasting performance based on multiple short-term projects (Davies & Brady, 2000) that collate and integrate different knowledge and skills during the 'temporary project' (Pryke & Smyth, 2006; Winch, 2010). This form of organisation, which mainly operates on project forms as a domain (Hobday, 2000), embedding different projects into their permanent organisational context, helps to address the dynamics of management in a more adverse environment. However, with the absence of management of capabilities within the PBO, the remaining phase of a project or future endeavours will continue with less development of crucial business insight (Aerts et al., 2016), which could lead to operational failure.

Davies and Brady (2000), extending Chandler (1992), explained how suppliers of CoPS build the capabilities required in the concept of construction project activities (e.g. bidding, project design, implementation and de-commissioning). Within the changing environment, the PBO needs the ability to reconfigure multi-organisational supply network capabilities by linking supplier integration with the performance outcome (Vanpoucke et al., 2014). The challenge is that it can be a rather perpetual and cyclical process that requires constant re-evaluation and change from one project to another (Zerjav et al., 2018), in which each cycle needs management in putting in place the organisational changes, routine and learning processes (Davies & Brady, 2000) for the owner and multi-organisational supply network to provide the capabilities to mitigate failure. This study acknowledged how the concept of a 'repeatable solution' by cycling experience from one bid project to another could help owners in capturing valuable capabilities, thus leading to a better management in reducing quality cost that further mitigates the operational failure.

It is argued that, within the nature of complex projects, owners and operators play the most important roles in keeping and advancing the range of capabilities (Winch & Merrow, 2012) that is generated through different individuals and expertise across the organisations (Hobday et al., 2005). This perspective, brought by Winch and Leiringer (2016) and Winch and Merrow (2012), showed greater linkage to how owners in the permanent firm will impact its project organising and the operational sides of the project (Winch & Leiringer, 2016); thus, suggesting the role of capable owners to better manage capabilities in mitigating failure. With the temporary nature of projects (Lundin & Soderholm, 1995), a repeatable solution needs to be captured by concentrating on operational impacts (Slack, 2005) and involving a diversity of capabilities from professional managers to technical engineers. This may be achieved through understanding the right distribution of capabilities in a complex project. Integrating the strategic and operational capabilities (Bredin, 2008) may be needed, but attention needs to be focused on the capabilities of failure mitigation. This will help to generate systematic integration that combines both front-end and post-project details of perspective in identifying potential process improvement (Peña-Mora et al., 2008) to mitigate failure.

3.4 Complex product system (CoPS) as a PBO

3.4.1 The CoPS – How are they formed?

According to Hobday et al. (2005), PBO are more suitable to manage CoPS but require strong integration between the owner (often as a source of innovation) and other collaborating companies, which will provide the opportunity for the owner to manage different capabilities to mitigate failure. Accordingly, Hobday et al. (2005) have suggested that CoPS are high-technology and high-value capital goods, such as telecommunications systems, flight simulators, high-speed trains, air traffic control systems, intelligent buildings, weapon systems and baggage-handling systems. Gann and Salter (2000) mentioned that CoPS are usually supplied as one-off items or in small batches for individual business users that require systems management in the project and business process. According to Hobday (2000), each of the CoPS is designed in a hierarchical manner and tailor-made for a specific customer; they are high cost and made up of many interconnected systems that often involve customised parts (e.g. control units, sub-systems and components). Due to the high cost, physical scale and composition, CoPS are frequently produced by projects or small batches, which allows for a high degree of direct user (sometimes owner-operator) involvement in the innovation process (Hobday, 2000). Consequently, this requires the capabilities from the owner, multi-organisational supply and operator network to achieve the desired innovation for the CoPS to avoid operational failure, and yet these capabilities are not well described in the literature of how they could mitigate failures.

Each CoPS is a highly innovative form that makes different demands on innovation of the product. This is frequently experienced in the forms of project management in the PBO, which acquire cycles of creating and re-creating organisational structures and processes around the needs of each product and customer (Davies & Mackenzie, 2014). In some cases, as explained by Hardstone (2004), firms that once produced stand-alone products have the opportunity to increase the degree of complexity of managerial choice and have more opportunity to become 'system companies'. System companies can operate from a considerable diversity of strategy and structure that would appear to give a considerable scope for strategic variety in the industry in re-forming the emergence of CoPS (i.e. due to technological changes) (Porter, 1980; Bonaccorsi et al., 1996). Bonaccorsi et al. (1996) further elaborated that the interaction between components cannot be solved through a fixed set of physical parameters at the beginning of the design process, but changes over time during the process. Therefore, CoPS are those products that result from:

> …a *great variety of components and subsystems with high technology content, are realized in small series or as single models, present high levels of customization, and are normally realized through a project-based organization and a wide range of inter-organizational relations* (Bonaccorsi et al., 1996, p.540).

In summary, CoPS are product components that by themselves are a complex system composed of subsystems or components (Hardstone, 2004); the system exhibits a high degree of customisation, reflecting the huge heterogeneity of user requirements. This is due to the fact that systems are, in most cases, pieces of capital requirement, whose physical characteristics reflect a wide variety of requirements and operational conditions

(Pellegrinelli, 1997). According to Hobday (2000), the characteristics of CoPS can be summarised as:

- Multifunctional and involve multi-disciplinary skill/knowledge inputs.
- A system lifecycle that may last for decades and has a large product or system breakdown structure.
- Using many customised components and equipment often involving long delivery lead times.
- System requirements analyses that are owner-operator driven. It involves high levels of people-embedded knowledge in systems engineering, design and development.
- Its success depends on a high level of core competencies in systems engineering and integration and complex programme management.

Therefore, inherent complexity (Hardstone, 2004) is created from large product components, tasks and human interactions that could possibly be a major source of project risk and uncertainty in contributing to project challenges, failure and impairment. Ahern et al. (2015) emphasised that CoPS are different to traditional projects (that may be very complicated but fully specified), where they can be defined as projects that cannot be fully specified and planned in advance. Typically, the goals of complex projects and the initial assumptions can often only be specified in outline or in part, which entails incomplete project plans at the start (Pitsis et al., 2003); this requires a ‘discovery-driven’ planning approach for complex projects in promoting continuous learning over the lifecycle based on the project end goals (McGrath et al., 1995).

Accordingly, the complexity of CoPS and the organisational arrangements for their design, development and commissioning are capable of supporting a wide variety of firm structures, strategies and capabilities that will enforce the CoPS (Davies & Brady, 2000) to build the capabilities required to successfully expand the new product or services (Söderlund et al., 2008). However, these capabilities frequently can only be specified after the project is delivered and this thus impedes the innovations. Ethiraj et al. (2005) argued that the interactions between these components in a product system condition the research and design that will incentivise firms, which means the incentives are also increasing prior to the investments in the capabilities. Yet, this logical problem of incomplete pre-given knowledge together with its practical implication for developing a capability for production and learning in CoPS are not fully understood by the construction stakeholders. Although management of multi-organisational alliances and owner institutional arrangements to facilitate system implementation is common in undertaking innovation for production (Hobday, 2000), CoPS requires the mobilisation and management of a wide range of capabilities (Gann & Salter, 2000) that are rarely found within the sphere of control and ownership of a single enterprise (i.e. the owner). Rosenbloom and Christensen (1994) concluded that incumbent success or failure is independent of the technical capabilities that are required or made obsolete by innovations. However, owners differ greatly in their ability to transform the generic need into the detailed specifications of the required product, thus what factors will enable the CoPS to be more effective in dealing with mitigating failure capability, both foreseeable and emergent, are still not fully understood.

3.5 Capabilities in project-based organisations

3.5.1 What is capability?

Generally, capability is the *ability* to perform a specific task (*Oxford Dictionary*). Thus, capabilities may come in many forms and variations, such as: individual, managerial, operational, marketing-based or technological. In organisational capability theory, capabilities are embedded in idiosyncratic social structures that are developed through the context of organisational resources (Schreyögg & Kliesch-Eberl, 2007); thus, capabilities are complex in nature, involving both formal and informal processes that are conceived as a distinct behavioural pattern (Dosi et al., 2008). In achieving superior performance and a unique historical development, the ability to recognise, sense and shape the developments of capabilities is needed to build the foundation for sustainable competitive advantage. However, the ability to recognise opportunity differs depending on the individual capability and extent of knowledge or according to the knowledge and learning capacities of the organisation to which the individual belongs (Mayer & Salomon, 2006). Specifically, in projects; the ability refers to meeting the owner’s need and requirement for functionality, quality cost and schedule.

In the literature of organisational capability, Richardson (1972) made an early observation on how co-operations arrangements have influenced many studies in various definitions of ‘organisational capabilities’. The co-operative arrangement will not be successful without the elements of organisation, knowledge, experience and skills. He elaborated that large numbers of activities carried out by a firm have to be carried out with appropriate capabilities, which are, in other words, appropriate knowledge, experience and skills. He further mentioned: *“organisations will tend to specialise in* *activities for which their capabilities offer some comparative advantage"* (Richardson, 1998, p.888). Within this, organisational capabilities were later identified and defined by others as 'organisational routines' (Spender, 1996; Nelson & Winter, 2002), as 'strategic and functional' (Chandler, 1992), as 'architectural and component knowledge' (Rebecca & Kim, 1990), as 'a source of organisational synergy' (Chandler, 1992), and as 'a high-level routine' that represent a repository of historical experience (Zollo & Sidney, 2002; Winter, 2000), and recently many studies have started to acknowledge capabilities as 'organisational learning' (Winter, 2000; Davies and Mackenzie, 2014; Ahern et al., 2015). These different definitions of capabilities make it difficult for the owner and multi-organisational supply network to align expectations about the project's outcome, as it is frequently assessed with multi-dimensional measures of operational performance (Peng et al., 2007) that include cost, quality, flexibility and delivery measures. Thus, this may lead to consequences of failure at its final output.

Capabilities are seen to be evolving and developing through the pursuit of business objectives. This may be through the innovation cycle of goal, practices, learnings and developments or through reflection (Davies & Brady, 2000). Although every organisation may uphold specific specialty in certain activities, the organisational industry may also adapt itself to the fact that activities may be complementary from one to another (Graham, 1999); this also applies to the capabilities. Capabilities are observed as evolving activities through an iteration of doing, learning and repeat doing, in which each sequence will expand knowledge and enrich core competencies (March & Levinthal, 1993). However, in Ahern et al. (2015), capability development is described as uncertain in terms of its outcome, as capability learning that is poorly understood can lead to enactment of poor execution or learning that is forgotten. Capability emerges with better managerial discipline alongside its development in a complex project as long as the combination of these capabilities and its interchange is well understood by the multiple parties that are involved (Peng et al., 2007). However, subsequent change has to be communicated and coordinated through the project lifecycle in order to mitigate failure.

In project capability building, Penrose (1959) described a resource-based theory of firm growth and capability building as a 'learning theory of the firm', and has suggested capabilities as a source of firm resources. However, Chandler (1992) argued that resources alone do not create value, but need to draw upon the knowledge and experience – or the 'organisational capabilities' – in working together to control both the use of resources and the performed activities that create competitive advantage. This requires specific knowledge, creative activity, and the ability to understand user and customer decision making and practical wisdom (Nonaka & Toyama, 2005). Given the numbers of different organisational entities, one common assumptions associated with capability is that capabilities are inherently complex, causally ambiguous and difficult to replicate (Barney, 1991; Teece, 2007). This prescription is therefore relatively straightforward for areas in which an organisation has relatively weak capabilities: Mayer and Salomon (2006) suggested it is more efficient for this organisation to use different forms of governance to gain access to the skills and capabilities that it lacks, because it will be very difficult, costly and time consuming to try to develop those capabilities from scratch. Accordingly, the capabilities differentials holds important applications for the identification of 'mistakes' and will only help firms mitigate some contractual hazard (Wu et al., 2010).

Capabilities are tacit in the nature of social process; they emerge gradually over time, and need to be explored, experienced and innovated through dynamic interplay between a firm's internal capability and the changing nature of the project (Leonard-Barton, 1992; Davies & Brady, 2000), which will influence a new set of services (Davies & Mackenzie, 2014) in gaining learning for future inter-organisational-network capabilities to mitigate failures. Davies and Brady (2000) later introduced the additional concept of 'project capabilities' in referring to the core activities of firms that design and produce complex product in low volumes. They have further referred to 'project capability' as the ability of project-based organisations to deliver 'complex product systems' by managing the organisation, processes and procedures for bidding for and delivering projects to customer specifications. This needs to be developed with the project management capabilities to conceive, design and coordinate the development of large-scale systems that include multiple disciplines and many participating organisations (Sapolsky, 2007) at strategic, project and functional levels of multi-level approach projects. Many still wonder how the functional level may be defined in the project capability. For example, for a purchasing owner organisation, the functional level is almost always dynamic because they extend the resource-base of that organisation, but not its 'core business' (Kay, 1993). Therefore, Winch and Leiringer (2016; p.272) have proposed the owner project capabilities as:

> *…the dynamic capabilities required by the owner organisation for the acquisition of infrastructure assets in order to extend or improve its operational capabilities in distinction to the operational capabilities deployed by the project-based firms which supply those assets.*

Within all the different contexts of how capabilities are defined, it is envisaged that there is a need to advance the capabilities definition in relation to failure mitigation. This thesis will consider the underlying definition of capability theory, as the distinctive managerial knowledge, experience and skills located within an organisation which are required to establish, coordinate and execute a project. This includes a distinct behavioural pattern of content and structure that supports the construction business, project-programme process, and the diversity of stakeholder involvement in developing a better understanding of an organisation's capabilities.

3.5.2 Why is it important to understand capabilities in mitigating failure?

Capability priorities are often tacitly held by individuals, and are frequently embedded within the wider business organisation and strategic context of the firm (Brady & Davies, 2004). In project management, Jugdev et al. (2007) explained that not all assets constructed with the input of interest (either tangible or intangible) will generate competitive advantages. Consequently, the outcome obtained from the project management process determines the degree of competitive advantage. Thus, it is important to improve the understanding of these tangible and intangible elements as project inputs that are used as the project management capability of the firm in mitigating failure at the output of a project outcome. Firms vary systematically with the availability and allocation of resources that are rare and superior in use, through the unique historical development, thus capturing capabilities leads to a greater configuration of resources (Schreyogg & Kliesh Eberl, 2007) and facilitates problem solving (Dosi et al., 2008). However, multi-organisational capabilities are acknowledged to be embedded within projects around the transmission of resources and people (Davies & Brady, 2016). These capabilities are believed to be nesting in different projects, and stronger management is needed to capture and acknowledge their value in improving project management (Flynn et al., 2010). However, the understanding of capturing the diversity of capabilities for capable owners to generate competitive improvement has not been widely addressed, specifically in mitigating failure.

For a firm to compete in a fast-moving construction project environment, it requires continuous creation, extending, upgrading, protecting and maintaining the relevance of the capability towards the project objective; the firm also needs to embrace its capacity to shape the ecosystem it occupies and capture sufficient value (Teece, 2007) to deliver superior long-term financial performance and assist in mitigating failures. This is significant because different capabilities have different costs and benefits associated with their development or acquisition (Ethiraj et al., 2005), and this needs management attention in making such investments in the capability development to improve the establishment of project competence and project capabilities (Davies & Brady, 2000; Soderlund, 2005). For Colotla et al. (2003), capabilities are a primary source of profits, as most empirical and theoretical findings have shown how certain capabilities have impacted performance in various ways (Brady & Davies, 2004; Rangi, 2014), but more work is needed to develop practical advice from the operational perspective (Whyte et al., 2016) and particularly pertaining to operational performance and failure mitigation. Typically, the capabilities emphasised organisation, management, coordination and governance (Kogut & Zander, 1992), but the set of these activities need organisation and coordination of distinctive competencies (Soderlund, 2005). In line with Rungi (2014), different activities impact different outcomes; thus, project capability changes when the surrounding environment changes. Reasonably, disaggregating capabilities into several measures may create difficulties as capability is a social construction (Ethiraj et al., 2005; Peteraf et al., 2013) but, as the capabilities are specialised and are complementary to the output of a project, the deployment of these sets of activities is essential in generating value for owners to mitigate operational failure.

There is still scepticism as to how capabilities are generated or as to how investment of money, time and managerial effort is required in building them in relation to failure mitigation. Ethiraj et al. (2005) emphasised that the development of capabilities requires deliberate and sustained investment of both financial and managerial resources. Each has alternative uses and it is important to understand the costs and benefits of such investments. In other words, it is believed that different capabilities may entail different financial and managerial costs and yield dissimilar performance benefits (Barney, 1991) that are needed in addressing the uncertainty and the ambiguity of operational failure through the integration of capabilities for failure mitigation. The systematic understanding of such trade-offs should promise the enrichment of the theory and practice of strategy for owners to increase operational capability performance (Winch & Leiringer, 2016), and to reduce the construction operational failure cost (Love & Irani, 2002; Barber et al., 2000). Yet, this has not been clearly explored. Given the strength of these arguments, capturing integrated capabilities across a multi-organisational network should be addressed in expanding the knowledge of project-operational capabilities that could assure operational success.

3.6 Capabilities in failure mitigation

3.6.1 The project and capabilities to mitigate failure in reducing quality cost failure

Building upon the organisational capabilities literature (Chandler, 1992) which explains firms are a collection of capabilities that range from routine, knowledge, skills and experience (Davies & Brady, 2004), it is critical to exploit the potential cost saving of future development by understanding the diversity of capabilities in managing projects. Hence, looking at CoPS in PBOs, the projects are more tailored to the unique environment of each asset, as according to Morris (1994) and Winch (2014); thus, it is assumed that capabilities are not only resources but rather represent the way of allocating, coordinating and deploying the resources (Schreyögg & Kliesch-Eberl, 2007). The importance of these capabilities is to create, extend and modify the ways in which a firm operates, which are embedded within the processes; this includes coordination, learning and transformation in project organising (Söderlund et al., 2008). Therefore, it is agreed that the capabilities have become central in the competitive advantage of complex infrastructure projects (Davies & Brady, 2000; Brady & Davies, 2004; Davies & Hobday, 2005) that incorporate the management of each capabilities deployment in mitigating failures and reduce the quality cost of failures.

Capabilities are influenced by the acts of an organisation's decision makers (Flynn, 2010), and need important distinctions between organisational and managerial processes, procedure, systems and structure that undergird each class of the capability (Teece, 2007). The higher the strategic importance of capabilities management to the PBO, the more likely the failure mitigation will be performed either by the owner or by the multi-organisational supply network in delivering the project. Davies and Brady (2000) explained that an organisation needs to create and utilise its capabilities through experience to distinguish and determine its capabilities and adapt its ability with different organisations in the project. Therefore, in different projects, an organisation needs to acquire sustained performance (Melkoniaq & Picq, 2010) that is aligned with the project objectives to foster evolution and respond to a changing environment. This requires sustained integrated measure of different organisations' capability to measure the project quality cost in mitigating failure.

The emerging working practices resulting from the constantly changing environment of a project have now forced organisations to manage capabilities (Flynn et al., 2010) that will improve decisions in preventing failure. Through the iteration process, organisations expand their knowledge and enrich their core competencies (March & Levinthal, 1993), which helps them gain a better understanding of how future failure could be prevented; thus reducing the quality cost failure. Although the unique embedded sets of capabilities are known by most researchers, these distinctive dimensions of capabilities are rooted in values which are established but often overlooked (Leonard-Barton, 1992), especially in relation to failure mitigation. There is a need to enhance emerging theory by examining the way capabilities inhibit failure as well as enable development, to deepen the description of the nature of core capabilities and detail evidence of how capabilities is related to the development of projects.

Recently, there has been growing concern that a project may not perform in the long term to satisfy the project owner, and this means construction performance relies on different dimensions of project management. Studies have shown that an integrated approach in conceptualising, planning and implementing large, complex projects is needed (Jafari & Rodchua, 2014); this is beneficial to developing capabilities in mitigating failure generated from the diversity of capabilities in different projects. It is understood that the structure of the organisations operating within construction projects is different to those of the functionalist and traditional view of the theory of the firm. The differences of these organisations operating in projects is not only diverse in nature owing to the internal and external environments surrounding them, but also due to the dynamic factors influencing the processes of the construction project lifecycle (Kusuma, 2016) and thus is believed may cause the occurrence of failures. Thus, from the above, to understand capabilities, there is a need to distinguish the differences between the owner and multi-organisational supply network capabilities in accordance with how their capabilities influence failures in the project lifecycle. This will enable a more strategic approach to managing capabilities to mitigate failures and reduce quality costs.

3.6.2 Owner's and multi-organisationals' programme and portfolio

Complexity in construction projects generates uncertainty and ambiguity in defining failures. Mostly, owners are responsible for the operationalisation of an asset (Hughes & Murdoch, 2001), in managing and reducing the quality cost to mitigate and make good on problematic assets. Although resources and inputs are available within the supply network, the 'capability' to deploy them productivity is not uniformly distributed (Ethiraj et al., 2005), and demands a more active and supervisory role in response to failure. Turner and Keegan (2003) elucidated the use of programme management from owner to managed project in PBO. They described how the owner forms a network in which individual companies fulfil different roles in the operational process. Effectively, an isomorphic network is created project by project to meet the individual customer's requirement, the product and process (see Figure 3.3), while in an isomorphic project team structures are created with a bespoke command and control structure.

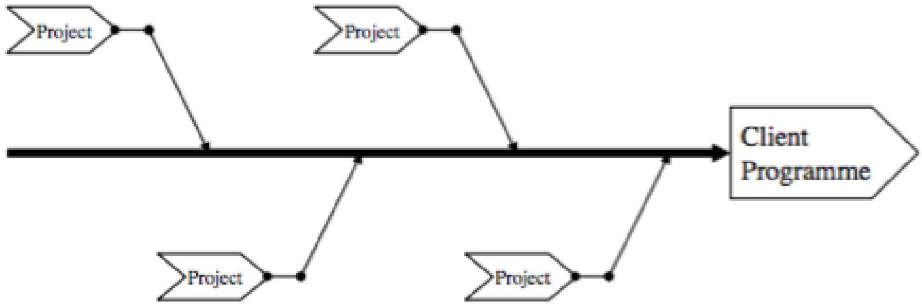


Figure 3.3: Programme delivery of multiple projects in a PBO for the owner (Source: Turner & Keegan, 2000)

In a large project, wider stakeholders will be involved in judging whether the output, input and impact have achieved the desired objectives (Turner & Zolin, 2012); this gives the owner the opportunity to identify the divergence of capabilities in aligning project objectives. Therefore, as a new way of managing projects, Hobday (2000) explained that PBO is able to cope with emerging properties in production and respond flexibility to the changing needs of owners, and in integrating different types of knowledge and skills. PBO is organised to cope with project risk and uncertainty commonly found in complex projects (Bourne et al., 2003); however, this does not reduce the occurrence of failure. There is a need for more advanced organisational structures designed to comprehend the uncertain context of project operations (Hagström et al. 1999). It is believed that the dynamic process of organising and strategising in the new forms of organisation within the project-oriented organisational forms (Aubry et al., 2007) could develop capabilities for failure mitigation that are significant for an owner and its multi-organisationals in CoPS.

Projects are now seen as a portfolio, which introduced the new idea of managing the organisation by projects (Pemsel & Wiewiora, 2013), and has also been proposed as a corporate view of project management (Dinsmore & Associates, 1999). However, in most PBO organisations, capable owners assume that projects will integrate with operations. Some place significant weight on the capabilities of contractors and suppliers in understanding how this is achieved, but research perhaps shows that the owner's project and operational capabilities are key (Davies et al., 2009). Different projects are adopting different approaches and strategies through programmes development in responding to operations management (Turner & Keegan, 2000). Turner and Keegan (2003) suggested that organisations utilising a PBO approach need to recognise the differing approaches and when they are appropriate for different businesses to adopt. As stated by Davies and Brady (2016), although capabilities are frequently held by the project supply network, and distributed across an inter-organisational network, they need to be simultaneously managed (Davies & Brady, 2016) and, most importantly, recognised by the owner. This is because the choice of mechanism or interface for the governance of an owner and its multi-organisational network relationships critically relates to the subsequent performance (Caldwell et al., 2009). In this way, capabilities for failure mitigation must be understood at the critical intersection between providers and the focus should be on the relationship between project and quality management approaches.

The owner's ways of managing a project may have substantial positive or adverse effects on the achievement of project objectives (Bresnen & Haslam, 1991). Currently, the nature of temporary project has forced construction organisations to foster their own capabilities as a project management strategy in expanding their core competency and moving from a traditional-based view in focusing on developing capabilities at the front-end of the project towards development of capabilities to operate and maintain facilities (Davies et al., 2009). Currently, it is understood that capabilities which apply during the strategic stage of a project later become a part of project operations (Winter, 2003), but the acquisition of these dynamic capabilities towards operational capabilities needs further investigation (Chin et al., 2014). Accordingly, these capabilities need stronger capability on the part of the owner (Winch & Leiringe, 2016) to coordinate the process, resources and capabilities across the organisation as whole. Owners should be aware of their own capability as well as the multi-organisational capabilities. Lindahl and Ryd (2007) suggested that looking at the owner's perceptive will lead to an integrated approach that enhances innovation and improves managerial competency and will stimulate the reformed management of construction. By knowing the capabilities required to mitigate failure, owners will be better able to drive continuous improvement to reduce failure cost throughout the owner and multi-organisational supply and operations network.

3.6.3 Integrating capabilities within PBOs to mitigate failures

The impact of integrating capabilities on improving project values is a central issue, but one yet to be understood in relation to mitigating failure. Davies and Brady (2016) suggested that capabilities based on multiple short-term projects need to be integrated to continuously add value to a competitive project. The development of project capabilities thus requires deliberate and sustained investment of financial and managerial time, as different capabilities could impact performance differently (Ethraj et al., 2005). A study by Bredin (2008) suggested the integration of people capabilities with project and functional capabilities will enhance the people's competencies. The organisational process factors and the desired target outcome are key managerial decision variables (Tatikonda & Montoya-Weiss, 2001) that need greater understanding on the integration between the operations and strategic development. Project integration will generally have a positive influence on project performance (cost, time, quality, environment impact, work environment and innovation) with a more collaborative effort (Eriksson & Westerberg, 2011) within the project portfolio. The connections between owner and multi-organisational supply network capabilities integration in improving operations performance (Frohlich & Westbrook, 2001) is still unclear. There has been limited consideration of the challenges, in that capabilities may create complex integration for an owner and their multi-organisational supply network when they need to address unanticipated failure mitigation.

Although the owner is generally known as the primary consumer of a construction project, the source of project finance and, in many cases, the end user of facilities (Huang & Hinze, 2006), owners are not a simple system (Cherns & Bryant, 1984), but complex, with different interests and influences (Teece, 2007). This requires capabilities that need to be tailored according to different project environments (Morris, 1994; Winch, 2010). Research by Davies et al. (2016) shows that the role of integrating project requirements and capabilities relies on the owner. Within this, the relationship of how owners could have managed these capabilities in responding to operational failure is still not clear. Most participants in the construction process will usually focus on their own responsibilities rather than on the realisation of the owner's objectives (Hughes & Murdoch, 2001), which leads to misalignment of project capabilities. Therefore, in different projects, an organisation needs to acquire sustained performance to carry out capabilities (Melkonian & Picq, 2011) that are oriented to the overall project objective. There is a need for the owner to be more knowledgeable by developing their own organisation through the use of project managers and other professional roles (Lindahl & Ryd, 2007) in increasing communication about understanding the quality needed to mitigate failures.

Strategic project management analyses the outcome of the overall project performance behaviour, while operational project management undertakes detailed analysis of how time, cost and resources meet the determined target (Pena-Mora et al., 2008). Within this, the capabilities distributed during the strategic stage play a significant role, albeit they are necessary but not sufficient (Eisenhardt & Martin, 2000) to build new resource configurations, and to respond to the external environment that has adapted capability or resilience in gaining operational success. Although the PBO research view provides insight into the view that integrating capabilities is likely to generate value, comparatively little attention has been devoted to address the problem in capabilities distribution during the project lifecycle that influence the project, especially at the operational delivery.

Research by Davies et al. (2016) shows that the role of integrating project requirement and capabilities relies on the owner. Most participants in the construction process focus on their own responsibilities rather than on the realisation of the owner's objectives (Hughes & Murdoch, 2001), which leads to misalignment of project capabilities. Sustained firm performance is required to carry out capabilities that are oriented to the overall project objective. Although literature discusses capabilities that are path dependent, integration of capabilities in a project could, if fairly distributed by the owner, reduce the occurrences of operational failure. However, the relationship of how owners could have managed these capabilities in responding to operational failure is not clear. Construction perceptions of value, system integration and integrated solutions that suggest the concept of built environment solutions are still at an early stage of development (Brady et al., 2005) in understanding the capabilities, although the choice of mechanisms or interfaces within this relationship is critically related to subsequent performance (Caldwell et al., 2009). Currently, it is understood that capabilities applied during the strategic stage of a project and later become a part of project operations, but the acquisition of these dynamic capabilities in relation to operational capabilities needs further investigation.

3.7 Resource-based view in managing capabilities to mitigate operational failure

3.7.1 Supporting the operational capabilities for failure mitigation

Capabilities are explored in terms of delivery and feedback mechanisms linking one firm's technical capabilities with those of other enterprises with whom the firm collaborates, in order to produce one-off projects (Gann & Salter, 2000). For a firm to expand its capabilities, it needs to gradually acquire the knowledge and experience from the people and resources involved in its projects. Operational capabilities may not be easily obtained, as these are also a firm-specific sets of skills, processes and routines that are developed within the operations management (Flynn, 2010) as a continuation from the project's capabilities. The distinction of each capability in the project may not be well ascribed by most of the literature. The extant theoretical work on project organisations has emphasised the importance of 'project capabilities', as shown in Figure 3.4 (Brady & Davies, 2004; Davies & Brady 2016; Winch & Leiringer, 2016); these studies recognise the importance of the operational side of a project which is where the operational outcome between inter-organisational settings is recognised (Zerjav et al., 2018).

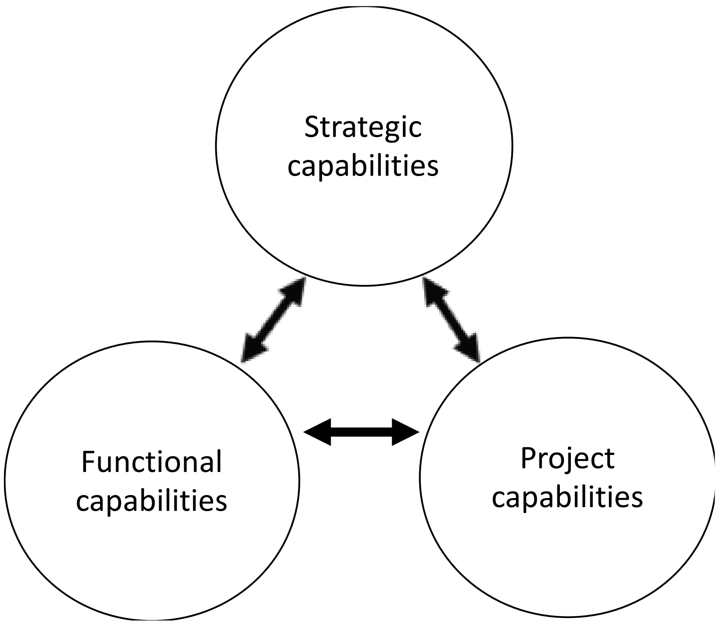


Figure 3.4 Organisational capabilities in CoPS (Adapted from: Davies and Brady, 2000)

It is understood that an operation's capabilities are regularly used in solving the problems faced by the departments that impact on operational failure. Nonetheless, the identification of the gap in operations drives the implications for project improvement (Whyte et al., 2016) in the context of PBO system lifecycle approach. The consideration of integrating strategic delivery and operational considerations through understanding the cost impact (Ethiraj et al., 2005) has provided a basis to support the understanding of integrated capabilities to mitigate failure in a multi-organisational setting. Thus, operations management could provide integration and direction to resources and operational practices in dealing with the uncertainty of projects, as a way to reduce the quality costs. Construction capabilities must be a two-way process that simultaneously supports the project process (Melkonian & Picq, 2011) and should also include operational needs and prevent operational failures.

The importance of an operation's capability is not only as a repetitive routine to support the operation but as an initiative taken to achieve defined project strategy (Lee et al., 2006). The operation's capability, hence, needs to be involved at the project level and identified as continuous elements of the project, to align the organisational aim and the temporary nature of construction projects (Hedlund, 2007). This capability should be taken as a mechanism for transforming various organisational aims in deploying different resources through customised ways of manging a project to mitigate the occurrences of operational failure; in other words, operational capability can serve as a critical mediating factor (Thoo et al., 2015) to align ambitious supply network practice to reduce the occurrences of operational failure and in mitigating failure. It is agreed that the owner should own the capabilities to integrate the acquisition of the project (asset) in supporting the extent of its operational capabilities (Winch & Leiringer, 2016), which consists of the whole lifecycle of the project elements. Consequently, these capabilities can be validated (Flynn, 2010) through their application during the project process as well as their deployment when operating the asset.

3.7.2 Learning and capturing capabilities for failure mitigation in complex networks

Projects are fundamentally network-based organisations (Styhre et al., 2004) that consist of different capabilities. These capabilities, transferred within projects, should be captured and managed (Pemsel and Wiewora, 2013) in improving, renewing and reconfiguring resources into new capabilities and competences (Teece et al., 1997). Due to the unique and temporary nature of projects, complex projects face substantial challenges in harnessing the capabilities to exploit lessons learnt from previous projects (Bellini & Canonico, 2008) to prevent repeat failures. However, projects may be referred to as similar when the same capabilities and routines are required for their repeated execution (Davies & Brady, 2000). This gives owners a great opportunity to recognise these valuable capabilities as a way to improve (Winch & Leiringer, 2016). However, this may not be achieved if project objectives are different from one organisation to another in completing specific projects (Kwak et al., 2015). To achieve common project objectives, the supply network needs to temporarily reconcile the differences in aims and cultures amongst the teams (Hobday et al., 2005), as learning can only be reconciled through group activities rather than individuality (Styhre et al., 2004). In construction projects, learning emerges as the firms cooperate and generate trust in major collaborative works (Wu et al., 2010) as a network of learning capabilities (Styhre et al., 2004) that may help organisations to manage and prevent possible operational failure.

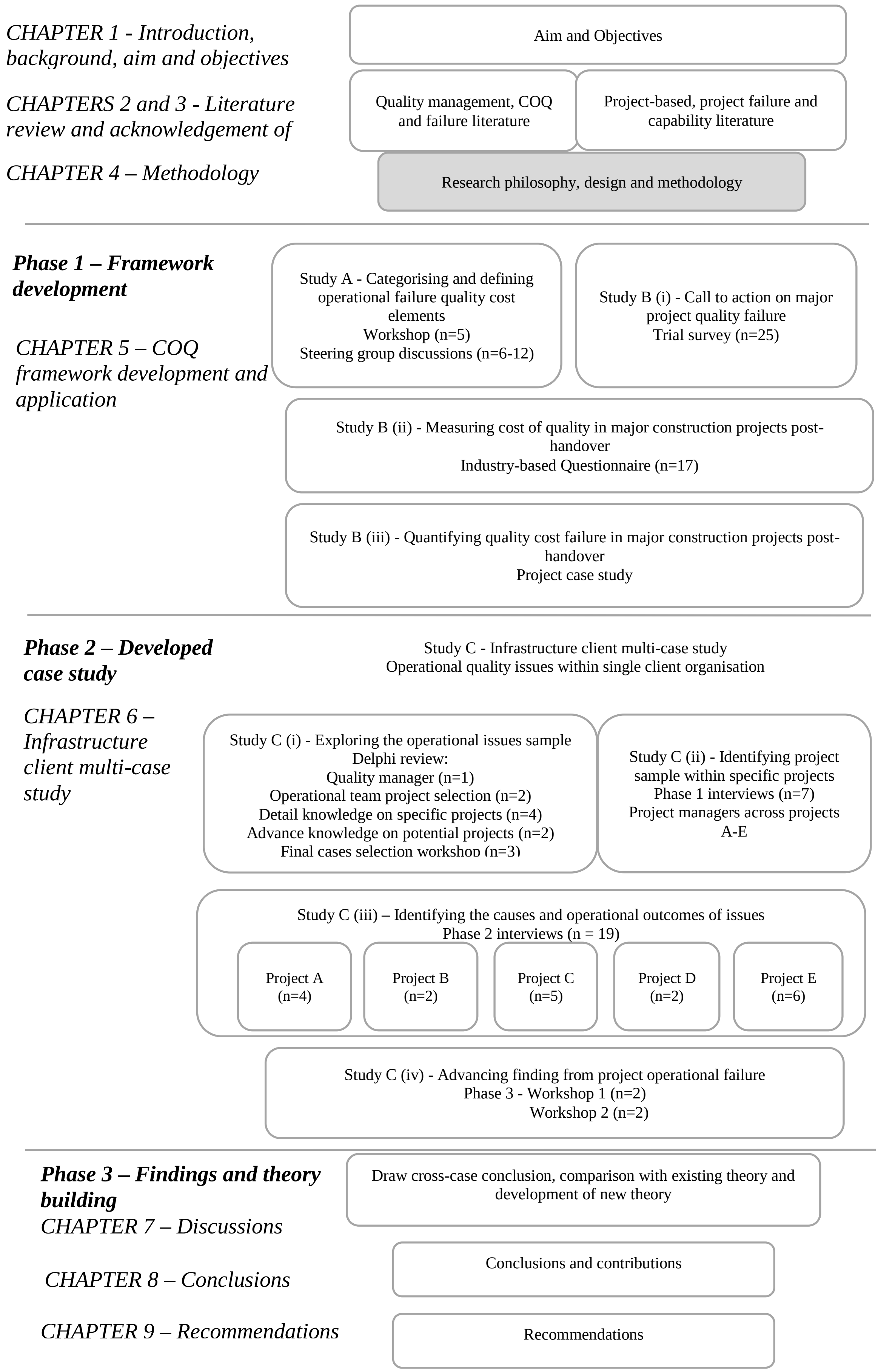
Establishing networking learning capabilities may reduce the firm's capability to innovate (Styhre et al., 2004) and the firm may lose its value over time (Coates & McDermott, 2002). Therefore, the interaction process in learning capabilities is critical as a mechanism guide to the evolution of dynamic capabilities (Easterby-Smith & Prieto, 2008) and as a nourishing ability to learn from project to operations (Whyte et al., 2016) in extending the opportunity for knowledge coordination. Ahern et al. (2015) argued that complex project capability is developed through dynamic organisational learning that continuously creates knowledge over the lifecycle of complex projects but cannot be fully planned at the outset. The greatest challenge is thus how learning and capturing capabilities could be passed from one project to another, as learning is always seen as dissipated and lost to future projects by repeating the same mistakes (Winch, 2014).

Despite a large body of literature on project management and organisational design, little research has been found on how a firm builds links between operations at the project level, portfolios of projects, and its central, routine activities in responding to learning and mitigating failure. Love et al. (2002) suggested that learning should be coordinated with quality management to better visualise the total COQ and quality cost failures. It is believed that the visualisation of these costs could assist in advancing learning about the prevention of project failure, but this need better clarification. Organisations frequently learn from projects that have been completed (Kerzner, 2009), which needs an interplay of commanding and enabling strategies to integrate project innovations (Pemsel & Wiewora, 2013), which is expected to improve quality in construction projects. This is similar for owners (Winch, 2014) to identify and acquire externally generated knowledge to be able to analyse, process, interpret, understand and act on information needed to support the operational capabilities in mitigating failure. Therefore, poor capture of capabilities leads to enactment that is poorly executed or learning that is forgotten and would be valuable in failure mitigation. Capturing capabilities through experience helps an organisation to make sense of the environment to configure its resources at various levels (Schreyogg & Kliesch- Eberl, 2007) that then facilitate problem-solving decisions under conditions of uncertainty (Dosi et al., 2008).

Hence, capabilities that lie under the dynamic nature of a project need to be combined with the operational capabilities (Davies et al, 2016) to comprehensively respond to the changing nature in providing greater innovation. In addition, there is a need for an innovative approach that develops the roles of the relationship to satisfy the owner's business objective (Lindahl & Ryd, 2007), and provide a stronger role in dealing with operational failure. This innovation should include integration of capabilities that need to be managed and aligned not only to respond to the temporary nature of a project but to be captured, used and improvised by the owners in extending the capabilities (Winch & Leiringer, 2016) to fit the operational needs. This is because a capable owner relies on its resources to deliver the project-based outcomes.

3.8 Chapter summary

This chapter has provided an overview of the elements that constitute complex infrastructure projects. It has shown that capabilities within the PBO have a strong influence on the occurrences of failures. What is of particular significance is the capabilities distributed across the project lifecycle within the PBO that may be adopted by the supply network to mitigate failure and may reduce the quality cost failure. Within the existing literature, little is known about how capabilities impact project outcomes, cost or quality costs. The next chapter considers what methodology might inform a better understanding of the failure-related capabilities that an owner and their multi-organisational supply network requires to ensure operational success.


CHAPTER 1 - Introduction, background, aim and objectives
Aim and Objectives
CHAPTERS 2 and 3 - Literature review and acknowledgement of
Quality management, COQ and failure literature
Project-based, project failure and capability literature
CHAPTER 4 – Methodology
Research philosophy, design and methodology
Phase 1 – Framework development
CHAPTER 5 – COQ framework development and application
Study A - Categorising and defining operational failure quality cost elements
Workshop (n=5)
Steering group discussions (n=6-12)
Study B (i) - Call to action on major project quality failure
Trial survey (n=25)
Study B (ii) - Measuring cost of quality in major construction projects post-handover
Industry-based Questionnaire (n=17)
Study B (iii) - Quantifying quality cost failure in major construction projects post-handover
Project case study
Phase 2 – Developed case study
Study C - Infrastructure client multi-case study
Operational quality issues within single client organisation
CHAPTER 6 – Infrastructure client multi-case study
Study C (i) - Exploring the operational issues sample
Delphi review:
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on specific projects (n=4)
Advance knowledge on potential projects (n=2)
Final cases selection workshop (n=3)
Study C (ii) - Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) – Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) - Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

4 Research design and methodology

4.1 Addressing the complexity of the problem

The complex nature of the construction industry has led to significant problems in quantifying quality cost, with fragmentation of supply networks leading to intractability. As a result, there is a need to apply a grounded and action-based study to investigate the ontological and epistemological knowledge assumptions (Crotty, 1998).

A mixed-method abductive with grounded theory approach was taken to provide flexibility in data collection and theoretical sampling was used to explore the generalisability of the complex construction process (Creswell, 2009). This includes qualitative and quantitative methods.

This chapter presents and discusses the research philosophy, methodologies (design, approach and strategies) and methods (Figure 4.1) used to achieve the research aim and objectives. It provides a brief summary of the overall research methodology and the philosophical underpinning. This is followed by the research process, approach and description of the data collection methods utilised in each research phase further to the emergence of a new theoretical integrated measurement of the cost of quality in the construction supply network. The chapter ends with a reflection on the research reliability and validity, and a mention of the ethical considerations.

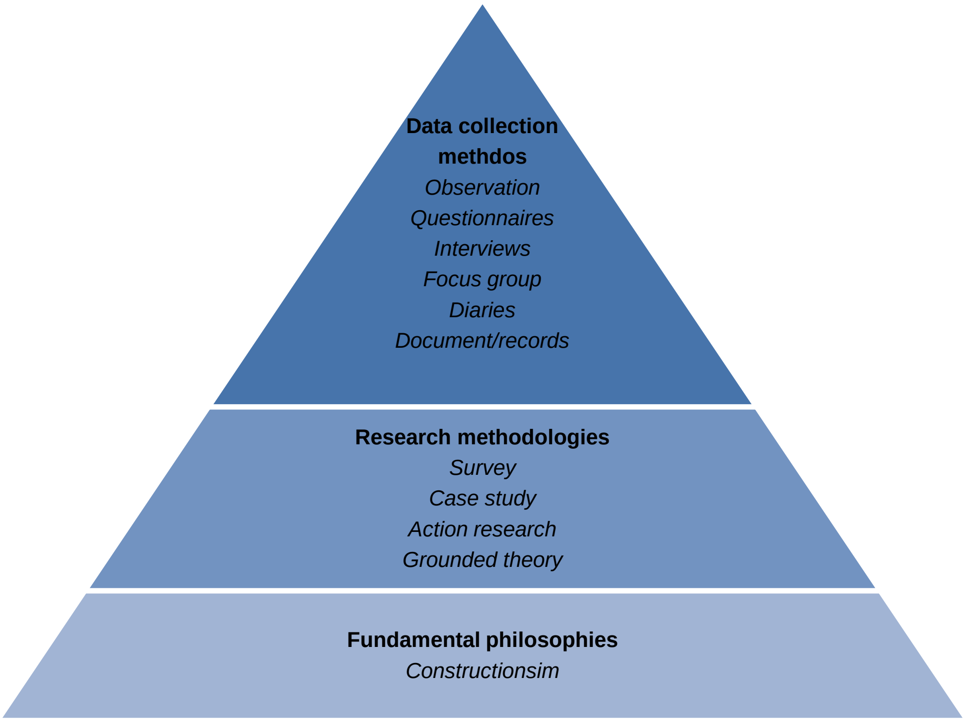


Figure 4.1: The methodological pyramid (Adapted and developed from Quinlan et al., 2015)

4.2 Research philosophy – ontology and epistemology

4.2.1 *Ontological views*

A research philosophy is vital (Holden & Lynch, 2004) for the researcher to develop the nature of knowledge that is of benefit to the research, in turning the data into tangible outcomes. It is the belief that data relating to a particular phenomenon should be gathered, analysed and used. By using an appropriate methodology, researcher will gain both enrichment of skills and enhancement of confidence (Holden & Lynch 2004).

Ontology is a branch of philosophy that focusses on the assumption or theories about the nature of the world and of reality. Ontology describes the basic relationship of entities (i.e. the product, process and people) and asks the question: "*What is the nature of what we know?*" However, it is not possible to describe the ontological reality using static terminology or a paradigm of thought; rather, reality is to be viewed as emergent, dynamic and temporary (Holden & Lynch, 2004). Within this thesis, the relevant ontological questions include:

- *What is the cost of quality?*
- *What is the quality cost elements incurred due to operational failure?*
- *What is the nature of COQ and how is it related to the occurrence of failure?*
- *What are the capabilities for failure mitigation?*

- *What is the influence of the capabilities distributed in the project lifecycle in mitigating failure?*

Consequently, there are many different ontological starting points in how a researcher should acknowledge COQ in developing capabilities for failure mitigation as: (i) there has been relatively little exploration of how it is measured in the construction industry; (ii) or how it is defined in the construction industry; and (iii) there are many difficulties in applying the COQ (Jafari & Rodchua, 2014) in mitigating failures. Literature shows the interrelationship of quality cost and failure, where quality cost is not easy to eradicate without widespread changes in attitudes and norms of behaviour within the owners and multi-organisational supply networks' management. The key to understanding failure in construction is human nature, processes and the outcomes, which involves various interactions of the construction context from initiation to its delivery and operation of an asset. What is needed therefore is an understanding of this interaction to define and asses the cause of failure. This interaction is critical in this thesis to an emergent view of quality cost, as a capability which does not consider its embedded nature within people and their values in shaping the quality process and behaviour is likely to result in an operational failure outcome.

Thus, how the researcher perceives and views the world relies on this early ontological perspective of the subject matter (Saunders et al., 2009), followed by why the specific research approach or method was chosen (Guba & Lincoln, 1994), which is explained later in this chapter.

4.2.2 *Ontological objectivism and constructionism*

As ontology is sought to describe the nature of reality and asks fundamental questions about how the world operates (Fellows & Liu, 2008). It challenges the system of beliefs and interpretations of individuals about what constitutes a fact. In doing so, the social entities that were involved during the construction process were perceived as both objective and subjective (Saunders et al., 2009) and helped to create a universal understanding for both 'realism' or 'relativism' (Easterby-Smith et al., 2012) and to what constitutes failure.

In this study, ontology describes the nature of the construction supply network itself with regard to the concept of COQ in developing capabilities for failure mitigation (the process, organisation and services). COQ elements that fall under the traditional categories of Prevention- Appraisal- Failure were included to raise the operational failure quality cost in understanding what was done during the project process that further developed the integrated capabilities approach for failure mitigation. This helps to elaborate the fundamental nature of the quality costs that exist in the project, and for which it offers a different kind of perspective in mitigating failure for different entities depending on their role, position and background.

What had caused the occurrence of operational failure was explored through a selection of multi-case study appraising the COQ and this provides clearer understanding of capabilities in failure mitigation. How the project organisation was structured (Jospehson, 1998) was questioned to see how this influences the operational failure. The position of where social entities (people and organisations) exist in reality to where the existence of that social entities in the construction project was considered as independent of the social actors (Bryman, 2012). Objectivism says that social phenomena have an existence that is independent or separate from the researcher's mind, and the phenomena of that object are measurable and testable. Therefore, to further see this relationship of these consequences, it was explored through the research process. Data was used to construct meaning and interpret reality (Guba & Lincoln, 1994) and was then concluded to provide a contribution to the existing knowledge of project and quality management.

In contrast, constructionism asserts that social phenomena are created through ongoing social interactions (Bryman, 2008). It shows how culture evolves as the product or service is developed. The nature of social and political perspectives is thus also considered in describing the social entities. An organisation as a tangible object, with rules, regulations and procedures, with different jobs for people under a division of labour with a hierarchy, mission and vision (Bryman, 2012) were considered as the nature of reality. The diversity of project procurement routes was taken into consideration to see how organisational structure and process and divergence of supply network capabilities later impact on project outcomes.

Differing from the relativist positions, the assumed complexity of gaining direct access to the reality encourages multiple perspectives to be adopted (Easterby-Smith et al., 2012) through both triangulation of methods: the surveying of views and experiences of large samples of individuals (Gay et al., 2009). Within this, the difficulty is where to investigate the relationship between an individual's perceptions and actions, and the effect of external factors (Easterby-Smith et al., 2012) that evolve during the occurrence of these quality elements during the project process. With regard to operational failure, this thesis takes the position that within each project there is a universal list of quality cost elements that are used as a starting point for defining, assessing and demonstrating the cause of operational failure. This position is taken to see how each organisation responds to and is responsible for the operational failure quality cost and is later incorporated into the project management-related theories.

4.2.3 *Process epistemology*

While epistemologically helps the researcher to understand the questions of ‘What do you know?’ and ‘How do you know it?’, this research means to appraise the COQ in the construction supply network by understanding the project processes by which information or materials are flows and are channelled in the desired direction as they are handed from team to team (Winch, 2010). Thus, as referred to by Branca and Lopes (2011), ascertaining what level of quality is provided by an organisation is a major challenge. Therefore, this research views and explores where quality stands in between this process to see its relationship to understand how quality carries benefits and costs as well as failures. As such, the meaning of the project process with COQ categories takes an event-driven approach to lead the author to the development of the way(s) (in acquiring and justifying) where the quality cost subsists and how to eliminate operational failure quality cost with an understanding of the ontological behaviour of the entities undertaken in this study.

To explain further, a process epistemology is concerned with how things evolve over time and why (Langley, 1999). The ‘process’ chosen in this study helps the combination of quality issues (‘failure’) to be fully understood through supply network involvement. The process epistemology helps articulate the research design and case study selection as a starting point to appraise the operational failure quality cost. Thus, the information gained counts as acceptable knowledge in the COQ field, affecting its evolution and how it should be acquired and interpreted in the construction supply network management field.

Differing from positivism, epistemology interpretivist ideology requires a strategy in determining differences between people and objects of the natural sciences (Love et al., 2002); thus, it requires an understanding of the subjective meaning of social action (Bryman, 2008). However, it is essential to maintain the understanding that there are differences between the actions of social actors (Fellows and Liu, 2008). This allows a subjectivist view in the way of both reality and truth (Denzin & Lincoln, 2011) of what constitutes quality issues or ‘failure’. The challenge for interpretivist researchers is to adopt an ‘empathetic stance’, which requires them to enter the social world of the research subjects and make sense of what is found (Saunders et al., 2009).

In this research, quality issues or ‘failure’ are the core beginning. Thus, in exploring these quality issues, extensive discussion with each participant is required to achieve agreement on the representation (description) of their truth and reality (Fellows and Liu, 2008). However, the difficulty is the finding of an interpretivist approach which cannot be generalised to a larger group of people as different people may interpret things differently in different social settings (Easterby-Smith et al., 2012) such as in different organisations.

4.2.4 *Epistemological perspective taken in this thesis*

Taking the epistemological subjectivism perspective, this thesis relies on a constructivist grounded theory basis that allows the theory to reshapes the process between the interaction of the participant and the researcher (Mills et al., 2006) and the co-construction of meaning (Hayes & Oppenheim, 1997). It involves both deductive and inductive methods that allow the understanding of what constitutes valid knowledge and how to obtain it. Therefore, it is difficult to pin down or rather clarify in a precise manner to what extent subjectivism was used in exploring the quality cost in this thesis, as it is used in a number of different ways by different authors (Bryman, 2008). In this thesis, quality cost elements were used as a tool to help the participants understand the concepts of what existing knowledge is before it is developed through their knowledge and experience, and thus developing the knowledge of what constitutes operational failure quality cost. Thus, although through the positivism lens the social world is measureable, in the construction industry, the individual’s behaviour, culture and process are believed to be interconnected and need to be understood together with the rigours of observation.

4.2.5 *Constructivist grounded theory*

Research needs to address four elements of epistemology, theoretical perspective, methodology and method (Crotty, 1998). Taking the universal and robust underpinning in understanding the existence of high operational failure quality cost in construction, an abductive with grounded research design was built in accordance to constructivist grounded theory philosophy. It was first proffered by Charmaz (2006) as an alternative to the classic grounded approach of other authors (Strauss & Corbin 1997; Corbin & Strauss 1990; Glaser & Strauss 1967). Bryant and Charmaz (2007) considered neither data nor theories are discovered either as the data or the analysis: it offers an interpretive portrayal of the study not an exact picture of it; while the classic grounded theory introduced by

Glaser and Strauss (1967) talks about discovering theory as emerging from data. For Charmaz (2006), research that is conducted with grounded theory has implicit meaning and experiential views, and thus provides the construction of reality (Charmaz, 2006). Charmaz (2014) explains constructivist grounded theory as:

> *…it takes the middle ground between postmodernism and positivism, and offers accessible methods for taking qualitative research into the 21st century* (p.250).

As grounded theory focuses on data, it allows the possibility for the construction of multiple meanings (Charmaz, 2014) that requires research to go beyond the surface to search for and question more tacit meanings in a subject, and, because constructivists see facts and values as linked, they need to acknowledge what was seen and what was not seen. It creates individuals that interact with and interpret these objects rather than relying on dormant information within objects waiting to be discovered (Crotty, 1998). Constructivism thus challenges the belief that an objective truth can be measured or captured through research inquiry (Crotty, 1998).

In taking this perspective on the nature of reality, researchers needs to immerse themselves in the data (Mills et al., 2006) in a way that embeds the narrative of the participants in the final research outcome and be naturally critical to discover latent patterns of behaviour within the data (Charmaz, 2006). Therefore, in this thesis a careful and critical exploration of constructivist grounded theory is explained in every section of the method undertaken during the research study. This requires the author to combine the different data sets that is collected during the whole research process in making the interpretation towards the final contributions.

4.3 Research approach

4.3.1 *Overview of the research approach*

This section describes the research approach taken in addressing the research aim and objectives. There are three major methods of reasoning: deductive (where theory guides research); inductive (where theory is an outcome of research); and abductive (where theory and knowledge are developed concurrently) (Bryman, 2008; Fellows & Liu, 2008; Creswell, 2009). These research approaches can be used either independently or concurrently and will lead to the decision-making for constructing the research design and data collection method (Easterby-Smith et al., 2012) as well as better consideration of research strategies (Fellows & Liu, 2008); greater understanding of the research questions is thus embodied. The main characteristics and differences of deductive, inductive and abductive forms of reasoning are discussed in the following sub-sections followed by the selection of the research approach undertaken in this thesis.

4.3.2 *Deductive, inductive and abductive approaches*

The deductive mode moves from a general statement towards a specific one, informally called a 'top-down' approach (Fellows & Liu, 2008). It starts with the general theory or known fact (drawn from the literature) towards making a specific hypothesis related to that theory or fact (Figure 4.2). However, the deductive mode involves intuitive aspects in testing the prediction, where its inference strongly depends on the initial step of generating hypotheses from general theories (Love et al., 2002).

Deductive reasoning is where *''laws present as the basis of explanation, allow the anticipation of phenomena, predict their occurrence and therefore permit them to be controlled''* (Saunders et al., 2009, p.124). This shows science is seen to be proceeded by trial and error (Fellows & Liu, 2008) but within the boundaries of existing knowledge (Love et al., 2002). Mainly, a deductive mode employs quantitative research strategies and empirical observation to validate or reject the generated theory or to modify it through replication in the study (Bryman, 2012; Creswell, 2009). Figure 4.2 below shows both deductive and inductive approaches in illustrating the research process.

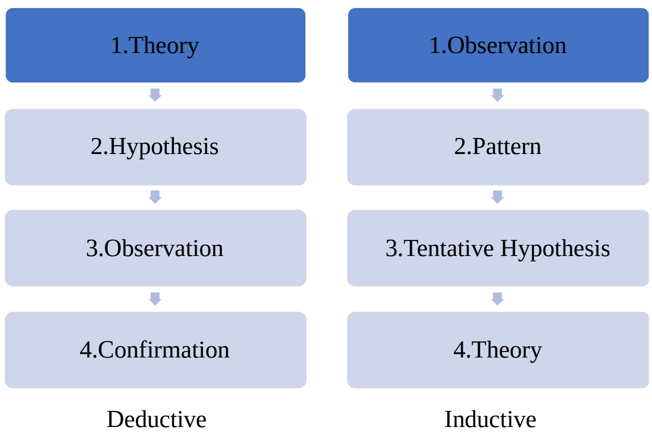


Figure 4.2: The deductive and inductive research processes (Source: Author's own)

With the inductive form of reasoning, the researcher moves from specific observation to broader generalisations and theories, informally called a 'bottom-up' approach (Fellows & Liu, 2008) see Figure 4.2. Inductively, theory is developed or generated as the outcome of data analysis (Saunders et al., 2009). Data collection is obtained through specific observation of certain social phenomena and either interviews or pilot studies are then analysed to generate new theory or develop a conceptual framework (Bryman, 2012). It involves clear selection of data (Love et al., 2002) to ensure its applicability in achieving a robust conclusion.

Theories that are developed inductively move towards discovery of a binding principle, hence it is more likely that these theories will be useful, plausible and accessible (Partington, 2000). Inductively, they attempt to extract implicit knowledge, patterns and meanings through a process of data collection and analysis (Gray, 2004). In the main, the inductive mode applies to qualitative studies rather than quantitative ones. Differing from deductive reasoning, the inductive mode needs a relatively small sample of research subjects (Saunders et al., 2009) as it deals with issues and events that have already taken place (Love et al., 2002). This form of reasoning thus provides a better understanding of the meanings of participants' actions and behaviours (Creswell, 2009), avoids misunderstanding in different theoretical perspective (Hyde, 2000), and offers a low risk that the data will not be useful when the researcher is confident about the sample selected (Saunders et al., 2009).

Most researchers assume there is a rigid division between both types of reasoning (Saunders et al., 2009); thus, they are used independently. However, an integrated combination somehow provides increased advantage (Miles and Huberman, 1994). It is explained as a 'theory-forming or interpretive inference' that is more profound than inductive or deductive approaches (Saunders et al., 2009) and which leads to deeper understanding of the data (Sandelowski, 2000). It is also referred to as the process of studying facts and devising a theory (Peirce, 1995; Cunningham, 1998) in providing an explanation for observed facts. This process is therefore an essential concept within pragmatism (Richardson & Kramer, 2006). It was originally meant to capture the nature of scientific progress as in finding new explanations for phenomena (Peirce, 1995). As explained by Saunders et al. (2009), abduction starts with a real-life observation (through literature), followed by explaining patterns, discovering themes and examining phenomena, and finally producing or changing a theory. This approach moves back and forth between both deductive and inductive approaches (Figure 4.3) to integrate them and to gain more theoretical insight through the use of both approaches.

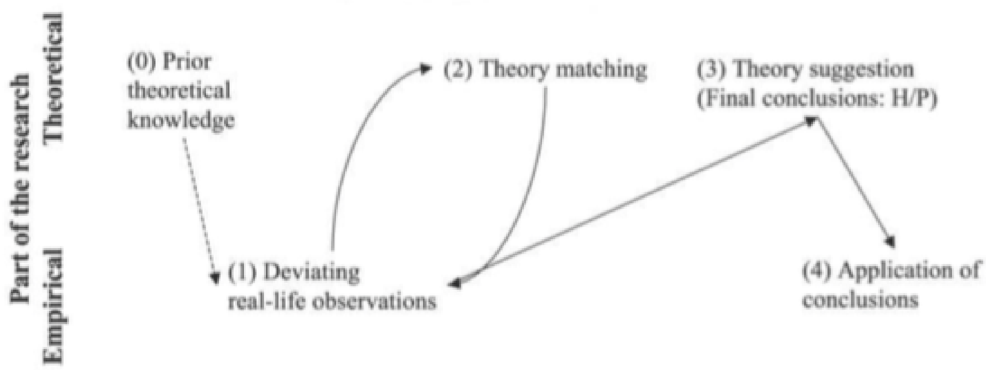


Figure 4.3: The abductive research process (Source: Kovács & Spens, 2005)

4.3.3 *Research approach taken in this thesis*

This study uses an abductive approach to continually appraise and refine the COQ failure elements within the construction supply network to understand and develop strategic project and quality management approach to failure mitigation. This form of reasoning allows an iterative, pragmatic and dynamic approach in dealing with research data sampling (Creswell, 2009). This study uses a mixed-method research design to understand the occurrence of operational failure within the multi-organisational network of complex construction projects. At the initial phase, in order to understand the current status of operational failure and its quality cost in the construction industry, a deductive approach was used to investigate the perceptions of construction stakeholders and the influences of the supply network based on a few hypotheses of the need to clarify COQ (Jafari & Rodchua, 2014; Tye et al., 2011) in developing the capabilities for a failure mitigation approach:

1. The dynamic nature of the construction project that involves numerous parties, non-standardisation and the uncertain nature of the bidding process (Honnakkera et al., 2010), which has created inconsistency and misconception.
2. Lack of an appropriate system and incorrect methods of collecting quality cost categories.
3. Lack of support from the senior leadership team (improper management) such as in the accounting and finance departments; thus, managers and employees are deficient in their knowledge of COQ and capabilities in failure mitigation.
4. There is inconsistency among the various plans and ineffective process standards that lead to a lack of clear instruction and inadequate information for proper design and implementation.

The inductive approach was then used to obtain a more generic picture of the status and to appraise how and who compensates for operational failure quality cost throughout the project supply network, as the inductive mode explains ‘why’ and ‘how’ rather than describing ‘what’ (Creswell, 2009). The existence of operational failure quality costs is known to be intangible within the construction supply network (Taggart, 2014), and yet failure costs are still highly recurrent in construction projects (Snieska et al., 2013). This required a spiral (constantly going back and forth) flow (Figure 4.3) by the author to move from deductive to inductive mode to allow the best explanation of the hypothesis or theory developed (Josephson & Josephson, 1996), as it captures advantages and systemic character of data both empirically and theoretically (Saunders et al., 2009) in further clarifying and understanding the operational failure and its quality cost.

Thus, the abduction approach is seen as an appropriate method in making sense of new (or unknown) situations (Richardson & Kramer, 2006) to obtain better insight into a situation. Furthermore, as an integration of induction and deduction approaches, the abductive reasoning used in this research allowed the researcher to creatively break out of limitations to obtain and compile more data before the theory was developed at the end of this thesis. The result of this provides clearer framework of COQ elements that suits the construction scopes, which is then to subsequently develop further understanding on operational failures. There is also considerable discussion on how the abductive approach allows more explanation and investigation to be conducted around the research area of cost of quality and how it links to the construction project supply network, thus providing deeper understanding in achieving the research aim.

4.4 Research process

4.4.1 *The research methodology*

This section details the research methodology used in achieving the research aim and objectives. The methodological framework was developed as emerging from a conceptual framework (Quinlan et al., 2015). The research process was divided into three phases (Figure 4.4). The first phase was a framework development phase which attempted to identify the link between the COQ and capabilities for failure mitigation literature, the position in the industry participants’ view and the research gap. The second phase was a developed case study phase, which detailed a sample of multi-case study in confirming the status of operational failure quality cost within construction company participants and then further examined the causes of operational failure. This included refining the understanding of COQ and capabilities for failure mitigation in its integration with project and quality management to mitigate failure through a series of workshops with Delphi experts. Finally, the third phase provides a discussion of the findings and evaluation of theory development.

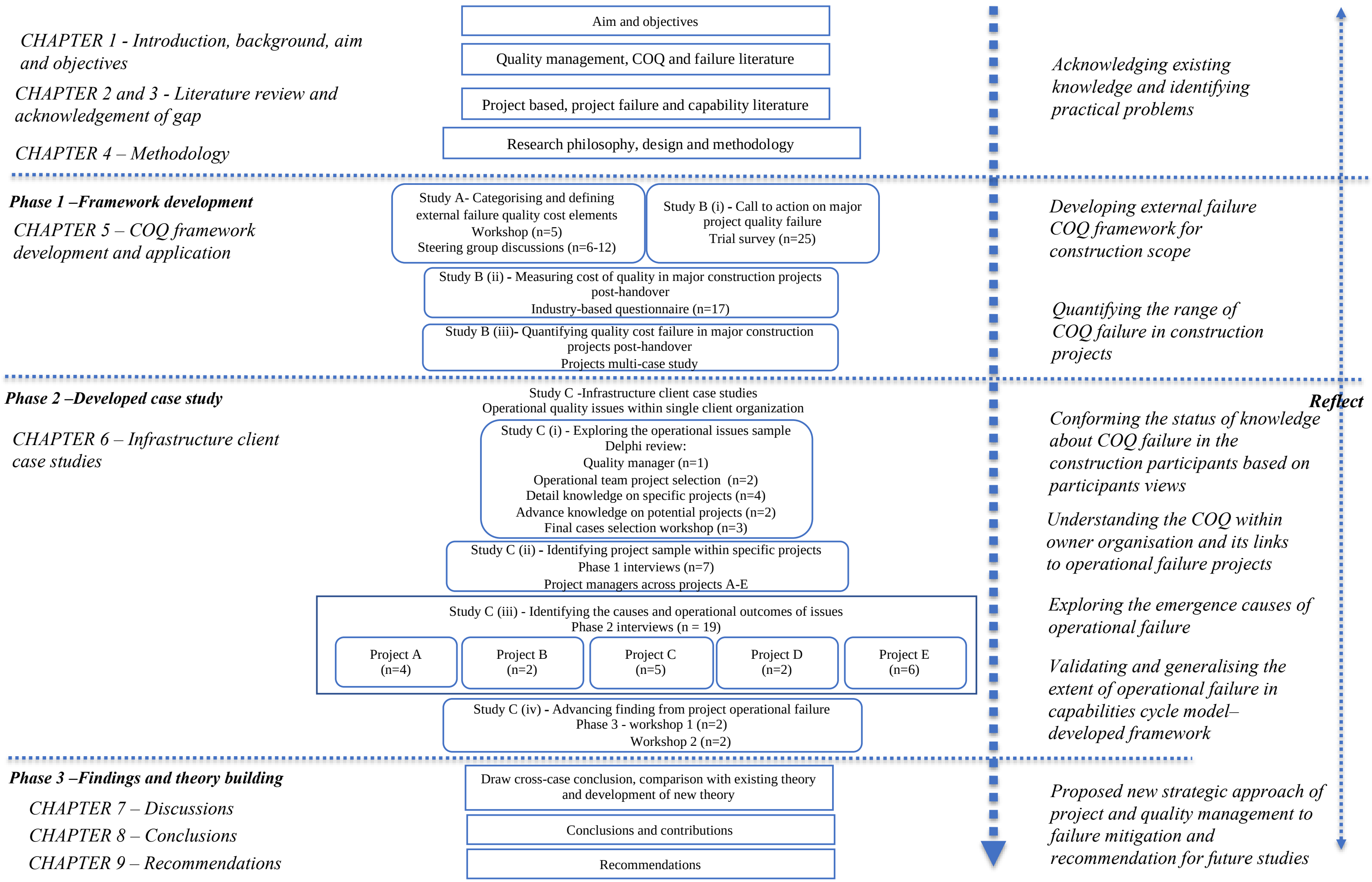


Figure 4.4: Methodological framework (Source: Author’s own)

The research was designed and supported by the Chartered Quality Institute (CQI ConSIG group) with the aim of understanding Cost of Quality in the UK construction industry to reduce the operational quality costs. A case study protocol was used in generating data to help ensure reliability (Yin, 2003) with the use of an abductive mixed-method grounded theory approach. It provides greater benefits to best deal with construction complexity and considers human factors and social context (Quinlan et al., 2015) to further explore COQ and elaborate on the empirical application within an overarching view of the complex inter-organisational network. The case study research method included a workshop, surveys, interviews and various data analysis methods, in which the author worked closely with one of the experts who has great involvement in the owner organisation and the project environment. An expert Delphi review has been used in selecting all samples for both survey and interviews.

4.4.2 Phase 1 – Framework development

The initial concept guiding the research process was the cost of quality in the construction industry focusing on operational failure quality cost and, secondly, on the area of the construction supply network examining collaborative working with practical practices. As a starting point, this phase involved a critical review in these two fields with a combination of literature review, steering group discussions, workshop and trial questionnaire conducted by the author with the Chartered Quality Institute (CQI ConSIG group) to develop the new COQ framework that links quality cost to the organisation system and knowledge. This literature and the steering group discussions have demonstrated the initial model of COQ presented in Chapter 5 and informed how this may be perceived by the construction industry. In appraising the operational failure and its quality cost, the COQ model developed has been used in validating the operational failure quality cost elements. Thirteen operational failure quality cost elements have been identified, used and tested throughout the study (Figure 4.5). During this phase, quality elements in the model were used to categorise the operational failure and its quality cost in extracting data. The model was further defined and categorised in each study stage.

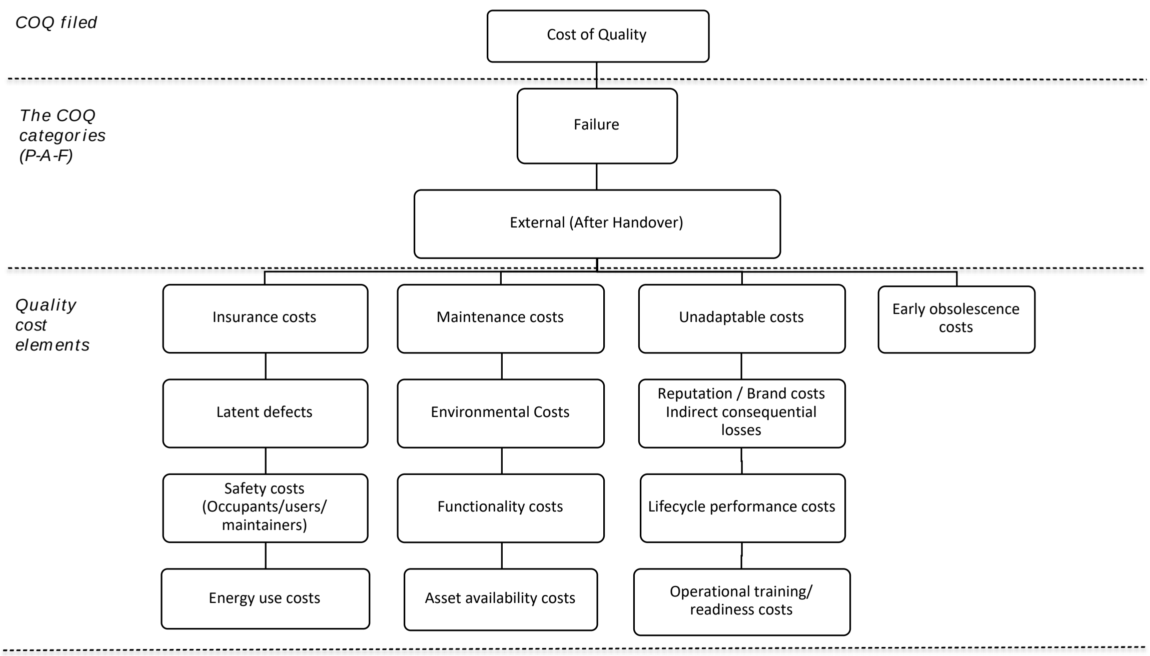


Figure 4.5: The COQ field and classification of quality cost elements (Sources: Author's own)

In this phase, Study A consisted of a workshop conducted with CQI group members (n=5). A card-sorting methodology (Jahrami, 2012) was used to classify the quality cost elements (e.g. to show dependence and interrelatedness). Participants were first asked to indicate (through sorting) which organisation positions accrued costs related to each operational failure quality cost element (based on their experience), then think about how groups could be categorised. Different categorisations were then discussed and notes were taken.

Study B (i) involved a web-based survey that investigated the respondents' experience of operational failure and its quality cost and their perceptions on COQ, and was used to gain an understanding of various owner and supplier influences on operational failure quality cost. The survey was distributed to a selected sample within the industry-based experts. Data was collected from 25 respondents – advisors (n=2), suppliers (n=4) main contractors (n=9) and owners (n=10) – in the UK construction industry who mainly had responsibility for multiple assets (rather than a single one-off project), and the value of these assets ranged from £400m to £5billion per annum.

Study B (ii) included a second questionnaire which was then sent to 17 quality managers selected from amongst the industry-based experts, both owners (n=10) and their supply and operator network (n=7), who had experience with operational failure to test and validate the constructed elements. This pilot study is to show the various categorisations of operational failure quality cost elements and explore the complex nature of the measurement of operational failure quality cost through the construction supply and operator network. The perception and influence of construction participants in relation to operational failure and its quality cost elements were analysed.

4.4.3 Phase 2 – Developed case study

Following on from the first phase, samples were characterised and re-defined within the wider industry context for comparison with the responses from the case study. A range of construction industry stakeholders and experts were selected and classified according to a supply and operator network framework to suit the interviews.

In the second phase, this research involved one of the most well-known, intelligent owner in the UK infrastructure sector to look at how complex product system capabilities are managed in capturing and reducing operational failure quality cost. During this phase, the research methodology process was summarised into three phases: first to understand and appraise the operational failure quality elements; second to explore the causes of operational failure within specific projects; and lastly to develop a strategic project and quality management approach to integrated capabilities in failure mitigation (Figure 4.6).

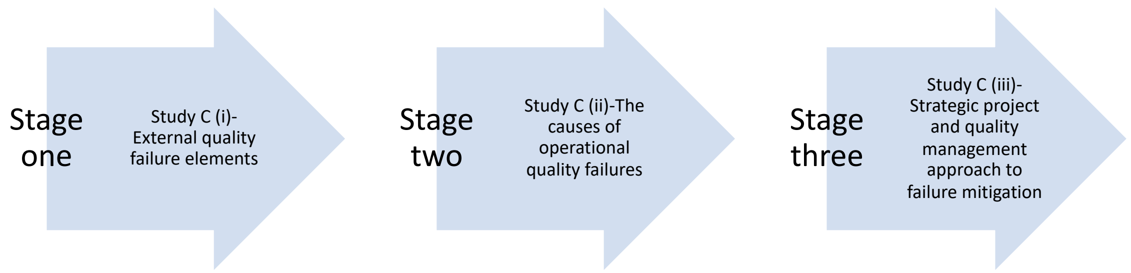


Figure 4.6: The study C methodology process (Sources: Author’s own)

The sample population ranged from operations and asset managers, owner quality directors and managers, contractors and consultant project/commercial managers, to designers and technical staff/specialists. Infrastructure owner multi-case study were conducted with three sessions of Delphi review (n=9) to select the most appropriate projects with operational failure, final selection of projects with operational failure workshop (n=3), stage two interviews (n=7) in identifying the project sample within the specific projects and, during the third stage, semi-structured interviews with the project supply and operator network (n=19). The Delphi reviewed selection helped to identify five projects that had costs incurred within all operational failure quality cost elements and seven project managers from each project were interviewed to understand the operational quality issues and costs incurred as a result of the operational issues. During the second stage interviews, using the card-sorting method, interviewees were asked to select the cost elements which they believed to be incurred in each specific case, the estimated cost of those selected elements and others who were involved with the operational issues. This was to see how the project context and structure influenced operational delivery and quality, and finally to understand the cause of operational quality issues (failures). This method was then repeated with the interviewees during the third stage of interviews.

A retrospective perspective was abstracted from all five of the projects in the multi-case study in appraising the nature of COQ in the construction industry and thus provide insight into the project-specific complexity of the supply and operator network in relation to failure elements (in building an in-depth qualitative examination) to develop the strategic project and quality management approach for integrated capabilities for failure mitigation. The first stage of interviews led to a snowball sampling to find additional expert project participants. The occurrence of quality issues (operational failure and its quality cost elements) was explored during the initial stage of interviews to gain understanding of the characteristics and the relationships with quality cost elements. Thus, the author used unstructured observation and note-taking activities during the semi-structured interviews with a cross-section of project participants to gain understanding and opinions (Fellows & Liu, 2008). All activities, including informal conversations, were summarised and recorded in field notes and a research diary.

The multi-case study thus provided relevant information on the development of capabilities for failure mitigation theory relating to the existence of quality issue, quality cost, capabilities in project and operations, and their relevance to the construction collaborators. This was gathered on the basis of the author’s assumption, with rich information gained through the expert consultations (Gay et al., 2009). With consideration of the viability of the case, earlier informal interviews showed strong willingness, experience and knowledge of the cost of quality phenomenon, which supports their full understanding and commitment during the multi-case study. Qualitative research multi-case study offer a useful means of answering ‘how’ and ‘why’ questions (Gay et al., 2009) that require systematic arrangement. Therefore, following Yin (2003) during this phase, the definition of the key elements and the selection of cases together with clear units of analysis was justified. However, the concept and content including level of analysis emerged during the justification of findings phase.

4.4.4 Phase 3 – Findings

In the third phase, the author conducted rigorous multi-case study and collected data to answer the how, what and why questions. This study was built on multi-case study (Gill & Johnson, 2002) relating to projects with different characteristics. In research, the majority of multi-case study rely on confidentiality to persuade participants to disclose information (Gill & Johnson, 2002). During this phase, a reflection on the whole data collection was thought to contribute to the practical concerns within the organisation (Taggart, 2014) in terms of how learning from quality issues can further integrate project and quality management to improve collaboration, thus mitigating operational failures.

Phase 3 involved two workshops (n=4) which each lasted between two and three, in validating and generalising the overall findings from phases one and two. The expert was used to help in generalising the findings into the broader project context. Steering group discussion was also used throughout the whole research process in advancing, confirming and generalising the data gathered within all phases of study. This provided the opportunity for the author to compare and advance the findings to provide greater clarification to elicit further project context or situation-specific details in defining the new, emergent empirical data.

Data analysis was carried out to synthesise the substantial amount of diverse qualitative data produced. A flexible design approach was selected to manage the data. The author rigorously examined both the qualitative and quantitative data in adherence to the grounded theory. The method involved ‘assessment from experiences’ and ‘the use of calculations’ (Olawale & Sun, 2015). In analysing multi-case study, a cross-site analysis was used (Gay et al., 2009) to provide interpretations on the data and to make comparison of arguments (Stake, 2006). The quantitative medium of the case study was to strengthen the breadth of the data and analysis in addressing the research questions on the investigation of COQ, as an advanced project and quality management approach to develop integrated capabilities in failure mitigation and to make a contribution to knowledge.

4.5 Research Design

4.5.1 *The selection of the research design*

Research design allows framework development (Bryman, 2012) to provide guidance about all facets of the study (Creswell, 2009), beginning with philosophical ideas towards the data collection and analysis procedures. Mainly, research design is the decision-making about the data required (Naoum, 2013), to suit the data selection technique and the decision about the data analysis method. This research was influenced by many factors, including the context of quality cost, quality management, supply network practicality and its management with philosophical perspectives to design the research method and data collection. Usually in social qualitative research, quantitative and mixed-methods are the command methods used (Creswell, 2009). The following table provides a summary of the quantitative, qualitative and mixed-methods before they are further elaborated.

Table 4.1: Quantitative, qualitative and mixed-method procedures

Quantitative Method	**Qualitative Method**	**Mixed-Method**
Pre-determined	Emergent method	Both pre-determined and emergent methods
Instrument-based questions	Open-ended questions	Both open- and closed-ended questions
Performance data, attitude data, observational data and census data	Interview data, observation data, document data and audio-visual data	Multiple forms of data drawing on all possibilities
Statistical analysis	Themes, patterns interpretation	Across-database interpretation

Source: Creswell (2009, p.17)

4.5.2 *Quantitative and qualitative*

Quantitative methods are often used when the information is not abstract, hard and reliable (Naoum, 2013). This includes uses of post-positivist claims (Creswell, 2009) in understanding the application of COQ in construction. Quantitative research thus typically undertakes an objective approach to focus on measurement of quantity, the analysis of numerical data and the causal relationships between variables (Creswell, 2009). In this research, a questionnaire was used to quantify the perceptions of industry participants in relation to each operational failure quality cost element. A deductive mode was used to develop and validate the questionnaire with initial hypotheses concerning why COQ was ignored and difficult to apply in the construction industry, and helped to clarify the relationships amongst all operational failure quality cost elements. Yin (2009) stated that the findings from a quantitative study are easily understood and presented.

Quantitative research is thus defined by Kerlinger (1977) cited in (Rowell, 1997 p.125) as:

> *…the theory and method of analysing quantitative and obtained from samples of observations in order to study and compare sources of variance of phenomena.*

In contrast, qualitative research is said to be 'subjective' in nature (Naoum, 2013) and focuses on the qualities of entities as well as the meanings and interpretations of words (Denzin & Lincoln, 2011). It can be classified into two areas (Creswell, 2009), which are exploratory and attitudinal research. Exploratory is used when knowledge is limited while attitudinal is used subjectively in evaluating a person's opinion, view or perceptions of a particular object (Naoum, 2013). In qualitative research methods, the initial process focuses on exploring and collecting data through various techniques (interviews, case studies and ethnography) followed by analyses of data inductively and so towards a holistic understanding of the subject (Fellows & Liu, 2008). Thus, the placement of the theory can be at the end of the research process as it emerges during the data collection and analysis process (Rowell, 1997).

Qualitative data is said to be attractive (Miles & Huberman, 1994); it provides well-grounded, rich descriptions and explanations of processes in a local context. Thus, researchers are allowed to preserve chronological flow, assess local causality and derive fruitful explanations. To simplify, qualitative research is defined in (Strauss & Corbin, 1998, p.11) as:

> *… Nonmathematical process of interpretation carried out for the purpose of discovering concept and relationship in raw and the organizing these into a theoretical explanatory scheme.*

4.5.3 *Mixed-method design*

A mixed-method design is a combination of both quantitative and qualitative approaches (Creswell, 2009). It is best used to generalise the findings into a population for the development of a detailed view of a phenomenon or concept for individuals. The study usually begins with a broad survey to generalise the results (to a population and determine the focus), and then, in the second phases, detailed qualitative, open-ended interviews will be used to collect detailed views from participants (Creswell, 2009). Gay et al. (2009) state that this approach is used not to replace either of the two approaches but rather so that they can complement each other, by drawing from strengths and minimising the weaknesses of each single research study. A mixed-method was used to contextualise the relationship between the two; thus, at the exploratory stage it was used to first establish a number of propositions which were later tested in the quantitative stage (Naoum, 2013) of the multi-case study. This has been seen as exploratory (Plano Clark & Creswell, 2008) or, on the other hand, the researcher may use a parallel study design, which is both qualitative and quantitative and is carried out concurrently (Creswell, 2009).

The use of mixed-methods in construction research is currently gaining in popularity (Creswell, 2009) and has proven to improve validity and reliability of the research outcomes (Zou et al., 2014). It is further explained in Zou et al. (2014) but is subject to criticism, in which critics argue that this method carries different epistemological commitments and may not be merged. Some have also suggested that both quantitative and qualitative methods are not rooted in separate paradigms and thus should be used separately. If the findings are contradictory, it may also lead to confusion (Dainty, 2008), yet Creswell et al. (2008) suggested that collecting additional data or reanalysing the original data may be useful to achieve satisfactory results. Thus, the researcher can gain benefits from both techniques, instead of being restricted by the use of a single one (Plano Clark & Creswell, 2008; Bryman, 2012).

4.5.4 *The selected research design*

In this research, a mixed-method was used combining both qualitative and quantitative methods to understand the COQ approach in relation to construction projects and thus to appraise the existence of operational failures. This has further helped the development of a strategic project and quality management approach for the owner and multi-organisational supply and operator network to mitigate the occurrences of failure. As noted in Zou et al. (2014), greater use of mixed-methods provides benefits particularly as it is oriented towards human factors and the social context of management within the construction sector. To explain the complexity of the construction industry dealings with COQ and the capabilities to mitigate failures, a mixed-method approach helped establish the research aim in understanding the interrelationship of the construction supply network with the existence of operational failure quality cost. The research objectives are then to be further elaborated in an empirical application within an overarching framework of current quality and project management, thus allowing more comprehensive data to be obtained through two approaches.

However, the use of qualitative and quantitative arms can also be applied either sequentially or concurrently (Griensven et al., 2014). In this study, an exploratory method was first used to deal with various elements in COQ to understand the status and nature of operational failure quality cost within complex projects. The quantitative approach quantified the perceptions of construction participants towards the operational failure quality elements within the quality cost area. The use of this quantitative concept helped to reinforce the later qualitative research (Creswell, 2009) in further investigating the root cause behind operational failure and its quality issues, and thus led to the development of new integrated and collaborative management of capabilities in mitigating failures. Therefore, the aim of Phase 2 of the qualitative research was thus used to understand, represent and explain where and who is responsible for the operational failure quality cost in responding to the main research aim and objectives.

4.6 Research methodology

4.6.1 *Overview of the research methodology*

There are many different methodologies in social research (Quinlan et al., 2015), as per Table 4.2. The methodologies are used to show how the research was conducted and what philosophical assumptions underpin the research. The research strategies selected in this thesis are survey, case study and grounded theory, which are explained in the following sub-sections.

Table 4.2: List of research methodologies

Survey	Life history
Case Study	Phenomenology
Experiment design	Narrative analysis
Ethnography	Semiotics
Action research	Attitude research
Grounded theory	Image-based research
Content analysis	Archival analysis
Discourse analysis	Textual analysis
Documentary analysis	Meta-analysis
Historical analysis	Feminist research

Source: Quinlan et al. (2015, p.145)

4.6.2 *Survey*

Surveys tend to be either quantitative research projects or largely quantitative research projects that are quantitative with some qualitative elements (Quinlan et al., 2015). Quantitative research that includes qualitative elements gives additional information that needs interpretation of meanings and explanations from words and images to develop an understanding of social constructs (Ahmed et al., 2016). Largely quantitative research depends on measurement with numbers and analysis with statistical procedures (Quinlan et al., 2015). This strategy uses exploratory and descriptive research with a deductive method (Plano Clark & Creswell, 2008). As mentioned earlier, this thesis used a survey in combination with quantitative and qualitative questions at the beginning of the research to achieve the initial objectives in the exploratory stage to help ascertain the COQ and the capabilities for failure mitigation approach in construction quality and projects.

However, in conducting a survey, there are two major errors, random sampling and systematic error (Quinlan et al., 2015), that need to be considered during the research design stage. The questionnaire used probability sampling that was established through the members of the steering group (CQI ConSIG group) to permit statistical inferences for the subsequent phases. The questionnaire was discussed with the experts from the steering group to ensure clarity of the questions and gain information about any deficiencies and suggestions for improvement (Gay et al., 2009). As explained in Quinlan et al. (2015), random problematic sampling could lead to statistical error by chance variation in the sample selected. Thus, probability sampling is oriented to the development of idiographic knowledge, as a generalisation from samples to populations (Sandelowski, 2000). In this way, the use of quantitative data was to measure quality elements' perspective descriptively around the construction supply network and consequently to validate COQ within the existing literature.

Accordingly, in order to answer the research questions (who, what, why, how and where?), it is important that the content and structure of what is being measured is being considered. Qualitative research is thus best used with the aim of understanding the population's emotion, as attitudes and perceptions exist within the knowledge that is measured. Initially, a questionnaire and interview survey was used to understand the divergence of COQ knowledge and help to develop and clarify the sample, thus narrowing the subject. A follow-up questionnaire was then used specifically with quality managers in industry and with the case study specifically to provide robust insight into the status of operational failure quality cost.

4.6.3 *Case study*

This methodology is an extensive examination that is conducted in a single or few instances of a phenomenon within a real-life context (Yin, 2009). Case study research can be located in a bounded entity, specific space or place, or in a particular incident (Quilan et al., 2015). Moreover, it is used to generate in-depth understanding of a situation, relationship, experiences or processes, and other sets of issues occurring in an organisational setting (Yin, 2009). The use of a case study will draw on qualitative or quantitative data, or on a mixture of both (Gay et al., 2009). The strength of using a case study is that the author will be able to use various techniques in collecting data, such as documentation, interviews, direct observation, archival records and questionnaires (Saunders et al., 2009) to generate more empirical data.

This thesis used a case study as explanatory (when real-life is too complex for a survey or experimental strategies), exploratory (those situations in which the intervention being evaluated has no clear, single set of outcomes) and descriptive (to describe an intervention or phenomenon and the real-life context in which it occurred) work to investigate the problems. Based on Figure 4.7, a case study can be conducted either in simple single-case (holistic) design, single case (embedded) design, multiple-case study (holistic) design or multiple-case (embedded) design.

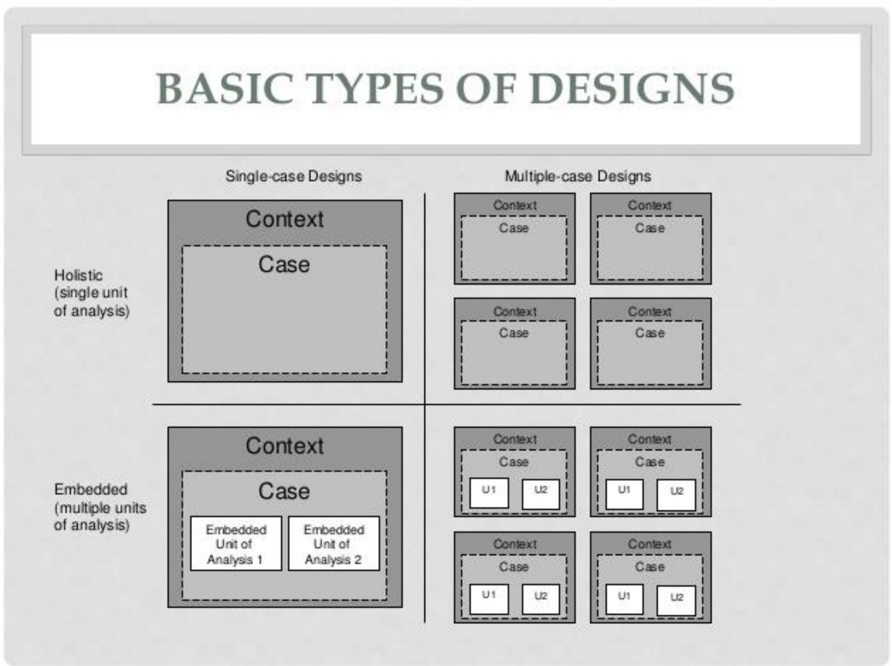


Figure 4.7: Basic types of case study design (Source: Yin, 2003)

This study adopted a single case organisation with multiple projects for the multi-case study. The study provides cases from a UK infrastructure single-owner organisation, and comprises buildings, a water treatment plant and a runway project within the airport construction industry. Multi-case study was selected based on a number of reasons, with one most important element being the ease of access. As one of the major owners in the UK construction industry, this organisation provides a significant sample of operational failures involving a multi-tier network organisation with the supply and operator network and complex processes for the operational programmes. Engagement with this will thus better illuminate the existence of operational failure and provide sufficient articulation across the project process including execution.

Once the case had been determined, it was important to consider the additional components such as the application of the conceptual framework (Miles & Huberman, 1994); development of research questions ('how' and 'why'); logic linking data to propositions; and the criteria for interpreting findings (Yin, 2003) that will lead to the obtainment of explanations for the complexities of real-life situations (Miles & Huberman, 1994). Although the projects are operated within the same organisation structure, different failures occurred. The failures occurred with different contexts that involved massive cost, systems and people. Thus, multiple cases provide a stronger effect (Yin, 2003), yet each case must be carefully selected. This methodology and the case study characteristics are further described in Chapter 6.

4.6.4 *Grounded theory*

Grounded theory is used when the specific research aim is to build a theory from the emergence of data (Quinlan et al., 2015). As a main methodology for this research, this thesis began with an inductive approach (when little is known about the research phenomenon) to appraise the COQ during construction post-handover, which is also known as operational failure quality cost. Although the COQ field has long been introduced in the construction industry, the high occurrence of failure raises the important questions of *why*, *how* and *what* contributes the most to its existence. Generally, grounded theory focuses on social processes or actions (Sbaraini et al., 2011); it asks about *what happens* and *how people interact*. The research aimed to understand why failures mainly occurred post-handover, considering the unique and complex construction projects; the research thus explored what had happened and how the construction supply network responded to the failure. The research later developed a strategic project and quality management approach to failure mitigation to understand how different capabilities were distributed in different phases of a project lifecycle.

In grounded theory, the literature review is either short or absent. A short literature review may be acceptable as little is known about the phenomenon under investigation (Quinlan et al., 2015), yet sometimes it is difficult for the researcher to find a relevant literature review in the specific area (Charmaz, 2014). Studying the literature review gives researchers preconceived ideas about what is to be found in the data. In this thesis, a narrow literature review of the COQ was conducted, followed by a focus on failure specifying operational failure quality cost, which was then further explored within the multi-case study investigation to develop the strategic approach of integrated capabilities for failure mitigating. This allowed theory to be generated from data and thus led to the concluding chapter that is theoretically rich.

Creswell (2009, p.14) declared that grounded theory helps a researcher to *"derive a general, abstract theory of a process, action, or interaction grounded in the view of participants*". There is also a strong relationship between data collection, analysis and eventual theory (Strauss and Corbin, 1998). In this strategy, there are two central features: development of theory out of data and an iterative approach (repeated back to data and engaged with the process of continuous meaning-making and progressive focusing inherent to analysis processes). Grounded theory was developed by Barney Glaser and Anselm Strauss (1967), who later split on their understanding of the methodology. Glaser and Strauss sees grounded theory as quantitative and qualitative or a mixture of both, while Strauss and Corbin (1997) only presented qualitative as the methodology within the research strategy. Despite these two variants, Kathy Charmaz later introduced 'Constructivist Grounded Theory' and argued that: "*neither data nor theories are discovered either as given in the data or the analysis"* (Charmaz, 2014, p. 17). In other words, to make grounded theorising visible and to keep it flexible and heuristic, abductive inference is accepted as the means of grounded theory (Coffey & Atkinson 1996; Kelle 1995).

The application of abduction in grounded theory is that it helps:

> *…to explain new and surprising empirical data through the elaboration, modification, or combination of pre-existing concepts. Within this context, the theoretical knowledge and pre-conceptions of the researcher must not be omitted*. (Kelle, 1995, p.34).

Referring to Charmaz's (2006) principle, the concept provides a place to begin rather than ending the research; thus, it is not necessary to have hypotheses early in the process. With this concept, abductive iterative-grounded theory was adopted to allow more flexibility within the hypothetically deductive research, theoretical knowledge and pre-conceptions of high recurrence of operational failure quality cost within the construction supply network. This thus serves as a heuristic tool for the construction of concepts which then can be elaborated and modified on the basis of empirical data (Kelle, 1995). This includes understanding *how* to reduce the existence of operational failure quality cost, *where* the cost lies, and *who* is associated with the costs, which leads to a more pragmatic approach in deriving measure and metrics and applying them in a specific setting to evaluate to what extent the quality cost can be measured and reduced if the occurrences are to be universally understood.

The complexity in the construction supply network project ascribed to non-standardisation of the quality cost definition, system and its quantification is understood to be related to the uniqueness of each construction project. Thus, the research problem can only be understood with an investigation into the social process that allows the development of theory within the study of the phenomenon itself. Table 4.3 below lists the fundamental components of a grounded theory study and how these components may appear in different combinations in different studies, and these components were mostly adopted in this thesis.

Table 4.3: Fundamental components of a grounded theory study (Source: Sbaraini et al., 2011, p.3)

Components	Stage	Description	Sources
Openness	Throughout the study	Grounded theory methodology emphasises inductive analysis. Deduction is the usual form of analytic thinking in medical research. Deduction moves from the general to the particular: it begins with pre-existing hypotheses or theories, and collects data to test those theories. In contrast, induction moves from the particular to the general: it develops new theories or hypotheses from many observations. Grounded theory particularly emphasises induction. This means that grounded theory studies tend to take a very open approach to the process being studied. The emphasis of a grounded theory study may evolve as it becomes apparent to the researchers what is important to the study participants.	Bryant & Charmaz (2007, pp.1-3, 15,16,43-46); Glaser & Strauss, (1967, pp. 2-6); Charmaz (2006, pp. 4-21)

Analysing immediately	Analysis and data collection	In a grounded theory study, the researchers do not wait until the data is collected before commencing analysis; rather, analysis must commence as soon as possible, and continue in parallel with data collection, to allow theoretical sampling (see below).	Bryant & Charmaz (2007, pp.12,13, 301); Glaser & Strauss (1967, pp.102); Charmaz (2006, pp. 20)
Coding and comparing	Analysis	Data analysis relies on coding – a process of breaking data down into much smaller components and labelling those components – and comparing – comparing data with data, case with case, event with event, code with code – to understand and explain variation in the data. Codes are eventually combined and related to one another – at this stage they are more abstract, and are referred to as categories or concepts.	Bryant & Charmaz (2007, pp. 80,81 265-289); Glaser & Strauss, (1967, pp.101-115); Charmaz, (2006, pp.42-7)
Memo-writing (sometimes also drawing diagrams)	Analysis	The analyst writes many memos throughout the project. Memos can be about events, cases, categories or relationships between categories. Memos are used to stimulate and record the analysts' developing thinking, including the comparisons made (see above).	Bryant & Charmaz (2007, pp. 245-264,281, 282,302); Glaser & Strauss (1967, pp. 108,112); Charmaz (2006, pp. 72-95)
Theoretical sampling	Sampling and data collection	Theoretical sampling is central to grounded theory design. A theoretical sample is informed by coding, comparison and memo-writing. Theoretical sampling is designed to serve the developing theory. Analysis raises questions, suggests relationships, highlights gaps in the existing data set and reveals what the researchers do not yet know. By carefully selecting participants and by modifying the questions asked in data collection, the researchers fill gaps, clarify uncertainties, test their interpretations and build their emerging theory.	Bryant & Charmaz (2007, pp. 304, 305, 611); Glaser & Strauss (1967, pp. 45-77); Charmaz (2006, pp. 96-122)
Theoretical saturation	Sampling, data collection and analysis	Qualitative researchers generally seek to reach 'saturation' in their studies. Often this is interpreted as meaning that the researchers are hearing nothing new from participants. In a grounded theory study, theoretical saturation is sought. This is a subtly different form of saturation, in which all of the concepts in the substantive theory being developed are well understood and can be substantiated from the data.	Bryant & Charmaz (2007, pp. 306, 281,611); Glaser & Strauss (1967, pp. 111-113); Charmaz (2006, pp. 114, 115)
Production of a substantive	Analysis and interpretation	The results of a grounded theory study are expressed as a substantive theory; that is, as a set of concepts that are related to one	Bryant & Charmaz (2007, pp. 14,25); Glaser

theory		another in a cohesive whole. As in most science, this theory is considered to be fallible, dependent on context and never completely final.	& Strauss (1967, pp.21-43); Charmaz (2006, pp.123-150)

4.7 Research sample

4.7.1 *Sample and sampling method*

The population and the sample selected from the population are fundamental aspects of this research framework. A sample is a subset of a larger population (Bryman, 2008) or a representative of the population (Quinlan et al., 2015). In general, a researcher does not possess complete information about the characteristics of the research population due to many factors such as confidentiality, lack of time, lack of access or cost, and the fact it is time consuming. Therefore, the determination of sample size is crucial (Fellows & Liu, 2008). Sampling can be classified into two types, probability and non-probability sample (Bryman, 2008) – see Table 4.4.

Table 4.4: Classification of sampling

Probability sample	A sampling technique in which units of the population have a known, non-zero probability of selection. The outcome is more likely to be a representative sample. Techniques: *simple random sampling* (the most basic form, where each sampling unit has an equal chance of being included in the sample), *stratified sampling* (simple random sub-sample that shared the same characteristic within the populations), *systematic sampling* (starting point is selected randomly followed by every nth number on the list selected) and *cluster sampling* (sampling is carried out by randomly selecting a sample of the clusters to study, rather than randomly selecting the population).
Non-probability sample	A sampling technique in which units of the sample are selected on the basis of personal judgement or convenience. Essentially, some units in the population are more likely to be selected than others. Techniques: include *judgmental sampling* (judgement or purposive sampling techniques where the researcher decides, or makes judgement on who or what to include in the sample), *quota sampling* (the researcher develops a sample of participants for the research using different quota criteria), *snowball sampling* (the researcher finds one participant in the research and that participant will lead to the next participant) and *convenience sampling* (the researcher engages those participants who are most conveniently available).

Source: Adopted and developed from Bryman (2008) and Quinlan et al. (2015)

4.7.2 Establishing samples for Phase 1 and Phase 2

This whole research was designed and supported by The Chartered Quality Institute (CQI ConSIG group). Phase 1 included a workshop, questionnaires and steering group discussion. The Study A workshop involved construction experts (both owner and their supply network: a quality manager, quality consultant, two contractors and owner) within different sectors of project-based firms (n=5) to show the various categorisation of operational failure and its quality cost elements, and explored the complex nature of its measurement through the construction supply network.

Study B (i) was a survey that investigated the respondents' experience of operational failure quality cost and enterprise perceptions in COQ and to understand various owner and supplier influences on operational failure. Data was collected from 25 respondents – advisors (n=2), suppliers (n=3) main contractors (n=2) and owners (n=7) – in the UK construction industry who mainly had responsibility for multiple assets (rather than a single one-off project) and the value of these assets ranged from £400m to £5billion per annum.

Study B (ii) was a second, web-based survey, issued to quality managers (n=17) from owners and contractors in the UK construction industry who have experience of more than 50 projects ranging from PFI (n=10), private sector (n=5) and central government (n=2) projects. Half of the participants had experience within airport construction, and five others within railways and hospitals.

In conjunction with study C, a case study protocol was used in generating data, to help ensure reliability (Yin, 2003) and provide greater benefits to best deal with construction complexity that consists of human factors and social contexts (Quinlan et al., 2015) to further explore COQ and the capabilities for failure mitigation, and elaborate on its empirical application within an overarching owner organisation of the complex inter-organisational network. The Phase 2 case study research method includes a workshop, survey, interviews and various data analysis methods, in which the author worked closely with one of the experts who has great involvement in the owner organisation and the project environment. Consequently, an expert Delphi review has been used in selecting all samples for both surveys and interviews.

4.7.3 Establishing samples of project multi-case study

In this thesis, with a combinations of non-probability sampling techniques, purposive sampling was used to find participants from owner construction projects who had experience with operational failures. A sector-specific project was selected after expert consultation as well as the expert steering group recommendation at the beginning of the research stage. The sample was selected according to the project timeline, project relevance, participant support, access consent and explicit expertise available within the research area. A Delphi technique allows reliable consensus from experts (Okoli & Pawlowski, 2003) and was used in selecting the most eligible samples for case study purposes. The Delphi review involved experts who were interested in exploring and discovering what is actually known or not known about the operational failure quality cost.

The aim of this Delphi review was to select the most eligible projects to form the case study sample. The author worked actively with a quality manager who was also a representative of the research steering group (a total of 15 meetings from May 2015- May 2018). Her position in the project management office team provided information and supported the collaborative selection of the samples and the information for the case study. From initial enquiries, expert knowledge was most frequently found in the building control team. Therefore, a few meetings were set up with this team to identify and discuss projects that would provide the most insight for the research. These meetings are further described in chronological order:

1. Two hours of meeting with the head of the building control team (n=2): the purpose of this meeting was to seek advice on the project selection. The aim and objectives of the study were explained and the signed non-disclosure agreement (NDA) was discussed.
2. Variation of 1-2 hours' discussions made with the building control team (n=4) to help obtain more knowledge about specific projects. The building control team provided a list of 18 potential projects and key contacts.
3. A one-hour interview with the quality manager and a delivery director (n=2) who offered to share knowledge on one potential project. He further explained about the potential case and person to contact.

Following these project identification and key contact identification meetings, the author worked with the quality manager to best classify projects into operational failure quality cost elements. A total of 15 emails, four meetings and three document reviews contributed to this. This was then validated in a workshop, as described below:

4. A two-hour workshop facilitated (n=3) by the author, the quality manger and one of the head building control managers was used to validate the findings, with the building control team using card sorting. This provided clearer information and classification of quality cost elements according to specific case study projects. The result of both categorisations for projects with quality costs was determined based on: (1) includes best involved experts (still and have been involved with the operational failures) and (2) is an excellent informant (has political influence with operational failures) samples for the selection of multi-case study.

The five eligible case study projects were chosen for relevance, opportunity, expert availability, timeliness, strong support from top management and ease of access. These projects were also selected based on the reasons listed below:

1. The similarities in organisational structure, yet there was a differential in team dynamics. This showed the divergence of each quality issue in relationship to similar operations in the organisation.
2. Five projects were on the different organisational-specific models of tender with traditional contract award (no preferred supplier) and long-term partners (three years of contract). This showed the owner and multi-organisational supply and operator network relationship to the quality issues.
3. All projects had a similar budget range, which showed that the cases were similar in size.
4. All projects work under the same NEC contract.

4.7.4 Identification of Study C (ii) Phase 1 interview – expert project participants

Based on these selected projects, an initial sample of seven (n= 7) owner project managers for each project were selected for the Study C (ii) Phase 1 interviews – identifying the project and operation of commercial, supplier and operational participants in the project. This allowed theoretical sampling to address the research questions. This initial sample provided the starting point to characterise operational failures and to group them according to the operational failure quality cost elements as per the framework proposed in Phase 1 – framework development. Semi-structured interviews were employed to "*learn the respondent's viewpoint regarding situations relevant to the broader research problem*" (Blumberg et al., 2008, p.386); thus, a snowball method was used to elicit further stakeholder- and situation-specific details when quality issues were explored to understand failure. This theoretical sampling (Charmaz, 2014) allowed for the emergence of concepts from the initial data to reach saturation. It helped to delineate and develop narratives around quality issues at the operational stage of a project.

4.7.5 Identification of Study C (iii) Phase 2 interview – expert project participants

Following the above, the snowball sampling provided a series of possible samples and convenience sampling was then used to further select interviewees. The interviewees were asked about who was involved with specific operational failures to generate further insight into the link of operation issues, quality cost and construction supply network. Nineteen (n=19) interviews were then conducted within the identified project and operational team. Table 4.5 provides a list of interviewee roles.

Table 4.5: List of participant roles and unique anonymous identifying participant codes

Projects	**Project A – Buildings (car park)**	**Project B-Water treatment plant**	**Project C-Infrastructure (track transit system)**	**Project D – Building escalator**	**Project E – Infrastructure (runway)**
Project and operational team participants	Owner project manager (A1) Owner project manager (A7) Owner project engineer (A14) Owner commercial manager/ contract lead (A11)	Owner project manager (B2) Owner maintenance manager (E18)	Owner project manager (C3) Owner quality manager (C10) Contractor quality manager (C8) Contractor project manager (C9) Operation engineer (C19)	Owner project manager (D4) Owner asset manager (D15)	Owner project manager (E5) Owner project manager (E6) Owner airfield transformation manager (E12) Owner project engineer (E13) Owner airfield senior transformation led (E16) Owner airfield senior transformation led (E17)
Total	4	2	5	2	6

4.8 Data collection method

4.8.1 Questionnaire

A questionnaire is one of the most popular data collection methods, as it allows for a wider range of participants (Saunders et al., 2009). However, designing a good questionnaire is challenging (Love et al., 2002), and it influences the response rate and reliability of data collection (Fellows & Liu, 2008). This method was used through a highly-structured questionnaire where respondents were required to tick boxes and answer some open-ended questions in generating quantitative descriptive views of the industry-based perceptions in relation to operational failure quality elements. In the beginning, in order to design the questionnaire, the author decided precisely what data was required (Quinlan et al., 2015), which required both time and skill (Gay et al., 2009). Generally, literature input was used to construct both structured and unstructured items. A pilot test was first sent out to the Chartered Quality Institute (CQI ConSIG) steering group members to discovered where questions were unclear or unnecessary, which led to information being gained about deficiencies in the questionnaire, as well as suggestions for improvement (Gay et al., 2009). Based on the pilot study, a sample was then determined using a stratified sample to later select for purposive sampling. This was to ensure that the questionnaire result would be generalisable to the population (Gay et al., 2009).

4.8.2 Interview

Interviews are a deliberative discussion between two or more people (Saunders et al., 2009) in which the researcher is seeking information from the interviewee(s). There are three types of interview, as explained by Saunders et al. (2009), which are structured interview (based on pre-determined and standardised questions which require short and precise answers); semi-structured interview (list of themes and questions that may change from interview to interview, used to understand the reasons for the behaviours, opinions or decisions of participants); and unstructured interview (informal and contain open-ended questions; interviewees have the opportunity to express their opinion freely; produce rich and large data based on wider questions). Quinlan et al. (2015) classified interviews into five different types: the one-to-one interview, the group interview, the telephone interview, the online interview and the photo elicitation interview.

In this study, a semi-structured interview was used in discovering and elaborating participant information to appraise the operational failures and discover causes, values, benefits and characteristics behind the whole supply network. This method requires the author credibility to explore interviewees' views, attitudes and behaviours in developing ideas (Fellows & Liu, 2008), which later were used in shaping the research objectives and forming the framework through the grounded theory principle. This is rather appropriate when little is known about the study phenomenon or where detailed insights are required from individual participants (Gill & Johnson, 2002).

4.8.3 Steering group discussion

The steering group was usually conducted with six to 12 people around a table (Table 4.6). There was one moderator who guided people around the table to focus on a particular topic (Quinlan et al., 2015). In this research, the author was actively working with the Chartered Quality Institute (CQI ConSIG) during the whole research process. This consisted of 14 meetings of 2-3 hours each. The focus group members ranged from UK construction owners, to consultants and contractors. Every activity and data collection for the study was discussed, validated, generalised and elaborated upon during the meetings. This helped the author to gain advanced understanding of how data collected was a reflection of other construction organisations. All discussions and observations were noted and kept for data analysis.

Table 4.6 : Steering group meetings with the Chartered Quality Institute

Year of study	**Date of steering group meeting**	**No of people (n)**
1st year, 2015	13th May 2015 8th July 2015	8 12
2nd year, 2016	20th Jan 2016 9th March 2016 5th May 2016 21st Sept 2016 2nd Nov 2016	7 8 8 5 7
3rd year, 2017	18th Jan 2017 17th May 2017 21st June 2017 13th September 2017 29th November 2017	9 7 6 6 8
4th year, 2018	7th February 2018 18th April 2018 6th July 2018	6 5 5

The discussions were conducted on the basis that all information was confidential. The author needed to ensure the best quality discussion was obtained during the group sessions. A flexible format was used to encourage dialogue amongst the respondents during each steering group to ensure the most empirical information was obtained and would be helpful to the research. Data was gathered through participant-focused discussions (Quinlan et al., 2015) to then produce new knowledge and insight.

4.8.4 Observation, documentation and other materials

In addition to the above methods, observations were recorded whenever necessary during the research process to gain rich insight on a particular aspect, including directly monitoring and evaluating the actions and behaviours of the participants. Field notes or diaries were used by the author to keep memos. As mentioned in Table 4.3, in grounded theory, memos were used to stimulate and record analysis to developed further thinking. Other material, such as organisational management structures, project reports, working programmes and strategies or approaches to procurement and other related materials, that increases knowledge concerning the operational failure and COQ within the project, system, process and supply network organisations were also studied. The documentation was all project specific and was used to support the formulation of framework development as well as for references purposes in articulating the findings of this thesis.

4.9 Data analysis

Grounded theory requires a coding scheme to enable relevant data to be grouped together and involves sense making and understanding of the data to emerge. Consequently, data analysis is the most difficult aspect during the research process and needs a mix of creative and systematic skills. There are different methods of analysing qualitative data depending on the type of data, the method used in collecting the data, the research subjects, and the research design and objectives (Saunders et al., 20009).

Qualitative data can be analysed in four stages (Miles & Huberman, 1994): data reduction, data display, conclusion drawing and verification, in which analysis can only be completed when the volume of data is organised in a way that is manageable. This involves coding the data, dividing the text into small units, assigning labels and then grouping the codes into themes. Analysis involved both inductive and abductive inferences in a process that involves either subsuming data under existing categories, derived from previous research and current policy, or assigning new categories on the basis of surprising or unexpected incidents of data. Qualitative data is usually concerned with searching for the patterns of various types, to hypothesise relationships by either searching from the data or employing theory and literature (Fellows & Lui, 2008).

In this thesis, the definitions of the COQ concept and operational failure quality cost content of the multi-case in this study were determined during the COQ categorisation workshop and quality failure framework development phase. The level of analysis later emerged during the framework development phases that contributed to the wider perspective of project and quality management in failure mitigation through integrated capabilities. By this, using the data to search for patterns provided an opportunity for the author to see the new and potentially important relationships in the data. Thus, the author has scrutinised all transcribed texts of discussions, statements and other documentation, looking not only at the content but also the linguistic context. This is to establish the meanings, intentions and interpretations of the people concerned (Fellows & Lui, 2008).

In this study, various methods have been used in analysing different sets of data. However, in general, three methods of qualitative data analysis were used. These methods are as follows:

1. *Content analysis*

This method is a form of qualitative study focusing on the explicit and implicit meanings that surround strategic communications. It provides a quantified analysis of recurring or persistent and easily identifiable parts of a text's content (White & Marsh, 2006), and determines the main facets of a set of data by simply counting the number of times an activity occurs (Fellows & Liu, 2008). The content analysis method can be defined as systematic, using replicable techniques to make inferences about a text, where the notion of inference plays an important role in determining the purpose and object of methodological study (Krippendorff, 2004). A series of analytical constructs allows the researcher to go back and forth between these texts and context to describe the phenomena (Hayes & Krippendorff, 2007). Thus, once the data categories have been established, a content analysis will yield quantitative data for each content category (Fellows & Liu, 2008). Qualitative content analysis was used accordingly for most of the data collected during Phase 1 (studies A, B (i) and B (ii)). This yields numerical values of the categorised data by rating and ranking participant perception through different maturity level and influences of participants' knowledge about COQ failures. Comparisons were later made on the basis of hierarchies of categories. The relationships between categories of data and between groups were later examined in answering the research aim. The statistical evidence from the qualitative study was used to determine the direction of the relationship (causalities) when combined with theory and literature (Fellows & Liu, 2008).

2. *Thematic analysis*

This method involves the identification of emerging themes through careful reading and re-reading of the data to form a pattern recognition within the dataset (Miles & Huberman, 1994). Accordingly, assessments were made in face-to-face interviews and multi-representative workshops, and all interviews were then professionally transcribed. As suggested by Miles and Huberman's (1994), data was collected, displayed, reduced and verified. The analysis used thematic methods that began with several rounds of coding transcribed interviews, case-by-case, to abstract and transform the data into emerging pattern codes and then into categories. The cases were then mapped through concept mapping to provide a clearer explanation of the events that constituted operation failure. Comprehensive literature was 'constantly compared' during the coding cycle once the first open coding was conducted. This was to allow for the development of theoretical ideas in generating second coding that focused on the theoretical constructs. Selective coding was then used to generate the core categories from each case to then compare and further abstract into higher level of categories that incorporated instances from each case. Figure 4.8 summarises the process from codes to theory in performing thematic analysis. The development of theory is not always a necessary outcome in qualitative inquiry, as pre-existing theories may drive the entire research enterprise (Saldaña, 2016). Therefore, referring to Charmaz (2014), grounded theory codes require a cycle of coding to understand the analytic issues within each cycle of coding in providing direction to the researcher.

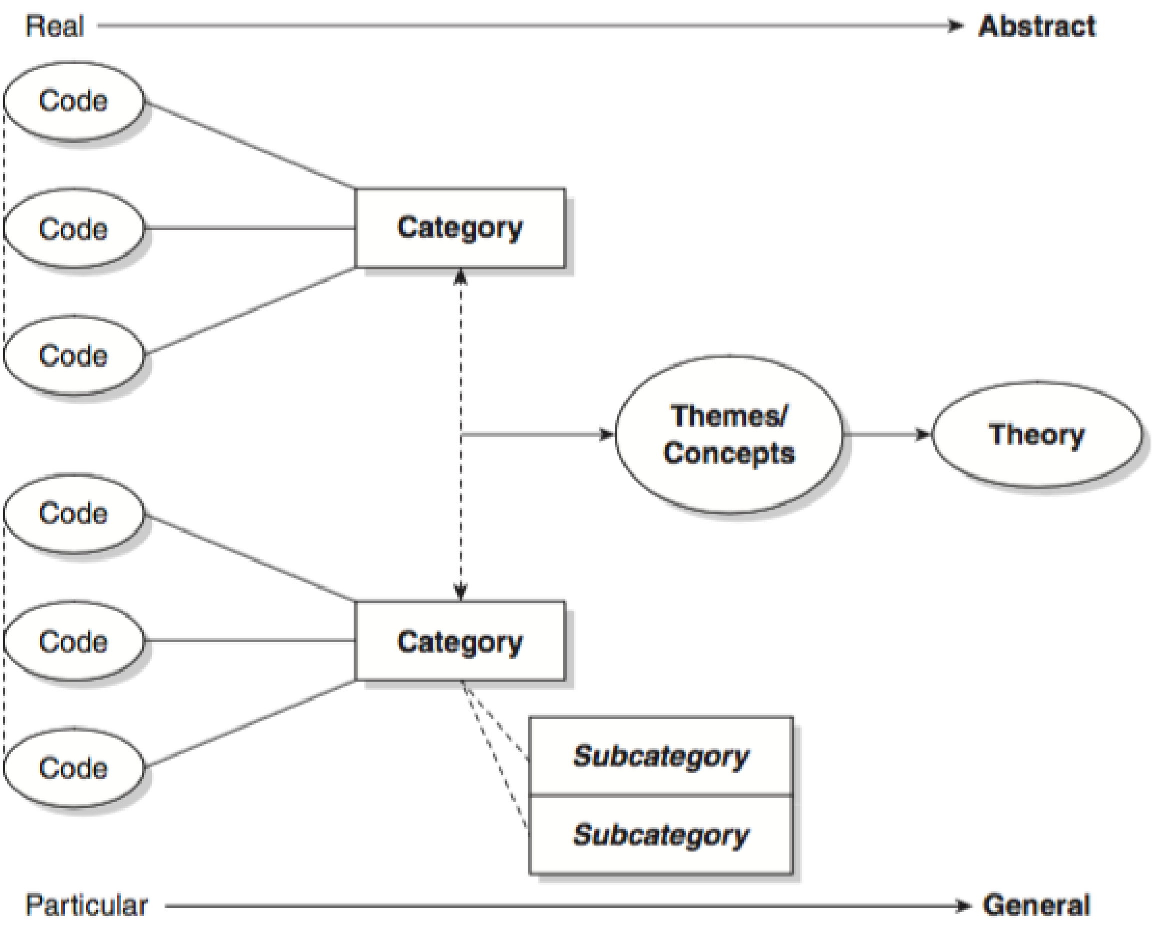


Figure 4.8: Analysis process from codes to theory model for qualitative inquiry (Source: Saldana, 2016, p.14)

3. *Cross-case analysis*

These categories and their respective themes are further explained and analysed in the cross-case analysis to compare findings. Furthermore, pattern-matching, data displays and explanation-building analytical techniques (Yin, 2003) were used primarily during the cross-case analysis. Pattern matching allows comparison of cases to be made in determining similarities and differences, and thus provides clearer explanation in making sense of the exploratory stage. This approach helps in drawing conclusion by searching for patterns, themes and verifying them against the literature (Miles & Huberman, 1994).

4.10 Research quality

Quality of research is important in presenting a logical set of statements; it pertains to judgement in balancing between questions and methods, subject selections, analysis of the outcomes, and protection against biases or inferential error. Thus, commonly, quality research is a precursor to quality evidence. This involves consideration of a sound methodology to show how well the research methods have been applied throughout the research design and how applicable the results are. Therefore, in achieving confidence of the research findings, it is important to be sure of the validity and reliability of the work (Fellows & Liu, 2008).

4.10.1 Validity and reliability

According to Yin (2014), four tests have been commonly used to establish the quality of social research, which mostly involves case study research. Yin (2009) categorised validity into construct (establishing multiple sources of evidence), internal (establishing robust and efficient causal mechanisms of data analysis) and external validity, which concerns the generalisation of the research findings. The final one of the four tests is reliability, which is the repeatability of the study, which is essential for the overall process (Yin, 2003). This is to ensure by the systematic description of the research steps that the next researcher, in using an identical research process, will obtain similar results (Yin, 2009). As in grounded theory, Charmaz (2014) stated the quality of the research relies on the data, as the depth and scope of the data shows credibility. Where reasoning is used in streamlining the data collection towards the relevance, workability and modifiability of the resolving problems. In justifying these, the method used, in which the case study occurs are described in Table 4.7 below.

Table 4.7: Case study tactics for the four design tests

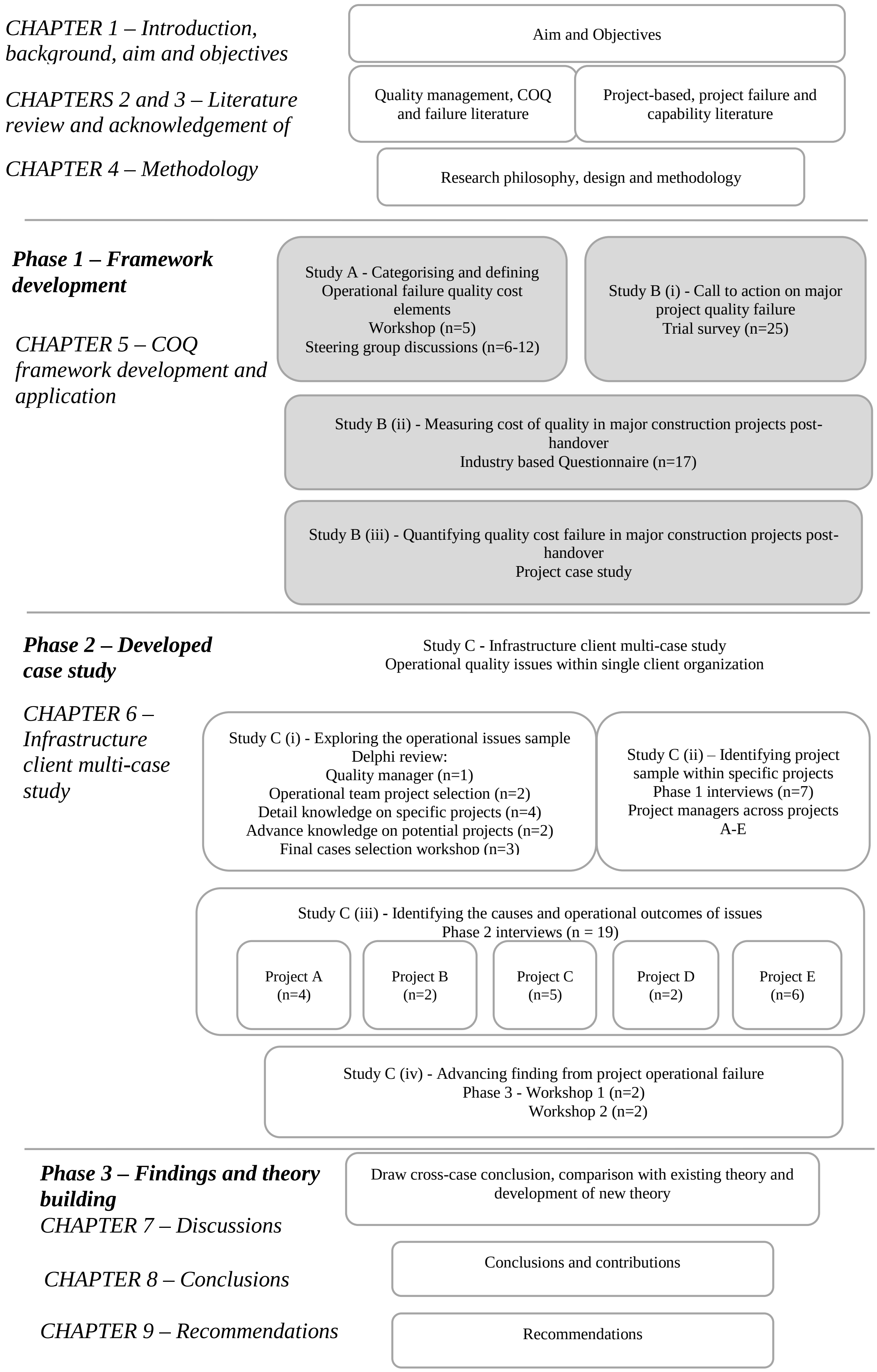
Four tests	Case study tactic	Approach taken on which tactics occur
Construct validity	Multiple sources of evidence Establish chain of evidence	Multiple sources of evidence were used in developing the COQ framework and were tested against case study findings and found to be robust.
Internal validity	Pattern matching Explanation building	Exploratory interview data was used with snowball sampling; all interviews were taped, then transcribed in real

		time.
External validity	Use replication logic in multi-case study	Multi-perspective interviews were conducted during framework development (multi-tier project supply network) and validation with multiple owners.
Reliability	Use case study protocol Develop case study database	NDAs were signed with the organisation before data was collected; a consent form was given to all participants.

Source: Developed and adapted from Yin (2009)

4.11 Chapter summary

This chapter has described the research methodology and methods adopted in this thesis. It has described the emergence of data through mixed-method and multi-case iterative cases using a grounded theory method. First, the ontological and epistemological standings of the research were explained, followed by a description of the research approach, process and research design as well as the research methodology. The methods of data collection and analysis were also described with a final reflection on the overall research quality which was presented in justifying the validity and reliability of the research.


CHAPTER 1 – Introduction, background, aim and objectives
Aim and Objectives
CHAPTERS 2 and 3 – Literature review and acknowledgement of
Quality management, COQ and failure literature
Project-based, project failure and capability literature
CHAPTER 4 – Methodology
Research philosophy, design and methodology
Phase 1 – Framework development
CHAPTER 5 – COQ framework development and application
Study A - Categorising and defining Operational failure quality cost elements
Workshop (n=5)
Steering group discussions (n=6-12)
Study B (i) - Call to action on major project quality failure
Trial survey (n=25)
Study B (ii) - Measuring cost of quality in major construction projects post-handover
Industry based Questionnaire (n=17)
Study B (iii) - Quantifying quality cost failure in major construction projects post-handover
Project case study
Phase 2 – Developed case study
CHAPTER 6 – Infrastructure client multi-case study
Study C - Infrastructure client multi-case study
Operational quality issues within single client organization
Study C (i) - Exploring the operational issues sample
Delphi review:
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on specific projects (n=4)
Advance knowledge on potential projects (n=2)
Final cases selection workshop (n=3)
Study C (ii) – Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) - Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) - Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

5 COQ Framework Development and Application

5.1 Introduction

This chapter focuses on understanding the status of COQ in the construction industry. It will present, illustrate and describe the initial findings from the Phase 1 framework development (study A, B (i) and B (ii) data collection), with a focus on operational failure quality cost elements. The work was fully supported by the Chartered Quality Institute (CQI ConSIG group) which involved various stakeholders in steering the group meetings during the whole research period. The COQ is still fragmented within the construction industry and it is evident there have been many failures. In order to understand the application of COQ systems in the construction industry and investigate the current status of operational failure quality cost, Phase 1 explores the perceptions and influences of multi-organisational project supply network on operational failure quality cost. The aim of this phase is to generate clarification regarding the COQ in the construction industry to develop a consistent definition of operational failure quality cost elements that fits in with the construction scope.

During Phase 1 of the study, data was collected through conducting workshops and surveys. The steering group discussion was used to assist and validate the data that arose from both the workshop and surveys. The research method involved at this stage included:

1. Study A - Categorising and defining operational failure quality cost elements
    - A number of two-hour of cost of quality workshops (n= 5)
    - A number of two-hour of steering group discussion (n=6)
2. Study B (i) - Trial questionnaire survey: call to action on major project quality failure
    - Selective sample of industry experts (n=25)
3. Study B (ii) - Focus questionnaire survey: measuring cost of quality in major construction projects post-handover
    - Selective sample of quality managers (n=17)

5.2 Defining and categorising the operational failure quality cost elements

The underlying cost occurrences within the construction stakeholders remain unspecified. This is because it is easier to measure in a single organisation rather than in complex and unique construction projects that involve a multi-organisational supply network depending on the project situation. Although in COQ literature, most researchers have quantified quality cost using a quantitative method, data in this section is described in a more explorative way than previously seen to help the construction industry to better understand the operational failure COQ. Seven steering group discussions (from May 2015 to November 2016) are presented within the qualitative measure of operational failure quality cost. It is hoped that these will better allow the systematic structuring of quality cost during the construction process, delivery and asset operation.

5.2.1 Defining the operational failure quality cost elements

Throughout the whole research process, the author has continuously discussed and defined the operational failure quality cost elements within the steering group meetings with the Chartered Quality Institute, which involved a sample of a number of experts (n= 6-12) for a total of two hours per session, equivalent to 312 hours over a period of two years. The aim of this steering group was to define, quantify and understand the operational failure quality cost in the construction industry. Operational failure quality cost was perceived to be key in understanding the project failure. It was clear that project owners and their multi-organisational were unaware of the total COQ in every project, but did understand that COQ is part of their business cost. The diversity of definitions of failure amongst the project participants was the problem that needed addressing. The first model of COQ that was created through this working group emphasised the categorisation of the final output (Figure 5.3) which has been tested and validated across this research process. The first COQ model (Figure 5.1) identified the quality elements involved across the prevention, appraisal and failure (P-A-F) traditional model.

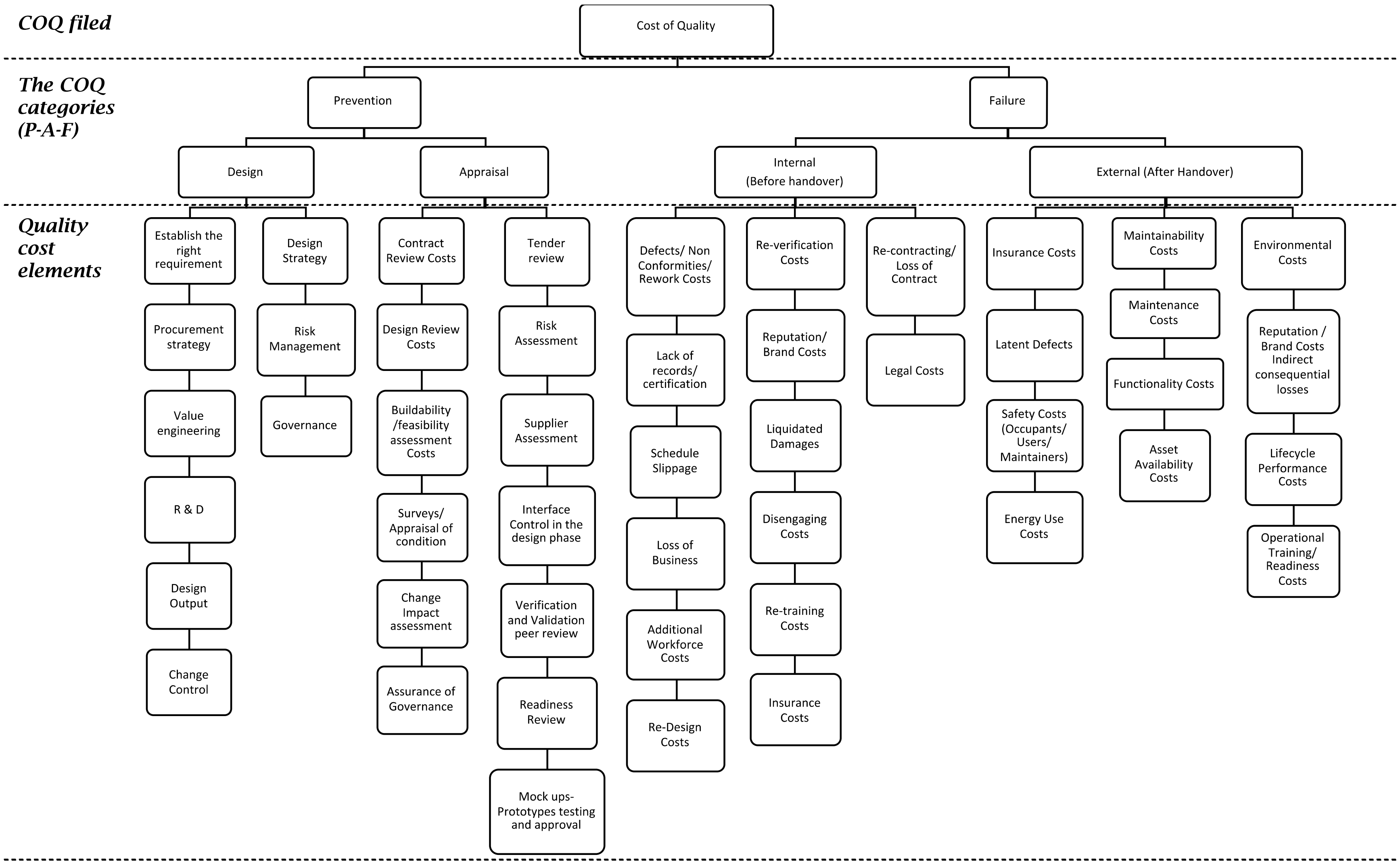


Figure 5.1: The COQ field and classification of quality cost elements

This study has focused on appraising the operational failure quality cost, as opposed to the historical focus on the prevention and appraisal phases. The classification of the operational failure quality cost helps to increase the maturity in understanding of the operational failure quality cost element to further integrate the COQ concept during project planning, design and construction. Figure 5.2 below shows the initial framework for 13 elements focusing on operational failure quality cost.

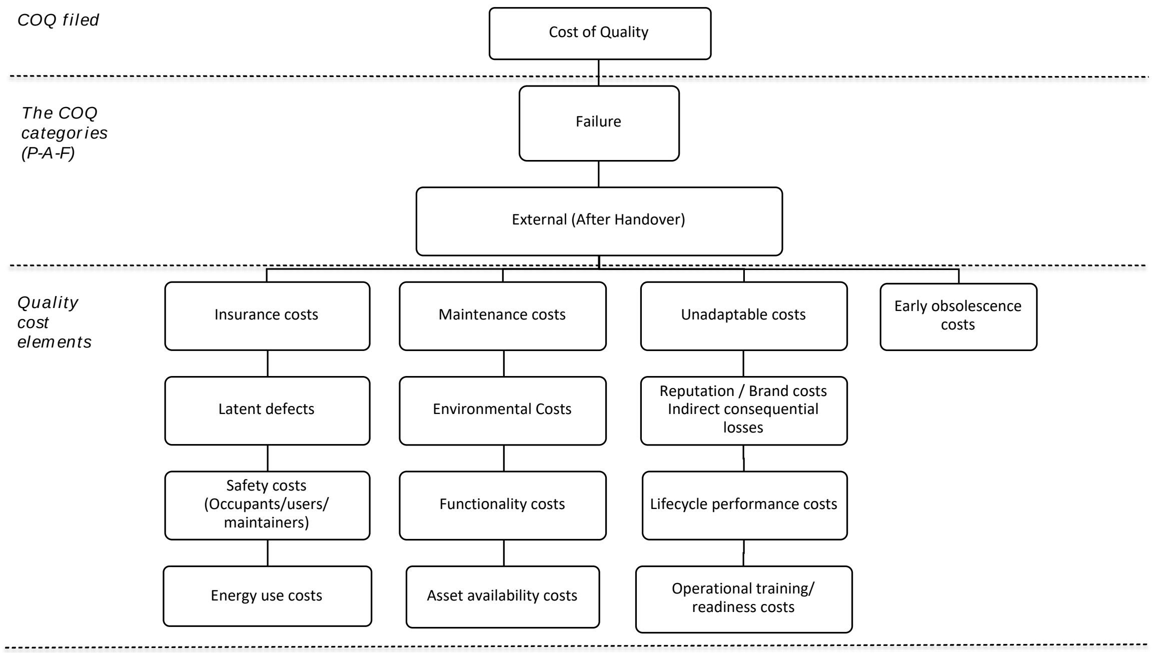


Figure 5.2: The COQ field, failure category and classification of operational failure quality cost elements

All elements of operational failure quality cost together with the definitions found in Table 5.1 were used in this research to understand the perception and influence of the project supply network. Most of the elements were understood by the participants but needed further definition and combinations of data through the case study phase. The steering group meeting was used to further clarify and validate the categorisation and definition of operational failure quality cost. Table 5.1 below shows a comparison of definitions used in the case study and definitions discussed and agreed by the steering group experts in comparison to the revised operational failure quality cost elements and their definitions. The revised quality cost elements were re-defined and arranged according to their significance.

Table 5.1: Operational failure quality cost elements and their definitions

	Definitions (v1- used in case study)		Definitions (v2- discussed and agreed by CQI steering group meetings)
1. Insurance Costs	An arrangement by which a company or the state undertakes to provide a guarantee of compensation for specified loss, damage, illness or death in return for payment of a specified premium.	1. Safety Costs for Operators and Occupants	Claims and legal consequences due to incidents, hazards, fire or injuries caused to occupants, users and maintainers. May be due to underperformance or incorrect selection of products or system failure or unforeseen outcome. This will cause a treatment, lost working time and remedial action and includes consequential costs for rectification.
2. Latent Defect Costs	Hidden defect in material and or workmanship of an item which may cause failure or malfunction, but is not discoverable through general inspection; or defects that are not apparent at the time of completion but which subsequently become apparent months or years later.	2. Asset Availability & Functionality Costs	A tangible asset's availability to be put to its intended use. When assets are available, work processes can operate more efficiently and cost effectively. The sum of costs due to the non-availability of an asset for beneficial use. It also includes the costs due to reduced functionality either by failure to specify or failure to deliver and any additional cost of rectification (new project).
3. Safety Costs for Operators	Insurance claims and legal consequences due to incidents, hazards or injuries caused to occupants, users and maintainers. May be due to underperformance or incorrect selection of products or system failure or unforeseen outcome. This will cause a treatment, lost working time and remedial action.	3. Energy Use Costs	Expense for generating, distributing and using energy, including monetary and non-monetary expenses. The additional costs of energy consumption incurred by the owner, compared to the specified energy requirements in the contract.
4. Asset Availability Costs	A tangible asset's availability to be put to its intended use. When assets are available, work processes can operate more efficiently and cost effectively. The sum of costs due to the non-availability of assets for beneficial use (loss of functionality).	4. Maintenance Costs	The cost incurred to keep an item in a good condition or good working order to deliver performance requirements throughout its lifecycle. Excess cost outside of the planned maintenance programme and design intent.
5. Energy Use Costs	Expense for generating, distributing and using energy, including monetary and non-monetary expenses. The additional costs of energy consumption incurred by the owner, compared to the specified energy requirements in the contract.	5. Environmental Costs	Costs connected with the actual or potential deterioration of natural assets due to economic activities. It is either costs caused (potentially causing environment deterioration) or costs borne (costs incurred by economic units independently who may have caused the environmental impacts). These include additional costs incurred to mitigate environmental failures in effluents, traffic, noise and natural habitat.

6. Maintenance Costs	The cost incurred to keep an item in a good condition or good working order. Excess cost outside of the maintenance programme and design intent.	6. Additional Operational Training Costs	Additional cost incurred to train operators. This is usually caused by lack of training before handover and major changes after handover.
7. Environmental Costs	Costs connected with the actual or potential deterioration of natural assets due to economic activities. It is either costs caused (potentially causing environment deterioration) or costs borne (costs incurred by economic units independently who may have caused the environmental impacts).	7.Early Obsolescence Costs	Product or asset becoming outdated or no longer used earlier than its originally designed life. Includes new project costs to replace a product or asset earlier than originally planned due to failure or not having the ability to change.
8. Lifecycle Performance Costs	Excess cost of an asset or its parts throughout its lifecycle while fulfilling the performance requirement where specified.	8.Reputation/Brand/Indirect Consequential Losses Costs	Widespread belief about something due to a particular characteristic which has caused failure (indirect cost). It includes the loss of revenue caused by a well-publicised failure in the media and costs incurred to manage the goodwill of products and services, and loss of future contracts.
9. Functionality Cost	Cost of the production and delivery of the product. It includes price of parts, labour, overheads, etc., which means the value of the product. Sum of the costs due to reduced functionality either by failure to specify or failure to deliver.	9. Insurance Claims Costs	An arrangement by which a company or the state undertakes to provide a guarantee of compensation for specified loss, damage, illness or death in return for payment of a specified premium. Includes insurance claims made by any party post-handover due to defects during design or delivery.
10. Unadaptable	Costs of not having the ability to change or be changed in accordance with altered circumstances.	10. Latent Defect Costs	Hidden defect in design, material and or workmanship of an item which may cause failure or malfunction, but is not discoverable through general inspection; or defects that are not apparent at the time of completion but which subsequently become apparent months or years later. This includes loss of revenue, not claimed by insurance or any other category, caused by poor performance on less obvious defects.
11.Early Obsolescence	Product becoming outdated or no longer used.		
12.Reputation/ Brand Cost/Indirect Consequential Losses	Widespread belief on particular characteristic which has caused failure (indirect cost)		
13. Operational Training/Readiness Cost	Additional costs for training incurred due to inadequate or ineffective training and additional cost incurred to train operators.		

Definitions in V2 summarise the final categorisation of all 10 operational failure quality cost elements as agreed by the Chartered Quality Institute (CQI ConSIG) during the two years of steering group meetings with the expert sample (n= 6-12), who were all involved in the operationalising of construction projects. A detailed review of all 13 elements has been summarised and re-categorised into 10 final categories, as shown in the table above. This is an addition to the reduced and finalised operational failure quality cost elements, which include similar elements in one category and were then re-defined as a new combined statement of definition wherever necessary. The discussion was made from a combination of data collected from the initial workshop, two questionnaires, a preliminary review and what has been seen in the exploration of an in-depth case study review all conducted with industry-based participants.

From each steering meeting, the feedback from each phase of the study was discussed until a set of final definitions was achieved and validated by all the Chartered Quality Institute (CQI ConSIG) members. The steering group agreed that 'functionality cost' needed to be combined with 'asset availability' as they provide the same meaning as to how assets need to function during the operational stage. Also, it was agreed to removed 'unadaptable cost' as it carried the same meaning as 'asset availability and functionality category'; and 'lifecycle performance cost' has been combined with the element of 'maintenance cost', due to them having a similar meaning. All the other elements remained, although a few were re-defined into clearer definitions. For example, insurance cost was re-defined as insurance claim cost to include the insurance cost paid to cover the project as well as the insurance cost claimed due to any failure. Figure 5.3 shows the final framework constituting operational failure quality cost with the construction COQ field.

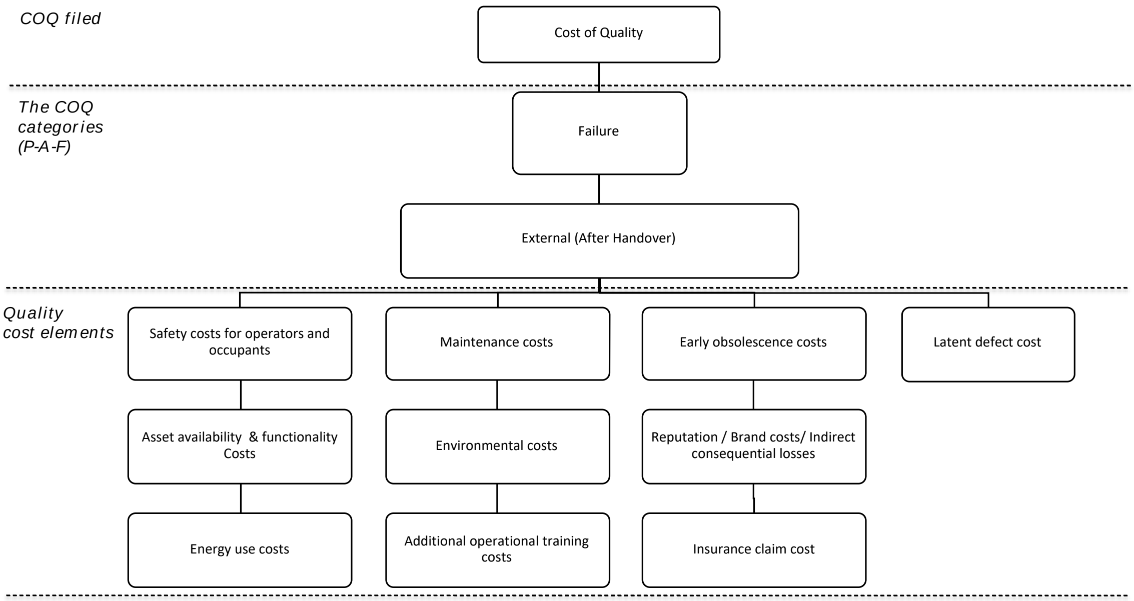


Figure 5.3: The COQ field, final failure category and classification of operational failure quality cost elements

5.3 Categorising the operational failure quality cost

5.3.1 Cost of quality workshop

As an initial step in the study, the workshop was set up to first categorise the operational failure quality cost elements within the construction scope. By means of categorising these quality elements, the adoption of a better understanding of each quality cost element was achieved. A workshop method was used to clarify, re-define and structure the categorisations of the operational failure quality cost. The categorisations demonstrated the importance of identifying the distinctive cost incurred within the construction industry supply network to allow for a bigger opportunity to understand in detail each individual element and its relationship to the construction process. The relationship of each element was justified and discussed within the steering group, as mentioned in the following sub-section. This workshop realised the complexity in categorising these quality cost elements. Operational failure quality cost was then simplified, grouped and re-defined at the end of the study, as mentioned in section 5.2.1.

5.3.2 The categorisations of operational failure quality cost elements

A selection of individual opinions regarding the relationship of cost incurred by the supply network and each element is summarised in Table 5.2. Data was collected during the steering group meeting, and pictures and notes were taken for analysis. The workshop detailed the discussions about the relationship of parties who incurred cost and the quality cost elements. The early definitions of each element were provided for each participant

(Figure 5.4). Each operational failure quality cost element was then clearly defined and understood during the workshop. This was used as the starting point for defining and categorising individual expert statements in the workshop. Experts selected the relationship of cost incurred to the construction supply network before grouping the operational failure quality cost elements into categories with their own theme (Figure 5.5). They were then displayed on the table to be shared and discussed, and were finally agreed by the whole steering group.

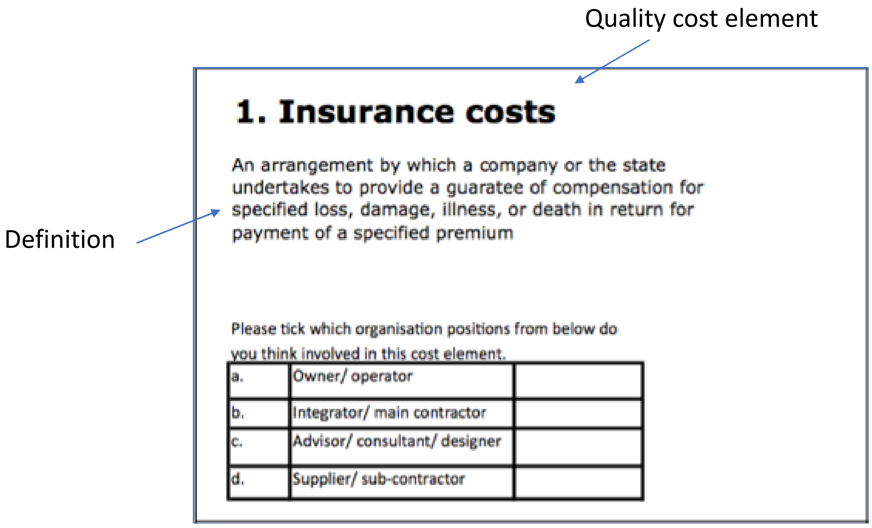


Figure 5.4: Example of a card used during the workshops

Figure 5.5: Participants' card categorisations for operational failure quality cost elements

Table 5.2 shows the lack of consensus about who pays for operational failure quality cost. Participants remarked that this outcome confirmed that the apportionment of the responsibility for cost is part of the problem, and observed that this can shift and change depending on the stage of the project and build of the asset environment. Looking at the table, it clearly shows all operational failure quality cost elements were incurred by the owner/operator, similarly to the integrator/main contractor and advisor/consultant/designer. The group discussed this situation, highlighting that ultimately it was the owner during the operation that carries the operations cost of failure. One outlaying expert perceived that costs are shared throughout the multi-organisational supply network, through either negotiations or claims. Owner/operators were seen to be the most impacted party, as they ultimately bear the operational failure quality cost, while integrator and designer costs were less frequently incurred. Suppliers/sub-contractors appear to have the least cost impact from all the failure cost elements. Although the workshop participants where mainly contractors and owners, they disagreed with the statement that sub-contractors have the least impact as mostly the supplier/sub-contractor would have some financial responsibility for the project. However, the experts agreed that designers/consultants were the least impacted by the costs incurred. Supplier responsibility was for discreet products, while all other cases were for the larger whole system impact. However, the unadaptable cost and obsolescence cost may not be affected by the integrator once the contract ends. This demonstrated the impact of non-quantifying quality cost in generating and stimulating benefits alignment across the project process, which needs to be stimulated by the construction industry.

Table 5.2: Relationship between organisation and operational failure quality cost elements

	Quality Cost Elements	**Owner/operator**					**Integrator/main contractor**					**Advisor/consultant/designer**					**Supplier/sub-contractor**				
		P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
1	Insurance Costs	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1
2	Latent Defect Costs	1		1	1	1	1	1	1	1	1		1	1	1			1	1	1	1
3	Safety Costs for Operators	1	1	1	1	1	1		1	1		1	1		1					1	
4	Asset Availability Costs	1	1	1	1	1				1					1					1	
5	Energy Use Costs	1	1	1	1	1			1	1					1					1	
6	Maintenance Costs	1	1	1	1	1				1					1					1	
7	Environmental Costs	1	1	1	1	1				1	1	1			1					1	
8	Lifecycle Performance Costs	1	1	1	1	1				1					1					1	
9	Functionality Cost	1	1	1	1	1	1			1	1				1	1				1	
10	Unadaptable Costs	1	1	1	1	1						1			1						
11	Early Obsolescence	1	1	1	1	1	1					1		1	1						
12	Reputation/Brand Costs	1	1		1	1		1	1	1	1				1	1				1	1
13	Operational Training/ Readiness Costs	1	1	1	1	1	1			1	1				1					1	

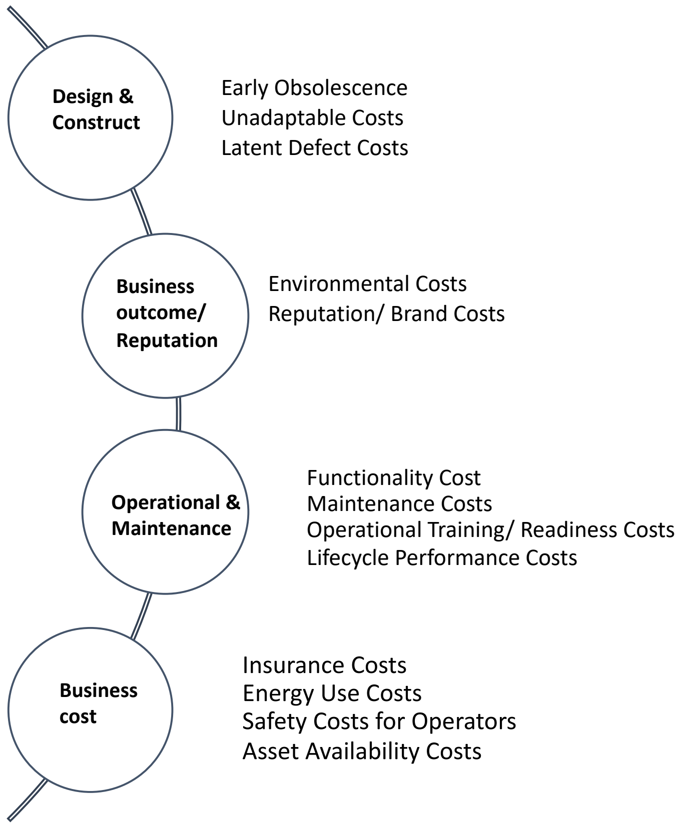


Figure 5.6: Categorisation of operational failure quality cost elements – expert one (P1)

Figure 5.6 shows the first expert's (P1) opinion on how operational failure quality cost elements could be categorised. The figure shows four categories of operational failure quality cost element, which are: design & construct, business outcome/reputation, operational & maintenance, and business cost. The categories that emerged were based on the nature of the process of construction projects. The categorisation simplifies a more complex picture of where each element falls. The operational failure quality cost elements were classified in a clearer picture to place these elements by project process for the purpose of looking at the 'root cause' of operational failures.

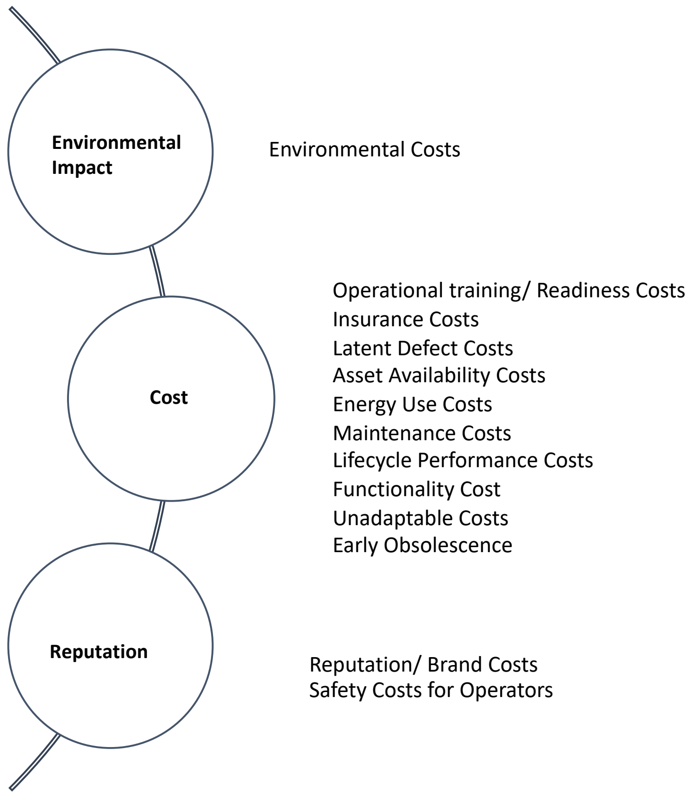


Figure 5.7: Categorisation of operational failure quality cost elements – expert two (P2)

Figure 5.7 shows the second expert's (P2) opinion on how operational failure quality cost elements could be categorised. The figure shows only three categories of operational failure quality cost elements, which are: cost, environment impact and reputation. Most of the cost elements were placed under the cost category. Only environmental cost is categorised as environmental impact, and both reputation/brand costs and safety cost for operators were categorised in the reputation category. The cost category was classified as the major cost among all the quality cost elements and perhaps illustrates a major cost focus. This participant explained that all the major costs are project-based except environmental impact and reputation.

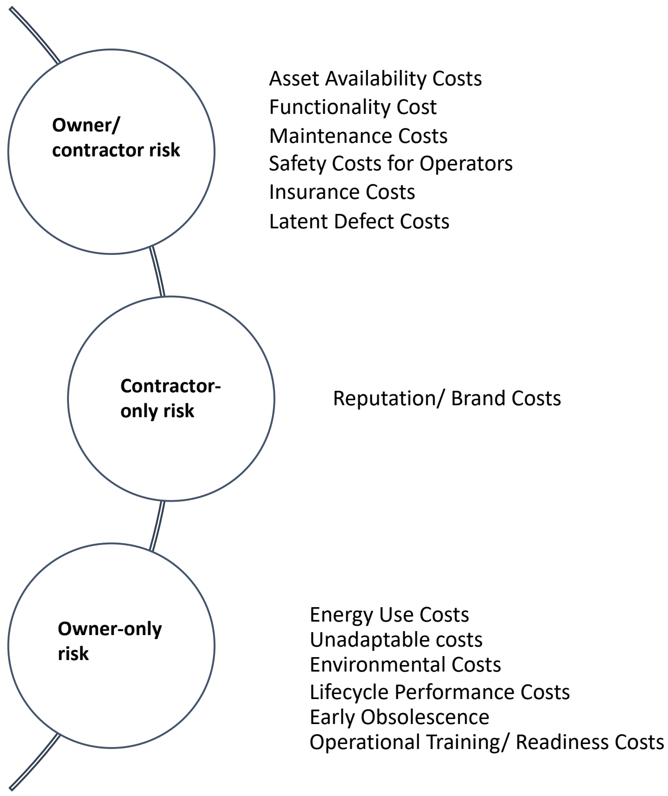


Figure 5.8: Categorisation of operational failure quality cost elements – expert three (P3)

Figure 5.8 shows the third expert's (P3) opinion on how operational failure quality cost elements could be categorised. The figure shows three categories of operational failure quality cost element, which are: owner/contractor risk, contractor-only risk and owner- only risk. These categories were mentioned based on the risk allocation by an organisation/organisation type. Each quality cost element was categorised according to risk allocation towards either owner or contractor. It was explained that the cost elements occurred through the indication of project risk, in which asset availability, functionality, maintenance, safety cost for operator, insurance and latent defect are all costs incurred by a contractor and owner. Reputation and brand cost are contractor-only risks while energy, un-adaptability, environmental, lifecycle performance, early obsolescence and operational training cost are all owner-only costs. This categorisation was agreed by most of the participants as risk could be used as an indication of cost incurred. However, there was scepticism on how each element should be grouped – into owner, contractor, both owner and contractor, or other members of the supply network.

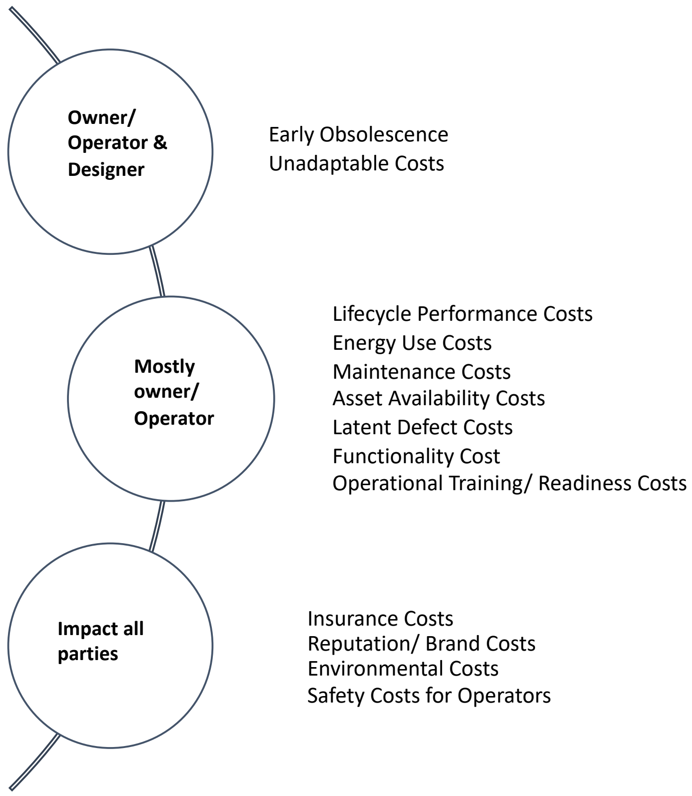


Figure 5.9: Categorisation of operational failure quality cost elements – expert four (P4)

Figure 5.9 shows the fourth expert's (P4) opinion on how operational failure quality cost elements could be categorised. The figure shows three categories of operational failure quality cost element, which are: owner/operator & designer impact, mostly owner/operator impact and all parties' impact. This participant explained that the categories were based on the impact of cost incurred upon responsible parties, which is similar to the previous categories. This categorisation shows that most of the elements were placed under the impact to owner/operator with only four elements impacting all parties.

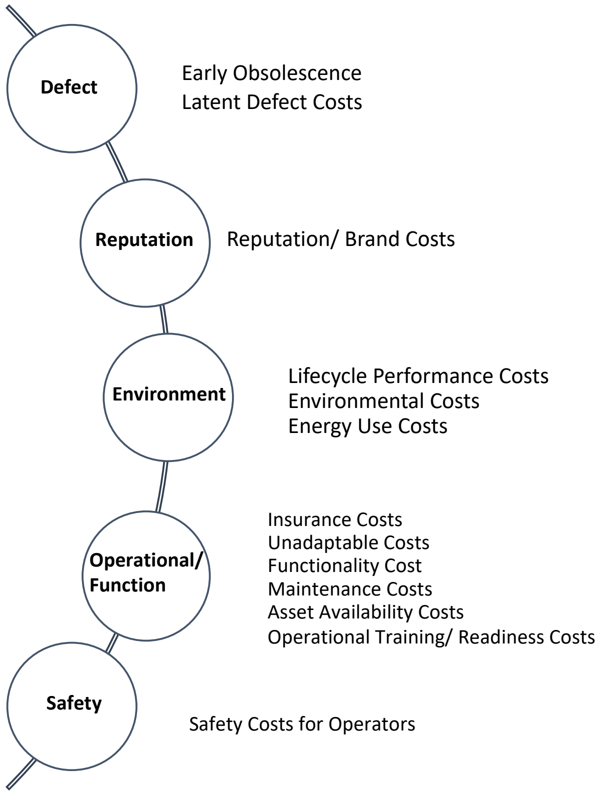


Figure 5.10: Categorisation of operational failure quality cost elements – expert five (P5)

Figure 5.10 shows the fifth expert's (P7) opinion on how operational failure quality cost elements could be categorised. The figure shows five categories of operational failure quality cost elements, which are: defect, reputation, environment, operational/function and safety. The categories were categorised based on type of costs. Interestingly, this categorisation is similar to participant two's (P2), who also classified these quality costs against the cost categories, which shows the attempt to re-groups all the costs into broader categories.

Overall, through the five categorisations suggested by the experts, it was concluded that the operational failure quality cost element should be categorised either through its supply network or by the type of quality cost depending on the organisation. Table 5.3 shows the total selection of costs incurred by the construction supply network towards all 13 operational failure quality cost elements. The table illustrates that the highest total cost incurred is by the owner/operator. This differs from the cost categorised by the P3 and P4 experts, who only partially see the quality cost elements that have an impact on or risk to the owner/operator. In contrast, the Supplier/sub-contractor has the least cost incurred within the whole supply network. The table also shows that insurance costs were the cost that were both the most selected and the most incurred by the owner and integrator, followed by the latent defect cost, safety cost for operators and reputation/brand costs. The cost that was least incurred by all parties is the unadaptable cost. Almost all quality costs are incurred by all owners and the supply network, except unadaptable and early obsolescence cost. This significantly contrasts with how operational failure quality cost was categorised by all the experts, who concluded that there is no better group of all operational failure quality costs as they are incurred by and may be the responsibility of all depending on project-based failures.

Table 5.3: Selection of quality costs incurred by different organisations

	Quality Cost Elements	**Owner/ operator**	**Integrator/ main contractor**	**Advisor/ consultant/ designer**	**Supplier/ sub-contractor**	**Total**
1	Insurance Costs	5	5	4	4	**18**
2	Latent Defect Costs	4	5	3	4	16
3	Safety Costs for Operators	5	3	3	1	12
4	Asset Availability Costs	5	1	1	1	8
5	Energy Use Costs	5	2	1	1	9
6	Maintenance Costs	5	1	1	1	8
7	Environmental Costs	5	2	2	1	10
8	Lifecycle Performance Costs	5	1	1	1	8
9	Functionality Cost	5	3	2	1	11
10	Unadaptable Costs	5	0	2	0	7
11	Early Obsolescence	5	1	3	0	9
12	Reputation/Brand Costs	4	4	2	2	12
13	Operational Training/ Readiness Costs	5	3	1	1	10
	Total:	**63**	31	26	18	

The analysis of this workshop shows two key findings in understanding the nature of operational failure cost within the supply network. Firstly, all operational failure quality cost elements are partially incurred by the owners/operator followed by the integrator/main contractor and advisor/consultant/designer. Discussion of these facts between the experts showed that there are difficulties in quantifying operational failure quality cost during the operation of an asset. This showed that most of the cost is absorbed as part of the day-to-day operational cost. Although the main contractor, advisor and supplier are aware of the cost incurred and are responsible for reporting or confirming the cost that was partially incurred by them, it is frequently assumed to be only incurred by the owners. This is based on the assumption that owners are responsible for operating the assets. Therefore, frequently, the unquantifiable amount of operational failure quality costs was either anonymous or only carried by one party. Secondly, different categorisations of the operational failure quality costs shown earlier demonstrated of the non-standardisation of quality costs in construction, which further illustrates different attitudes towards the operational failure quality cost. Each expert (with their different roles) produced different categorisations of the operational failure quality cost elements, according to when they are involved or according to the risk owner (e.g. to the owner, supply network or shared). This illustrated the need for greater awareness by management and better communication in project chains that are linked to the quality culture and behaviour of the project stakeholders. Thus, the need for better management of these operational failure quality costs with closer integration throughout the supply network, as investigated in the next phase of the study, has shown the emergence of findings that are discussed in the next chapter.

5.4 Call to action on major project quality failure

A trial COQ questionnaire was sent to 25 professionals through a convenient and selective sample across the UK construction industry. Participants were found through the use of the Charted Quality Institution network. The respondents range from integrator/owner, supplier/ sub-contractor and advisor/consultant, who were mostly from the infrastructure sector. Most had 20-36 years of experience. The questionnaire analysed the perception of construction stakeholders in dealing with post-handover quality cost. The results reflect the maturity of organisations in dealing with operational failure cost elements. The organisations rated their measurement and management of quality cost elements to be insufficient, with most expressing low maturity.

The results in Table 5.4 show how owners (O) and their supply network (S) judge their own maturity. There was a limited expression of maturity shown at the level of ‘managed’ or ‘optimised’ experience. Most elements were judged to be understood at the ‘defined’ level or lower. The insurance element showed a significant misalignment within the owners and suppliers, who show the highest level of maturity but also demonstrate that they are ‘unaware’. This shows a variance between owner and supply network maturity and that there are different levels of information for each element. There is significant variance in how maturity about ‘safety’, ‘asset availability’ and ‘energy use’ is perceived, with responses that range from ‘unaware’ to ‘managed’. ‘Functionality’, ‘unadaptable’, and ‘early obsolescence’ were scored highly at the lowest level of maturity. There was strong alignment between both owners and suppliers on ‘operational training’, ‘environmental’ and ‘lifecycle performance’ and there was a moderate level of awareness on ‘latent defects’ and ‘maintenance’. Overall, the table demonstrates that there is a low level of maturity among the supply network about COQ failure.

Table 5.4: Owner (O) and supply network (S) perception in measuring operational failure quality cost elements

		Operational failure quality cost elements																									
		Insurance		**Latent Defect**		**Safety**		**Asset availability**		**Energy use**		**Maintenance**		**Environmental**		**Lifecycle performance**		**Functionality**		**Unadaptable**		**Early obsolescence**		**Reputation**		**Operational Training**	
Level of maturity		**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S	**O**	S
	Unaware	**4**	1	**1**		**3**	2	**2**	3	**2**	1	**2**	2	**2**	1	**1**	1	**4**	2	**4**	3	**4**	3	**3**		**2**	1
	Aware	**1**	2	**4**	5		2	**2**	2	**2**	2	**3**	4	**2**	3	**4**	3	**1**	2	**2**	1	**2**		**2**	3	**1**	3
	Defined		2	**1**	2	**2**	2	**1**	2	**3**	2	**1**	2	**2**	3	**1**	3	**1**	3	**1**	2		3		2	**3**	3
	Managed	**2**	3		1	**2**	2	**1**	1		3	**1**		**1**		**1**		**1**			1	**1**	1	**1**	2	**1**	
	Optimising			**1**				**1**																			

The following section in the questionnaire judged the perception of owners (O) and supply network (S) in influencing operational failure. Respondents frequently differed in how they rated their own maturity versus that of others, with the maturity of the supply network judged to be the lowest. Table 5.5 shows both owners and supply network saw their own level of maturity as above fair (either very low, low or fair). In judging suppliers, most owners and supply network participants indicate moderate maturity (ranging from fair, low to very low), although the supply network participants score themselves and other suppliers as good. The table also demonstrates that the level of maturity of the owner and supply network in dealing with quality cost elements is understood but not managed; however, there is a great confidence in the ability to influence operational failure. Thus, increments in the maturity towards quality cost elements will help greater management and measurement of the quality cost. This is believed to depreciate the occurrences of operational failure quality cost trough more integrated system of quality costing.

Table 5.5: The owner (O) and supply network (S) perception in influencing operational failure

		Own Enterprise		Customers		Suppliers		Overall ability to influence	
Level of maturity		**O**	S	**O**	S	**O**	S	**O**	S
	Very Low			**1**	1	**1**			
	Low		2		1	**2**	2		
	Fair	**4**	2	**2**	1	**2**	3	**3**	5
	Good	**1**	2	**3**	4	**1**	2	**1**	2
	Very good	**1**	1					**2**	

The owners and supply network participants commented there was a belief that the owner roles were unclear in dealing with failure cost, which supported the need for stronger owner leadership. COQ failures were perceived to be in low maturity and there was a lack of knowledge on what defines project value. Some presumed poor understanding of project context, and different acceptance levels in relation to non-conformance costs. To improve operational failure, a rigorous assurance during design and construction is needed, to change and control project scope for a clear definition of operational requirements during the pre-project stage. In addition, better management in order to improve collaborate between supply network is necessary to provide knowledge transfer, to align awareness and to increase maturity in relation to COQ failure. Table 5.6 illustrates some examples of qualitative comments in improving measurement and prevention or reducing the risk of operational failures. Clearly, there is a need to address COQ to prevent operational failure. The result of this is combined with wider perspective of construction participant from the case study in judging the overall maturity of owner and their supply network towards their perception in influencing operational failure.

Table 5.6: Examples of qualitative comments on improvements to reduce operational failure and its quality issues

Question 13. How could improvements be made, or measures taken, to prevent or reduce the risk of operational quality issues?
"Better measurement (data), GAP analysis and root cause analysis of issues."
"Better evidence needs to be sought/built in service of demonstrating need for spend up front to ensure connectivity/interface/fundamental rectitude of project rationale."
"...more rigorous assurance during design and construction."
"Focus on clear definition of operational requirements before projects are undertaken."
"Better management of changes to scope, etc."
"Collaborate and discuss issues before they happen…"
"Fully integrated management system."
"Ensuring operational requirements are clearly defined to the project team."

5.5 Measuring cost of quality in major construction projects post-handover

To generate further understanding on the status of quality cost in the construction industry, a second questionnaire was sent to selected quality managers across the UK construction industry. Respondents consisted of 17 quantity surveyors selected by the Chartered Quality Institute (CQI ConSIG group) with experience of more than 50 projects covering the PFI, private and government sectors. However, the quality managers' experiences differed in terms of the type of project, where most have experience in the airport industry, a quarter have experience with railways and one has experience with hospitals. All projects have an overall annual capital ranging from £500 million to £1 billion. This questionnaire further analysed the perception of quality managers through the level of maturity in dealing with operational failure quality cost. The findings demonstrate that quality managers understand and have managed the operational failure quality cost elements well. These findings show a significant contrast from the first questionnaire that showed low maturity of other supply network members.

Table 5.7 shows a strong agreement between quality managers about maturity, with most elements perceived to be 'managed', with only one element, 'unadaptable', that was less well defined, with some who believed that they were unaware of this cost element. 'Latent defect', 'asset availability' and 'lifecycle performance' were perceived to be in between understood (at the level defined, aware and unaware) and matured (at the level managed and optimised), while ‘insurance’ differed significantly, where most participants rated it as matured but some said least understood. The dissimilar rating of maturity level between quality managers and others in the supply network shows incoherence in terms of information transmission of the quality management system during the project process within the construction supply network.

Table 5.7: Quality managers’ (QM) perceptions in measuring operational failure quality cost elements

		Operational failure quality cost elements												
		Insurance	**Latent Defect**	**Safety**	**Asset availability**	**Energy use**	**Maintenance**	**Environmental**	**Lifecycle performance**	**Functionality**	**Unadaptable**	**Early obsolescence**	**Reputation**	**Operational Training**
Level of maturity		**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**	**QM**
	Unaware	**1**									**1**	**1**		
	Aware	**1**		**1**		**2**	**1**	**1**	**1**	**1**	**3**	**1**	**2**	**2**
	Defined		**3**	**2**	**3**	**2**	**1**	**2**	**3**	**2**	**2**	**2**	**2**	
	Managed	**6**	**5**	**4**	**5**	**4**	**5**	**4**	**4**	**5**	**1**	**4**	**4**	**5**
	Optimising			**1**	**1**		**1**	**1**						**1**

The discrepancy of information transferred among the construction supply network could lead to wrong information being provided in different stages of construction (plan, build and operate); thus, different capabilities may cause limited ability to align the project aim to reduce operational failure. In judging the level of influence, quality managers were confident in their ability to influence operational failure but not with their tier 1 contractors and tier 2 and 3 suppliers’ ability, as shown in Table 5.8. This finding demonstrates similar results to the previous trial questionnaire that showed the owner and the supply network members had a strong capability to influence operational failure.

Table 5.8: Quality managers (QM) perceptions in influencing optimisation, integration and continuous improvement of operational failures

		Tier 1 contractors	**Tier 2 and 3 suppliers**	**Overall ability to influence**
Level of maturity		QM	QM	QM
	Unaware	1	1	
	Aware		1	
	Partial implementation	1	1	1
	Managed	2	1	2
	Optimising	1	1	2

There was a strong agreement perceived in showing strong capability to influence the optimisation, integration and continuous improvement of operational failure. However, this responsibility to influence the implementation of a quality system was only further investigated during the detailed case study interview. Table 5.9 illustrates some examples of qualitative comments on how quality mangers could be of influence to improve operational failure. Quality managers agreed that they have full control over operational failure and have a strong commitment, with sufficient support from data and resources, and thus are able to influence the quality issues. Also, they are well aware of operations and maintenance problems at an early stage and have a well-established/defined link of collaborative working with the project team in influencing the project context. However, the only reason that impedes quality managers' ability to influence is when there is a lack of input at the early stage of the project, which is the project contract. This shows that there is a need to integrate information from operations up-front, in order to mitigate failure.

Table 5.9: Examples of qualitative comments on level of maturity to influence COQ

Level of maturity to influence COQ	**The overall ability to influence the optimisation, integration and continuous improvement of operational failure.**
Managed and optimised	1. *"We have full control of operational issues."* 2. *"Commitment. Financially sound and willing to support with specialists, resources and training as needed."* 3. *"With being responsible for FM post-completion, we are aware of operation and maintenance problems early and design out."* 4. *"Well established/defined links of collaborative working."*
Unaware, aware or partial implementation	1. *"Lack of input early in the project – current contracting frameworks."*

This result provides significant evidence for the need to improve data analysis for each quality issue, with strong support and feedback from the supply network such as contractors and suppliers. Further, Table 5.10 illustrates quality managers' perceptions on the need to improve technical awareness and support during the procurement and project planning stage. This is believed to enable better implementation of training programmes to enhance and support national initiatives in terms of improvising project capabilities. Thus, this resulted in the need to change the contracting framework by adding more operational input at the beginning of a project. Also, the result of this is combined with wider perspective of construction participant from the case study in judging the overall maturity of construction industry towards their perception in influencing in influencing optimisation, integration and continuous improvement of operational failures.

Table 5.10: Examples of qualitative comments on ways that quality managers could make improvements to reduce operational failures.

Question 15. How could improvements be made, or measures taken, to prevent or reduce the risk of operational failure?
"Improve data analysis and feed back to contractors."
"Improved technical awareness/support during procurement and pricing activities. Implementation of training programmes to enhance and support national initiatives to grow and mature technical and trade skill capabilities."
"Better lifecycle considerations; 'minimum compliance' is the contractors attitude, quite rightly."
"Essential to have a robust tender/bid review process with the best available teams on both sides."
"Changing contracting frameworks. Getting more operational input at the beginning of projects."

5.6 Understanding the perception of construction participants to measure and influence operational failures

The perception of construction participants to measure and influence operational failure where judged through their perspective of their level of maturity and influence questionnaire. The results of these questionnaire provided a status of how quality cost was perceived by the construction stakeholders. Most quality cost elements were rated with a low level of maturity in capturing operational failure quality cost. This is in contrast with the quality managers' perception. In the organisational management context, with statements refined as poor alignment of project and operation capabilities, the result demonstrates poor information delivered within the construction supply network as a factor leading to operational failure. The ability to influence was perceived to be significant and most participants were confident about their capability to influence the operational failure, but expressed a need for integration among all supply networks.

Open-ended questions provided more specific understanding by showing the participants' unfamiliarity with the operational failure quality cost elements. This perhaps demonstrates the equivocally captured quality cost that may be interchangeable/overlaid in between the incurred cost elements. This requires better collaboration between members of the project supply network to make clear which cost elements were incurred and borne by who. There is a need to align the project aim to increase similarity in awareness among organisations about the operational failure quality cost. This finding raised further questions of *who* influences the implementation of advanced quality systems in reducing operational failure and *how* different organisations could best collaborate in aligning the project goal. The subsequent stage of the study was conducted to gather more insight in understanding COQ by exploring its existence in the project and operational context. This is further discussed in Chapter 6.

5.7 Quantifying operational failure and its quality cost

5.7.1 Operational failure quality cost elements that contributed to the operational failure

This study justified the need for a valid framework and mechanism to acknowledge and define COQ within organisations' capability and their project structure. Based on the COQ failure framework developed in study A, a card-sorting method was used to further test and quantify all the 13 quality cost elements in the exploratory case study. During the interviews, the first 15 minutes were used to ask the participant to select quality cost elements resulting from the operational failure within the specific project multi-case study. The participant was then asked to provide a cost estimate for the impact of this issue in each selected quality cost element in relation to their organisation. Table 5.11 show the distribution of operational failure quality cost elements selected by the participants during the first phase of case study exploration – Study C (ii).

Table 5.11: Distribution of quality cost elements in operational failure

	Project A							**Project B**			**Project D**		**Project C**				**Project E**				**Project F**			**Total**
Interviewee	**PM (1)**				**PM (7)**			**PM (2)**			**PM (4)**		**PM (3)**				**PM (5)**				**PM (6)**			
Project Budget	**£150m**				**£150m**						**£30m-50m**		**£30m**				**£30m**				**£30m**			
Operational failures	*I1*	*I2*	*I3*	*I4*	*I1*	*I2*	*I3*	*I1*	*I2*	*I3*	*I1*	*I2*	*I1*	*I2*	*I3*	*I4*	*I1*	*I2*	*I3*	*I4*	*I1*	*I2*	*I4*	
Who was involved																								
a. Owner/operator	●	●		●	●			●			●	●	●	●	●			●	●		●	●		
b. Integrator/main contractor	●	●	●	●	●			●				●	●	●	●	●		●	●		●	●		
c. Consultant/designer		●		●	●			●													●			
d. Supplier/sub-contractor	●				●							●												
Quality elements																								
1. Insurance costs			✓			✓	✓			✓		saving					✓				✓			7
2. Latent defect cost	✓	✓	✓		✓	✓	✓		✓				✓				✓				✓		✓	11
3. Safety costs for operators	✓	✓	✓								saving		✓				✓							6
4. Asset availability costs	✓		✓						✓	✓	saving	saving	✓	saving		✓	✓	saving	saving		✓	✓	✓	15
5. Energy use cost	✓										saving			saving					saving					4
6. Maintenance costs			✓	✓	✓	✓	✓	✓	✓	✓	saving	saving	✓	saving	saving		✓	✓	saving	✓		✓	✓	19
7. Environmental costs	✓	✓	✓												saving									4
8. Lifecycle performance costs		✓	✓	✓				✓	✓		saving	saving	✓	saving	saving			saving	saving			✓	✓	14
9. Functionality costs		✓	✓						✓		saving	saving			saving									6
10. Unadaptable costs			✓								saving			saving										3
11. Early obsolescence costs													✓				✓	✓						3
12. Reputation/Brand costs			✓			✓	✓				saving	saving				✓	✓						✓	8
13. Operational training/ readiness costs	✓	✓	✓		✓				✓	✓	saving		✓	✓						✓	✓			11
Total	6	6	11	2	3	4	4	2	5	3	9	6	7	6	4	2	7	4	4	2	4	3	5	

This table shows that different quality cost elements arise in different issues with at least two elements incurred in each operational failure. The table also demonstrates that not all operational failure resulted in quality cost failure, but it also provides the cost of quality savings. COQ is thus embedded and dynamic in the complex and evolving nature of project-based organisations. Among them all, ‘maintenance cost’, ‘asset availability cost’ and ‘lifecycle performance cost’ are what most frequently occurred across all five projects case study. Interestingly, the distribution of COQ at some point provides a long-term saving for some other quality cost elements; thus, COQ is interlinked. As an example, one interviewee explained that the cost of correcting quality issues leads to bigger savings for the long-term ‘maintenance’ and ‘lifecycle cost’ of a project. However, there was no concrete mechanism to capture these quality cost savings that reflects the benefits; thus, it is difficult to realise what needs to be done. In other savings, change of project specifications leads to longer functionality of an asset, thus providing cost savings. For poor quality, interviewees mainly referred to it as revisiting work where ultimately costs were based on actual cost as in the contract; thus, cost was captured by either the responsible contractor or supplier. In a complex system, cost was split into a different system; cost of poor quality or savings that was then not realised. This finding showed that the distribution of COQ is significant as it could have impacted the overall COQ failure differently based on project conditions.

Following this activity, participants were asked about the estimated cost of each selected quality cost element. However, not all participants were able to provide an estimated cost, although most were aware of the costs. Table 5.12 shows that almost all operational failure quality cost elements were captured and able to be quantified during the multi-case study. All figures mentioned by the participants were tabularised, analysed and summarised into content analysis, as shown in the table below.

Table 5.12: Percentage of operational failure quality cost in building and infrastructure projects

	Project type: Buildings, water treatment plant and infrastructure **Project cost: £20m- £77m**					
Quality Cost Elements **Value**	**£0-£100k**	**£101k-£500k**	**£501k-£1m**	**£1.1m-£5m**	**>£5.1m**	**Range of percentage (%)**
1. Insurance Costs		(A=1) 14%				14%
2. Latent Defect Costs	(C=2; E=1) 20%,20%, 30%	(E=3) 8%,8%, 17%	(A=1) 13%		(A=1) 7.8%	7.8%-20%
3. Safety Costs for Operators						
4. Asset Availability Costs	(E=1) 30%	(C=2; D=1) 40%, 12%,6%	(A=1) 9%	(C=2) 7%,9%		7%-40%
5. Energy Use Costs						
6. Maintenance Costs	(C=2, E2) 20%, 20%, 20%, 20%	(C=1) 15%	(E=1) 25%	(A=1, C=1, E=1) 18%, 6%, 9%	(B=1;C=1) 45%, 21%	15%-45%
6. Environmental Costs						
8. Lifecycle Performance Costs				(D=1) 13%		13%
9. Functionality Cost					(B=1) 50%	50%
10. Unadaptable						
11.Early Obsolescence						
12.Reputation/ Brand Cost/ Indirect Consequential Losses					(C=2) £400m, £50m	£50m-£400m
13. Operational Training/ Readiness Cost	(A=1) 10%					10%
14. Rectification Cost/New project					(A=1) 10%	10%

This table shows the estimated costs across the various infrastructure project types and project costs (which range from £0.1m to £400m) of quality cost values as judged by participants from the infrastructure client multi-case study (n= 26). The quantification of these costs demonstrates the breath in the percentage of cost incurred that is significant and that if managed will reduce operational failure. Most project in the multi-case study indicated that costs were shared/exchanged among the owner and the multi-organisational supply network. Overall, eight (n=8) quality cost elements were quantified, except 'safety costs for operator', 'energy use costs', 'environmental costs', 'unadaptable costs' and 'early obsolescence costs'. All cost percentages were coded according to the project type: A- Building car park, B- Water treatment plant, C- Infrastructure, D- Building escalator and E- Infrastructure runway.

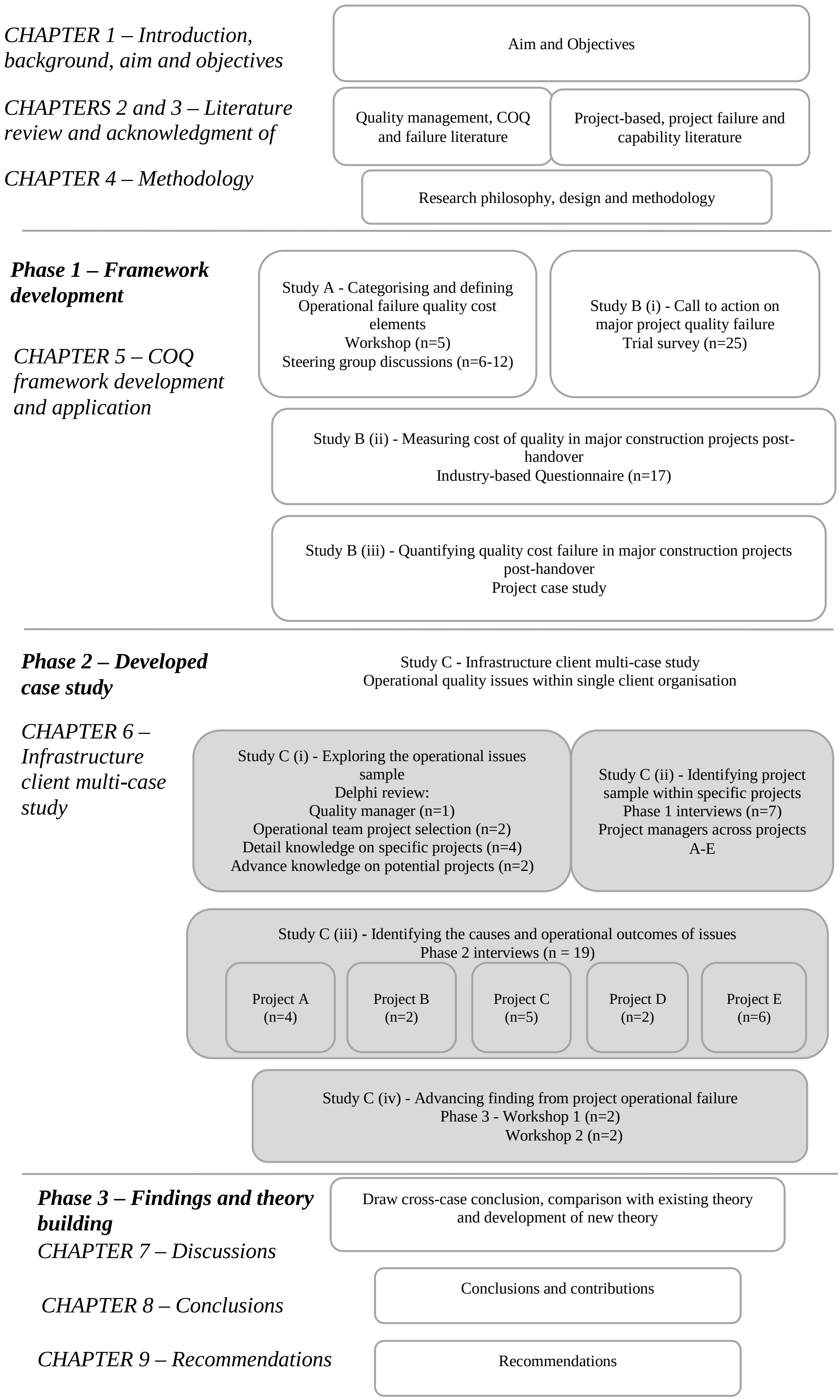
All the captured costs were first categorised into the value of £0-£100k, £101k-£500k, £501k-£1m, £1.1m- £5m or >5m, then simplified into cost percentage. The average percentages were calculated according to [value of quality cost element/project cost] x 100. More than five of the costs were quantified by different participants but have the same percentage range (i.e. latent defect cost and maintenance cost). This indicates that cost was almost certainly acknowledged by all the project participants. 'Asset availability cost' (7%-40%), 'maintenance cost' (15%-45%) and 'latent defect cost' (7.8%-20%) are the most quantified elements, while 'operational training and readiness cost' was the lowest, with only 10%, which ranged from £0 to £100m. This was followed by 'insurance cost' at 14%, ranging from £101 to £500m, and 'lifecycle performance cost' at 13% and £1.1-£5m of the total project cost. 'Reputation cost' was described by two participants as a potential cost incurred, and it ranged from £50m- to £400m.

The additional cost element was described by one of the participants as rectification cost/new project cost – element no 14 in Table 5.12. This element was described as a new budget for newly set-up projects to rectify the operational failures. In project A, a new project with 10% of the total cost was put in as a new budget to rectify the operational failure. This shows that COQ was not acknowledged as cost of failure but was rather allocated as a new budget to rectify failure. These costs were then fully the responsibility of the owner.

Due to the limitation of the research area, there are many more potential and actual costs of quality failure that could not be captured in this second phase of the study. However, the data obtained has helped to justify the complexity of capturing operational failure quality cost in construction projects. This has further helped the author to understand and clarify how operational failure has occurred and impacted the occurrences of COQ in the construction industry. The inter-dependency of each element was witnessed as one of the difficulties faced by the construction industry in quantifying operational failure and its quality cost. However, this proved the significance of quantifying COQ. By clarifying the extent to which the operational failure has impacted the supply network, the fair distribution of these COQ will promote an improvement in the share of project risk to align the project goal.

5.8 Chapter summary

This chapter has shown the development and application of a new COQ framework. Framework definitions and categorisations have been tested through an expert workshop. Pilot and questionnaire surveys have shown that the maturity and influence with regard to COQ is low in current construction projects, but also highly relevant. The preliminary findings have shown that there are a range of COQ failure measure that contribute to our understanding of operational failures. The estimated percentage of operational failure quality cost illustrates the range of quality cost failures that the owner and multi-organisational supply network could significantly reduce. The reason behind what constitutes each quality cost was further mapped through the wider context of project management and all of these reasons are illustrated in the following chapter.


CHAPTER 1 – Introduction, background, aim and objectives
Aim and Objectives
CHAPTERS 2 and 3 – Literature review and acknowledgment of
Quality management, COQ and failure literature
Project-based, project failure and capability literature
CHAPTER 4 – Methodology
Research philosophy, design and methodology
Phase 1 – Framework development
CHAPTER 5 – COQ framework development and application
Study A - Categorising and defining Operational failure quality cost elements
Workshop (n=5)
Steering group discussions (n=6-12)
Study B (i) - Call to action on major project quality failure
Trial survey (n=25)
Study B (ii) - Measuring cost of quality in major construction projects post-handover
Industry-based Questionnaire (n=17)
Study B (iii) - Quantifying quality cost failure in major construction projects post-handover
Project case study
Phase 2 – Developed case study
Study C - Infrastructure client multi-case study
Operational quality issues within single client organisation
CHAPTER 6 – Infrastructure client multi-case study
Study C (i) - Exploring the operational issues sample
Delphi review:
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on specific projects (n=4)
Advance knowledge on potential projects (n=2)
Study C (ii) - Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) - Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) - Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

6 Infrastructure Owner Multi-Case Study

6.1 Introduction

This chapter will present, analyse and describe the findings from data collected in the fulfilment of this thesis aim. The focus on the exploration of the operational failure within complex infrastructure projects is thus presented, illustrated and described based on Phase 2 – the developed case study from Study C (i), (ii), (iii) and (iv). The multi-case study was explored through interviews as follows:

1. Study C (i) and (ii)- To understand the knowledge of COQ within an owner organisation and its link into operational projects.
    - Five (n= 1-4) one- to two-hour sessions of Delphi review in exploring the operational failures sample
    - Stage 1, one-hour interview (n= 7) to identify project sample within project-specific case study
2. Study C (iii) – To explore the emergent causes of operational failure
    - Stage 2, one-hour interview (n=19) to identify the causes and operational outcomes of issues
3. Study C (iv) – To validate and generalise the extent of operational failure
    - Two (n= 2) two- to three-hour workshops to advance findings from operational failure

In other words, the aim of this phase of multi-case study exploration is to understand and describe the occurrences of operational failure in terms of: (a) confirming the status of operational failure quality costs in relation to the occurrences of operational failures, operational failures and their influence on future learning, and (b) the causes behind these operational failures. Further, based on the first stage of the methodological framework, as ascribed in Chapter 5, the application of the COQ measure in the construction industry was also examined and is explained in section 6.2. As such, this chapter establishes a framework that is starting to inform the collection of data in characterising the capabilities for failure mitigation. Validating and generalising the extent of the relationship between operational failure and its quality cost demonstrates the project-specific nature and content in forming the capabilities for failure mitigation.

6.2 The status of knowledge about COQ

6.2.1 Understanding the knowledge of COQ amongst case study participants

Multi-case study participants showed that COQ is well perceived, but the level of understanding differed according to participant role. This shows the breadth of COQ maturity amongst the project-based organisation's participants. A card-sorting approach was used to help participants to evaluate their own experience and, as mentioned by

Canter et al. (1985) cited in Budhwar (2000), the categories and concepts used in practice were elicited to provide a view of an individual's cognition. During the interviews, 13 elements of operational failure quality cost elements were used. Each element was written on a separate card with a standard definition and represented the initial 'construct'. The participant was asked questions around these cards, and carried out sorting to determine priorities and to describe information based on their individual concepts of categories. Card sorting describes 'an outcome of one's preference, experience, identification, memory and learning that can have profound effects upon individual's inferences and behaviours' (Budhwar, 2000); it provided an understanding of the causal relationship between the COQ elements and their outcomes (e.g. measures of operational failure in project delivery). The card-sorting process is described in Figure 6.1.

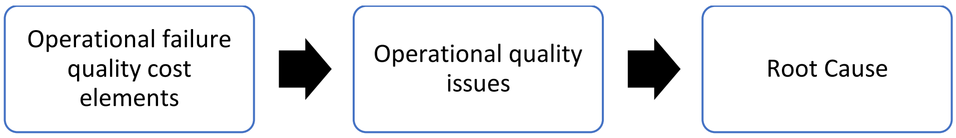


Figure 6.1: The card-sorting process

Table 6.1 shows participants' knowledge of operational failure quality cost and operational failure and participants' perceived level of their influence for future improvement. It shows that the quality managers have a range of knowledge of COQ elements and the values of the quality cost elements involved as well as the impact of operational failure, and this may have a strong influence for future learning. The project managers have a high level of understanding of the operational failure, both towards its impact and the root cause. However, they are not aware of the quality cost that has been incurred due to the failure. The commercial manager could explain the COQ elements and values, but could not describe the root cause of operational failure. For the asset manager and project engineers, they were better at communicating the operational failure issue in terms of its technicality. Lastly, the onsite transformation leads were able to explain the COQ and the operational failure, but may have less confidence in influencing future learning.

Every participant was influenced by their contextual setting in describing the operational quality issues. This table shows that the information was not consistently transferred among the project supply network, due to the immaturity in measuring and defining COQ. The quality cost elements were not ascribed constantly and thus were unquantifiable by most construction participants. Consequently, the interviews illustrated that quality was not well defined and expectations differed between individuals from different contexts. Thus, different goals, behaviours and cultures for quality were shown to exist in complex multi-organisational supply networks.

Table 6.1: Case study participants' knowledge of operational failure cost

Knowledge of operational failure cost								
		Cost of quality		**Operational failure**			**Influence**	
Profession	Quantity	Quality cost elements involved	Value of the failure	Awareness of quality issue	Impact on project stakeholder	Root cause	To make a correction	Learning for future projects
Quality manager	**2**							
Project manager	**7**							
Commercial manager/ contract lead	**1**							
Maintenance manager	**1**							
Asset manager	**1**							
Project engineer	**3**							
Onsite transformation lead	**4**							
Total	**19**							

Chapter 5, Table 5.12 showed that most of the operational failure issue costs between £0.1 million and £400 million. In study C, all participants showed high awareness of operational failure, but the expertise and the responsibility for resolving the quality issues to reduce failure was still in doubt. Also, most participants were not aware of who was responsible for the quality costs. Table 6.2 demonstrates the number of quality failure cost elements selected by the experts during the exploration of multi-case study in Study C (ii) and (iii). All elements were selected more than once in almost all projects. One element, 'early obsolescence', was only selected in two projects (C and E). Energy use costs, environmental cost and early obsolesces cost were selected as the least important of the elements. A particularly important element is 'maintenance cost'; overall, this was selected 31 times. Different projects show a different range of quality cost incurred with different awareness on quality cost selected. Project B shows the lowest selection among all quality cost elements and Project A and E has more range on the selected quality cost with average 2-7 times on most quality cost elements.

Table 6.2: Cost of quality failure elements selected in specific project of the multi-case study

Quality cost elements	Project A	Project B	Project C	Project D	Project E	Total no. selected
1. Insurance cost	6	1	1		2	10
2. Latent defect cost	7	1	6	2	7	23
3. Safety cost for operator	4	1	3	1		20
4. Asset availability costs	2	2	7	3	7	21
5. Energy use costs	1		2	1	2	6
6. Maintenance costs	6	4		2		**31**
7. Environmental costs	3	1	1		1	6
8. Lifecycle performance costs	4	2	5	2		21
9. Functionality costs	2	2	1	2	2	9
10. Unadaptable costs	1		2	1	3	7
11. Early Obsolescence costs			2		4	6
12. Reputation/Brand cost/ Indirect consequential losses	5	1	5	2	5	18
13. Operational training/ readiness costs	6	3	6	1	4	20

6.2.2 Benefits and risks in the application of cost of quality

There was an agreement on the relationship of COQ incurred and the occurrences of operational failure in all projects case study. However, there was still lack of understanding about its measure and application within project-based organisations. Table 6.3 shows a summary of the benefits and risks of the application of COQ observed and discussed within the multi-case study and steering group. The findings show there were benefits and risks perceived in combination with how COQ was understood by the steering group (SG) members, and why it was not understood by the industry through exploration of the case study (CS). The combination demonstrates why COQ and operational failures were not well understood by owner, contractor, suppliers, facilities management or design consultant. This shows the need of integrated approach to align and rationalise the fragility of ‘non-standardisation’, ‘poor definition’ and ‘un-quantification’ of quality failure cost in construction projects.

Table 6.3: Benefits and risks of the application of COQ

	Owner/Owner	Contractor/Integrator	Supplier	Facilities Management	Designer/Consultant
Benefits of understanding the CoQ	Increase co-learning from operational failures (CS) Conformance to specification (CS) Understanding opportunity for improvement (CS, SG) Ability to intervene when a project is failing (CS, SG) Ensured project scope (CS) Reducing cost of poor quality Increase opportunity for profit sharing (CS) Maintaining a good and collaborative relationship with supply network (CS, SG)	Conformance to specification (CS) Understanding opportunities for improvement (CS, SG) Reducing cost of poor quality (CS) Increase profitability (CS) Ensured project scope (CS) Maintaining a good relationship with the owner (CS) Create a collaborative relationship with the supplier (CS, SG) Increase project margin by becoming a high-ranking contractor (SG) Discovered new opportunity for innovation (CS)	Conformance to specification (SC) Understanding opportunities for improvement (CS, SG) Reducing cost of poor quality (CS) Increase profitability (CS) Managing project systematically (CS) Ensured project scope (CS) Maintaining a good relationship with owner (CS, SG) Discover new opportunity for innovation (CS, SG)	Improved operation and assets delivery (CS, SG) Increased competence in response to operational failure (SG) Improve ability to share knowledge for service department in terms of action needed (SG)	Understanding opportunities for improvement (SG) Expedite information transferred to delivery integrator (CS, SG) Strong cooperation with delivery team for instant response to operational failure (SG)
Barriers to understanding the CoQ	Exposing organisation weakness and loss (CS) Reputational damage with customers (end users) (CS, SG) Friction in the relationship with supply network(CS) Internal conflicts, creating blame culture (CS) Exposed internal conflicts, creating blame culture (CS, SG) Discontinuity with tactical operation delivery aim (CS) Misalignment with external parties (CS, SG) (different organisational process/ quality and risk definition)	Exposing weakness (CS) Reputational damaged with owner (CS, SG) Judging and perception by others (CS) Hinder opportunity for further project award (CS) Downstream reputation within industry (CS) Internal conflicts, creating blame culture (CS, SG) Discontinuity with tactical operation delivery aim (CS)	Exposing weakness (CS) Friction in the relationship with owner (CS, SG) Downstream reputation within industry (CS) Internal conflicts, creating blame culture (CS) Discontinuity with tactical operation delivery aim (SG) Unsecure product sales (CS, SG)	Create culture barriers in organisation, blaming culture (CS, SG) Causes and weakness of operational failures were not understandable (CS, SG) Lack of learning (SG) Limited ability to plan for future prevention and appraisal, dealing with uncertainty (SG)	Poor collaboration with project stakeholders (SG) Create culture barriers in organisation, blaming culture (CS, SG) Designed to fail (SG) Causes and weakness of operational failures were not understandable (SG) Lack of learning (SG)

By looking at the operational failures and its quality cost, the data shows that more benefits could be achieved. These include: increases co-learning from operational failures, ability to intervene when a project is failing, provides conformance and clarity on project scope, better understanding of opportunity for improvement, maintaining a good and collaborative relationship between supply network, projects are managed more systematically, as well as increased profitability and greater opportunity for innovation. These are also beneficial for the facility management to increase competency in responding to operational failures for better prevention and problem solving. For the designers, better understanding of operational failure and its quality cost results in stronger cooperation with the delivery team in responding to operational failures, where information transferred can be expedited.

However, quality costs were frequently overshadowed by the negative outcomes (barrier of understanding COQ) relating to their application. Participants from the multi-case study have expressed the barriers in applying COQ as it will have exposed the organisation's weakness and losses that will give reputational damage towards their owner for the contractor and towards the customers and user for the owner. Consequently, for the project supply network, the discussion on COQ barriers has pointed out further friction for the whole multi-organisational relationship, which will create internal conflict and a blame culture. For the contractor and suppliers, there was a belief that the supply network may have a possibility to 'discontinue with the tactical operational delivery aim', which will hinder the opportunity for future project awards. This will further lower their reputation within the industry. Frequently, there was a fear of what the outcome could be. Consequently, the study acknowledged that poor understanding of COQ during operation will lead to wrong information delivery, lack of learning from failure and frequently lead to designed to fail.

This data supports the belief that attention is not paid to operational failures and its quality cost experienced by the construction industry. This has been validated by the steering group meetings, which included construction industry participants who have acknowledged the importance of its application.

6.3 Project context and structure and its influence on operational delivery

Table 6.4 lists all the five project multi-case study and shows the different quality issues that were articulated by project managers during the first phase interviews. These quality issues were further quantified by all other interviewees. From all the operational failures, not every operational failure has impacted quality cost failure. Some operational failures have demonstrated quality cost saving. This has impacted on how the quality issue was prevented and appraised.

Table 6.4: Details of the quality issues experienced by the multi-case study projects

Project type	Project budget	Project cost	Project duration	Operational failures	Cost of quality failure	Cost of quality saving
Project A – Buildings (Car Park)	£150m	£77m	3 years	Incomplete ducting for street lighting resulted in abortive cost from UK power network.	X	
				Poor drainage, design and installation. Not cleaned appropriately (e.g. asphalt blocked)	X	
				Level 50 leaks and patches due to poor water tightness.	X	
				Ponding at level 50 due to poor quality construction of asphalt being laid.	X	
				Floor leaking at forecourt due to poor waterproofing.	X	
				Water bubbles at floor decking (level 10) due to concrete plank system.	X	
				Emergency exit sign turns off during testing		X
Project B – Water Treatment Plant	£10-20m	£20m	5 years and more	Non-compliance chemicals were used to dilute mixed fluid.	X	
				Silt clogging the grip blaster.	X	
				High detergent used causes foaming.	X	
Project C – Infrastructure (Track Transit System)	£31m	£33m	3 years	Vinyl flooring tiles lifting and bubbling.	X	
				Adaptable passenger conveyor was easy to maintain and delivered OPEX saving.		X
				Changing LED lighting specification to one that is cheaper to maintain.		X
				New car and platform to support the TTS system successfully introduced.		X
Project D – Buildings (Escalator)	£40m	£38m	3 years	Introduction of parallel system to the security operation.		X
				Escalator failing on a daily	X	

				basis due to difficulty in coordination with maintenance worker.		
Project E – Infrastructure (Runway)	£50m	£50m	2 years	High ambient air temperatures and engine blast heating cause runway to develop ‘elephant feet’.	X	
				Long-term crack treatment with asphalt increased life of the runway’s overall surface.		X
				Tungsten lamp changed to LED lighting that lasts longer.		X
				The mud flap laid in together with asphalt caused break up on the runway.	X	
				Cleaning machine for airplane tyre rubber used on the runway destroying the asphalt due to its high power.	X	
				Old joints underneath runway cause cracking because no treatment made.	X	

6.4 Summaries of the backgrounds to the multi-case study projects

6.4.1 Project A – Building (car park)

This project has delivered a multi-storey car park. The project was constructed within three years and, at the point when the interviews were conducted, the car park was partly handed over. It was not fully handed over due to unresolved technical issues, leading to operational failures. The main contractor had a long-term relationship with the owner and was involved in all the remedial works, in order to fully hand the project over to the owner.

6.4.2 Project B – Water treatment plant

This project was initiated in order to offer water treatment capability to the owner as an alternative to moving the polluted water off site to be treated. A new water treatment facility has been built; however, due to several issues around the operability and handling of the system, it has not been possible to use the asset for a few years following completion and handover to the owner. There has been difficulty in getting the project operationally ready, which has created major COQ failure throughout the years.

6.4.3 Project C – Track transit system

This project was created in response to passenger congestion issues at an airport terminal. An underground walkway project was set up to connect three buildings in supporting the system to transport people from building to building. Within this project, there are four outcomes that were pointed out by the project manager during the first stage of the interview. Three of the outcomes were positive (successes), which were linked to cost of quality savings, and one outcome has contributed to cost of quality failure.

6.4.4 Project D – Building escalator

Project D was delivering an additional escalator at a security area, in order to optimise the waiting time in this area. Thus, the project was constructed in a live operational area and included structural work between two floors. The works included fitment of the escalator, removal of an existing retail shop, creation of a baggage system and a travel escalator for people. This project is included as one that had a positive impact on COQ savings. Although there was an issue that led to external quality cost failure, this was effectively resolved and resulted in long-term cost savings.

6.4.5 Project E – Infrastructure (runway)

This project was fundamentally a maintenance project. In airport runways, the maintenance work involves removing old asphalt and relaying new asphalt every 10 years and conducting major maintenance every 30 years. This project delivered major resurface works on two runways. The case study explored the project outcomes, which led to six operational failures – four contributed to the quality cost failure and two provided quality cost savings.

6.5 The emergent causes of operational failure

From the analysis, empirical data shows the distribution of capabilities in a project influence the occurrences of operational failures. In this section, the data demonstrates *what* causes the operational failure and *when* it occurred. Data was translated into three cycles of: (1) *transferring capability*, which explains the transformation of capabilities from owner requirement towards the project capability at the initial stage of a project; (2) *applying capability*, which explains the application of capabilities from the project brief during execution towards asset operations; and (3) *recognising capability,* which explains the new capabilities acquired to operate an asset and how project teams could improvise and learn in mitigating future failure. These three key aspects of the distribution of capabilities are described in the following sub-sections. Detailed data was all tabularised and is provided in Appendix 3.

6.5.1 Transferring capability

The distribution of capabilities by the owner during the transferring capability phase was influenced by four factors, which are: contracted end date, accuracy of project cost, relationship with supply network and demanding regulations. Table 6.5 shows the evidential examples of triggered factors of failure and their implications for project capability from the multi-case study projects.

Table 6.5: Triggered factors of failure and their implications for project capability during the transferring capability phase

Triggered factor of failure	*Evidential examples from the cases*
Contracted end date	"… we had assurance …, [contractor] had assurance and … second tier of supply they had assurance [but still] we get into a situation where everybody took a picture of something that was wrong… people didn't know what they were doing. ...some of it is, was time constraint because it was slightly behind and we need to get it finished…but if they look back now for the sake of a week or to two weeks then they could have finished it right the first time rather than come back and do things again."[Project A- A7- Owner project manager] "…if we produced a programme of works that went beyond their end date then we were unlikely to win that work. So… we would have been influenced by that end date. In a competitive world, you want to win the work… would you try and achieve something that you couldn't to win that work?" [Project C- C8-Contractor's quality manager]
Allocation of budget to fit project specification	"…they'd missed out half the things…we knew it was going to cost more than £77 million, so the final account included a number of elements where we added scope …" [Project A-A11-client commercial manager] "…we needed to get the engineering team to look at how they would maintain [and]... its all other contain; like engineering and operations. [to determine] how much time they have to spend on it …and the long term contract …" [Project B-B2- Client project manager]
Relationship with supply network to integrate project capability	"…[the contractor] are an organisation that have worked with [client] for many years. They were part of the joint venture ...for us and they are more than interested in supporting us on [other projects] etc. So, they know as an organisation that they need to sort this out. To just walk away …wouldn't be a sensible position for them to be in." [Project A-A11-client commercial manager "...Because of this relationship that [client] had with [supplier]… they were called in…should be at our end of the chain ..[to give] us advice and helping us to do the job. [but]..came in almost like a bullying, … with [client] next to them, there was a telling off, which felt completely wrong. And it shows you that the choice was made on [client's] side and we were just the installer. " [Project C- C9-Contractor project manager]
Reflecting project scope with demanding regulations	"If we do not do this, we will remain non compliant. Which means Thames Water can stop us from operating. That's the ultimate penalty to us. They can fine us millions. I think it's an unlimited fine…Thames Water, the Environmental Agency, came back to us and said, "We want you to exceed our levels and give us a better quality of water going into the river beds, into the system"… there's a reputational part there if we can deliver it… We're doing something for the environment. But if we don't do it, take away our licence to operate." [Project B-

	B18-Owner maintenance manager] “..due to the life of the tungsten lamp, [they] needed to be changed every 6 months, so we’ve now stuck LEDs in the whole thing, and they last for 10 years. So huge maintenance reduction, and operational cost of changing fittings continuously…”[Project E-E16-Owner airfield transformation manager]

(i) Contracted end date

Four out of the five projects showed that critical time for project completion significantly influenced operational failures. One project was abandoned while others absorbed the high quality cost failure. In the majority of these cases, the project end date was described as a fixed date or not moveable. The contractor described working to a critical date of completion as a ‘pressurised’ environment with interconnected works with multi-organisational, which led to poor work performance. In project A, less focus was given to project quality control due to the critical opening date. There was a limited time provided for the project team to work towards the anticipated quality in organising the programmed work. Thus, project processes were not followed accordingly and the project team was more focused on technical assurance rather than looking into the quality assurance that the work was focused on the need to complete.

Additionally, in complex projects C and E, the owner was restricted to project interdependency between projects to avoid an operational penalty; delay in one project will impact the owner’s other operation system. The contract for project C was structured with ‘payment milestone’ as a performance indicator for the contractor to ensure work was completed on time. Payment was given when the targeted milestone was achieved. However, empirical data showed the contracted end date changed the culture and behaviour of the project team. This influenced the contractor’s capability to maintain their work performance for the owner rather than performing in accordance to effective project quality implementation. Sub-contractors who were appointed late followed the initial owner’s work programme; thus, the suppliers’ work programmes were similarly in ‘critical time’. Regardless of the operation risk, the appointment of the contractor and suppliers was based on the poor work programme, and this impacted the execution of works and reworks. Therefore, the procurement process that was driven by the project completion date has resulted in poor-quality construction because of the project team. In project E, quality implementation was described as being only perceived partially or system-by-system basis, rather than being integrated with the whole project quality system. Quality was assessed according to part-by-part of the system and location due to the need to meet each system's critical operational date. In some sections, the project proceeded although the project team was aware about the possibility of failure implications. Delivery managers made the decision to construct with minimum maintenance for a quicker job and to complete more areas. As a result, the lifecycle of the asset decreased sooner than expected. Cost was perceived to be higher when the project execution covered only minimal works due to extensive reworks.

Within this factor, the culture and behaviour of the project team appeared to be more focused on completing the project, rather than working towards 'getting it right, first time'. Frequently, quality assurance was hindered; technical details and quality were given less prominence than project execution of the critical work programme (i.e. quality issues were not fixed). Although project A showed that quality issues were reviewed by the project technical team, prevention did not occur instantly, which led to quality issues at completion. The project was claimed to be poorly constructed. Similarly, in projects C and E, work was constructed with the awareness of failure implications, but the project teams would rather complete it first then fix the issues later. Therefore, critical time frequently had a negative effect on the operation.

(ii) Allocation of project budget to fit project specification

Cost was another factor that led to high recurrence of operational failure, as shown in projects A, C and E. The project budget was set according to the estimated cost, which led to different decisions being made during project execution. This influenced the owner's decisions to appoint a contractor with the lowest cost, buy cheaper material and in designing the project. Most of the project quality failure costs were only realised in hindsight. In Project A, the owner felt certain that, by appointing the lowest-bid contractor, the project would cost more than the project budget. However, the owner still assumed that the contractor would have the capability to construct according to the promising cost. However, the project required additional input and scope, which resulted in quality cost failure during operations. The contractor accepted the project at a low cost to secure a good relationship with the owner, but the owner only saw the low cost as a benefit to achieve lower project cost. Hence, within the limited cost constraint, the cost pressure was mainly adhered to by the contractor during the construction, but not by the owner. This has influenced the different quality cultures and expectations of capabilities that were transferred to the project.

In Project C, due to the limited project budget, the owner selected cheaper materials and nominated their preferred supplier. This caused some difficulties for the contractor to apply and maintain an unfamiliar product within a complex project environment. The unsuitability of the product was not realised by the owner or supplier during the planning stage, but the poor performance of the product resulted in high maintenance cost and early obsolescence during operations. Project managers may only see the functionality of the project but not the cost implications. Also, in project C, there was no budget allocated for operational problems; thus, this influenced how the contractor provided options on solutions to fix the problems. This has thus increased the total quality cost failure when problems are only fixed temporarily.

Project E showed a limited project budget, which led to limitations in delivering project innovations. The project was constructed using the same old design in delivering the maintenance programme. Thus, it became apparent that the project had not included enough treatment frequency for maintaining the runway, and the treatment was later shown to be unsuitable for the project's recent conditions. This later caused poor quality of the asset during the complex operations. Moreover, there was uncertainty about the project cost as product costs were frequently changing after years of planning. This influenced how the project team made the decision to allocate an appropriate estimate to allow for the fluctuation of cost. The cost incurred at operational level was later absorbed and borne through reducing other operational elements such as the maintenance cost. This again affected the long-term maintenance cost.

Empirical data showed that the owner was not aware of the construction failure cost but frequently suffered with many costs after the asset was operationalised. Thus, the owner needs to better understand both project and operational capability to balance the capabilities that drive a better quality culture, as the owner and the multi-organisational supply network may share the same failure cost responsibilities. Data also showed that the quality costs may not have been realised by the project team during construction but were absorbed differently by the owner and the contractor. This shows that the project innovation was not fully promoted by the team, who were frequently restricted by the budget. Hence, more information should be shared among the project team in making different decisions that should incorporate owner and multi-organisational supply network knowledge to mitigate failure. Failure mitigation should be based on their own experience as well as on the contractor's experience.

(iii) Relationship with supply network to integrate project capability

The owner's selection of a preferred contractor or suppliers has several implications for how a project is procured. This has shown both positive and negative effects on the project performance. Although a long-term relationship helps the owner to save time in gaining trust and familiarity with a contractor's past experience, it does not ensure that the contractor has the capability to perform. In project A, the long-term relationship between the contractor and owner provided more job opportunities for the contractor but did not prevent quality issues from one project to another. When the same contractor was selected for two similar projects, although that contractor was comfortable in delivering the same project, they had less initiative to provide improvements. This led to the owner receiving the same operational failure from the two similar projects. What was evident was the long-term relationship provided assurance for the contractor to complete and rework the quality issues, but did not prevent or mitigate future failure; thus, quality cost failure was still transferred and borne by different parties from one project to the other.

Project B showed the need to have a specialist in constructing the new product, but the project relied on contractor and supplier capability to provide product innovation. However, suppliers who have less understanding of the owner's operational needs only want to sell the product. This makes it difficult for the owner to operate, and the owner assumed that the supplier would be responsible for solving the problem. The supplier could not cope with the complexity, and thus abandoned the project. The project was further continued by the other supplier who provided a warranty to assure that the product could be fixed, but the product became more complex. Consequently, this project showed that a product warranty does not ensure the initiative will be taken to improve project performance, but only ensures that the supplier will stay with the owner to fix the problem. The new supplier was still able to leave the project once the warranty was over, and the product was still un-operationalised. Project C showed that a stronger relationship between the owner and the supplier led to fragmentation of the relationship between the contractor and the nominated supplier. The contractor found it difficult to influence the selection of material, as the nominated supplier provided greater assurance to the owner. This further influenced the project operations when the material was found to be unsuitable. Although the contractor had predicted the unsuitability of the material for the operational environment, the supplier was confident about the suitability of the product. This left the contractor with no ability to intervene in relation to the quality issues and they only managed to agree about the installation of the product; to ensure they obtained the supplier's approval for that installation and got the warranty approval. The owner perceived that it was the contractor's responsibility to fix operational failure as a long-term performance indicator to maintain a good business relationship; hence, the contractor had to absorb the quality cost failure to ensure the problem was fixed. Thus, no intervention was made on the unsuitability of the material as the contractor needed to comply with the owner's specifications.

Similarly, in Project E, contractor and suppliers were committed to fix the operational problem to ensure a good relationship with the owner; thus, the owner frequently relied on the suppliers' capability to fix the operational failure. Although operational failure were frequently repeated, the owner presumed it was a temporary problem; thus, initiatives were not taken to prevent or appraise the operational failures. The case study indicates that, as operational failures were commonly referred back to the contractor, the project team was more focused on delivering the asset and put operational failures as less important.

(iv) Reflecting project scope with demanding regulations

A complex project with demanding regulations needs configurations and innovation on project capabilities. Project B demonstrated a high demand on regulations and the need for new technology, which led to project abandonment. This caused the project to be completed with high asset availability cost. The project was restricted to non-compliance towards environmental regulations, which was not resolved due to the need for new capability involving a specialist. The project faced non-compliance with environment issues such as pollution and also interruption of other system operations. The complexity in the regulations caused high COQ for the owner and termination for the contractor who is not capable. Although quality issues were acknowledged by the owner early in the process, the contractor assured them that the project would not fail. However, during execution, the contractor was unable to cope with the complexity. The demanding regulations needed the owner to integrate the contractor's capability with the operational technical capability to better understand the capabilities needed for the project. This can only be achieved by early involvement from a specialist, to research the feasibilities needed for the complex project and provide innovation in the form of new technology.

Project E was frequently restricted by airline regulations about not closing the runway for more than a few hours; thus, the project was always critical to operations. This meant that the project team was less able to provide innovations within the limited time. The contractor does not predict the operational problem, only design the project based on the critical working window to ensure the project is successfully delivered.

6.5.2 *Applying capability*

This section illustrates how the application of capabilities from their distribution during the project brief has implications for the asset's operations capability. This study shows that the application of capabilities was influenced by the project team's understanding of real-life operational technicalities and constraints in design, contractor expertise and resources, and technical competency relating to on-site operations. Table 6.6 below shows the evidential examples of triggered factors of failure and their implications for operational capability from the project multi-case study.

Table 6.6: Triggered factors of failure and their implications for operational capability during application of the capability phase

Triggered factor of failure	*Evidential examples from the cases*
Understanding of real-life operational technicalities and constraints in design	"I would say quite a bit of these are construction related issues, quality control on site. Some of it will be design related in terms of the detailing. Sometimes you may get such a detail come back from the designer which looks good, but actually when you give it to somebody to try and build out on the site you can't build what they've drawn." [Project A-A14-Owner project engineer] "…so [client] make the decisions but the designer develops it and says, 'What do you think?' And they struggle, because they don't deliver the job, they don't get the learning we're getting." [Project C-C9-Contractor project manager] "I'd imagine it would have been heavily design-related in terms of aesthetics. I imagine it would have been aesthetics over function, because all of us have said numerous times that with the benefit of hindsight I think all of us would have just polished the floor." [Project C-C10-Owner quality manager]
Trusting the contractor's expertise and resources	"In theory if it had been done to the detail provided by the designer it should have worked but it wasn't done…it wasn't as the designer specified…no top hat detail so the water went down the hole." [Project A-A7-Owner project manager] "…but when we came to build it they (contractor) didn't follow that process." [Project A-A14-Owner project engineer] "…then [they repeat] exactly, same design, same specification and then you get the same issues." [Project A-A14-Owner project engineer]
Technical competency in on-site operations	" [state] "you're the builder, you're the professional, let us know if you've got any problems"... but that model is completely different to what we do ... we don't really have the technical team to do inspections or anything like that" [Project A-A1-Owner project manager] "... so we're going back to projects to try and get that resolved. But again it's what you can see, and with self-certification there's a lot which we can't see. " [Project A-A14-Owner project engineer] "But what is interesting is we don't do the design ourselves. In anything. We didn't do the design not even in [other] project. However, this particular one is so different from what we do that we have no expertise at all…if we were to start again, I cannot see what we could have done differently." [Project B-B18-Owner maintenance manager]

(i) Understanding of real-life operational technicalities and constraints in design

Four out of the five projects showed that project design influenced asset operations. Designers frequently designed the project according to the owner's needs, but there was a lack of capability to include different knowledge from different phases of the project. This was described as designers were only involved during project development and thus had limited knowledge about project execution and operations. Project A revealed that the complex design detail, which was compounded by not being integrated with the contractor's capability to build, hindered quality control during construction. The contractor, who had limited technical competency in on-site operations, was not able to build the complex design. Not having the right capability to apply led to the contractor constructing the project according to their own experience and knowledge, which resulted in a poor-quality presentation.

Projects B and C were designed without involving the contractor at the initial stage. Project B's design was developed later by the contractor based on the options provided by the owner. The options were designed according to the suppliers' suggestions on how the system could be operated but during execution the contractor could not construct the complex system, thus the asset was not workable. Operational failures were not resolved and understandable, and the project currently has a high COQ. Thus, the system was not designed in the way that it should have been, dealing with the construction process and operations environment. The designer sees the need to satisfy the owner's aesthetical requirement but has not reflected it with the owner's operational environment. Project C showed that the designer was limited by the owner's specifications, and so the project suffered due to the wrong selection of material. The contractor experienced technical difficulties due to the poor design but had no opportunity to influence the selection, which led to quality issues during operations.

Projects A and E showed that operational failures were perceived due to the used of an old design that did not fit the current operations environment. Also, operational failures were fixed and referred to the old design; thus, they were not effectively resolved. Therefore, the project faced difficulties in providing continuous understanding based on in-operative design; thus, solutions that were compatible with the current conditions could not be achieved. Project E suffered from more maintenance costs in less than one year after completion than the expected 10-year lifecycle of the asset. The project team frequently worked with the supplier to resolve the operational failures without the involvement of the designers; thus, the design was not updated to reflect operational failures. Issues were then repeated on similar projects. Project managers always see operational issues as the process embedded within their work routine rather than as quality problems, as they are only seen after completion. Due to this, operational issues were not prevented and appraised to mitigate future failure.

(ii) Trusting the contractor's expertise and resources

Empirical data demonstrated that a project needs the owner's involvement to carefully understand the contractor's capability as it affects project performance. Data showed that the owner's technical expertise was pertinent in terms of transferring operations input as the contractor may not be fully aware of the owner's unique operations environment. Owners were perhaps over-reliant on contractors' competency, and contractors who had limited influence on project procurement did their best to construct the asset according to the owner's requirement. In all projects, the owner trusted the contractor's capability to construct, but projects A and C showed poor performance after the construction, which led to the projects' non-compliance, to their owners' dissatisfaction. In both projects, the owner trusted that the contractor would comply with quality standards, but operational complexity needs continuous quality support from all parties to ensure project success. Contractors who focus on execution may not be aware of the quality cost for operations; thus, project quality was focused on to be delivered at the targeted time and cost. As a result, maintenance was difficult due to the poor construction.

The build for Project C continued even though the contractor was aware of the unsuitability of the selected product, and this led to the asset's poor quality during operations. Quality issues were frequently only notified by the owner's representatives at completion rather than by the contractor's delivery integrator during execution. Contractors always see completing on time as necessary to maintain their good reputation and relationship with the owner, while quality issues are commonly resolved as rework during operations. This resultant quality cost is absorbed as part of the day-to-day operational cost (i.e. maintenance, lifecycle or asset ability cost). The divergence of project performance expectation resulted in different quality expectations; thus, quality issues were not understood at project execution.

Quality control is always placed as the contractor's responsibility when the owner trusts the contractor's capability. However, in Project E the operating team was challenged with continuous quality issues that were difficult to understand because they had no knowledge of how the asset had been constructed. Although the project was constructed by an experienced contractor, quality issues were not prevented or resolved.

In Project D, it was difficult for suppliers to work together to fix the quality issues due to their unfamiliarity with the technical aspect. Although the owner provided early involvement for suppliers to get to know the material used, there were still discrepancy between the project team and the suppliers on technical capability to construct. This led to different organisations making different decisions that were not aligned with the whole supply and operator network.

(iii) Project team's technical competency in on-site operations

Empirical data showed the importance of strong capabilities within the project team. In most cases, poor competency meant problems were not identified early, which meant operational failure was not prevented and appraised at the right time. Owners assume contractors are more responsible, thus the owner's technical expertise was less valued by the project team, who assumed that the contractor had full understanding of the owner's operational environment. In some cases, the owner did not have the technical expertise, and thus fully relied on the contractor's technical competency. In other way, contractors believed owners should provide some insight when they needed that as, through integration of technical expectations, operational failures could be better prevented.

In Project B, the project team faced difficulties in operating the new asset due to demanding requirements in the operational environment that required more information and higher knowledge. Projects C and D showed complex design and technical problems that were not understood and resolved by the contractor due to limited capabilities. The projects indicated that operational capabilities were not integrated during the project execution, which led to the project not performing. Moreover, in some cases, less emphasis on the technical expertise role created a low level of motivation among the technical experts. Quality issues were not critically solved and thus indirectly resulted in poor learning capabilities, because each specialist tended to work according to their individual assignment rather than integrating the systems.

Project A was also a complex project that experienced difficulties during operations due to the limited technical capabilities from the owner's technical perceptions. Although the technical aspect was reviewed by engineers, the comments were not appreciated and there was no coordination in the delivery of the project. The supply network found it difficult to explain the importance of the technical specifications during execution, because the management may not fully understand the technical language, thus affecting different decision; as a result, the quality issues were only realised when they caused a failure. In Project E, operational failures were repeated from one project to another, similar project due to the same contractor being involved in both projects. This is because the owner, who was less involved during project execution, was not aware of the root cause of failure and needed the same contractor to resolve the issue. This provided an opportunity for the contractor to obtain more work, but quality failure costs increased.

6.5.3 Recognising capability

This section illustrates how the capabilities acquired during transferring and applying the capability phases are used to operate an asset and how, if not recognised, the operational capability can influence future failure. This recognising capability phase was influenced by the need for technical expertise during operations and because learning was not captured on a project, and is described in the following sub-sections. Table 6.7 below shows the triggered factors of failure and their implications on operational capability within the project multi-case study.

Table 6.7: Triggered factors of failure and their implications on owner's capability to operate during recognising the capability phase

Triggered factor of failure	*Evidential examples from the cases*
The need for technical expertise during operations	" I took it over because it wasn't in a good state, it was behind program and there were some quality issues." "All of the things where people have taken their bonuses and sort of run for the hills and said it is all working. Basically I have to make it function as it should do for the next forty years. " [Project A-A7-Owner project manager] " In the fact it's been leaking so the previous guy tried to resolve it in a number of ways but we never really got to the cause of the issues." [Project A-A7-Owner project manager]
Learning not captured on project	"… so you'd have [numbers of] technical engineer[s] come out and look; whereas a field engineer, or clerk of works role, tends to be a bit more of a master of all…the technical experts or technical team would critique something, but because of the nature of the schedule, would almost pale into insignificance because "yeah whatever we've got to get it done." [Project A-A1-Owner project manager] "…two different contract models… that has a big influence. So, every time the regulator says, "You are going to deliver that' and we create a new model, we are kind of resetting, so, in a way, we cannot learn long-term." [Project E-E16- Owner airfield transformation manager]

(i) The need of technical aspects for operations

The projects cases showed that the project managers (PMs) from all projects were appointed due to the operational failures, and none of the PMs were the initial PMs who were involved with the project from the beginning, which resulted is operational failures that were not understandable. In projects A, C and E, operational failures were difficult to resolve as the root cause was not fully understood. The projects indicate that project execution relies heavily on the contractor and its supplier but they were less involved by the operations team. The project team may not have the opportunity to share capabilities, as complex projects were always constructed towards the critical time and cost, which leads to less involvement in operational requirements. People who were involved during project execution frequently left for other important projects, which led to knowledge not being fully transferred. New PMs struggled to meet the critical time and thus made different decisions based on their experience, putting projects at operational risk. Operational failures were thus difficult to understand in relation to how projects were constructed and what was causing the problems as it involved different people and methods.

As an example, the PM in Project B mentioned that the project was only taken over when it was in a poor state, thus it was difficult to reduce the quality costs. Quality issues were recognised as design faults, but, due to the number of attempts to resolve the issues, the project became more complex. Causes were described differently by people who had been involved, thus involving high quality cost failure due to the different attempts to resolve the issues. The operational maintenance team worked with the suppliers to find the best solutions but quality issues were frequently concealed by the project team and contractor to avoid responsibility for faults. The operational team found discrepancy between the project specification on-site operations and the original scope but the technical experts who made different decisions due to some complexity (i.e. time or cost) were now needed for a new project. This left the operations team with an unresolved problem. Operators who needed to maintain the asset could only understand the operational failures at the operational stage; this increased the whole maintenance costs due to their unfamiliarity with the project history.

The owner wants to deliver a project with the best innovations, but it is difficult for the operational team to adhere to project innovations. Technical aspects distributed during operations were different to those proposed by the technical team at the project stage. This discrepancy increases the operational complexity involved in management and maintenance. Project D showed that the operational manager made an effort in providing information to avoid operational failures but this was not fully recognised by the project team. The project team commonly sees operational failure as frequently unpredictable, which needs interplay by the operational technical engineer. However, complex projects need instant solutions, thus operational failures were not recognised as a priority.

Unresolved operational failures frequently create a blaming culture due to the cost and reputational impact. Hence, technical aspects were not always willingly understood by different professions. Often, operational failures were perceived as another's (operational team) responsibility, which indirectly led to non-appreciation of technical expertise in relation to the operational aspect.

(ii) Learning not captured from projects

The empirical data shows that operational failures were frequently not captured and learned, while operational success was almost forgotten because it was overshadowed by the project quality issues. In Project A, operational failures were repeated by the same contractor in another, similar project. Although the owner recognised the increased quality costs failure, the lesson was not captured. The operational failure was always acknowledged by different team (i.e. the operational team) and was resolved by the operational team; this experience was not being taught to the people who were involved earlier (i.e. the construction team). Hence, the lesson was not realised and acknowledged by the whole multi-organisational supply network. People try to avoid responsibility for failure; thus, project teams always see that learning is from others (different organisations and projects) rather than their own project.

The owner managed their project-based organisation (contract model) within a five-year programme cycle as an incentive for their competitive improvements. However, long-term learning was difficult to capture as the whole governance changed at the start of every new project due to the length of the project. Thus, the lesson learnt from the previous contract model was not transferred to the new contract model because, frequently, this model was developed whilst the project was being executed. Lessons were only learnt at the end of a project. In Project C, the project team was integrated with the operational maintenance team to reduce the operational risk, which led to project success. The project team had critically integrated with a different supply network to ensure that the operational system was not interrupted, which resulted in project success. Project collaboration helped the identification of mitigation in project planning to prevent operational failures. There was realisation about the shared risk of failing to deliver, and thus those involved in the project collaborated to prevent failure.

In Project D, operational failures were treated early, at the beginning of the project, which showed great improvement in its operations. The initiative resulted in better coordination between project teams and operations and thus achieved savings on maintenance cost. The predicted operational difficulties foreseen by the project team were appraised and prevented. Integrated solutions were made with collaboration, which drove the project's success. This was learned from a similar project that had huge maintenance and reduction of lifecycle costs due to poor project execution. Although, frequently, it is difficult to stop projects and work on the operational failures, this made a big difference to the project's long-term savings.

However, information on a successful project was commonly not shared in terms of how this could provide benefits as people moved to another project with a different focus, and assumed that every project is unique and different. Therefore, a project was perceived to be a success only with on-time completion or within the project budget, but the operational failures was seen as a different project. The full benefits of the project's success or failure thus were not realised. People maintain their good reputation by supressing failure, and project governance is always perceived as starting a new project with different procurement procedures.

6.6 Integrated capabilities in failure mitigation

The realisation of these factors during data collection has led to efforts looking into the mitigation of these failures. Although the research is predominantly looking at operational failures, this section describes data where mitigating capabilities are emerging. In this section, data from the project case study describes *why* integrated capabilities in failure mitigation are needed and *how* these failure issues can be mitigated. Within the selection of project multi-case study (Table 6.4) there were some operational failures that demonstrated operational quality cost saving. This data is described in the sub-section below and is tabularised in Appendix 4.

6.6.1 Why integrated capabilities in failure mitigation are needed

In most cases, operational failure was not measured and acknowledged, which led to projects losing the opportunity to capture the value of developing integrated capabilities to mitigate failure. As the majority of project cases were deliberately delivered with the focus on getting the project operational ready, most operational failure was not known by the top management, i.e. the owner. The operational failure were only brought to their attention when they involved massive quality costs for failures. Frequently, when the project team recognised potential failure, each organisation only focused on completing its own task. As an example, in projects C and D, the contractors were provided with an indemnity to secure project completion on time. This shows that projects need to develop the integrated capabilities in failure mitigation for the project team to ensure the projects can be stopped prevent potential failures.

In certain contexts, because operational failures were only realised at the end of the project, quality costs for operational failures were only recognised by the operational team. The capabilities for failure mitigation were then not captured by the rest of the project chain. The quantification of operational failure and its quality costs helps teams to visualise the benefits and failure generated from the operational issues. As shown in Project C, most of the project team only recognised the operational issues that caused poor quality cost but not the operational issues that resulted in quality cost savings. Consequently, the project team acknowledged that measuring quality cost of the operational failure helps to provide a clearer view on recognising the project benefits, and thus helps in generating the integrated capabilities to mitigate failure. This is because, although there is uncertainty on the project lifecycle, some operational failure could be predicted based on experience.

Also, all projects showed poor judgement on the quality management provided during the delivering and operational stages. Thus, project teams recognised that there is a need to improve quality management within the project management. By identifying the failures, projects could be easier to stop and deal with the problem and thus reduce the operational failures and its quality cost. Project teams agreed that measuring COQ could act as a performance indicator to integrated capabilities in failure mitigation; which will show whether the project is lagging or advanced in delivering the desired operational quality expectations.

6.6.2 How operational failure could be mitigated

A project needs the integration of capabilities among owner, contractor and supplier to select what is best for the project and its alignment with the nature of the owner’s operations. Project A showed that a long-term relationship helped to incentivise the contractor to continuously fix the operational failures for the owner. This provided an opportunity for the owner and contractor to develop integrated capabilities for failure mitigation that could reduce future failures. The owner agreed that selecting the right capabilities is important as a project relies on people, but the owner need to integrate their in-house capability for the contractor to better understand the owner’s operations environment. As in Project B, the owner developed a contractual agreement to ensure that the supplier could provide continuous assistance in solving operational failures. However, the owner did not capture this capability to prevent future failure; and thus to rely on the same supplier. The owner could have better mitigated potential failure if the right capability was captured.

The project team needs to integrate the specialist capability with operational team. The project team realised the need to rely on specialists and operational capabilities to deliver the right capabilities in a project. The multi-organisational supply network needs to integrate different capabilities to mitigate failure. Project B showed that early involvement from the designer could help to provide better understanding of the drawing in visualising the complexity of project operations but the designer needs to incorporate operational knowledge. Also, in projects C and D, the project team involved early engagement form different stakeholders, which led to some successful operations. The project team was integrated with operational capability in developing the drawing as well as testing the project; thus, smooth delivery of operations was achieved. Project D described that early engagement from project stakeholders provided clear information as to what quality needed to be delivered. Thus, the project team had worked together with the operational team to reduce the risk of failure.

Additionally, front-end management should not only involve planning on the design of the project, but needs to incorporate the technical knowledge. As described in Project A, the owner's lack of technical inspection at the front end caused difficulty in understanding the drawing. Thus, the design team should work together with the operational team to mitigate the failures. Quality expectation could be aligned at the beginning of the project through contractual agreement that included both design and technical aspects. As a successful operation, Project D showed that the heavy planning at the beginning of the project helped to mitigate the failures. This project was planned and designed together with different stakeholders to reduce the risk. The visualisation of project failure drove different behaviours of the project team to ensure that the project did not fail. Also, in Project E, the learning from previous failure was captured and recognised during the beginning of another, similar project, which helped the projects to mitigate the operational failure and resulted in quality cost savings in relation to maintenance.

Project D had a different procurement strategy, with a long-term relationship that gives the owner the opportunity to understand and capture the right capabilities. The long-term collaboration provided the capacity to capture and share the risk of project failure with the multi-organisational supply network; thus, failures were mitigated during the process rather than affecting the operations. By developing integrated capabilities to mitigate failure, project benefits could be realised and help to promote a different culture for achieving better quality. The project teams could then provide proactive actions to deal with predicted and potential operational failure, as shown in Project E.

6.7 Validating and generalising the extent of operational failure

This chapter has described the emergence of new grounded theories of what constitutes the operational failure as well as the emerging data on failure mitigation. The multi-case study described the problems of the capabilities cycle in three phases, which are: transferring capability, applying capability and recognising capability. The multi-case study illustrated how the distribution of capabilities influences the failure and how this has impacted project, operation and owner's capability.

This section demonstrates the development of a framework in understanding the cause and effect of operational failure. Two focus workshops were conducted following the in-depth multi-case study analysis with an owner's representative expert (n=2) using the Delphi review. The workshop representatives involved expert samples with more than eight years' experience in construction strategic and operation management. The workshops discussed, analysed and generalised the findings from each project of the multi-case study. They also agreed a common set of operational failure trigger factors. The workshop discussions lasted between two and three hours and included the translation of the experts' experience into a shared understanding and statement of the cause of project team behaviour, organisational elements, design statement and quality culture as well as the operational strategies. The outcomes from all the multi-case study were combined and framed to gather the factors affecting the operational failures that are aligned with their impact on quality cost failure incurred.

The workshop compiled and cross-compared all the elements that emerged from the multi-case study into a wider mapping of the chain of cause and effect of operational failure. All the selective coding from the interviews were used in looking at the cause and effect of each project case. This was then re-categorised again to categorised the similar code and according to the project stage to see the relationship of each project phase.(i.e. from owner capability to project capability and to operational delivery) The discussion later generalised, re-defined and quantified the findings from the multi-case study analysis. This focus workshop has shown that the volume of data collected in each element does not necessarily indicate the importance of the data in generating meaning. In some elements, only relative information was provided, but the information in the context of the project was important. Thus, the workshop assisted in justifying the relationship of that data to other data that can also be important to the meaning it can bring. In summary, this framework used the selective codes from detailed multi-case study to map the cause and effect of each code from one to another. Figure 6.2 shows the link of cause and effect during the transferring capability phase of how each factor influences the operational failures.

This phase shows how owner's capability during project planning on the relationship with the supply network, the budget, time and demanding regulations influences the occurrence of operational failure. In a project-based organisation, the owner programmes management play a significant role in managing projects, which leads to different governance of each project. The framework mapping shows examples of how owner's influence different capability behaviours and cultures in relation to the quality of construction, which leads to operational failures. The distribution of capabilities during the development phase impacted the different focuses on different organisations, which led to different expectations for the project outcome. The supply network only sees the owner's satisfaction as a performance indicator, and thus places less emphasis on other stakeholders' capabilities. This puts projects at risk.

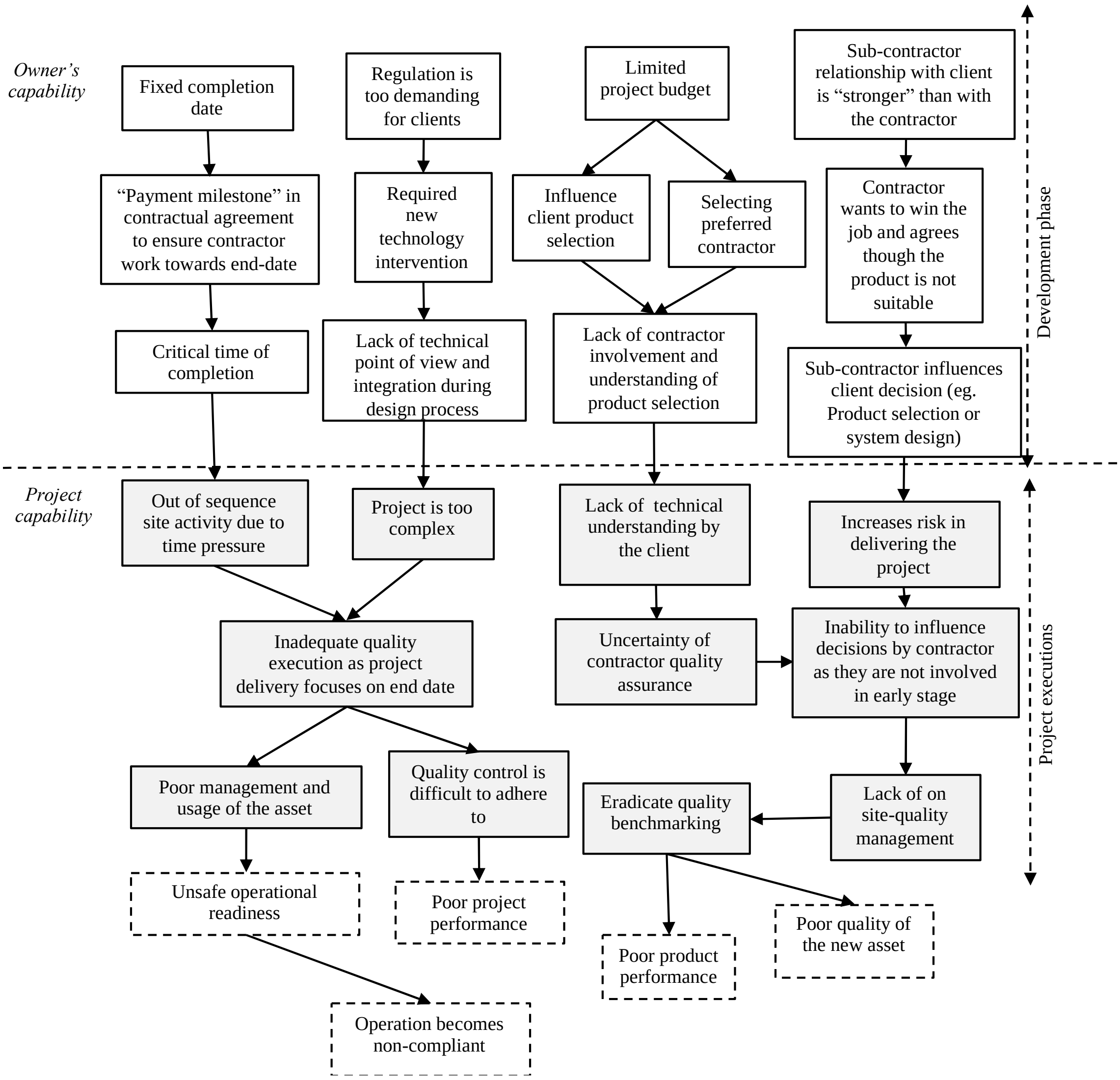


Figure 6.2: Framework mapping the cause and effect of how owner's capability is impacting project capability

Figure 6.2 mapped the applying capability phase of how the different capabilities are applied during project execution, which influences the formation of operational capability. This shows the performance of operational capabilities is generated through the organisation's decisions and experience held during the transferring capability phase. This intervention demonstrates different knowledge and expertise are brought to operations, which shows the project and operations are linked one to the other.

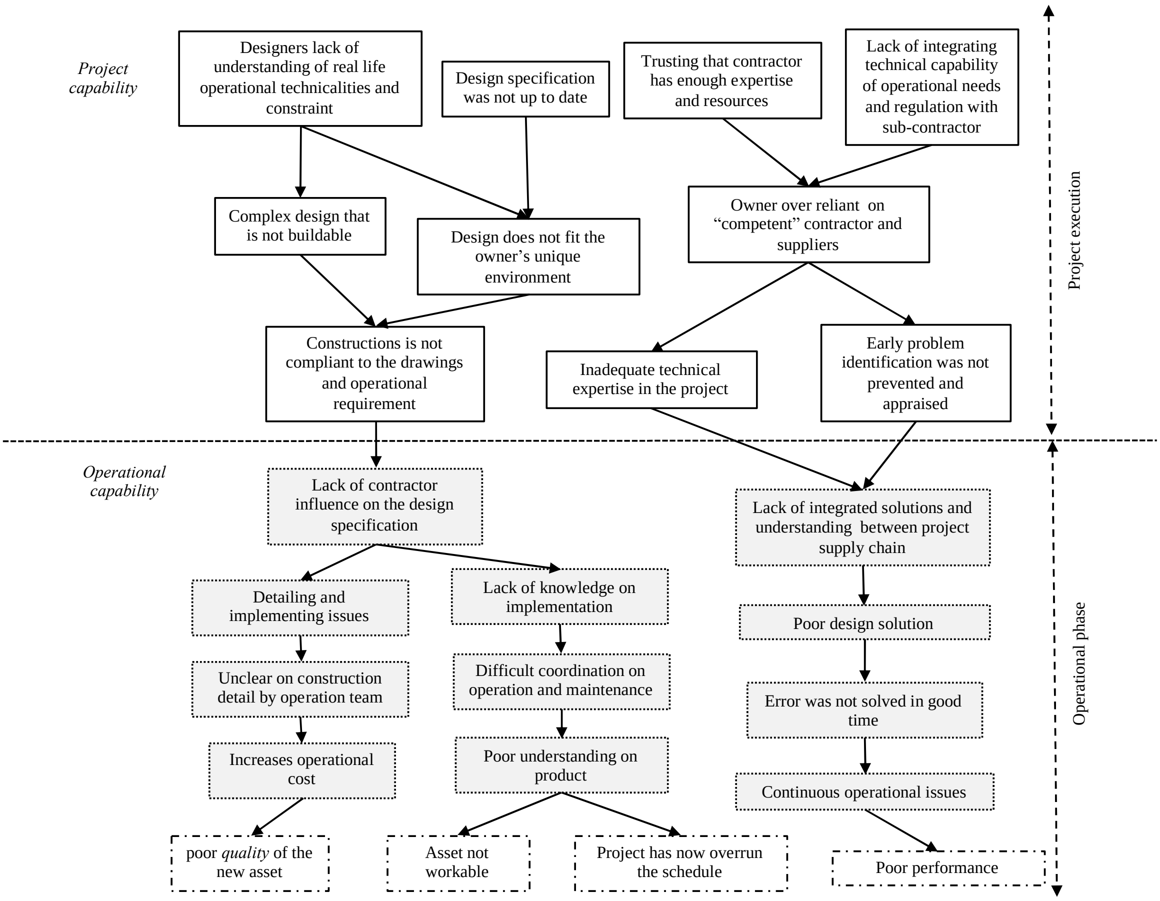


Figure 6.3: Framework mapping the cause and effect of how project capability is impacting operational capability

Owners need operational capability to operate the product or project. These operational capabilities further help owners to plan and execute new projects, thus they are recognised as owners' capability. Figure 6.3 mapped examples from the multi-case study that show how operational capabilities influence an owner's capability to operate.

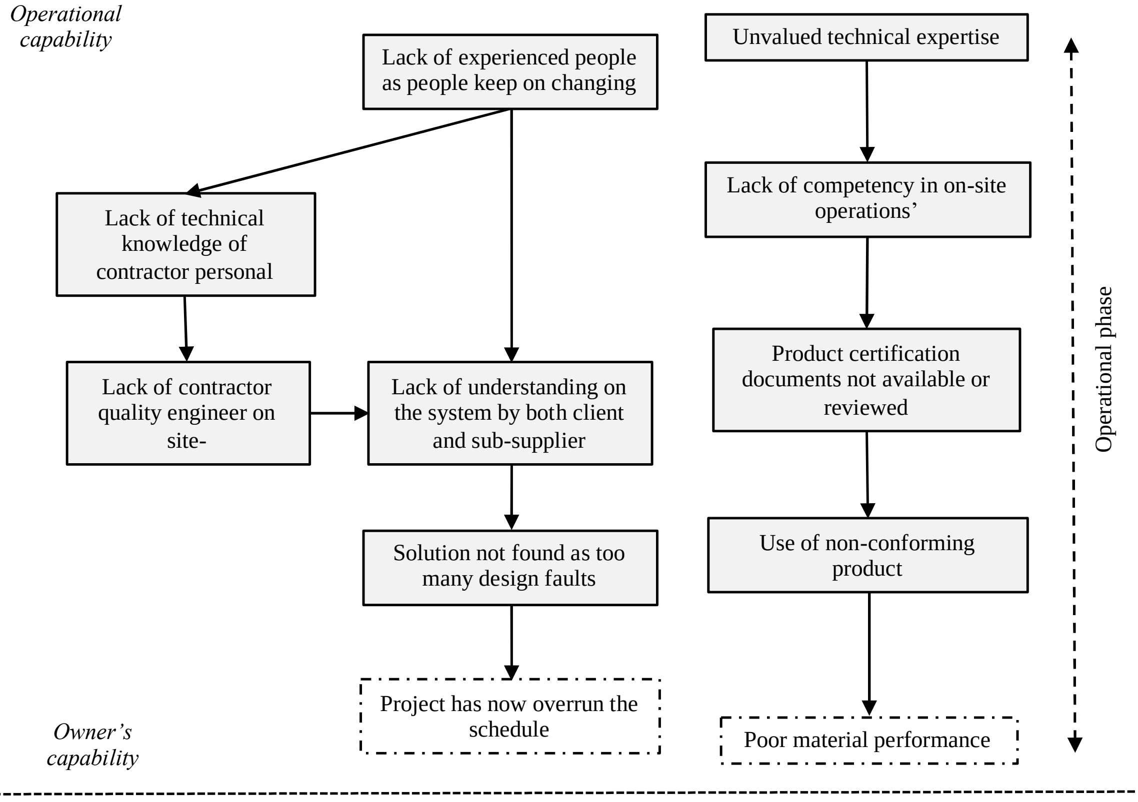


Figure 6.4: Framework mapping the cause and effect of how operational capability is impacting owner's capability to operate

Operational failures trigger factors were grouped and categorised according to the capabilities cycle shown in Figure 6.4. The multi-case study showed that the transferring capability phase was triggered by contracted end date, the allocation of budget to fit project specifications, owner's relationship with supply network and investment in innovation with demanding regulations.

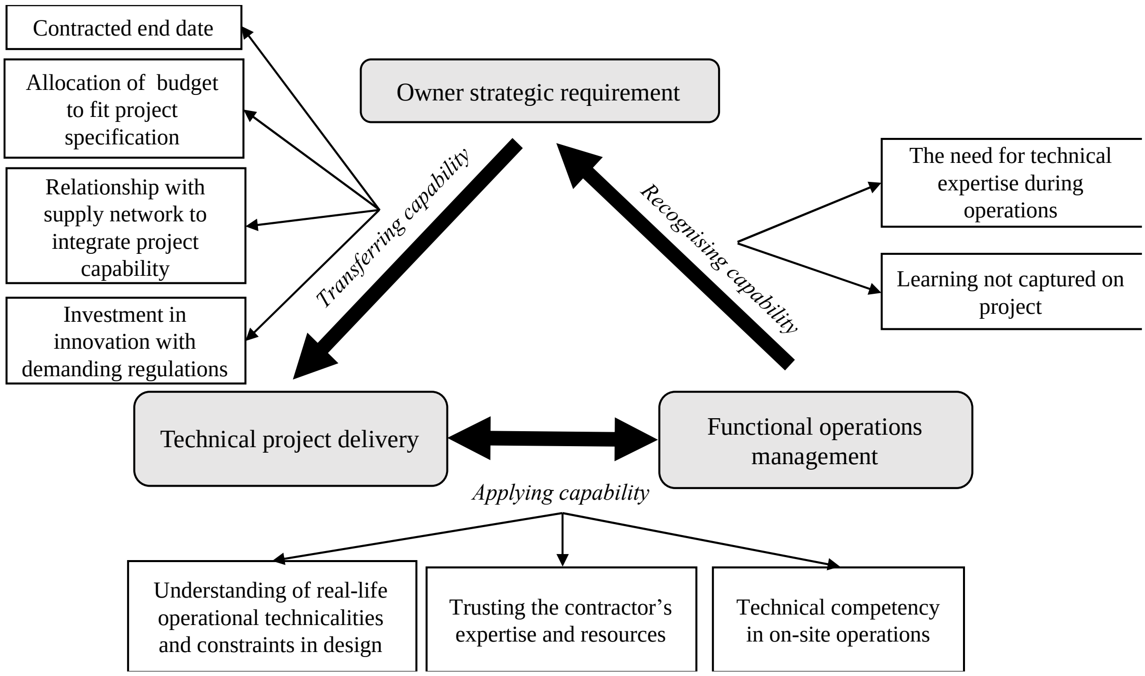


Figure 6.5: The triggered factors of operational failure in capabilities cycle

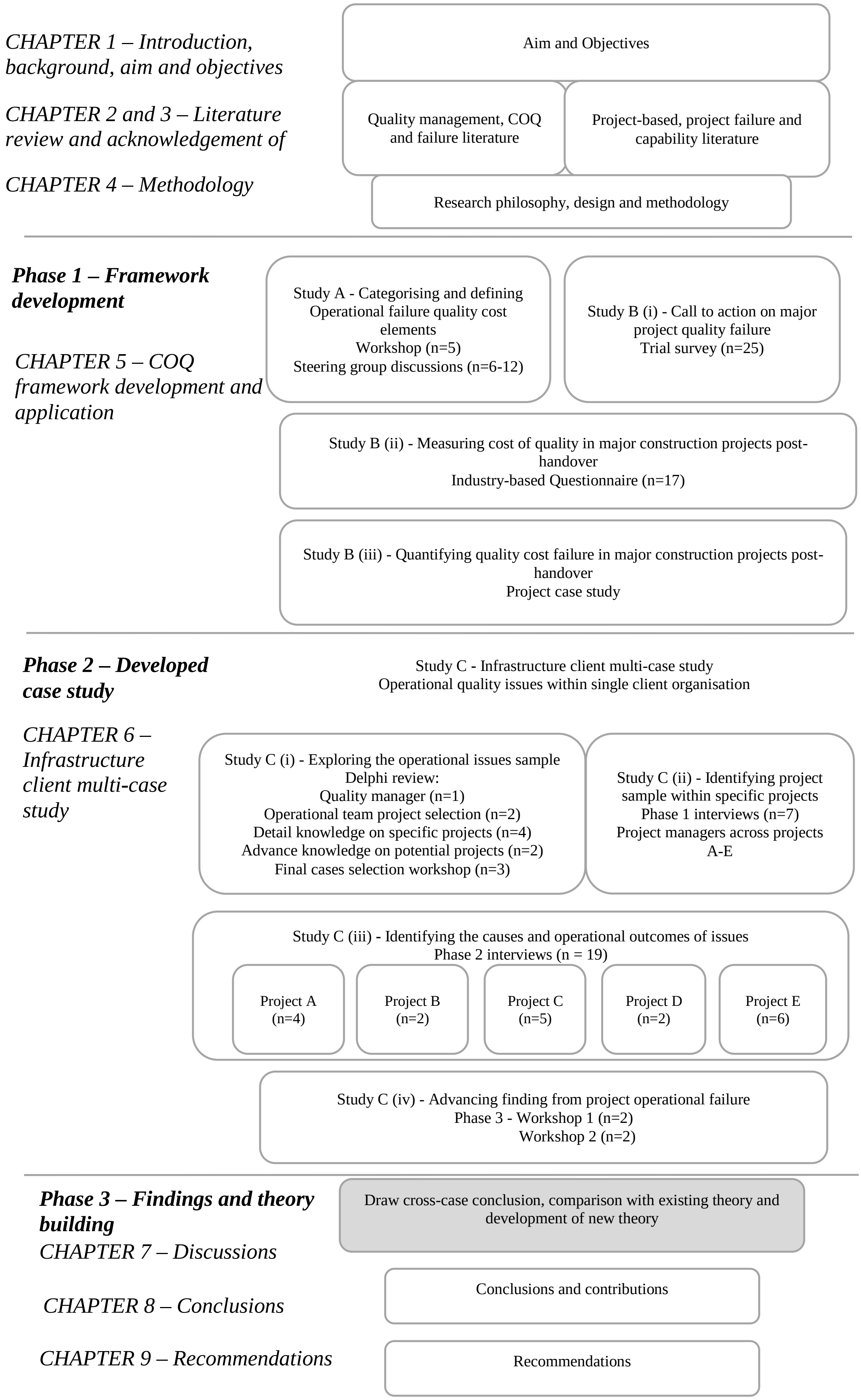
In the applying capability phase, project and operational capability were triggered by the understanding of real-life operational technicalities and their constraints in design, owner trusting the contractor's expertise and resources, and technical competency in on-site operations. Finally, the recognising capability phase was triggered by the need for technical expertise during operations and learning that was not captured on the project. All the events that occurred and emerged from the multi-case study were justified and generalised across other relevant incidence to generate a consensus of what influenced the operational failures. It was agreed which elements constituted the most projects and programmes across the organisations and an understanding of the capabilities cycle was agreed on. The distribution of capabilities across an owner and its multi-organisational network in the capabilities cycle shows a significant influence on how the owner, from the strategic requirement phase, transferred the capability needed to develop technical project delivery capability (Figure 6.5). Capabilities that were applied during project execution were then developed as functional operations management capability, which were later recognised by the owner as the owner's capability to operate the asset.

The workshop provided data for organisation-level understanding on operational failures and its causes according to various groups and departments. This analytical information was then used in the following discussion of how owners could develop integrated capabilities across owner's strategic requirement, technical project delivery and functional operations management to mitigate failure.

6.8 Chapter summary

This chapter has presented an introduction to the identification of a strategic project and quality approach to mitigate failure. The developed new strategic project and quality approach addressed the problem of the distribution of capabilities in capabilities cycle of PBOs. The new project and quality approach specifies the underlying theories of operational failure that are embedded throughout the three phases of a project's lifecycle, from owner's strategic requirement to technical project delivery and functional operations management. The causes of operational failures are grouped based on the capabilities cycle of the different phases: transferring capability, applying capability and recognising capability. A comprehensive list of coding, group of interviews and quotes can be found in Appendix 3.

Following this analysis and findings, the overview of the new project and quality management approach is explained in Chapter 7. This can be further understood and explored based on the evaluation made on the key elements of quality cost failure that contributed to the occurrences of failure. The data analysis in this chapter and the previous one are combined and discussed in Chapter 7 in relation to how the new approach contributes to the failure mitigation.


CHAPTER 1 – Introduction, background, aim and objectives
Aim and Objectives
CHAPTER 2 and 3 – Literature review and acknowledgement of
Quality management, COQ and failure literature
Project-based, project failure and capability literature
CHAPTER 4 – Methodology
Research philosophy, design and methodology
Phase 1 – Framework development
CHAPTER 5 – COQ framework development and application
Study A - Categorising and defining Operational failure quality cost elements
Workshop (n=5)
Steering group discussions (n=6-12)
Study B (i) - Call to action on major project quality failure
Trial survey (n=25)
Study B (ii) - Measuring cost of quality in major construction projects post-handover
Industry-based Questionnaire (n=17)
Study B (iii) - Quantifying quality cost failure in major construction projects post-handover
Project case study
Phase 2 – Developed case study
CHAPTER 6 – Infrastructure client multi-case study
Study C - Infrastructure client multi-case study
Operational quality issues within single client organisation
Study C (i) - Exploring the operational issues sample
Delphi review:
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on specific projects (n=4)
Advance knowledge on potential projects (n=2)
Final cases selection workshop (n=3)
Study C (ii) - Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) - Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) - Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

7 Discussions

7.1 Introduction

The purpose of this chapter is to extend the findings from the exploratory multi-case study and discuss the emergent triggered factors of operational failures.

With a discussion of its general objectives as well as the methodological direction taken in its application to this research, this chapter brings together the outputs of all the data collection and analysis. It discusses the data collected from all three phases of the study and conceptualises and characterises the capabilities for failure mitigation into three phases of the capabilities cycle, namely: (1) transferring capability, (2) applying capability and (3) recognising capability. All operational failures that triggered factors within each phase are elaborated on and discussed. Finally, it presents the evaluation of these findings with respect to each other and to existing literature provided in chapters 2 and 3. By doing so, it contributes to the strategic project and quality management approach of integrating capabilities for failure mitigation for owners, multi-organisational supply and operator network that could be developed in managing the capabilities cycles to reduce quality cost and operational failures.

7.2 The core purpose of understanding the operational failure COQ

This research has attempted to understand the causes of operational failure in infrastructure projects. It was shown that the low maturity and the fragmentation of the construction owners and multi-organisational supply network in measuring and capturing COQ failure are the reasons for the high occurrences of operational failures. Empirical data confirms quality cost incurred at operational failures are complex, hidden and difficult to quantify (Rosenfeld, 2009); therefore, identifying and confirming their existence may be necessary. The complexity of construction infrastructure projects is the reason why the quality cost is not well captured, involving both the occurrences of the quality issues and the procurement process (Hall and Tomkins, 2000). Failure can occur in the forms of technicality and functionality, but these also involve the human aspect, such as supply network behaviour and culture and work motivation as well as company reputation (Love et al., 2018). This has hindered the ability to further quantify all the quality cost failures, which in some cases involve issues of commercial confidentiality and the potential impact on business reputation.

COQ is still in its infancy stage in terms of its application in construction. The first phase of the study indicated that maturity within the industry is relatively low and suggests the need to understand the contextual and organisational differences between projects with regard to COQ measures, as proposed by Schiffauerova and Thomson (2006); it confirmed that there were different ways to capture COQ (Yasamis et al., 2002), so standardisation through the owner and multi-organisational supply network was necessary. Operational failure cost was classified in different ways in different projects and sectors, and there are variations in owner and supply network maturity and influence. Although Snieska et al. (2013) used quantification steps, there were model variations and no overarching or suitable model (Omar & Murgan, 2014) found in construction projects. Most of the research effort has focused on identifying quality cost elements, calculating COQ, and reducing the costs and the relationship between cost components during the prevention and appraisal, but no research has explored the relationship of the construction multi-organisational supply network in appraising operational failure cost. An emerging theory of what constitutes failures is provided on how operational failure cost could be reduced within the complex and dynamic nature of operational failure.

There is a known benefit in visualising hidden costs, and in monitoring and quantifying (in financial terms) the effects of poor quality (Hwang & Aspinwall, 1996; Jafari & Rodchua, 2014), but there is limited knowledge on the risk of quantifying these costs. Study C showed that alongside the benefits of quantifying COQ, there are many risks perceived by the construction participants in applying COQ. There is a fear of reputational impact on quantifying the COQ that will further lead to friction in the whole multi-organisational relationship, creating internal conflict and blame culture. This shows that there is a need to align the shared responsibility to manage failure; thus, applying the COQ will provide equal benefits. However, there are practical difficulties that have underlined the specification of COQ and failure cost in construction (Barber et al., 2000); hence, the true cost of failure is difficult to quantify. Studies A and B have shown the perception on how owners and suppliers influence the occurrences of failure cost is judged to be low in maturity and uncertainty. This study demonstrated that information was not consistently transferred among the project supply network and that failure cost was defined differently depending on the contextual setting of different individuals. This has illustrated the need to use a broader management perspective in managing the COQ that does not only quantify the failure costs but includes the necessary thought to reduce the number of failures.

As in Porter and Ryner (1992), it is hoped that this work will facilitate quality management improvement and help to eliminate waste, and point out the strengths and weaknesses of a quality system (Srivastava, 2008). Although it is agreed that cost may be a good indicator in assessing project performance (Henri et al., 2014) and in assessing project quality (Josephson & Chao, 2014), projects needs better understanding on how cost and quality are interlinked so that project performance may also be influenced by the different capabilities developed within the project lifecycle. As it was demonstrated through study A, B and C, all operational failures are linked to the different quality capability provided in the project and which will resulted in quality cost. In a broader project management perspective, it is hoped that understanding COQ deficiencies will help to define the quality programme (Yang, 2008), lead to time and cost savings (Love & Li, 2000; Tang et al., 2004), enhance profit sustainability (Palaneeswaran, 2006), reduce customer dissatisfaction and reduce lost reputation during the period of maintenance and operation (Devi & Chitra, 2013), and allow for immediate corrective actions (Love & Irani, 2002). From the owners' perspective, the interdependency amongst the supply network is still lacking in considering how COQ could be of benefit to all. The appraisal of operational failure and its quality cost showed that the quality management team must work with the whole multi-organisational supply and operator network to deliver improvements in quality. Understanding of COQ may help to integrate measure to understand the distribution of operational failure cost across the multi-organisational supply and operator network. It may also allow prevention and appraisal of failure to reduce the occurrence of failure. However, this study has shown that a quality management system that addresses COQ must be well managed to build strong collaborative quality relationships between all parties

7.3 The distribution of capabilities in a complex infrastructure case study

The case study exploration has shown that the PBO's management has directly and indirectly influenced the occurrences of failure in relation to project operational failure. Integration across the project supply and operator network is needed to ensure high-quality delivery, however, there is a complex mix of quality expectations that must be managed by the PBO. These findings can be explained by assuming capabilities are distributed in three phases of a temporary project capabilities cycle (see Figure 7.1), namely: (1) transferring capability, (2) applying capability and (3) recognising capability. Capabilities are intertwined from how organisational owners manage the PBO towards project process, operational process and back to how owners capture these capabilities for their competitive improvement. The strategic or operational management of these capabilities appeared to differ. What is needed for all is the interdisciplinary integration of the owner and their multi-organisational supply network teams with different capabilities in failure mitigation.

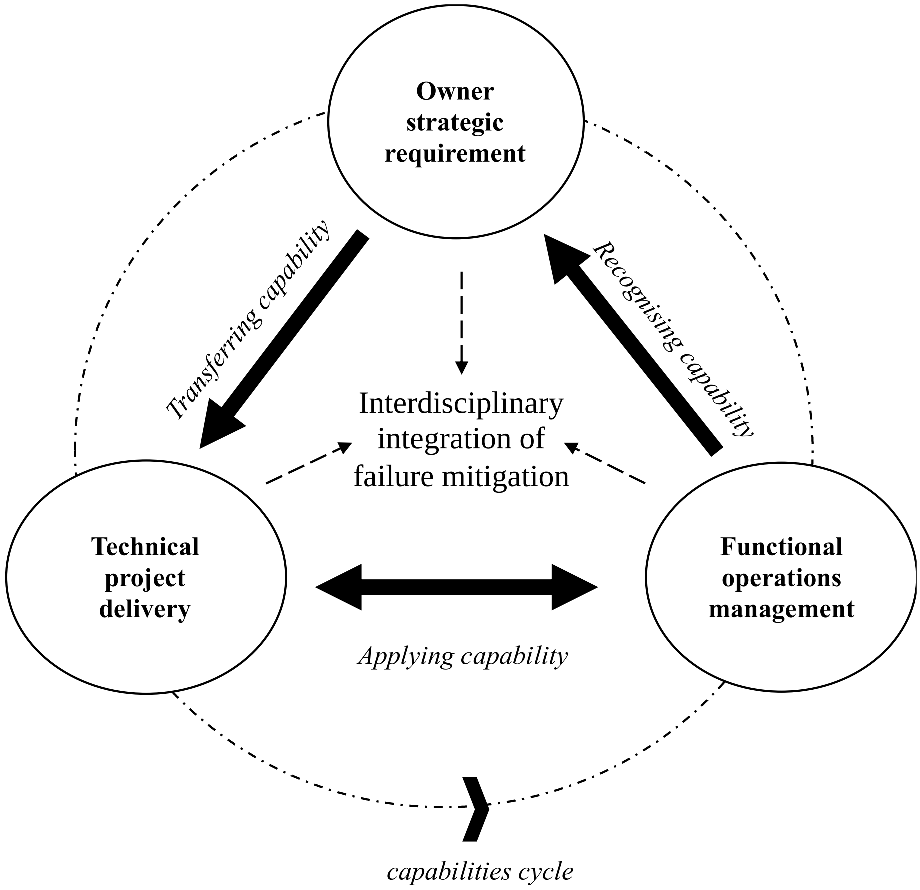


Figure 7.1: The capabilities cycle in a complex project

The project multi-case study showed that, based on their experience and learning, owners developed their strategic business plan and influenced how projects were procured. This is evidence in one of the project case, where project A was build according to the similar project plan that was delivered by the same contractor. Also, project B showed that the project was plan and improved according to the similar project that has constructed few months before. Both projects shows different result of on the project performance of how owner used the capabilities in constructing the project. In project capabilities cycle, owners procure different capabilities to execute a project. These capabilities are generated from their multi-organisational supply network and are transferred to the project process in delivering the project. These capabilities are distributed in a sequence cycle (from transferring to applying and recognising capability) in the completion of the project. Owners assumed the transferred capability will consistently be applied to the operational process, thus achieving successful operations. Capabilities were then recognised by the owners to generate competitive improvement in further projects. The capabilities cycle was dominant in the transferring phase as it influences project culture and behaviour where each unique organisation has individual expertise that needs to be integrated into a complex project. At this point, the project team should involve owner, contractor and supplier as an early involvement to obtain critical technical knowledge needed for each stage of the project. Although Davies and Brady (2016) suggested that the relationship between dynamic and operational capabilities needs to be reciprocal, recursive and mutually reinforced, the continuous flow of technical information will aid the project team to know how and when they need to structure the capabilities that influence the operational necessity. However, empirical data demonstrated that capabilities within the owner, contractor and its multi-organisational supply network were not integrated within the project and operational capabilities, which led to poor quality and project performance. An asset that was not workable and a design that was not buildable were perhaps the most significant disruption to operational readiness. These issues were triggered by different factors at different phases of the capabilities cycle and are discussed in the following sections.

7.3.1 Transferring capability

The capabilities cycle showed that 'the contracted end date', 'allocation of project budget', 'owner's relationship with supply network to integrate project capability' and 'investment in innovation with demanding regulations' made the owner disregard their strategic requirements and the contractor hide their speciality or failures. Thus, the capability transferred to the project technical delivery does not meet the desired requirement (see Figure 7.2); these are discussed in the sub-sections.

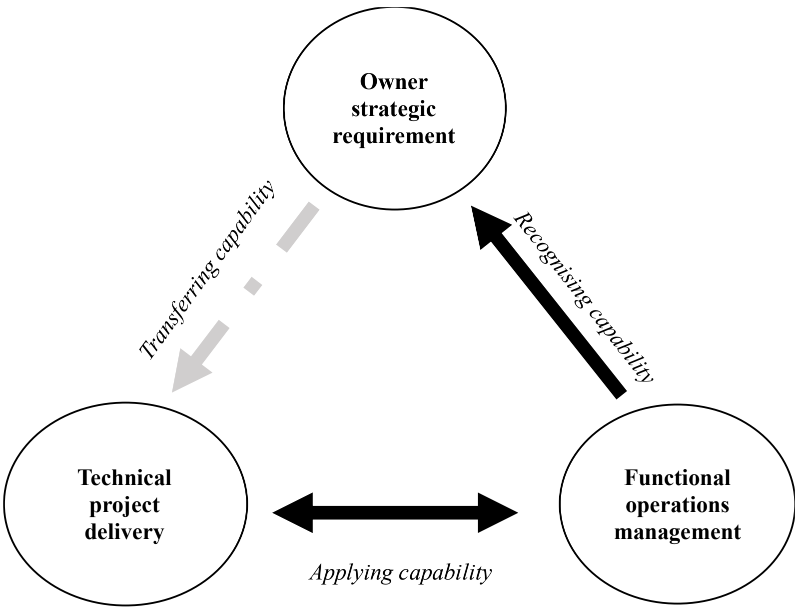


Figure 7.2: Un-integration of transferring capability in capabilities cycle

(i) Contracted end date

Transferring capability requires comprehensive information in the contractual agreement for the project team to successful distribute their capabilities. Mostly, operational failure was caused by the organisational structure of its procurement and contractual management. Multi-case study provided evidence of different behaviour and culture on quality issues, and quality failure may not have been fully addressed at the time that it occurred due to the contracted end date. The study has indicated that the owner defining and managing critical project parameters, such as scope, time, cost, supply network relationship and quality criteria, at the initial project planning stage, determined the project outcome. Project A, B and c showed a ‘pressurised’ completion environment for contractors which have impeded critical quality application across the multi-organisational supply network. Organisational capability development was impeded by a project’s focus. Short-term projects focused demand on a high COQ. A long-term COQ focused on saving was harder to accept than short-term, on-site problem solving. The quality issue from an innovative implementation perspective was that the site managers may be reluctant to try new solutions because they are continuously trying to reduce commercial risk for the project. Project team frequently allocate resources to prioritise urgent defects (Olanrewaju, 2012), which is the reason why constructors do not see more effective solutions in the operational maintenance relations and thus commonly fail to allocate maintenance cost.

The owner in the case study is restricted by the project interdependency, in that failure to deliver one project will cause operational penalties, thus they were strict in controlling the contractor’s performance. Project E were influenced by the critical operations of the runway which must be operated in the next working day. This has driven the contractor and project team behaviour that focused on project delivery rather than quality to delivery. There are strong owner role implications for project organising to enable the delivery of an asset to customers on a continuing basis (Winch, 2014) and which allows the functional exploration (Koskela et al., 2006). This shows that the project team needs two-way communication, in that the owner who has the entire responsibility for providing the project team with a definitive and unchanging account of its purpose and values should consider the suitability of the work environment for its multi-organisational supply and operator network.

There is a major challenge for the management of project quality culture and behaviour in a complex infrastructure project. There are sometimes legal consequences of decisions and control right allocations that are not present with respect to technical description of roles and responsibilities. Project cases described quality manager works as a paper based work rather than fully understanding the technical delivery of the quality, thus project fails to provide the best quality. The owner and its multi-organisational supply network need greater consideration to collaborate and work together in mitigating potential operational failures. Agreeing with Mayer and Argyres (2004), there is a need to include an extensive description of responsibilities during early contractual agreement, to distinguish different responsibilities from different organisations in manging the capabilities through contractual agreement (Adam et al., 2014). It is believed that this could be a way to mitigate operational failure.

(ii) Allocation of budget to fit project specification

Project budget is imperative for the owner and multi-organisational supply network in transferring the right capability to fit the project specification, but these capabilities need greater consideration in reflecting the operational side of the project. This is because, project budget reflects the capabilities needed for the project to be successfully delivered. This may have influenced the quality delivered in influencing the operational capability. Commonly, the project goal is shared (towards the completion date) but project participants differ in what they hope to gain from the construction process, which needs proper coordination among project activities (Demirkesen & Ozorhon, 2017). From the data, the case study shows that the owner would try to minimise their budget, while the designers and the contractors attempted to provide the services and product in the most efficient manner to meet the owner's specification in order to maximise their profit. In which, project A appointed contractor with the lowest budget to construct but the project was suffered with many operational failures due to contractor providing low quality or material and workmanship to meet the limited budget. This has led to the development of a critical quality management relationship between parties with different goals (Hoonakker et al., 2010). Moreover, the multi-case study show that the implementation of quality at project execution is different to what is expected to be delivered at project operation but this 'expectation' has not been clearly discussed by the owner and the supply network when transferring the capabilities.

The multi-case study has shown that the accuracy of the project budget influenced how quality was different at outset and at operations. It was confirmed that a focus on low bids, by selecting the lowest-cost contractors, increased the risk of cost and scheduled growth (Eriksson & Westerberg, 2011). The multi-case study revealed that the lowest-cost contractor may have tried to reduce allocated resources for quality management in order to maintain a healthy profit margin for their business, which thus resulted in operational quality failure. Therefore, to reduce project risks and mitigate operational failure, owners should set a quality standard for the project that reflects the operations in allocating the project budget. This should be in line with contractors' minimum requirement for their quality performance capability, which is based on their experiences with the owners. Owners should ensure that the project budget includes contractor quality management that has minimum requirements for their operational environment.

Allocating a limited project budget also influences project decisions in selecting suitable material. Therefore, the cost calculation has been proven to be problematic. For instance, one contractor faced difficulties in applying and maintaining an unsuitable product within a complex project environment. The contractor that followed the owner's specification did their best to comply, but the unsuitable product required much more effort from all project participants. Aliverdi et al. (2013) suggested that the project team should monitor the budgeted cost of work performed through earned value to indicate how efficiently they could utilise the project resources, but the multi-case study indicates that the project team does not quantify the quality costs, which results in high cost at operations. This indicates that quality cost of work was only absorbed and acknowledged by different organisations and not the whole project team. In order to reduce the operational failure, the project team should clarify and collaborate in monitoring work performance. Although, frequently, the quality management process works differently depending on the product and service nature of different organisations (Nilsson et al., 2001), integrated capability could help different organisations to collaborate in monitoring work performance based on the shared risk contract. As a result, the project manager will acknowledge the functionality of the project as well as the cost implications. This shows that an integrated approach is needed for a more reliable quality and cost control for project operations capability.

Project budget has an indirect impact on how the project team encourages the contractor to provide project innovations. New solutions must be negotiated (Winch & Merrow, 2012) by the owner with their multi-organisational network within the project arrangements, as the perception of degree to change and links to other systems can differ among the involved parties (Slaughter, 2000). It is likely that some solutions are good for one party but may impact other operational systems. The benefits are split between the owner and the participant in a complex project (Bygballe & Ingemansson, 2014), thus a proper incentives system must therefore be in place. However, there are differences between owner innovation in this respect: if the owner has no budget allocation to improve the existing design that leads to poor operational performance. Thus, collaboration between the construction participant and the owner is important in determining how new solutions are attempted. To transfer the capability, it will be important to incorporate measure from different sources. This will require the project team to gather information from multiple organisations on the quality practice and the degree of customer satisfaction in obtaining a better objective in relation to financial data for project performance capabilities.

(iii) Relationship with supply network to integrate project capability

Transferring capability procures an integrated capability from different supply network. The supply network in construction is frequently scattered, with different construction participants having separate responsibilities, and is separated at different phases of the construction lifecycle. The general contractor usually supplies the whole construction project, integrating subcontractors and suppliers for the owner (Hu, 2008); the project's effective implementation is perceived as dependent upon strong commitment from the owner. The analysis confirmed that the role of the owner and their advisor is to lead and champion the effective performance of the contractor in the construction project, but their role in the operational stage has not been specified. A long-term relationship between owner and contractor shows deep trust and familiarity with the contractor's capability but the multi-case study has indicated inconsistencies in operational quality assurance. Although a long-term relationship is perceived to be important, the type of quality behaviour does not match the competencies and culture needed in preventing and appraising failure in a multi-factor and dynamic operational environment.

The weakness of the development of a relationship between the owner and the multi-organisational supply network is that one supplier has a stronger relationship with the owner. The case study findings have shown that different levels of relationship will influence the complexity of the project process, which leads to operational failure. In spite of these multiple relationships, the frame of reference from the owner can serve as an important aspect to gain increased value from various stakeholders (Walker, 2000) but the efficiency and effectiveness in a project suffers from the greater number of participants. From the practical perspective, when the preferred supplier showed fragmentation of their relationship within the supply network at the early construction stage, they affected the project capability across the supply network and their performance towards the operational context. As shown by the multi-case study, the contractor's capabilities during the project were limited to the preference of the supplier but not to the owner. This shows that, although the owner frequently relies on the contractor's capability to perform with the desired quality, the owner needs a better strategy to manage the capabilities of the whole supply network (Winch & Leiringer, 2016) – specifically, in relation to the time of different cycles and to take into consideration a wider and greater variety of issues in relation to the impact of operational environment and regulations.

The project contract does not usually govern commercial relationships as different organisations have different quality orientation. The owner needs the capability to manage the necessary commercial capabilities that are shaped by suppliers' capabilities to deliver specific products (Winch & Merrow, 2012), but the influence on operational performance has not been clearly discussed. The empirical cases showed that the owner frequently trusts the procurement contract in governing the supply network work performance. However, integrating work packages is a major challenge; project teams have moved from having a detailed design competence to focus more on process and system control, which in turn has clearly affected the procurement and contract strategies. An example of this was the development of standardised specifications intended to improve design quality and reliability, but this affected the contractor's capability to construct. This strategy impedes the contractors' ability to influence the design as they have limited involvement with the procurement.

(iv) Investment in innovation with demanding regulations

Complex projects are triggered with an incentive to invest in innovation to cope with demanding regulations. Transferring capability requires specialisations and a reduced scope of contractor and supplier's activities to meet the demanding regulations in project delivery. This is regardless of the component product in which the supply network is the expertise (Ethiraj et al., 2005), that is to resolve the project constraints and thus expanding their capabilities. The data empirically demonstrates that interactions between components in a product system need deeper research and design incentives from the owner. Contractor and suppliers being unable to visualise the complexity of the project with the owner's operational system caused the system failure. The multi-case study project confirmed that a complex system accelerates innovation by promoting specialisation but the incentives increase with investment for new capabilities. The constraint on innovation has led to operational failures, and showed the technical imbalance during the project execution in constituting an inventive effort from the project team with the operations team. The difficulties in quantifying the cost impacts from the demanding technical constraints and project changes have resulted in high operational costs that were not bearable.

The complexity of technicality acquired during the project increases the system regulations. Owner operational systems are frequently interlinked from one to another (Davies & Brady, 2000), which needs allocation of different components in response to the unique operational environment. For example, project D was constructed during a 'live operations' where the building escalator has to be fitted in during the operations of the airport. This has led the project team to increase the capability to construct in ensuring non-disruptions to owner business operations. Also, in project B, a complex system that required one-off innovation was restricted by the 'environmental regulation' and this led to high COQ due to non-compliance. The owner faced continuous difficulties in complying with the environmental regulation, which needed greater innovation of the specific system. It appears that the owner needed the capability to extend the development by investment of choices to create new opportunities. The project team struggled to find contractors who understood the technical and schedule constraints raised by the owner and the further led to delays in dealing with operational problems. In some instances, the contractor had left the project, leaving it in conflict (i.e. new specification was required when the original scope was not clear), which again led to an increased pressure on maintaining costs and keeping to schedules. These demands caused difficulties for the owner to operate and the project suffered from weak team coherence and fragmented communication. A complex project requires frequent iterations with the owner to help meet the needs of engineers (Hobday, 2000), and requires team ownership of the project with good internal communication with both the contractor and its supply network (Paiola et al., 2013), which affect the transferred capability development choices. By establishing project ground rules at the initial stage, changes to design, project-operations misunderstanding and other uncertainties could be dealt with in a systematic approach in generating the desired capabilities for failure mitigation.

The different strategies used by the owner in manging projects with demanding regulations affect how a project can operate. The owner's strategy to select a preferred contractor and trust the capabilities promised by that contractor provides limited understanding of the technical aspect as well as quality assurance. This is because, within the new and temporary relationship in a complex project, the project organisation may have little or no prior knowledge of the other organisation's technical or fiduciary standard (Atkinson et al., 2006), thus there is a lack of time to become familiar with each other and develop shared experiences to demonstrate non-exploitation of vulnerability in mitigating the failure. The need for advanced capability through an integrated solution is inherent to the increased nature of construction complexity and specialisation; an extension of the capabilities may be needed beyond the original scope of what can be developed by the existing contractor. This leads to a mixture of other external capabilities' development with another organisation within the temporary project window. Therefore, complex services need strong management from the owner in identifying the capabilities needed for the right distribution of capabilities to meet their operational environment. Consequently, these different organisations need coordination, with respect to the demanding requirements of the project and its operations that should be included in the solutions.

7.3.2 Applying capability

In the capabilities cycle, problems with 'lack of understanding real-life operational technicalities and constraints in design', 'trusting contractor expertise and resources' and 'technical competency in on-site operations' influence the application of technical project delivery to fit with the functional operations management capabilities (see Figure 7.3). Thus, issues influencing the distribution of operational technicalities, contractor resources and technical competencies must be overcome to mitigate failure.

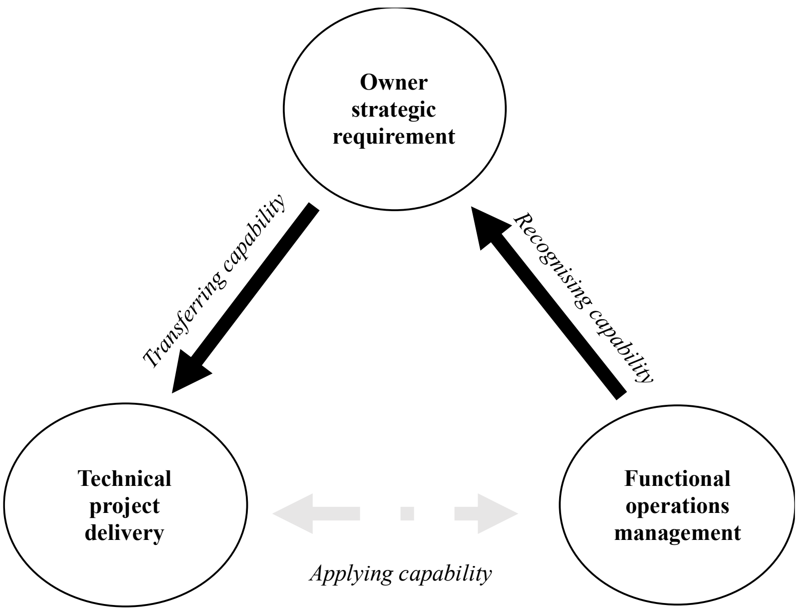


Figure 7.3: Un-integration of applying capability in capabilities cycle

(i) Understanding real-life operational technicalities and constraints in design

The generation of transferring capability provides comprehensive technical knowledge of what is needed for a project's operational environment as an applying capability for the owner to mitigate failures. It is believed that projects need on-going support from the beginning of the front-end supply network engagement, through project tendering and delivery towards the handover and post-operations lifecycle (Davies & Brady, 2000). In the multi-case study, a lack of understanding about operational technicalities demonstrated in design has hindered the application of effective quality control during construction. Although the project design showed an aesthetic need for the project, less emphasis was placed on the technical detail, which hindered the contractors' capability to construct. In a critical, complex project, contractor capability was driven by the complex design with limited technical constraints on the operational aspect; thus, the project faced operational failure. The multi-case study showed that project design does not reflect the operational practice. Project C showed that contractor constructed according to the design but during its operations, project could not withstand the complex environment and faced operational failure. Frequently, design is shaped by the absence of various required technical vocabulary (Daniel et al., 2014) that needs a transformative mediator of capability to interpret the operational technicalities and to transform the cognitive constraints in the design. In most cases, projects were influenced by the diversity of capabilities and owners frequently saw only that different capabilities were needed at different cycles, which lead to capabilities not being mutually altered and revised in enhancing the project strategy. This shows that the diversity of capability, if integrated and distributed in different project lifecycles, could be better applied for owners to mitigate failures through using the right capability at the right time.

Most previous literature describes the nature of practical performance that leads to poor performance, but a critical perspective is often missing. The construction activities are often mapped with a focus on the stages in the designing phase and execution phase (Soderlund & Tell, 2011), but the connection to the operations inbound logistic, e.g. the maintenance, functionality and adaptability towards owner operational management in general, is almost never included. In project A,B and C, projects were designed by a design consultant who had a limited understanding of the owner's operational requirements. This made it difficult for the project team to determine the quality of the output. The design was always reflected to the owner's satisfaction, but the owner needed a clearer vision of their operational needs in ensuring the applying capability allowed sufficient distribution of capabilities. This is because the features of the permanent facility can influence the construction design in both positive or negative ways (Behm, 2005), and many construction designers have not yet viewed how the owner's operation management is critical to mitigate failure.

In a complex project, the process of executing complex development and implementation of the project involves different organisations (Söderlund et al., 2008), but the articulation of how different capabilities are influenced by the design is not yet understood. The cases showed that, in order to apply the right capability, the project needs a combination of experience and knowledge to deliver better quality. As an example, the data showed the designer designed the project to suit the owner's specification, but, during construction, the design could not withstand the complex environment; thus, the product was not fit for operations. Therefore, the design needs greater accommodation of operational technical constraints as frequently problems did not interact with design and operations, which results in a limited ability to prevent quality issues. Capabilities can only be evolved when the problem is faced over time (Ulrich & Lake, 1991); this will help the project team to predict different components of the project lifecycle impact. However, to integrate the capabilities, a project needs stronger owner project and quality management to ensure the right capability is applied that reflects any design problems early. This can only be achieved if owners integrate with the different multi-organisational supply and operator network. Within all projects in the multi-case study, project capabilities were commonly associated with contractors' capability to deliver rather than capabilities to apply the intended operational performance. The data showed that quality of execution was one of the major challenges involved when delivering a complex project, which frequently contributes to operational failure. The study recognised that different organisations applied individual experience and knowledge to perform specific tasks; thus, complex problems were not resolved. The owner and the multi-organisational supply network need integrated solutions and this interdisciplinary shall involve early planning for design, which would provide better distribution of applying the right capability during execution.

(ii) Trusting contractor expertise and resources

The owner organisation's culture relied on contractor expertise and resources to deliver quality expectations. In integrating a complex system, the owner is responsible for how the project establishes a system integrator selected with capabilities to understand the whole project system and components (Davies & Mackenzie, 2014), but little has been discussed about the influence on complex operational environments. Empirical findings showed that owners place trust in the contractors' capability to execute a project. Yet there is uncertainty about how this is provided in regards to the application of quality assurance which then leads to poor project performance. The contractor with limited technical understanding of the operational requirements struggled to deliver. The ability of a system to respond to its operational environment is a key to its adaptive capability or resilience (Lemon et al., 2010); this capability in turn is legally determined by the information about that operational environment through an interactive relationship between the project's competitive capability and operational capability (Wook Kim, 2006). Without a set of detailed operating capabilities, the project team lacked technical knowledge and this triggered behaviour that lead to a project focused on relational competency aimed at obtaining project completion, thus putting operational quality as less important. This indicates that the project team needs a different organisation to address all aspects of the project in bringing together experience and capability that is developed for each process within the multi-organisational supply and operator network to mitigate operational failure.

This leads to the organisation losing the value of its own capability to collate and integrate project capabilities among the multi-organisational supply network in applying the capability for successful project operations. Moreover, any lack of integrative capability in managing a project can produce a dynamic that serves different mechanisms of project quality expectation, thus preventing operational success. Different teams may choose different alternatives that put them on different trajectories for capability development, and this may therefore lead to different outcomes (Helfat & Peteraf, 2003). As the empirical case demonstrated, the contractor had successfully constructed a few projects and delivered them to owner, but the owner realised that the buildings were not fit for their operations. Hence, the previous success performance of any organisation is not sufficient to ensure the successful operation of another project. To mitigate the operational failure, it is necessary for the owner to manage the integration of capabilities with their multi-organisational supply and operator network to distribute the project capability towards the desired operational performance.

Top management relies on strategic capabilities to coordinate and decide what needs to be done at lower hierarchical levels (Davies & Brady, 2016), but the multi-case study has shown that the operational risk increases with complex operational requirements. It is difficult for the whole supply network to work together to construct a complex system. COQ has been demonstrated as a useful tool to develop the integration between strategic owner, technical delivery and functional operations capabilities. Thus, the project process can only be operated if the improvement action is predictable (Kwak et al., 2015), where the concept is that the expected project outcome is affected by the extent to which the owner deploys specific practices in its process. With this, the owner acknowledges that different organisations may have overemphasised the project aim with different organisational values for the project alone, and thus need to manage their expectations to deliver the project towards the owner's operational environment. Literature has shown that quality failures may not only affect the owners but could also significantly impact the contractors' profitability (Love et al. 2018), but the multi-case study showed that contractors were willing to absorb the quality failure cost to sustain their future business. This shows that owners need better management of multi-organisational supply and operator network capabilities to distribute the applied capability that integrates the project and its operation in mitigating failure for long-term project operations.

A different perspective in managing the supply network management is to focus on procuring 'complex performance' (Caldwell et al., 2009); this suggests that the owner and operators should not only procure the asset but also need to secure its performance (Winch, 2014). Consequently, how owners could mitigate poor performance has not been widely discussed. The multi-case study has shown that, upon completing a project, the owner faced difficulties in operating the asset. The project team was struggling with complex and demanding regulations in compliance with the requirements, and a contractor who was not familiar with the option suggested by the supplier and could only manage to deliver the asset but not the quality required for functionality. In particular, owners should have clearly specified project objectives in becoming more creditworthy to build a trustable relationship within the project supply network (Adam et al., 2014); this would help to avoid misbehaviour in terms of the quality perspective. There is a tendency for the owner and the project team to confuse the resource and operational practices (Wu et al., 2010). Thus, operational capability is difficult to identify. The owner's operational regulations demand a more sophisticated system that acquires new technology intervention. This shows that projects need the ability to respond to the dynamic environment to configure asset structure, which is accomplished with cooperation with the necessary operational environment. This can only be achieved through integrated design change and delivery.

(iii) Technical competency in on-site operations

Putting the right technical competency in place is critical for the owner to apply capability for their operations. The delivery of technical capabilities is linked between organisations in delivering a one-off project. Products and services in complex projects provide the needs to support the owners' emerging social and economic activities (Brady et al., 2005) and should have the ability to meet new demands and improve performance through management of innovation (Gann & Salter, 2000). However, this needs clarification on the development of technical capability within the PBO, both with regard to the form of the technical aspect of the system and the construction knowledge in applying the right capability. Empirical data showed that, if the owner placed less emphasis on in-house technical expertise, this created low motivation among the technical engineers; technical problems were then not easily understood by the operational team, but this was not solved by the owner's technical engineers, who had limited knowledge about the construction work. The lack of technical expertise resulted in less commitment from the organisation's actions (Josephson,1998), which may lead to the project team having less control over the quality issues. Therefore, the dynamic nature of the project environment influenced the supply network in taking different trajectories and led to different points of achievement with different capability development.

Technical engineers should have the necessary information about the operation, which needs communication between project team and operational team or between different organisations. For instance, insufficient information involves lower motivation (Josephson & Saukkoriipi, 2005), in which, in the case study, the project team relied on the behaviour and attitude of management which drove the quality culture of the project. The operational process needs to be integrated into the project process to ensure integrated capabilities to mitigate failures are present. The underlying technical knowledge on which a project has been developed over the years has significant relevance in the development of the operations process that will enable the owner to deliver the asset to the competitive market. The organisation's operational routine should form the foundation of its knowledge basis in either forming or changing the project and production process (Cepeda & Vera, 2007). As the case study showed, the owner's operational technical issues were repeated from one project to another but were not fully appraised or resolved, which led to continuous maintenance costs. This shows that owners should use the experience generated from different projects to develop applying capabilities to apply the technical competency in mitigating potential failures.

Moreover, the construction supply network commonly depends on the contracted agreement to deliver the desired project. Although the owner assumes that the contractor and the supply network will provide innovation through interactions and relationship between an organisation and its external environment (Saad et al., 2002), empirical data illustrated that the contractor only provides what was specified in the contract. However, the contractor did show an interest in the owner’s influence and need their interactions for feedback mechanism on the development of innovations in order for them to prevent the occurrences of quality failures. The key to the performance of complex products and systems does not only need the management of projects and management of business process (Gann & Salter, 2000), but also needs the integration of project and business process within the multi-organisational network. In the multi-case study, the owner encouraged the contractor and the supply network to provide incentives for quality achievement. However, different organisations perceive quality differently (i.e. contractors want to get the job done, suppliers want to sell the products), so that the project predominantly focuses on business orientation rather than quality satisfaction. Thus, the contractor may have overlooked the deviation from technical specifications due to unfamiliarity with the owner’s operational environment due to lack of integration. This requires stronger management from owners in specifying the quality specification at the project’s front end, which will allow proper planning from the contractor and the multi-organisational supply and operator network.

This further shows that the project team needs to agree on mutual benefits which will encourage the making of decisions openly and the resolution of quality problems in a way that is mutually agreed when failure is expected. Thus, it is important that the project sets a functional contracting system to align the specialty knowledge with the owner’s expectation. Mostly, the knowledge to design the system in a contract requires tactical technicalities (Mayer & Argyres 2004), which articulates the benefits to owners. This articulation needs stronger management from owners to better distribute project and operational capability. Specifically, when the end-user requirements began to demand more than the specifications, the owner’s responsibility to develop the specification increases. Suppliers who may not be able to capture the complexity then influence the performance of the project. To distribute the right capability, the owner needs to continuously ensure that the supplier is aware of the technical aspect of both project and operations. The function defined in the brief is cumbersome to communicate and translate into production activities (Lindahl & Ryd, 2007), which could result in an insufficient definition of what the owner is demanding. In another way, this may explain the significance of technical specialists for owners to develop operational capability at the front end of the project in aligning project procurement through the collaboration of different interests.

7.3.3 Recognising capability

There is a need for the owners and multi-organisational network to recognise the capabilities provided during the transferring and applying capability phase in the capabilities cycle through all phases of a project to learn from experience and improve their capabilities to perform. There appears to be misalignment between the owner's strategic requirement in their project management organisation and the functional operations management team (see Figure 7.4), which the functional operations management team shows 'the needs of project technical expertise in a project's operations' and 'learning not captured in projects' and that these have influence the operational failures.

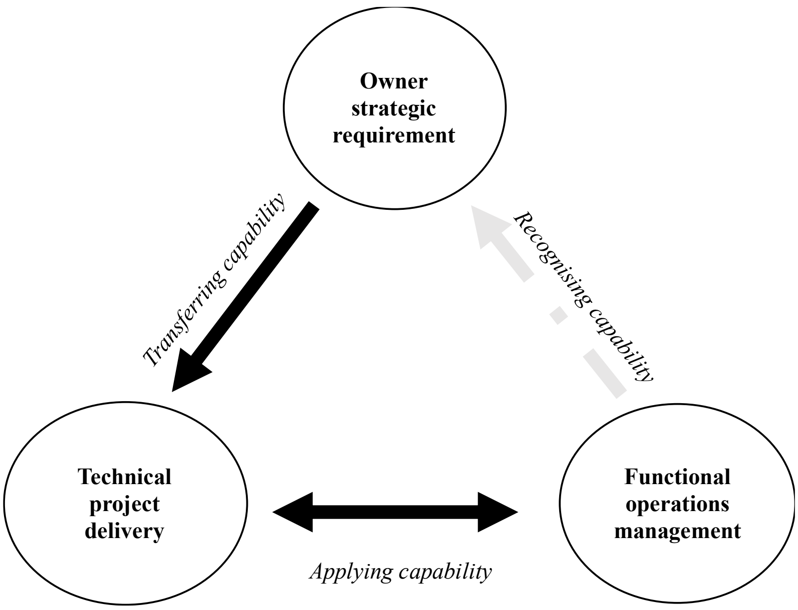


Figure 7.4: Un-integration of recognising capability in capabilities cycle

(i) The needs of project technical expertise in a project's operations

Recognising capability allows an owner to capture the right capability of what a project needs to include the technical problems experienced during operation in mitigating failure for their future projects. The research shows that owners' asset operations continually faced a series of quality issues such as the project not meeting its intended function, high maintenance for operations, early obsolescence and continuous defect cost. A project needs to continuously revalidate the assumptions made during the past experience (Pillai et al., 2002); this will help the project team to highlight the knowledge gained about the project during the process of its execution in considering the requirements for mitigating future potential failure. Data showed that operational failures were difficult to resolve due to lack of understanding of the causes of the issue, as most operational problems were not technically appraised against what was constructed during the project execution. The constraint to this was it involved different teams at project and operation. Thus, managing the quality cost failure for operations becomes very complex when different organisations have fragmented capabilities in mitigating failure, thus the quality issues are resolved in different ways and not from understanding the root cause. This means owners could strategise how capabilities were distributed to technical project delivery in achieving the desired functional operations management through an integrated capabilities approach that links various phases of the project lifecycle.

Owners need to have the ability to acknowledge and understand how project capabilities are connected, as the end product may be a challenge for their functioning operational management. This is because most organisations exhibit a generic culture based on behaviours or conditions (Atkinson et al., 2006), and this is inimical to effective quality management such as to recognise an opportunity and plan a change, or continuous checking of the result to identify learning or to act on what has been learnt in changing the next lifecycle plan. This will eventually avoid the ‘blame culture’ or ‘misdirection’ as an approach to integrated capabilities for failure mitigation. Essentially, such capability seems to prove the difficulty that project management has in coping with complexity and uncertainty to reduce the operational failures. Particularly, these capabilities showed the inability and the unwillingness of the managers or supply network to recognise the poor performance that will either not be under the control of management or construction uncertainty to apply proactive action in mitigating the operational failure. Recognising those experiences and learning from failure will eventually need project technical experience to share the lesson across different boundaries and time (Styhre et al., 2004), in which the case study showed that project technical engineers are always occupied with other complex projects and thus left the operations team to resolve the problem. Therefore, it is important for owners to manage these capabilities and allow opportunities to address such conditions as one of the most significant benefits of mitigating the operational failures.

The temporary context of the project as perceived by the project team frequently leads to demarcation of project and operational capability in the capabilities cycle. Commonly, operations are difficult when projects teams fail to carry out design and planning thoroughly, thus projects proceed with poorly defined specifications for operations (Atkinson et al., 2006). This is recognised when the case study described that projects were constructed based on contractors' capability, which was not reflected in the design, thus project problems were frequently hidden and described differently (by project and operational teams). This has further reduced the ability for project teams to proactively act on resolutions and led to unsolved operational failure. While, when managing a PBO, the owner often changes the team members as the project progresses in order to pass similar team capability from one project to another (Turner & Keegan, 2001); this limits the experience shared between operations for them to recognise the right capability. Project in multi-case study showed that project managers were interchanged from one project to another, leading to difficulty in resolving problems. There was a lack of sufficient knowledge about the alternative causes and so different managers faced uncertainty about the solution choices. As a result, many performances were evaluated based on project manager's limited knowledge of the project process and were not sufficient in reflecting on the present operations of the future asset in the long-term operational context. In this case, the control of the evolution of these capabilities cycles is necessary to have effective communication (Easterby-Smith & Prieto, 2008) and the set of parties involved in a project should not be treated as separate to the operations (Lee et al., 2006). They should be identified as continuous elements for the owner to be able to recognise in detail the capabilities needed to mitigate the failure as well as to integrate the capabilities again in the following cycles of different projects.

Recognising the technical problem faced during the project process will help the operational team know what went wrong that has lead the project to face the operational failure. This is because an effective operational capability depends on how well the strategic perspective and operational details of a project are balanced (Pena-Mora et al., 2008), although some failures are difficult to predict. Current construction project management has often treated project and operations separately, and so the consequent impact of operational failure is difficult to understand. Empirical data demonstrated that operational failures were impossible for the owner to overcome in complex environments without prior project technical knowledge. Organisations fail to collect such data on project experience and, even when it is collected, it is often not made available during the operational stage or even when new projects are started. Operational failure thus was not recognised and, frequently, projects were seen as non-repetitive and organisations tended to neglect the context of capabilities presented in the project cycle. COQ measurement can increase the integration across owner strategic requirement, technical project delivery and functional operations management capabilities to mitigate failure. This will allow for the availability of reliable data in efficiently resolving the operational problem, rather than resolving it in a different way without considering its root cause. Thus, a further plan could be developed in estimating and planning operational management which will contribute to mitigating potential future failure at an earlier stage of construction.

(ii) Learning not captured in projects

Project learning as one of the recognising capabilities is important, as the capability for future projects lies in how knowledge is coordinated, between obtaining the nature of the future work for operations and how experiences from project executions were captured within the time-constrained windows of a complex project. Empirical grounded data showed that projects are grouped into a development programme where the programme takes on the nature of a large project (Turner & Keegan, 2000) that has different forms of management, functional, hierarchy and line-management. That focus is on increasing efficiency. However, these management strategies impede the long-term learning gained during a specific project. Who undertakes projects within long-term programmes and the continuous relational strategy are important (see Figure 7.5). Owners who have different interfaces with many functional operators may not capture the valuable applying capabilities of the supply network. Doing so, it is believed, could provide owners with future capabilities to mitigate failure. Owners should adopt different approaches for different projects within a larger programme, and not adopt a single management style at one lifecycle. This could be achieved through continuously capturing capabilities for failure mitigation at different phases and integrate the capability to suit the different project environments. Owners frequently missed the learning that was experienced when the project-programme strategies changed, due to capabilities for failure mitigation being fragmented in managing the project-based organisation. This shows that owners need to adopt a versatile project-programme process in adapting to bespoke requirements that should be included early on, at the owner strategy and requirement planning stage.

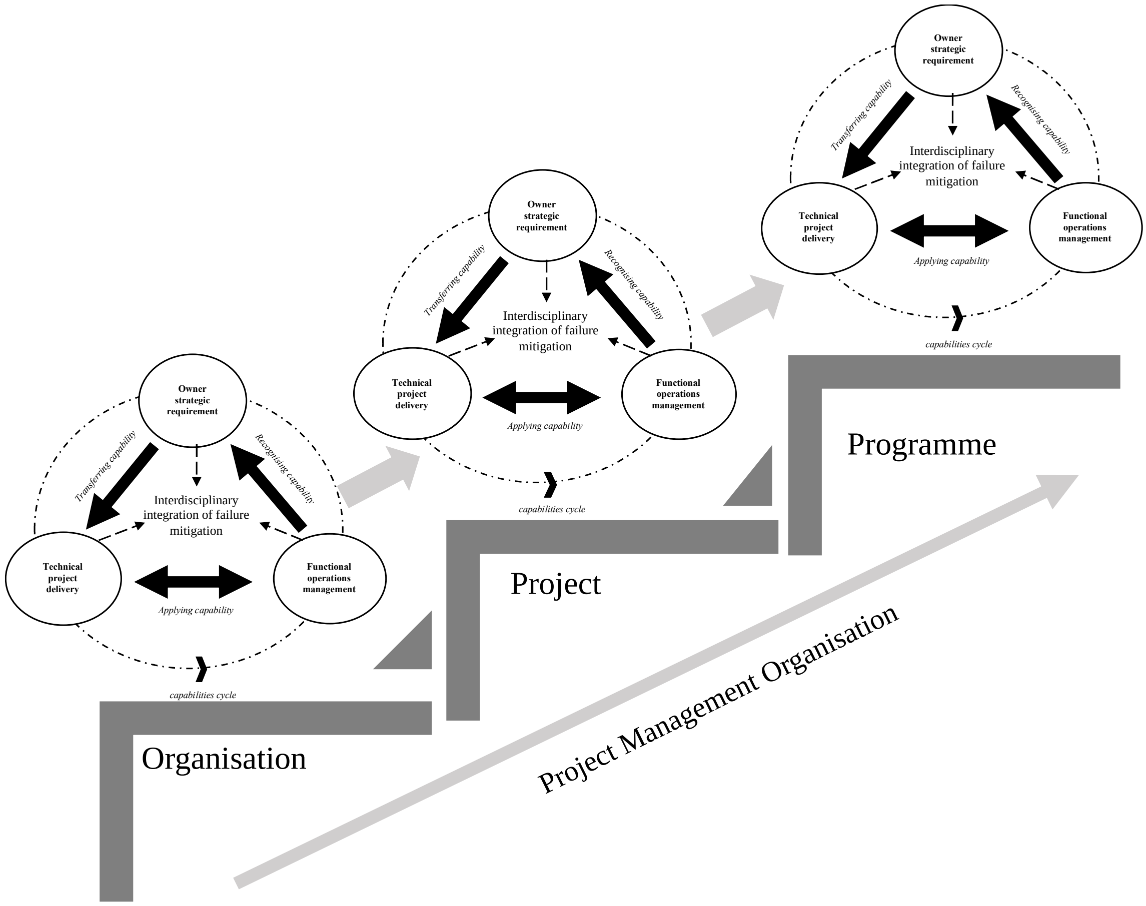


Figure 7.5 : Capabilities cycle within a long-term programme

Project organisations need to promote knowledge-based similarity with the functional operator management to develop common knowledge and specialisation technicality to extend relationships among similar organisations. Operational success needs continuous support from the project organisations' members (Wang et al., 2013), which needs interplays between construction and operational activities to distinguish the successful operational delivery (Zerjav et al., 2018). It was seen that, in some of the case, project benefits were frequently not fully realised while the operations team faced continuous operational failures. But, mainly operational success was often not recognised or was forgotten. Multi-case study recognised that project managers were replaced in failing projects but that this simply created distance from the impending failures. The replacement prevents the original explanation of what causes the failure, but instead creates the nature of how failure is often linked to the 'other' (Daniel et al., 2014). This has then impeded the capability to learn in the sense of exploiting repeated experience among the project team (Soderlund & Tell, 2011), which frequently needs stronger owner management of capability at the strategic planning stage. This will need the owner to bring temporally separated groups into contact with one another to foster the utilisation of a new knowledge combination and the establishment of development for project execution to reduce the potential operational difficulty. In this case, operation performance criteria are difficult for the owner to quantify and may lead to the negligence of the learning capability to understand quality issues and mitigate failure. Owners need to manage the associated risks that represent important aspects for future projects' long-term learning.

Quality management helps to ensure the desired project outcome is achievable. However, having quality management alone does not improve an organisation's performance (Akgün et al., 2014). Organisations need a valuable way to capture knowledge generated during the project process and post-project (Koners & Goffin, 2007) as a way to learn and to benefit future projects. An emergent finding from the multi-case study showed that operational failures treated early in the project provided long-term savings in relation to quality cost. However, in most project case, the project management practices did not effectively quantify quality costs and quality costs were frequently absorbed by different organisations, which led to quality management practice often failing to address the basic source of failure that has driven problems in the operational lifecycle. This shows that project and quality management need integrated management that will allow for a collaborative method in capturing the learning and mitigating the failures. In different project-based lifecycles, operation of a complex system is dependent on organisational characteristics, in which the project teams needs to proactively build critical capabilities before the project is initiated (Sullivan & Beach, 2009), and this has not been widely understood. Multi-case study showed that full project benefits are not always realised as different organisations only deliver the project based on different capabilities and this prevents the iterative process of capability distribution in developing integrated capabilities for failure mitigation. The result is project management is commonly concerned with ensuring things are done properly, assuming there will be a well-defined remit of what the operational needs are. This explains why quality issues were not collaboratively captured and learned from to recognise how different perceptions of responsibility could be upheld by owner organisations in mitigating failure in project delivery and operations.

In recognising the right capability, the owner and its multi-organisational supply network need to learn from one project to another. Organisational learning is an important element in developing capabilities to influence operational performance (Hussain et al., 2018) where construction projects are fundamentally distributed between organisations comprising different capabilities (Styhre et al., 2004), but this need an increased awareness from owner to manage the distribution of different capabilities in capturing the learning and mitigating future failure. The study shows that contractors have claimed they had few opportunities to influence the problems during project execution, and any interruption might cause the contractor to lose the opportunity to perform, as performances were always judged by on-time completion. On the other hand, owners believed that the contractor and project team could deliver the project in relation to their operational quality expectations, thus maintained a good relationship with the contractors to ensure operational success. In the cases, an operational failure was repeated from one project to another and the learning capabilities from the construction were not fully realised. Hence, the distributed capabilities is dynamic in that owners need a mechanism that integrates the various parts of the organisation to reduce and consequently mitigate failures.

7.4 Integration across owner's strategic requirement, technical project delivery and functional operational capabilities

7.4.1 The complex and emerging interrelationship between capabilities

It was shown that stakeholders expressed unique definitions and categorisation of quality cost incurred due to operational failure that was best described as operational failure quality cost by most of the construction participants. This may empirically confirm Snieska et al.'s (2013) view that operational failure costs are usually hidden and the quantification of these costs requires laborious work involving different departments and which leads to different definitions and categorisations. Literature described that investigating quality cost and poor quality cost are frequently forgotten (Josephson, 1998), where the multi-case study showed construction participants' perception in measuring COQ was hindered by the negative implications of quantifying the failures. The research showed their concern about exposing weaknesses and reputational damage that would hinder opportunities for future business, which was the barrier for the application of COQ in mitigating failure. There was a reluctance of exposing the operational failure quality costs, in which, these costs if acknowledged and shared will generate capabilities for failure mitigation. Quite often, no quantitative estimating method was used to understand the failure, and no clear distinction was made between monitoring and reporting the quality cost; thus, failure is not being well understood. It is agreed that quality failure costs have tended not to be differentiated among those parties who are responsible for the cost incurred (Love et al., 2018). This is because PBOs are frequently so complex and critical that quality would be the overriding criterion (Atkinson, 1999) for a project to develop capabilities for failure mitigation, with the project organisation focusing on individual product delivery.

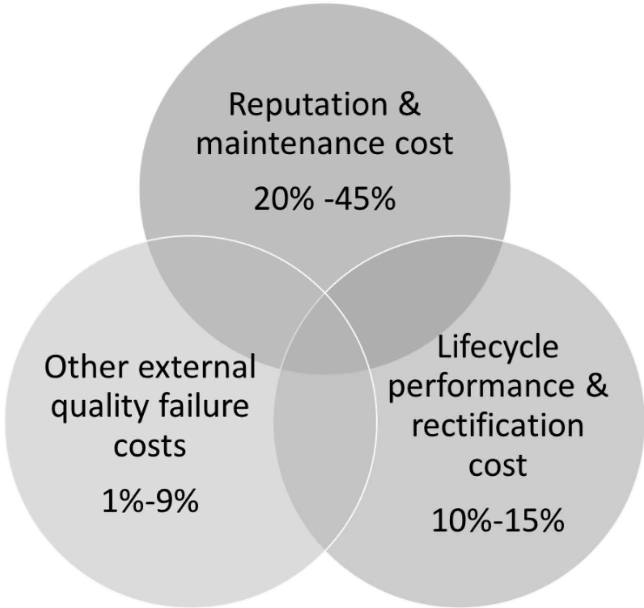


Figure 7.6: Range of operational failure quality costs shared by the multi-organisational supply network in the construction industry

The analysis provides a collection of percentages for operational quality cost within each operational failure cost element (Figure 7.6). There were a number of areas where data was likely to be under-reported or was incomplete; for instance, all costs described were only partially estimated by participants' knowledge (ranging from 0.1% to 20% of total project cost). Therefore, there is a possibility that the findings were an underestimation of the 'true' operational failure quality cost. Although the quantifications of these costs may not cover the 'total' cost implications incurred by the supply network for all projects in the multi-case study, as Barber et al. (2000) noted, this research process may not provide a complete analysis of quality cost over a whole project-operations cycle, but an estimate of the percentage of costs associated with quality failures could be established in showing the significance of quality failures studied. The estimated figure was shared by different parties across the multi-case study and was discussed in the workshop with owner representative in analysing the extend of the figures. It was rather impossible for the participants to make an entirely accurate assessment of the implications of quality issues for other organisations such as the suppliers and subcontractors beyond a reasonable estimate.

It is understood that failures are different from one another, but using the financial method helps to promote the significant need for integrated capabilities for failure mitigation in reducing failure by sharing the risk. Research on cost overrun by Adam et al. (2015) noted management as the most significant cause of cost overrun and agreed the key decision consideration should be at the early planning stage of the project cycle. Literature also showed lack of management support or management interest (Sower et al., 2007; Jafari & Rodchua, 2014) was the most frequent reason for non-quantification of quality cost in construction projects, but the nature of quality cost in complex infrastructure projects is yet to be understood. Thus, this research justified the complexity of capturing the operational failure cost where the inter-dependency of each element was witnessed as one of the difficulties faced by complex projects in quantifying operational failure quality cost. Developing capabilities to mitigate failure could be a way for management to realise the significant amount of quality cost incurred; this further helps in promoting the necessity to mitigate the failures. This research shows the need for integration across capabilities, which needs high consideration from management to promote an improvement in the share of project risk and alignment of the project goal; thus, quality cost could be reduced and shared.

Investment in COQ provides significant benefits in cost saving (Love & Irani, 2002) and as a tool in identifying failures, but there are many difficulties in introducing a measuring system for complex infrastructure projects. The research revealed necessary basics for measuring quality cost failures that need different cultures and behaviour in considering quality cost failure throughout the organisation. Although the success of COQ in implementing quality management is well known within total quality management (Dahlgaard et al., 1992), project-based management is still lacking a systematic investigation for the implementation and evaluation of the quality failure costs in mitigating failures. The systematic analysis requires preventative quality management activities to be effectively introduced in project management. Lack of information on the project operations may cause a lack of knowledge about how specific tasks fit into these operations. This confirmed Love and Josephson’s (2004) perspective that this may hinder the creation of an integrated model and may contribute to sub-optimisation of quality implementation in projects. The challenge for the owner’s capability is to manage their multi-organisational supply and operator network. This will involve all more openly admitting mistakes and generating new ideas based on what they have learned from those mistakes. Existing knowledge should be used to continuously improve operational failure in reducing quality failure cost; thereby the reduced quality cost should be used as evidence for encouragement to every other organisation in mitigating operational failure. Failure mitigation is therefore a shared team strategic project and quality management approach that aligns capability and incentive for mitigation and is integrated in its approach.

Although data showed that the supply network did measure quality costs, the nature of the temporary projects made it difficult. Research has previously shown that, by reducing failure cost, projects will reduce prevention and appraisal cost (Hall & Tomkins, 2000); however, this was achieved over a study through the whole lifecycle of a project. In this multi-case study, appraising prevention and appraisal activities could be applied to future research; currently, literature shows limited knowledge of the root cause of quality cost failure (Love et al., 2002; Molina-Azorín et al., 2015), which needs an exploration of its causality. With more knowledge on the mapping of non-value-adding activities such as reworks, errors, omission and changes (Burati et al., 1992), it is thus necessary to have knowledge of the causes, through examining their chain of events and cost identifications. These should be captured in the integration of capabilities across the owner and multi-organisational network of teams, or in a combined system of learning and sharing in integrating these capabilities to mitigate failure. There is a need for collaborative measure within the multiple organisations that are involved in all future projects to increase their maturity and align different terminologies and definitions of COQ to mitigate operational failures and reduce COQ failure.

7.4.2 A dynamic perspective of the distribution of capabilities in influencing operational failure

The owner and multi-organisational supply and operator network involved in a project will most likely increase the complex technical solutions and will provide more options for building methods and materials, but the volume and diversity of these capabilities, if not managed, will trigger the occurrence of failures. This supports the view of an emerging and dynamic development of organisational capabilities.

Capabilities are distributed within three phases: (1) transferring capability, (2) applying capability and (3) recognising capability. These triggered the occurrence of operational failures and its quality costs, which must be mitigated through the integration of project and operational capabilities. This research has shown the need for a stronger management from the owner in transferring the technical capability for a project, and thus the project could apply the right capability in executing the project. This will allow for more integration with operational management. Failures could be prevented and appraised at the right time rather than contributing to post-project operations. Further, the research showed that, through recognising capability at operational stage, owners could capture capability to improve future projects by learning through experience and continuously improve their capability to mitigate failures.

Owners need to take the multi-organisational capabilities into account when designing procuring strategies to transfer key capabilities that could reduce the project complexity. As the multi-case study showed, complex projects procured with critical timescale and limited budget may discourage collaborative efforts. The empirical data indicated that quality assurance was not multi-organisational and did not have all the capabilities to deal with failures and their causes; more could be done (Daniel et al., 2013) to explain the relative performance of different organisations in influencing failure. Hence, capable owners must integrate capabilities through transferring, applying and recognising the right capabilities.

Capabilities are a form of resource that can only be acquired, harvested and improved (Adam et al., 2014); therefore, the owner must manage their distribution and deployment. Empirical cases showed that the owner's distribution of capability influenced the development of competencies in fostering innovations. This was achieved by the owner's continuous engagement with the multi-organisational supply and operator network, thus integrated capabilities could be achieved. Owners need to collaborate with the contractor and the suppliers when designing procuring strategies. These long-term relationships should help owners to better distribute the right capability, based on past-experiences of failure mitigation. By distributing and integrating the capabilities of various project participants, failures could be foreseen, prevented and addressed at an early stage, as opposed to contributing to operational failure.

In applying the capability phase, the research views how organisational capabilities were nested and aligned with broader project capability to deliver the project. This explains how the capabilities transferred from the procurement and planning are now applied as project capability. The research showed that a lack of understanding about operational capability triggers most of the operational failures. Lack of operational capabilities in the project team limited the opportunity for the development of mutual interest to collaborate in preventing the operational failure. Typically, the supply network may see only the owner's quality expectation or targeted business goals, which cannot be compromised, and make sub-optimal collaborative judgement on quality implementation as a result. Project team capabilities were driven by different expectations and unique quality definitions rather than a combination of experience to share integrated capabilities for failure mitigation. As a result, different individual and organisations involved in a project perceived different levels of operational difficulties. Furthermore, late involvement from contractors may prevent the expression of capability, so project capability may be experienced differently and not align with the project's wider operational integration. Thus, project risk increases in terms of aligning the different capabilities needed for delivering a successful operational project, and so does the quality cost failure (Figure 7.7).

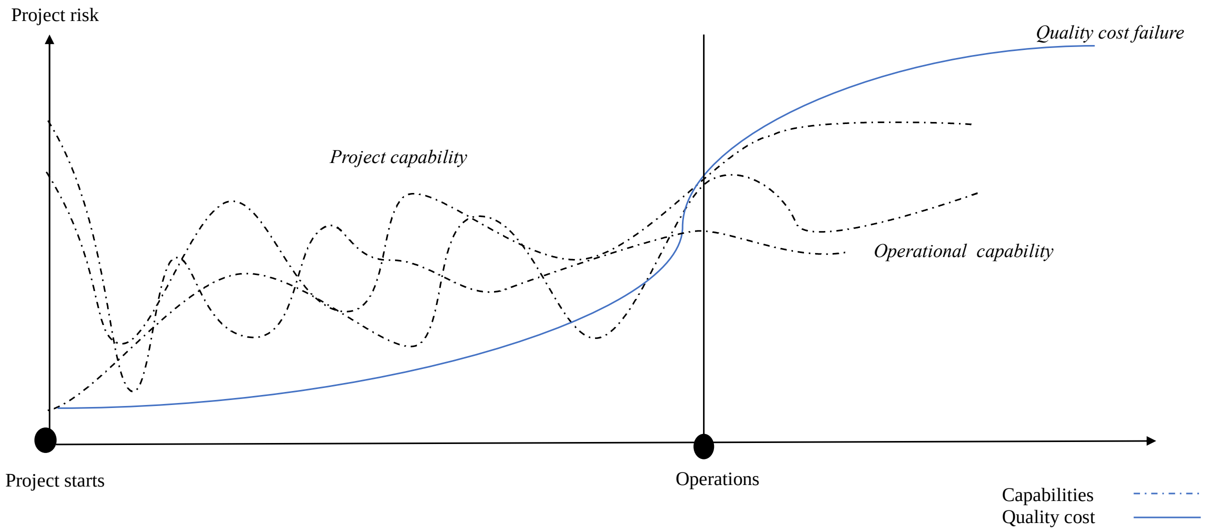


Figure 7.7: Distribution of un-integrated capabilities shown in the multi-case study projects

By identifying the needed capabilities, the applying capability phase should integrate the different capabilities from the multi-organisational supply and operator network to share similar information needed for successful operations. This needs owner involvement in promoting the shared strategic project and quality management approach to failure mitigation and its importance. Owners play a significant role in influencing contractors and other supply network members' performance, and in ensuring that culpability should not always be laid on the contractor's poor performance (Kometa et al., 1996) or that any other organisation involved in the project, but this needs owner and multi-organisational supply and operator network collaboration in working towards integrated capabilities to avoid failure. Owners should build trusting relationships that would aid in achieving a successful project operational outcome that needs a collaborative approach with all supply network. The integrated collaborative approach at this phase is beneficial to share the same visualisation of risk and responsibilities for the operational outcome, as opposed to viewing the project as merely another task to complete.

The recognising capability phase should allow owners to capture needed knowledge and learning in increasing their experience for competitive improvement. This phase should allow owners to modify capabilities distributed in the following cycle of owner programme direction. As agreed by Teece (2007) and Zollo and Sidney (2002), organisations can develop dynamic capabilities through articulation and codification of knowledge, so owners should generate effective learning mechanisms during the distribution of capabilities in the capabilities cycle of each PBO to mitigate failures. Complex projects are always emerging and dynamic, so every experience should be captured and learnt in understanding the causes of failures. This will help owners to predict and respond to failure in other project lifecycles and thus aid failure mitigation.

The distribution of capabilities in capabilities cycle differs from one project to another depending on the nature or the type of the project and its environment. By recognising the capabilities to mitigate failure, the owner and its multi-organisational supply and operator network could benefit from the complete process concerning the development and implementation of project-operational capabilities, thus the right capabilities could be captured. This would further allow for more integrated management in changing the culture for quality implementation, where an innovation through integrated capability will change the organisational routines required when developing a new project (Brady & Davies, 2004). Organisations with systematic repetition (Gann & Salter, 2000) may be a problem in project-based activities, as these are frequently non-routine behaviour; therefore, they need the owners to display continuous capturing capabilities to better improve the application of patterns of activities in other projects. Projects are referred to as similar when the same capabilities and routines are required for repeated executions (Davies & Brady, 2000); however, reliable data will be needed for owners to better mitigate failures. Recognising capability provides collaboration and proactive approaches for the owner, multi-organisational supply and operator network to better identify root causes and cost-effective failure mitigating solutions. This needs solutions to be integrated to reduce project risk and balance the responsibility to mitigate operational failure.

In illustrating the point, Figure 7.3 shows the ideal distribution of the integrated capabilities cycle within different projects. This alignment of capabilities could help the owner and the multi-organisational supply and operator network to better understand and capture the whole quality cost failure from one project to another. Thus, it provides greater solutions for preventing future failures.

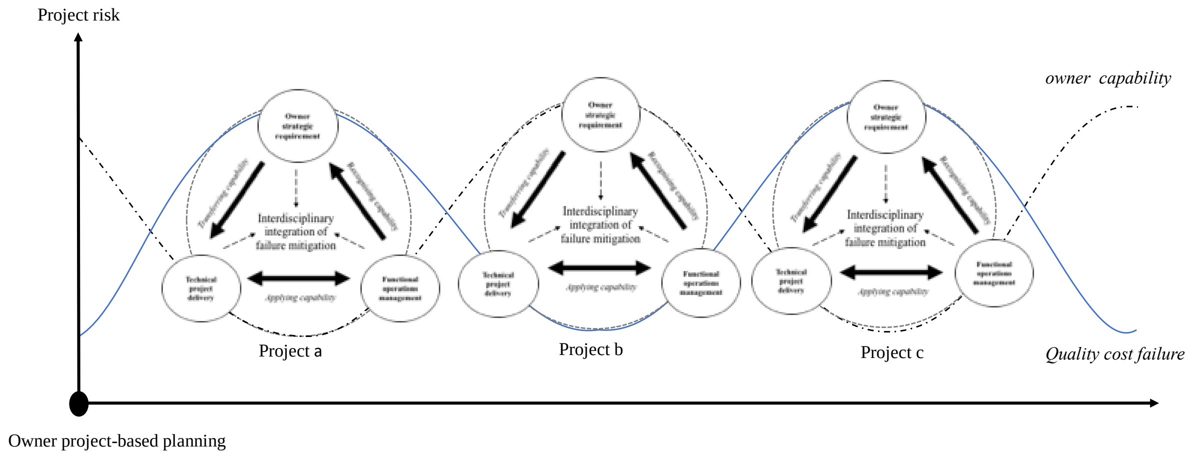


Figure 7.8: Cyclic Integration of owner's strategic requirement, technical project delivery and functional operations delivery capabilities in reducing the operational failure and its quality cost

Capabilities theories agree that firm use of resources and capabilities is needed to create competitive advantage (Helfat & Peteraf, 2003). Thus, organisational project management uses capabilities to achieve the organisation's aims through projects (Davies, 2004), but little is known about how project capabilities influence the operational outcome in different cycles, and specifically in relation to failure. The empirical grounded studies of the multi-case study demonstrated a lack of operational capabilities, which creates failure in the project-based organisation's management. Operational capabilities (routines, skills and process) are developed over a long-term cycle (Thoo et al., 2015), but, in a temporary project, operational capabilities need to be embedded project by project (Hobday et al., 2005). As such, the capabilities in failure mitigation need integration from both project and operational capabilities. Although the research has shown that operational capabilities are difficult to attain in temporary projects due to such projects involving a diversity of capabilities from the multi-organisational supply network, integration of the technical aspect between the owner and multi-organisational supply and operator network in transferring the capability phase could better prevent the occurrence of potential failure. What this research has shown is the need for integration capabilities between the owner and multi-organisational supply and operator network, to mutually support and share capabilities in fully understanding the project process and plan according to operational technical necessity, thus providing the right capability to apply.

Capable owners must integrate the contractor's capability across the whole supply and operator network in making sure the project is executed and operationalised. Understanding the complete cycle of capabilities is a fundamental source to understand diversity in a project. Helfat and Peteraf (2003); however, prioritisation of the right distribution of capabilities from owner to project and the operations capability in the capabilities cycle may compromise the quality of the interface with its complex environments to mitigate failure. Commonly, every project measure quality differently depending on the project environment. Construction needs to be delivered through the logic of the permanent organisation that uses the asset but not according to the 'project-by project' view frequently utilised by the construction sector (Lindahl & Ryd, 2007); this describes that the owner's capability should be considered together with the capabilities of the different supply and operator network members rather than only focusing on the project capability. Integrating contractor capabilities with project operations will reduce failure, as contractors will share the responsibility for project risk and thus will have more opportunity to provide greater quality realisation by working together with designers and suppliers in mitigating the failures. The integration of capabilities between owner and supply network shows the equal value of balancing and distributing project risk among the project stakeholders. System integration creates a stable and consistent process to coordinate the development of multiple systems (Davies & Mackenzie, 2014), in minimising unexpected interactions and responding flexibly to problems that might hinder the project's progress and owner's overall programme. This work has shown that integrating capabilities across owner's strategic requirement, technical project delivery and functional operations could provide clear solutions in response to failure that are integrated from the owner and multi-organisational supply and operator network.

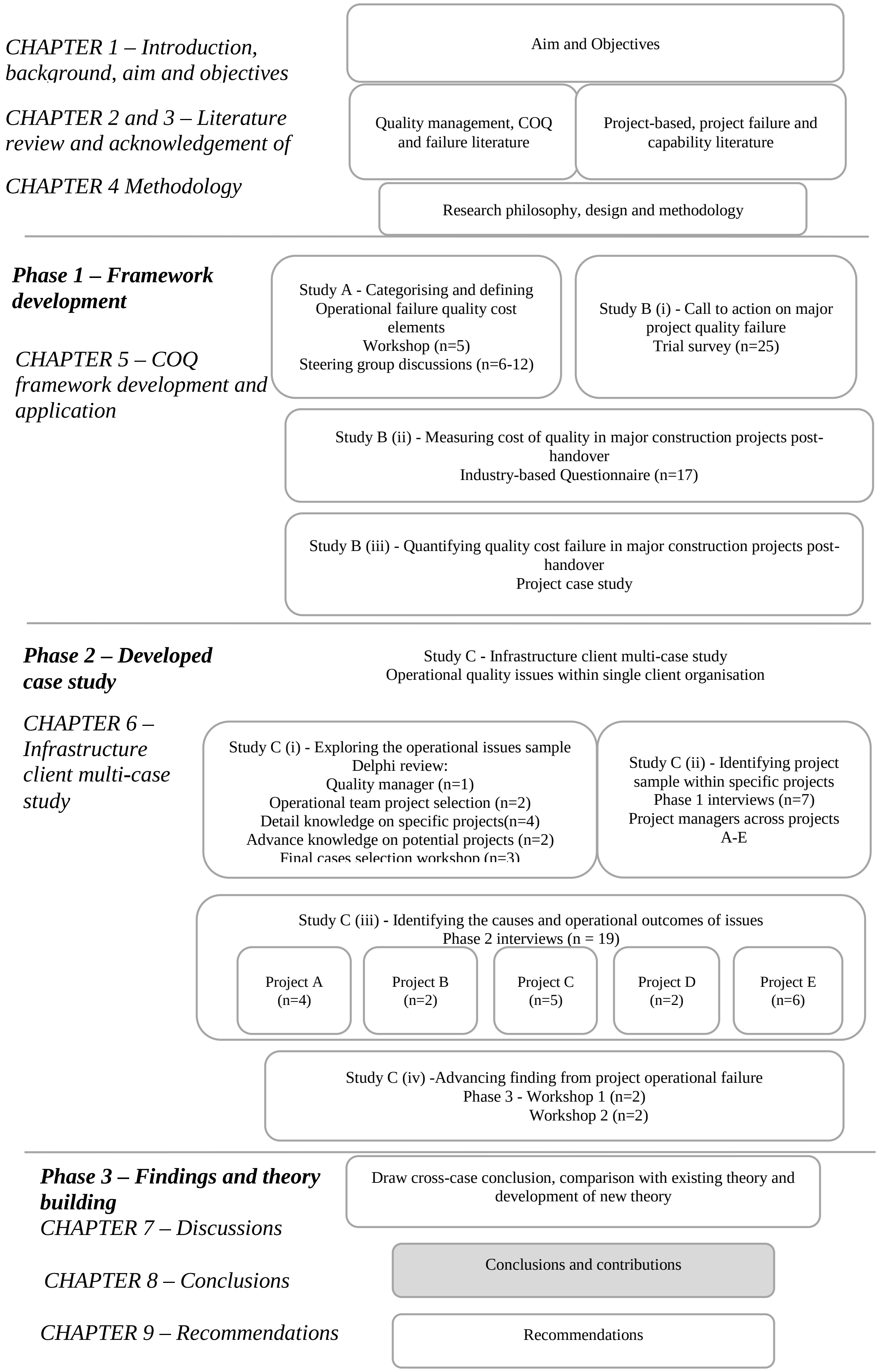
Quality capability is lost as an organisation moves from one one-off project to another one-off project. What is evident is that early engagement of the contractor could help to achieve greater understanding of project capabilities that respond to project operations, and thus increase the competencies among the project team to provide fair quality solutions and prevent failure. The multi-case study showed that failure in the system was influenced by the late design, which is not integrated early enough with the contractor and other supply and operator network members. Greater integration from the operational capability with the designer and contractor helps to align the project expectations. It is argued that, instead of providing clear roles for project management to engage in a wider range of tasks and activities (Lindahl & Ryd, 2007), there is a need for owners to better understand the capabilities that lie in their multi-organisational supply and operator network before distributing them (i.e., the capabilities) in the project. This will help owners to mitigate and improve competency during project operations when the benefit of these capabilities was learned and captured at the different phase of the capabilities cycle. As suggested by Winch and Leiringer (2016), owners need to capture the capabilities to identify and acquire externally generated knowledge that is critical to operations, whilst learning from past experience. Through providing stronger management to integrate capabilities, project risk will be shared among the owner and multi-organisational supply and operator network, thus quality execution will be more assured.

Construction projects generally do not have a mechanism to learn from the mistakes (e.g. causes of failure) that they have made (Love & Edwards, 2004) and that capabilities for failure mitigation is still fragmented within construction participants. By rightly distributing owner's strategic requirement, technical project delivery and functional operations capabilities, it will almost certainly help management to override certain 'dysfunctional' features through better establishment of project and operations capability, besides exploring new possibilities and exploiting what is already known from project capabilities. This research provides knowledge about the emergent causes of operational failure and presents a dynamic perspective of the distribution of capabilities in the capabilities cycle to develop a new strategic approach for the owner and multi-organisational supply and operator network to mitigate failure. This strategic approach will enable owners to fairly transfer capability, apply the right capability and recognise the capability to mitigate failure. Accordingly, this strategic project and quality approach needs integrated capabilities across the owner and multi-organisational supply and operator network. The integration of capabilities needs collaborative efforts among all stakeholders so that project failure could be effectively foreseen, prevented and addressed at an early stage, rather than contributing to operational failure.

7.5 Chapter summary

In summary, this chapter has discussed and presented the overall findings from the evaluation studies of failure mitigation through integration of owner's strategic requirement, technical project delivery and functional operations capabilities to address the problem of the distribution of capabilities in capabilities cycle based on the data analysis. It presents the causes of operational failure and discusses the findings in relation to the literature in developing the owner's and its multi-organisational supply chain and operator network capabilities to mitigate unforeseen events (unintended) as well as predictable contingencies (intended) of operational failure. The findings contribute to the development of a new strategic project and quality management approach in failure mitigation and demonstrate the potential of advanced integrated management of capabilities in mitigating failures.

Next, the conclusions and recommendations of this research are presented in chapters 8 and 9. In Chapter 8, the research aim and objectives are re-visited and summaries of the conclusions reached are elaborated on accordingly. This chapter also further explains the research limitations as well as the contributions to knowledge as the conclusion of this study, whilst Chapter 9 presents the recommendations for future research.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Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) - Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv) -Advancing finding from project operational failure
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Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

8 Conclusions

8.1 Introduction

In this chapter, the key conclusions that are reflected on throughout the thesis are presented. The conclusions are linked back to the research aim and objectives, and the findings that have been derived from the literature review and all the three phases of the study. The research limitations are also explained, to give an overview of the constraints faced in conducting this research.

8.2 Achievement of the research aim and objectives

Based on the research problem, this research's aim is to investigate why assets handed over to owners have failed during operation and how the complex interrelationship of an owner and its multi-organisational supply network members may influence the existence of operational failure and its quality costs.

In conclusion, this thesis has raised the importance of quantifying COQ in construction project management. Through study A and B, It delivers a quality cost framework that suit the construction scope, Study C described the process and theory to support the understanding on the dynamic and emergent owners and multi-organisational supply network capabilities' influence on the project lifecycle. In achieving the main aim, these thesis objectives were achieved and are detailed in Table 8.1.

Table 8.1: Achievement of the objectives

Research Objectives	Achievement of Research Objectives
1. To explore the existing COQ and investigate its empirical application within an overarching TQM system.	The literature provided a basic understanding of the existing costs of quality that are limited to the construction sector. COQ can be said to have established itself as one of the quality management tools used to achieve competitive advantage. COQ provides an improved strategic context for services, where both effectiveness and efficiency are achieved. Generally, as the literature showed, COQ is understood as being for organisations to reduce unnecessary costs and create a better-quality output. However, the complex nature of construction makes it difficult for the project team to quantify the COQ within the project management context. Therefore, construction failures are growing with non-quantification of their costs. COQ can continuously support both the short- and long-term quality achievement with a new definition and standardisation within the construction context. This can be achieved by embedding the concept of COQ into

	project and operational delivery management.
2. To investigate the status of operational failure cost and COQ within the construction supply network.	An abductive with grounded theory approach using literature, a pilot survey, a design workshop and multiple steering group discussions led to a new extended COQ and operational failure quality cost framework that integrates owner and supply network judgement into the set of quality cost elements that suits the construction scope. The framework elicited language and structure that enabled the definition and assessment of general construction-specific elements. The owner and supply network showed different perceptions in dealing with quality cost failures with different level of maturity judged but were confident in influencing the failures. The framework proved useful in developing understanding of its relations to the occurrences of failures. Furthermore, this framework provides a useful tool in developing theory to further understand the conceptual elements in reducing failures.
3. To investigate the causes of operational failure within an owner and its multi-organisational supply network capabilities.	Five projects provided detailed multi-case study for the abductive, grounded theory research. The COQ framework was used alongside questionnaire surveys, workshops, interviews and steering meetings. It was used to elicit and measure the owner and multi-organisational supply network perspectives on the occurrences of operational failures retrospectively. Owner and multi-organisational supply network also defined their understanding of each quality cost element and estimated the cost incurred within each one. An understanding of the causes of failures from the emergent and dynamic process is provided which describes the diversity of capabilities involved. Expert workshops provided a useful way to define, deliver and evaluate the emergent findings from understanding the diversity of capabilities as a cause of failure and its link to owner PBO management. The different behaviours and cultures in applying quality were expressed and the understanding of integrating capabilities as an approach to align the owner and multi-organisational supply and operator network quality expectations was proposed. The capabilities cycle in different phases was further shown and mapped, illustrating the link between different occurrences of failures. The capabilities cycle model between owner's strategic requirement, technical project delivery and

	functional operations capabilities was developed to further generate new theory.
4. To develop a new strategic project and quality management approach in failure mitigation to integrate capabilities between the owner and multi-organisational supply and operator network.	Appraising the COQ framework through a grounded theory approach revealed an empirical relationship between the quality cost incurred, distribution of capabilities and quality failures. This data was compared to literature using theoretical triangulation (Chapter 7) to understand the emergent findings. The relationship between owner, project and operational capabilities was summarised in a capabilities cycle. The model illustrated the need for the owner to integrate the distribution of capabilities within each phase of a project. This is for the organisation to be able to inwardly integrate and outwardly collaborate on the capabilities to change quality behaviour in reducing failures and quality cost failure. Integrating capabilities across owner's strategic requirement, technical project delivery and functional operations management is proposed for owner, multi-organisational supply and operator network address the problem of the capabilities cycle in PBO. The integration of capabilities will allow owners and their multi-organisational supply and operator network to equally share project risk and quality cost, thus mitigating the failures. Further research is required to test these findings.

8.3 Summary of conclusions

Based on the achievement of the objectives, the conclusions were devised based on the adoption of an abductive mixed-methods research design and the incorporation of the literature review and findings from all phases of data collection. Based on the empirical findings, this study makes the following propositions:

8.3.1 Conclusion 1

COQ in the construction industry is still at its infancy and the implementation of measuring the COQ needs a stronger approach from top management.

Literature, steering group discussions and data analysis from study A, B and C findings indicated that the perception of the construction industry towards COQ is still at its infancy and the implementation of COQ in construction is still low. It is understood that COQ can be a key tool in providing competitive improvement as it identifies the influences required for change in the project environment and to develop prevention and appraisal activities to accommodate it; thus, the application of COQ may provide improvement for a PBO if well applied. Generally, the nature of the construction industry makes it difficult for COQ to be quantified but the benefits of applying COQ in reducing unnecessary costs are apparent. Although the literature shows that some organisations have attempted to measure and quantify the COQ, it was emphasised that the COQ was not measured as a whole but only covered certain elements in the construction context. Thus, this needs a stronger management approach to better emphasise the quantification. There is no standardisation and definition of COQ that suits the construction context as each project is believed to be unique within its own environment.

To quantify the COQ in a project, the project needs systematic alignment between the multiple organisations involved. A standardisation using COQ framework that is developed to suit the construction scope would help to align the different definitions of quality by different organisations. The quantification could provide timely, relevant and accurate feedback for both short- and long-term benefits. However, the implementation of COQ measure would require a high level of support from the top management and commitment from the organisation involved within the project to understand the cost elements that will generate the input or outcome of implementing the quality process. The owner needs to explore in which phase (project or operations) the project frequently incurred the most cost; in this way, COQ could be better understood in relation to the significant differences of each category and how each element is impacting on another. Therefore, top management should set a parameter of how a construction project could have synchronised the quantification of quality cost within the multi-organisational network. An effective process will thus help project organisations to develop a standard framework which constitutes a range of quality cost elements to suit the capability needed in constructing a project and in successfully delivering its operations. It is believed that using a standard framework could offer a better implementation of quality measure through a clear identification of quality elements that reflect on the project strategy and need. In general, the study summarised that the COQ in the construction industry needs to be promoted for better quantification in relation to improving the quality performance.

8.3.2 Conclusion 2

Operational failure quality cost could be reduced through understanding the causes of operational failure.

Studies show that operational failure quality cost is still highly recurrent within construction projects. The COQ was understood to be absorbed differently by different organisations; this is because COQ and failure costs were not frequently quantified. The research shows that construction participants were confident that they could influence the occurrences of failures depending on their context, but this needs integrated management. They believed that quality failures could be predicted or foreseen if quality costs were acknowledged. In the main, the multi-organisational supply network was not aware of the implications of the incurred cost, as they were driven by different aims in delivering the project. The organisation believed that quantifying the quality cost would impact the relationship among the project chain, as well as with the owner. Analysis of the multi-case study has demonstrated that the project team were aware of the operational failure costs incurred due to failures, but lacked the ability to demonstrate the relationship of who bears the costs. Frequently, operational failure cost is assumed to be absorbed by the owner who operates the asset, but research showed that COQ is shared among the multi-organisational supply network members.

Quality failure was perceived differently by different organisations, thus operational failure costs were difficult to justify. With this knowledge, the focus of operational failure quality cost helped the research to generate further understanding upon what constitutes the occurrences of failures to reduce the quality failure cost. The research findings have suggested that, in order to mitigate and reduce failure, the owner and the multi-organisational supply and operator network need to understand the causes of these quality failures. It can be concluded that operational failure cost can be reduced if the owner and its multi-organisational supply network could tightly define quality and share the operational risk. Thus, the COQ framework indicates proven elements that are exemplary and could be used to develop the quality failure cost measure.

8.3.3 Conclusion 3

The diversity of capabilities that are distributed in a complex infrastructure project leads to operational failure and result in high cost of quality failure.

Findings from the Phase 2 analysis have demonstrated that the operational failures were triggered by the different capabilities that are distributed across the different phases of the project lifecycle. The cycle begins with the owner at the initial stage developing the strategic planning and procurement capabilities needed to execute the project. Capabilities are then transferred to the project through the multi-organisational supply network. The project team applies these different capabilities needed to complete the project aim and deliver the expected operations. Capabilities during project operation were recognised by the project and operation team; this provides competitive improvement for future projects. The diversity of these capabilities was triggered by different factors at different phases.

The transferring capability was triggered by the contracted end date, the allocation of project budget to fit project specification, the relationship with the multi-organisational supply and operator network in integrating project capability, and the reflection of a project scope with demanding specifications. The capabilities transferred at this stage showed the importance of early formation of the capabilities set at the beginning of each project in streamlining the management structure and procedures for quality implementation. Quality is set differently by different organisations; a procurement method that focuses on quality measure at the outset of a project would be useful in making sure the quality of the operational side of the project is successfully achieved. Project capability needs a clearer paradigm to achieve optimal efficiency in delivering a high-quality performance.

Applying capability was influenced by the imperative factors of how the understanding of real-life operational technicalities and constraints was placed in the design, trusting the contractor's expertise and resources, and the technical competency in on-site operations to influence the operational capability. Project capabilities lacked consideration of operational technicalities and constraints, which thus resulted in operational failures. Projects need to develop capabilities that reflect both the quality to execute and quality for operations. Thus, applying the right capabilities could generate relevant and effective capabilities in obtaining successful quality operations.

Lastly, the recognising capability seeks to foster the owner's capability by developing the lesson learnt from the project and the operationalisation of the asset. It is anticipated that operational capability, if recognised, can contribute significantly by comprehensively calibrating the effectiveness of the operations, which will improve the owner's future project performance and mitigate failures. The comprehensive set of capabilities distributed from the beginning of the project lifecycle should help the owner to evaluate the capabilities needed in terms of achievement and improvement. Lack of technical experience during the operations stage could prolong the operational failures and thus increase the COQ failure. Projects need to capture the operational failure to prevent the repetition of failures. This can only be achieved through recognising capabilities developed from past experience.

8.3.4 Conclusion 4

The owner and multi-organisational supply and operator network need to integrate capabilities across owner's strategic requirement, technical project delivery and functional operations management in different phases of the capabilities cycle to mitigate failure and thus reduce quality cost failure.

Analysis from Phase 3 draws a cross-case conclusion, theoretical triangulation and development of new theory that has indicated capabilities are distributed across different phases of the capabilities cycle. The overall distribution of capabilities shows significant implications if integration is achieved; this will further help the owner and multi-organisational supply and operator network to mitigate the failures and thus reduce the quality cost failure. The research claims that the integration of capabilities is needed across owner's strategic requirement, technical project delivery and functional operations management to balance the risk and share the responsibilities across the multi-organisational supply network through the use of the COQ measure.

By promoting the COQ measure, the owner and its multi-organisational supply and operator network could anticipate the risks and costs that could be incurred if integrated capabilities are not achieved. Therefore, integrating the capabilities will assist the owner and multi-organisational supply and operator network to collaborate in delivering a project towards successful operations. In this way, the owner and multi-organisational supply network could share and balance the possible COQ incurred throughout the project lifecycle. By integrating the capabilities, it is possible for the owner to obtain the required quality behaviour and culture when the right capability to execute and operate a project is achieved. A project team that integrates the different capabilities will demonstrate quality behaviour if the implication on COQ is known and shared. Moreover, there was a high need for the multi-organisational supply and operator network to openly discuss and quantify the quality failure cost as an enhancement tool for implementing the quality cost and taking full control of the capabilities provided to perform.

A few challenges are that it might not be possible to quantify the total COQ, as it is always absorbed differently by different parties; and the nature of the project is always dynamic and emergent, where the project might be changing at any time due to certain conditions or failures that are not always expected. There were also expectations that, by effectively implementing quality management as one of the commitments in delivering project management, quality failure could be reduced. But this needs alignment of the quality tool definition as a common language for different professions and organisations to better understand the quality expectation. It is hoped that the framework will help the owner and its multi-organisational supply and operator network in considering the operational failure and its quality cost, to incorporate those elements at the front end of the project. This suggests that the project and operations will have full control of the operational performance.

It is advocated that understanding the different risks and costs borne by different parties will encourage different organisations to be willing to cooperate in obtaining equal benefits. Failures thus could be learned from and improved in future projects when recognised by all construction participants. It was claimed that the incorporation of quality management helps a project to perform better, when it had been expected that more emphases would fall on the supply network to integrate the capabilities in resolving problems. In summary, integrating capabilities creates a collaborative effort among the owner and its multi-organisational supply and operator network, and this could help to effectively foresee, prevent and address failure at an early stage. Therefore, as a final output of this research, it is suggested that the development of a new strategic project and quality management approach is needed to mitigate failure. This could be achieved through integrating owner's strategic requirement, technical project delivery and functional operations capabilities to address the problem of the distribution of capabilities in the capabilities cycle of PBO. By integrating capabilities across different project phases, owners and multi-organisational supply and operator network will learn and be able to procure more integrated capabilities in failure mitigation to reduce failure throughout the project lifecycle.

8.4 Limitations

Research is frequently limited due to time and resources. Within this research, the research design was not intended to quantify the whole COQ and quality cost failure, or to produce results that account for or predict failure as created by people or through process predictability. However, it does show that COQ can be quantified and reduced in a normative sense, by the reflective, ongoing and well-structured consideration of a project and its operation in managing capabilities. In addition, the research explored a wider contribution towards how project management could reduce the quality failure. However, the study does have some, which include:

1. All five cases were investigated within one organisation; as such, there is limited operationalised generalisability. However, by using a single organisation as a multi-

case study, the researcher wanted to achieve an explanatory contribution to the domain of project-based organisation studies. This study limitation was overcome through exploring the inter-organisation context, within different projects, which is identified as important for achieving the nature and context of operational failures. Focusing on such projects allowed the researcher to achieve the analytical depth necessary to reveal the basic features of the phenomenon on which future studies should expand.

2. Within this organisation, this research has shown how operational failures were influenced by the distribution of capabilities across the capabilities cycle in a project, but are probably limited to major applicability in terms of other major infrastructure projects. Multiple cases across different sectors, and types and scales of projects could possibly show different results and, if there are wider projects that could be tested, the research may be more aware in terms of how the findings could be applied.
3. The application of grounded theory may have resulted in some researcher-induced bias and reapplication difficulties; however, these limitations were minimised by strong industry involvement, collaboration and validation. Research samples were all identified with an experienced senior manager. This allowed the researcher to provide rich data and in-depth arguments on a series of ideas, topics and issues related to the operational failures.
4. Within this research, it was neither practical nor possible to concretely understand all the variables that impact on operational failures. The investigation of failures and operational failure within the project context is multi-stakeholder, multi-timescale, multi-parameter, multi-purpose and multi-setting. The failure is unbounded, with often unknown variables and limited initial hypotheses. The results are more discursive than conclusive, but it would be possible to re-design, test and verify the theory generated in this thesis.

8.5 Contribution to knowledge

8.5.1 Academic contributions

- The COQ framework, as presented in Chapter 5, was developed as part of this research. The framework illustrates a range of quality cost elements within the categories of prevention, appraisal and failure that suit the construction project scope. This research opens up new possibilities for academic research. This study has unpacked the narrow study of COQ that was limited to quality management.
- This research thus offers a new understanding of the complex relationship between quality cost and operational failures. It highlights an understanding of failure

triggered factors that need to be emphasised in both research and practice. It gives an overview of the occurrence of operational failure and its relationship to the quality cost incurred, which serves as a good reference for other researchers.

- The capabilities cycle model integrates new understanding on project and quality management. This thesis has made evident the link of project management and quality implications. Quality is embedded within the project and operational capability. As such, promoting project management alone should not be enough to improve project performance; it requires a collective understanding of quality.
- An advanced strategic project and quality management approach is proposed to integrate capabilities to mitigate operational failure. The result of this thesis shows failure mitigation needs to be integrated across owner's strategic requirement, technical project delivery and functional operations management capabilities within the owner and its multi-organisational supply and operator network, which can be achieved through the use of COQ measure.

8.5.2 Industry contributions

- The development of the COQ model is set as a quality measure that can be used in different organisations to measure the quality cost of construction projects. It is anticipated to fill the gap relating to the non-existence of a quality cost framework or guidelines for construction projects. The COQ framework would enable construction organisations to understand the quality cost elements that could be measured in reducing the overall COQ of a project.

  The COQ framework is also anticipated to serve as a platform in bringing up quality management tools as an improvement to project performance management. Quality and performance have always been compromised in construction projects and the quality implementation has been consistently underrated. The emergence of quality cost should be able to attract top management's attention in applying more proactive management to improve industry performance and reduce the occurrence of failures.
- The distribution of capabilities in the capabilities cycle model gives further understanding of how capabilities in complex projects should be managed to mitigate failure and thus reduce the quality cost failure. This new contribution to the industry shows that this research has developed a solution based on establishing new understanding of the project and quality management perspective.

8.5.3 New knowledge

It can be concluded that this research poses evidences that it has demonstrated a new theoretical concept of integrated capabilities within project and quality management in mitigating failure, which has never been established in the project management field, especially focusing on the operational quality failure. A set of publications based on this research is also the supporting evidence where the knowledge of this research has been affirmed in academia. This thesis used abductive reasoning to demonstrate an iterative and intertwined relationship between quality cost and operational failure. Appraising the quality cost framework through grounded theory revealed an empirical relationship between the quality cost incurred, distribution of capabilities and quality failures. The overall contribution of this thesis is a new understanding of how capabilities are distributed in projects and operations and influence the occurrence of quality failures. The capabilities cycle illustrates the need for the owner and multi-organisational supply network to integrate capabilities within each phase of a project's lifecycle. This will help organisations to understand the need to integrate capabilities and thus be able to inwardly integrate and outwardly collaborate on the capabilities to change quality behaviour in mitigating failures and reduce operational failure quality cost. This research is important because quality and project management tools often lack identification of the organisation's unique capabilities development, which is frequently limited by the functionality of a project outcome. Commonly, the construction industry is narrowly focused on the sub-set of supporting project execution, rather than fully understanding the implication of the distribution of capabilities towards the asset operations. The functionality of a project is perceived as completing the project, thus there is no certainty about the operational outcome. Hence, this thesis generates a wider perspective of what has constitute the operational failure, and thus provides improvement and solutions in failure mitigation.

8.6 Impact and dissemination

8.6.1 Impact on construction organisations

This research applied a grounded theory approach and had a strong collaboration with an industry working group (the Chartered Quality Institute) as a means to continuously improve the relevance and usefulness of the research for the audience over the period.

This research informed and subsequently helped to address the recommendations made by the quality institution representing the UK construction organisation: that the industry needs to develop a set of COQ measure to reduce the failure cost; to educate the industry and its supply network in the provision of quality through understanding the causes of operational failures; and to develop the means to engage the owner and its multi-organisational supply network in integrating the capabilities that share the project risk and quality cost to develop capabilities for failure mitigation.

Investing in these quality costs that have the highest impact has shown that the integration of capabilities can assist the construction industry in mitigating failures. The research benefited from strong support by the owner organisation during the research process and this organisation has provided an opportunity for further research as a part of their quality development process. COQ has been adopted at the strategic level by the owner organisation and has formed a new capability focus and highlighted changes in the organisational structure. It was highly influential in the project delivery department, which has adopted the COQ framework presented in this thesis and worked with contractors to collect additional data on COQ. The method developed to understand the importance of COQ continues to draw considerable industry-level interest and the approach is being discussed further afield.

The framework has formed a starting point for the Charted Quality Institute to further generate empirical understanding from different organisations. The research provides an opportunity for other construction companies to learn lessons from it and demonstrating the relationship to operation failures and the quality cost incurred. The introduction of the capabilities theory has enhanced the explanatory influence of the existence of operational failure to further explore how exploration and exploitation practices in quantifying COQ in a project can be translated into value in improving construction performance.

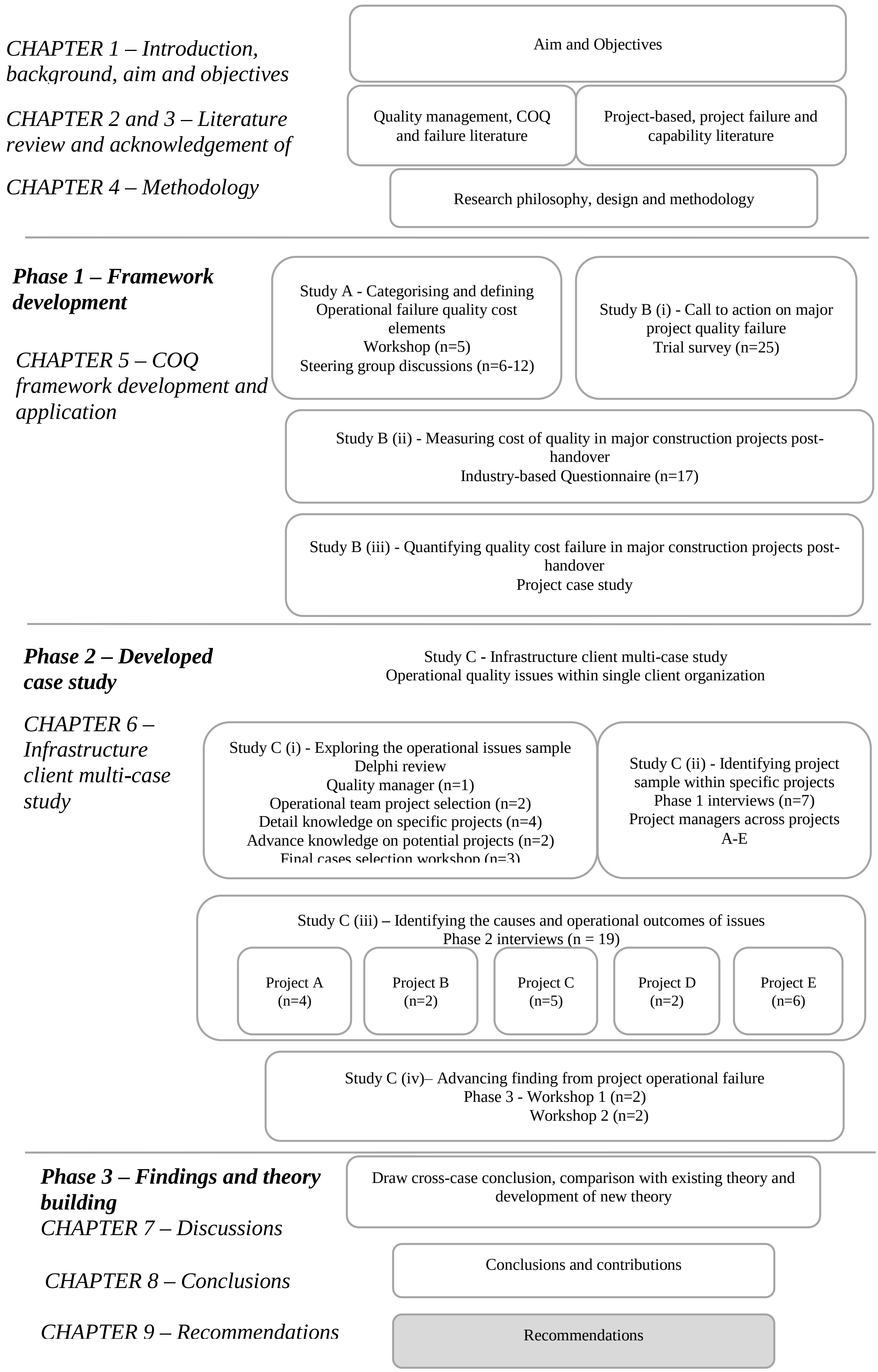
8.6.2 Dissemination of the research findings

The research has been presented at and published by the three conferences listed below:

1. Razak, D S A, Mills, G and Roberts, A (2016) External Failure Cost in Construction Supply Chains. *In*: P W Chan and C J Neilson (Eds.) *Proceedings of the 32nd Annual ARCOM Conference,* 5-7 September 2016, Manchester, UK, Association of Researchers in Construction Management, Vol 2, 881-890

2. Razak, D S A, Mills, G and Roberts, A (2018) Operational Quality Failure Issues: From owner perspective. *The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors (COBRA RICS),* 23-24 April 2018, RICS HQ, London, in association with University College London., rics.org/cobraconferences.
3. Razak, D S A, Mills, G and Roberts, A (2018) How Do Infrastructure Owners Build Capabilities to Reduce Operational Failure? *In*: Gorse, C and Neilson, C J (Eds) *Proceeding of the 34th Annual ARCOM Conference,* 3-5 September 2018, Belfast, UK, Association of Researchers in Construction Management, 756-765.

One journal paper has been accepted by Project Management Journal Special Issue on Project Transitions: Navigating across Strategy, Delivery, Use and Decommissioning tittle: "Addressing Operational Failure: A strategic project and quality management approach." (Accepted with revision on March, 2019) .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Study C - Infrastructure client multi-case study
Operational quality issues within single client organization
Study C (i) - Exploring the operational issues sample
Delphi review
Quality manager (n=1)
Operational team project selection (n=2)
Detail knowledge on specific projects (n=4)
Advance knowledge on potential projects (n=2)
Final cases selection workshop (n=3)
Study C (ii) - Identifying project sample within specific projects
Phase 1 interviews (n=7)
Project managers across projects A-E
Study C (iii) – Identifying the causes and operational outcomes of issues
Phase 2 interviews (n = 19)
Project A (n=4)
Project B (n=2)
Project C (n=5)
Project D (n=2)
Project E (n=6)
Study C (iv)– Advancing finding from project operational failure
Phase 3 - Workshop 1 (n=2)
Workshop 2 (n=2)
Phase 3 – Findings and theory building
CHAPTER 7 – Discussions
Draw cross-case conclusion, comparison with existing theory and development of new theory
CHAPTER 8 – Conclusions
Conclusions and contributions
CHAPTER 9 – Recommendations
Recommendations

9 Recommendations

This chapter provides recommendations for future work and practical applications. Accordingly, it focuses on future research, and the development of new tools, organisational system and cultural system for COQ. These recommendations should be carried out to compensate for the limitations to enhance the research findings.

1. Research studies
    - Other studies could focus on prevention and appraisal categories to better understand the relation of these quality cost elements based on the framework developed in this study. There is also an opportunity to conduct a specific study focusing on the testing of this COQ framework within different projects. Further analysis and studies would be beneficial in positioning the tested COQ framework in academia, and in the construction and other industries.
    - Work is required to examine the influence of various multi-organisational and their involvement at different stages, and different delivery models, such as early specialist supplier involvement or level of hierarchical authority (e.g. the planner team), could be incorporated in judging quality failures.

2. Development of tools
    - New innovative tools such as a software application to quantify the quality cost element can be developed to help construction organisations measure the COQ. The COQ can serve as a basis in developing this innovative software application.
    - A PM tool can be generated that combines the quality cost elements in aiding the project team to monitor quality work performance, thus providing prevention and appraisal of quality failures.

3. Organisational and cultural system for COQ
    - A paradigm shift is needed in leadership to cultivate a culture of positive and beneficial interaction in openly discussing and quantifying the quality cost between an owner and its multi-organisational supply network. The consideration of evidence on quantifying the quality costs during operations could support the understanding of the culture to incentivise the behaviour of different actors.
    - Joint or collaborative involvement plays an important role in instilling quality culture and awareness of operational failures. Positioning guidelines and research

works will provide assistance for projects to comply with the requirements and training.

- Industry needs a change in mindset to go against the conservative and protective practice. The perception on quality failure should be shifted towards more proactive campaigns such as capabilities to learn in improving construction projects.
- Embracing a broader range of project and operational COQ both at failure and in saving cases offers immense possibilities for stakeholders to make collective decisions towards a way of improving the whole industry.

There is a need for the researcher to understand both the theoretical and practical implications in increasing the validity of the findings. Confirmation of bias is difficult to overcome, as creating a change in the environment under investigation will inevitably impact on the reliability of the data, and earlier data and later data are inherently from different environments. A purely academic exercise to validate the framework and model through case study whether using a 'pure' interpretative or 'pure' positivist stance could be carried out. A detailed and in-depth case study could take a deep look into the realities of operational failures. In such a case study, a comparison of the outcome, in comparison to the final model of theory developed in this thesis, will expose the weakness in the closeness of the model to the live practical experiences of those experiencing the operational failures.

While a positivist research approach that looks into qualitative data gathering and analysis across a significant number of projects within a complex infrastructure project will enable an assessment to be made of the generalisability of the COQ framework designed in this case, this research has helped in unpacking both the narrow area of COQ and operational failures to understand the relationship of the QM in PM studies. This, it is hoped, will help to define a new approach to improve the quality thinking that can be added for owners to manage projects effectively and thus mitigate failures. A better understanding of the occurrences of operational failure in monetary language can help construction organisations in visualising the importance of quality implementation, and thus bring significant additional insight and knowledge for greater project delivery.

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APPENDIX 1

Appendix 1: Sample of Study B (i) - Trial questionnaire survey: call to action on major project quality failure

INTRODUCTION ____

Some participants will be influenced for the cost of end-product quality issues for a single case of an asset, others for a number of assets (e.g. a portfolio) and still others for their whole enterprise. Therefore you will first be asked to identify your level of influence in dealing with cost of quality (section I), then in section II asked to determine the level of knowledge you have about your asset, portfolio or enterprise) to reduce the cost of quality of specific elements.

SECTION I – YOUR EXPERIENCE OF COST OF QUALITY ISSUES

1. At any one time, what is your level of influence in cost of quality failure? (please tick one, and then indicate its overall cost)

		Cost (£)
One assets (e.g. Responsible for failures delivered by a project)	☐	___________
More than one asset (e.g. Responsible for failures delivered by a programme or contained in a portfolio), or	☐	___________
All assets and processes for your enterprise (e.g. Responsible for failures for a full asset management or quality management system)	☐	___________

2. Please provide your enterprise type, and the sector or sectors that operational failure most frequently occurs (please tick one or more):

Owner / operator: The enterprise that owns and operates the asset ☐

Sector(s): ____________________________________

Integrator / main contractor: The enterprise that has overall responsibility for planning and handing over the asset after design and construction ☐

Sector(s): ____________________________________

Advisor / consultant / designer: The organisation that provides advice and professional services to the owner or integrator. ☐

Sector(s): ____________________________________

Supplier / sub-contractor: The organisation that supplies materials, components, engineering systems, labour or construction services. ☐

Sector(s): ___________________________________

3. How many years have you worked in this industry? ______________________
4. What is your primary role within the organisation? _______________________
5. Based on your answer to question 1 and 2. What is the contract type that you most frequently use and where you have experienced quality issues? (e.g. PO, NEC, Framework, etc)
   ____

SECTION II – YOUR ENTERPRISE'S MATURITY IN COST OF QUALITY

6. Below are the quality cost elements that contribute to quality issues during an operational. of an asset. Based on your experience/ involvement (e.g. your answer to Question 1 and 2), please select your enterprise's level of maturity on the awareness and measuring these quality cost elements. (Please tick one level of maturity per element)

		Level of Maturity				
		1	**2**	**3**	**4**	**5**
Quality Cost Elements		**Unaware** **Enterprise has little or no intention to formally manage/ measure this cost element**	**Aware** **Enterprise is aware of and has intention to manage/measure this cost element**	**Defined** **Enterprise has put in place a basic infrastructure to support this cost element**	**Managed** **This cost element is well managed/ measured in the enterprise**	**Optimising** **This cost element is deeply integrated/ measure into the enterprise and is continually improved**
Insurance costs	The premium paid to compensate for a potential loss, damage, illness, or death after the asset handover (e.g. a lift failure).	☐	☐	☐	☐	☐
Latent defect Costs	Cost of a defect that is apparent after the project (e.g. a roof leak post handover).	☐	☐	☐	☐	☐
Additional safety Costs for Operators	Insurance claim or legal consequences due to underperformance or incorrect selection of safety product or system failure (e.g. malfunctioning safety barrier).	☐	☐	☐	☐	☐
Asset non-availability Costs	Cost of a disrupted service as a result of asset non-availability (e.g. school	☐	☐	☐	☐	☐

	classroom is out of service).					
Excess energy Use Costs	Additional energy cost as compared to a specified requirement or benchmark (e.g. low performance of energy generators).	☐	☐	☐	☐	☐
Excess maintenance Costs	Additional costs outside of the intended maintenance programme that is the result of inadequate design specification (e.g. correcting faulty water pipework).	☐	☐	☐	☐	☐
Quality Cost Elements		**<u>Unaware</u>** **Enterprise has little or no intention to formally manage/ measure this cost element**	**<u>Aware</u>** **Enterprise is aware of and has intention to manage/measure this cost element**	**<u>Defined</u>** **Enterprise has put in place a basic infrastructure to support this cost element**	**<u>Managed</u>** **This cost element is well managed/ measured in the enterprise**	**<u>Optimising</u>** **This cost element is deeply integrated/ measure into the enterprise and is continually improved**
Additional Environmental costs	Cost of tax, levy or credit incurred to maintain good environmental status due to requirement specification (e.g. an organisation must buy additional carbon credits).	☐	☐	☐	☐	☐
Lifecycle replacement cost	Excess cost of replacing an asset or part to fulfil a specified performance requirement (e.g. replacing underperforming lighting).	☐	☐	☐	☐	☐
Functionality cost	Costs due to reduced functionality either by failure to specify or failure to deliver (e.g. operating rooms are too small for mobile diagnostic equipment).	☐	☐	☐	☐	☐
Unadaptable cost	Cost of not having the ability to change or be changed to accommodate business service or product changes (e.g. a new production process must move to a new site)	☐	☐	☐	☐	☐
Early obsolescence cost	The cost of a product becoming outdated or no longer used (e.g. a non-used laundry chute or lift).	☐	☐	☐	☐	☐

Reputation/ brand cost	The indirect consequential losses / lost opportunities that result from a perceived weakness (e.g. negative PR as a result of some building failure).	☐	☐	☐	☐	☐
Additional Operational training	Costs incurred in training staff to operate a building while that building is in operation (e.g. inadequate or ineffective hand-over and training in the use of a security system).	☐	☐	☐	☐	☐

7. Please do you believe there to be any other specific contributors to quality issues? If so, please describe here.

____

____

____

SECTION III – INFLUENCE ON QUALITY ISSUES

8. Overall, how would you rate the level of maturity yourself in relation to the rest of the supply chain? (Please tick one per question)

	Very low	Low	Fair	Good	Very good
Your enterprise with regards to operational failure?	____	____	____	____	____
Your customers with regards to operational failure?	____	____	____	____	____
Your suppliers with regards to operational failure?	____	____	____	____	____

9. How would you rate your enterprise's overall ability to influence operational quality issues?

	Very low	Low	Fair	Good	Very good
Ability to influence	____	____	____	____	____

Please reasons for this?

____

____

10. How could improvements be made, or measures taken, to prevent or reduce the risk of operational quality issues?

SECTION IV - RESULTS FEEDBACK

11. Where did you hear about this survey?

12. If you would like to receive a summary of the results, or would like to be involved in a follow up interview, please provide your e-mail address below:

Thank you for your time in completing this survey.

APPENDIX 2

Appendix 2: Sample of Study B (ii) - Focus questionnaire survey: measuring cost of quality in major construction projects post-handover

INTRODUCTION ____

This questionnaire is to be completed by owners who are responsible for a building operational quality of the final asset delivered by a construction project. It investigates the cost of quality, which is known as the cost of poor quality, or the price of failing to create a quality product or service. In this questionnaire the CQI are particularly interested in scoping the operational failure cost (the cost incurred by the client after a built asset is delivered). For more information please follow this link. UCL will treat the results from this questionnaire anonymously. All data will be summarised to produce a final report and papers for scientific journals.

SECTION I – YOUR EXPERIENCE

1. How many projects are you usually responsible for delivering quality management to?

   1-2 building projects ☐

   3-5 building projects ☐

   More than 5 building projects ☐

2. What would you describe your project/ programme sector as?

   Private sector ☐

   Central government ☐

   Public private partnership/PFI ☐

3. What are the main project/ programme types? (eg Airport, commercial, hospital, etc.)

   ____

4. What is the overall budget of your organisations annual capital programme

   Over £5 billion ☐

   £1 billion - £5 billion ☐

   £500 million - £1 billion ☐

   £100 million - £500 million ☐

£50million - £100 million ☐

Under £50 million ☐

Please could you state the approximate capital programme? £______________________

5. What is the budget for quality management allocated to each project (as percentage of total project spend)?

   No budget ☐

   Less than 0.1% ☐

   0.1% to 0.3% ☐

   0.3% to 0.5% ☐

   Above 0.5% ☐

6. On what types of building have you delivered Quality Management? Please specify. ______________________________

7. How many years have you worked as a quality manager? _______________________

8. How many years has this been in your present organisation? ____________________

SECTION II –MATURITY OF OPERATIONAL QUALITY ___________________________

9. Below are the quality failure issues that may occur during the operation of an asset. Please select your organisations level of maturity in managing these quality failure issues. (Please tick one level of maturity per element)

	Level of Maturity				
	1	**2**	**3**	**4**	**5**
Quality Cost Elements	**Unaware** **Little or no awareness**	**Aware** **Formal intention to manage and measure**	**Partial Implementation** **Initial management and measurement**	**Managed** **Well managed and measured**	**Optimising** **Optimised and integrated for continuous improvement**

Insurance costs	The premium paid to compensate for a potential loss, damage, illness, or death after the asset handover (e.g. a lift failure).	☐	☐	☐	☐	☐
Latent defect Costs	Cost of a defect that is apparent after the project (e.g. a roof leak post handover).	☐	☐	☐	☐	☐
Additional safety Costs for Operators	Insurance claim or legal consequences due to underperformance or incorrect selection of safety product or system failure (e.g. malfunctioning safety barrier).	☐	☐	☐	☐	☐
Asset non-availability Costs	Cost of a disrupted service as a result of asset non-availability (e.g. school classroom is out of service).	☐	☐	☐	☐	☐
Excess energy Use Costs	Additional energy cost as compared to a specified requirement or benchmark (e.g. low performance of energy generators).	☐	☐	☐	☐	☐
Excess maintenance Costs	Additional costs outside of the intended maintenance programme that is the result of inadequate design specification (e.g. correcting faulty water pipework).	☐	☐	☐	☐	☐
Additional Environmental costs	Cost of tax, levy or credit incurred to maintain good environmental status due to requirement specification (e.g. an organisation must buy additional carbon credits).	☐	☐	☐	☐	☐
Lifecycle replacement cost	Excess cost of replacing an asset or part to fulfil a specified performance requirement (e.g. replacing underperforming lighting).	☐	☐	☐	☐	☐
Functionality cost	Costs due to reduced functionality either by failure to specify or failure to deliver (e.g. operating rooms are too small for	☐	☐	☐	☐	☐

	mobile diagnostic equipment).					
Unadaptable cost	Cost of not having the ability to change or be changed to accommodate business service or product changes (e.g. a new production process must move to a new site)	☐	☐	☐	☐	☐
Early obsolescence cost	The cost of a product becoming outdated or no longer used (e.g. a non-used laundry chute or lift).	☐	☐	☐	☐	☐
Reputation/ brand cost	The indirect consequential losses / lost opportunities that result from a perceived weakness (e.g. negative PR as a result of some building failure).	☐	☐	☐	☐	☐
Additional Operational training	Costs incurred in training staff to operate a building while that building is in operation (e.g. inadequate or ineffective hand-over and training in the use of a security system).	☐	☐	☐	☐	☐

10. Do you believe there to be any other specific quality cost elements that are not included in question 9? If so, please describe here.

____
____

____

11. Think back to a project where you experienced the most operational quality issues, and please state:
    a. Which quality cost element was most significant? _____________

    b. Please can you describe this operational quality issue?
    ____
    ____
    ____

    c. What was the approximate cost of correcting this operational quality issue?
    ____
    ____
    ____

12. Please now think back to a project where you experienced the least operational quality issues, and state:
    a. Which quality cost element was most significant during operation? _____________

    b. Please can you describe this operational quality issue?
    ____
    ____
    ____

    c. What was the approximately cost of correcting this operational quality issue?
    ____
    ____
    ____

SECTION III – INFLUENCE AND QUANTIFICATION ON QUALITY ISSUES

13. Overall, please select the <u>level of maturity</u> of your contractors (Tier1) with regards to operational issues? (Please consider the responses in question 9)

Unaware	Aware	Partial Implementation	Managed	Optimised
☐	☐	☐	☐	☐

14. Overall, please select the <u>level of maturity</u> of your suppliers (Tier 2, 3) with regards to operational issues?

Unaware	Aware	Partial Implementation	Managed	Optimised
☐	☐	☐	☐	☐

15. How would you rate your organisation's overall ability to influence the optimisation, integration and continuous improvement of operational quality issues?

Very low	Low	Fair	Good	Very good
____	____	____	____	____

Please list reasons for this?

____

____

____

16. How could improvements be made, or measures taken, to prevent or reduce the risk of operational quality issues?

    ____

    ____

    ____

SECTION IV - RESULTS FEEDBACK ____

17. Where did you hear about this survey?

    ____

18. If you would like to receive a summary of the results, or would like to be involved in the research, please provide your e-mail address below:

    ____

Thank you for your time in completing this survey.

APPENDIX 3

Appendix 3: Extract examples of triggered factor of operational failure.

Triggered factor of Operational failure	Implications on project capability	Project A	Project B	Project C	Project D	Project E
how - Contracted end date	lack of quality culture and behaviour	<u>Quality assurance does not ensure do right at the first time</u> "… we had assurance …, [contractor] had assurance and … second tier of supply they had assurance [but still] we get into a situation where everybody took a picture of something that was wrong… people didn't know what they were doing..."[A7-CPM] **<u>Not construct according to quality standard</u>** " ... because it was so late in the programme, they had pretty much laid the blacktop in the last week before [the project] opened, and it really was a bit of a stereotypical chuck-it-down … regardless of whether the quality of the base layers had been done, regardless of manholes and whether they'd been done correctly or not; and the quality ... thrown down in was just dire …there's numerous photographs in documented inspections where… there's industry standard ways of building manholes…[but], it's not going to be properly constructed, which they were." [A1-[CPM]		<u>Decision made without quality concern</u> "Their directors saying it's got to be live by this date, and then some comments back from the point of view of saying, yeah, but we've scheduled it to be finished here. Oh, no, we need it four weeks early... So [contractor] had to work significantly hard to get that done. So, they made some decisions which you wouldn't have done with a quality hat on, which were, put the floor down before they had completed a lot of the installation..." [C10-CQM] <u>impacting quality performance</u> "There was a self-imposed issue where we trafficked some heavy equipment across ... which probably masked the issue somewhat. There was the need to have it operational the next day. So the working window was very small and it needed to be safe and functional the very next morning." [C8-CONQM]		

	Lack of benchmarking on quality issues	Quality issues not immediately resolved "...some of it is, was time constraint because it was slightly behind and we need to get it finished, we need to get it finished but if they look back now for the sake of a week or to two weeks then they could have finished it right the first time rather than come back and do things again."[A7-CPM]	Quality issues not resolved "…this was projects that been kick for long time and it was comes in the end of relationship period within a year to get this thing going on, now the fact that it overrun the next [programme], the fact that the commitment needed to be made [and] delivered by that period, so there is the time pressure off what is the surface and...so we were very tight schedule..." [B2-CPM]	Quality issues not immediately resolved "…In an ideal world you would, upon discovering an issue such as this, you would stop and you would find out what's gone wrong and then put the counter-measures in place..." [C8-CONQM] benchmarking was effectively cut thus no quality intervention " ...That project is another one where there was pressure put on the project to deliver it earlier. Sometimes it's operational… we were effectively cutting out some of the benchmarking for the programme, so some of the quality interventions we weren't able to do, because the materials were literally being manufactured and then delivered direct to site and then hung the next day. "[C10-CQM]		Aware on the quality implication but no intervention made"… the person who made the decision knew the implications of that decision; the big issues [is]...being able to get sufficient productivity out of the night shift because you still need to hand the runway back at the end of the night shift [and] you can do a lot bigger area."[E13-CDM]
	limited risk assessment				Cost implication was not reflected to operations "But a lot of these decisions aren't made by comparing things. You'll get people saying, "Well, financially we can't afford that. We need to make it £20 million cheaper". I don't think it necessarily goes back to the operation, "Well if we're going to do £20 million of cost saving which £20 million do you want to save?" I don't think that necessarily happens as well as it could. And I think a lot	Decision made only to get the minimum level of detail " ... it's always about having enough time and resource to get to a point where you can make some conscious decisions…especially on a big project [with] lots of different people on it to influence it, everything gets pushed down the line until you get to an artificial decision point...and so whether we're ready or not, and truly understand what we need or not…that decision needs to be made, and [so] it's making sure that early enough we

					of the time it’s because it is time consuming." [D15-CAM]	understand at least a minimum level of detail we need before we go to the next decision…"[E12-CATM]
	Poor work programmed			Work programme made according to critical time to win the job“…if we produced a programme of works that went beyond their end date then we were unlikely to win that work. So… we would have been influenced by that end date. In a competitive world, you want to win the work… would you try and achieve something that you couldn’t to win that work?” [C8-CONQM] Sub-contractors were influence to deliver project in short period "we literally had to do a competitive tender again everybody else to win that piece of work and that always took time. So that time was always taken out of the delivery time and the longer that process went on, the end date got nearer and it never moved, so I wouldn’t say it was particularly fast track but there would have been elements of, it’s got to be done by this, this time scale, can you achieve that? The programme, as part of our tender, was always critical." [C8-CONQM] To avoid penalty "…if we delivered the project late, we will pay a penalty back to the	Limited time drive different procurement for different organisation - “The procurement of the escalator was obviously driven by the time constraint that we need to build these things. Our maintenance team were calling ... And one of four key players in the lift and escalator market, their schedule didn't allow what we wanted from the manufacturing perspective."[D4-CPM]	

				airlines. And the airlines community refuse to sign the triggered office complete, because of the triggered issue, the issues we have with the transit system."[C3-CPM]		
how-Allocation of project budget	Cost more than contracted cost	Owner knew the project will cost more but COQ is expected to share with SC " they'd missed out half the things…we knew it was going to cost more than £77 million, so the final account included a number of elements where we added scope..." [A11-CCOM] Selecting the lowest contractor "...So, we always knew at the very beginning that whilst he'd bid £77 million we would be going into pain. We had numerous debates as to whether or not we were actually going to appoint him on the technical, but for various reasons we won't necessarily go into that was the selection that was made..." [A11-CCOM]		Contractor had no influence in early budget "Cost were only foreseen after. When we're involved, it's too late, so these discussions were had definitely..by [owner]." [C9-CONPM] COQ failure was absorbed differently "... unless they're monitoring the cost that's following... most of these costs should be picked up by [supplier] really, because they've got the warranty." [C10-CQM]		
	Uncertainty on long-term operational cost			Contractor quality of work depends on owner budget to fix operational problem - *"there was no money in our plan, so it was a budget constraint projects... so, we had to come with the right options so we put to [owner] a*	COQ was absorbed to fix the problem - *"The £250,000 was unbudgeted so obviously, it's money which we have to find. In effect when I say we have to find it we either have to try*	

				number of option to fix the issue…" [C3-CPM]	*and get funding from elsewhere or we have to absorb that within the maintenance budget."[E13-CDM]*	
	Different project goal			Project managers were only concern on the functionality of the project but not cost related “the cost pressure, it’s very here and now, it really is, and we find it all the time, because the project managers… all they want is their job sheets through and they’re not interested in these bits really. .” [C9-CONPM]		
	Influence product selections				Suppliers were using un-quality material to reduce cost "… they said,[the product] “These aren’t ours” even though they had labels. [so] that was done off the back of a cost-saving initiative; [that] we bought a few and they’ve been nothing but trouble..."[D15-CAM] “Yeah, we can’t afford to change them, they’re too expensive…It’s a bit hard to swap out an asset because it’s bad when it’s somewhat usable but it’s not as good quality as the other ones."[D15-CAM]	Accuracy of project cost is difficult to estimate " … I’m making decisions today about the potential costs of a project [that] might want to deliver in seven years’ time, without any knowledge of survey accurate costs. [E16-CATM]
Relationship with supply chain	Lack of initiative on project improvement	same designs and specifications were duplicated with appointing the same contractor “…then [they repeat] exactly,	keeping the supplier to fix the issues by warranty"...but. pretty more contract less... well	Supplier are confident with the suitability of the product as their main driver is to sell the product “I think they were quite		same designs and specifications were duplicated with appointing the same contractor

		same design, same specification and then you get the same issues." [A14-CPE]	actually there is some sort of planning that we can keep the sub-supplier on board. [through]...warranty bases actually…so there is a basis at the back there were you actually should have." [B2-CPM] <u>Contractor couldn't deal with the complexity thus owner need involvement from specialist supplier</u> "... the complexity of readiness thing is what we now have to work out and the thing that we need to get. So main contractor or integrator if you like, did that bit.. individual elements of that plant em, witness- ary acting they should have, and I think that's where we have taken supplier to tell us so,to be very robust or there is in a specialist [to] all the quality treatment." [B2-CPM]	confident that it would be suitable. They're going to sell their product aren't they? So…the main driver is to sell the product." [C8-CONQM] <u>Difficult for contractor to interfere</u> "… the supply chain was procured, they were the right, they were the approved installer of that product. They were… you know, they had their usual control plans in place. The method statements, risk assessment, everything was planned." [C8-CONQM] "… So [supplier] then came along and [owner] were very conscious that if [supplier] didn't give it the nod... If the manufacturer said, 'This isn't installed correctly,' my 12 year warranty doesn't stand, so we're all stuffed." [C9-CONPM] "...Because of this relationship that [owner] had with [supplier], they were called in…they should be at our end of the chain ..[to give] us advice and helping us to do the job. [but]..came in almost like a bullying…and it shows you that the choice was made on [owner] side and we were just the installer. " [C9-CONPM] "(owner) don't try to do that and they just nominate, with a small n, as in, 'Here's the product we		"…they have used that method on Sierra C taxiway where they did the crack treatment first, and it seems to have proved relatively successful….Yes, same supplier, So, that's the kind of cracks on northern and southern. Then you've got…old joints underneath runway cause cracking due to no treatment – so that's what we talked about."[E13-CDM]

				want,' effectively, in the tender documents, and then you are forced, by the virtue of the fact that that's the product they want, to buy it from a certain company or … certain place….but we installed it through the hole in the grass in between the runways ."[C9-CONPM]		
	Lack of shared risk and responsibility	"... it's costing them[contractor] quite a lot of money to rectify a defect for which I'm not really holding...a few hundred thousand is not going to cover their cost for doing up all of this…"[A11-CCOM] reducing responsibility on owner " So, we select contractors who have got good quality processes so that they can actually then self-certify to say they've done the work in the right way; rather than having a really large project management structure. We've tried to be more of a owner than an active project manager." [A11-CCOM]	supplier is responsible to complete the work"… it is easy to get someone nominated supplier but then you are taken lot of advantages [to] come to them and then made them their responsibility to make sure it work." [B2-CPM] "They were an unknown supplier to us, so they were new, we hadn't used them before. We did all the usual checks and balances, so they have to go through our supply chain evaluation to even become a supplier. So financial, safety, quality, all the usual stuff; so they became approved… then we ensured we had their control plans for that installation… their inspection test process and such like.[but] I think what they probably didn't do was follow that process rigorously during	Risk sharing is the key to a successful project "that was a key, critical piece of work that was very heavily planned. I think there was at least [more than] one stand-back review…where an independent came in and checked all the plans and preparation for that piece of work. It was critical because they had to open a hole in the runway and drop it in and close it before the first aircraft landed in the morning…there was a lot of planning work went into that and it was deemed to be very successful..." [C8-CONQM] drove different behavior in critically plan the work "The whole driver around that piece of work was the risk. It was the risk to not doing it properly. We could not close the runway and the only way to access that… to do that piece of work was to put a hole in the runway. So that risk drove all the behaviours to plan this piece of work to the nth		

			the installation." [C8-CONQM]	degree." [C8-CONQM]		
	Different project goal lead to different quality expectation	Uncertain on contractor project goal "Because a contractor has got two choices: ...either to maximise profit or tries to do the right thing, still make a profit by actually doing things effectively and efficiently, recognising that his reputation and the opportunity to work with a owner comes back again and again and again…So, selection of the right contractor becomes absolutely important if you're going to go down a self-certification route. And that both in terms of design and in terms of construction." [A11-CCOM] Un-alignment of capabilities between multi-organisational can still cause quality problem. "… we are selecting an organisation because …they've got the right people and they've got the right skills…[but] they could still put the wrong person on the project. We've got the opportunity then to swap out… if it's not the right individual. But you're relying on people to build projects. It's the usual kind of thing: the bad apple spoils the whole barrel." [A11-CCOM]	Suppliers only sell the product " … the supplier [has left]. But it hasn't been completed. The work is not finished. There's a dispute over who's paying to get the auger done…" [B18-CAMAIN]	Owner is expecting contractor to take the responsibility to fix QI to keep good relationship "I don't imagine they would have charged less for any of that on the basis that it was instigated by themselves…their behaviour has been very good…if they'd turned their back and said, we can't afford that, and walk away, then clearly they wouldn't be getting any more business from us." [C10-CQM] Contractor want more future project thus follows owner preferred supplier "…We needed the warranty for more work to go up the chain.. so it was really important that we got [supplier]down." [C9-CONPM]		Owner is expecting contractor to take the responsibility to fix QI to keep good relationship "…it depends if we've got an existing relationship with them [contractor]. A lot of our key suppliers are still here… basically want to be here in the future because of the amount of work which is coming out ... So, yes we'd look at a starter for ten to always go back to the contractor who was responsible for building it…we've got a number of issues there which relate back to construction quality..." [E13-CDM]
Demanding	Need new		"… you're left with pretty			"…we installed … LED

regulations	technology		clear liquid coming out..that was in the design. [or] we didn't design it in the way we should have…"[B18-CAMAIN] "So we should have gone live probably about 2 years ago (2014). And it was ready, but…[not] fully operation readiness ... the early trials and to get in operation using it...isn't getting in expect[so] this system that take the soil out... didn't have the level of its workability.." [B2-CPM]			runway lights, previously they were all tungsten, sitting on both of the runways; …, effectively every tungsten lamp, due to the life of the tungsten lamp, needed to be changed every 6 months, so we've now stuck LEDs in the whole thing, and they last for 10 years. So huge maintenance reduction, and operational cost of changing fittings continuously…"[E16-CATM]
	Non-compliance to regulation		"Because the drivers pop landside, to a landside sweeper tip, they then have to abide by driving rules and regulations, and we have to have an operator license to cover that. Which means they must follow certain rules and regulations and compliance." [B18-CAMAIN] "If we do not do this, we will remain non-compliant…can stop us from operating. That's the ultimate penalty to us. They can fine us millions. I think it's an unlimited			

			fine." [B18-CAMAIN] "…We want you to exceed our levels and give us a better quality of water going into the river beds, into the system"… there's a reputational part there if we can deliver it… We're doing something for the environment. But if we don't do it, take away our licence to operate." [B18-CAMAIN]			
	Insufficient technical knowledge		"… it wasn't very voluntary tip process and therefore they need more intervention of the engineering team...there is different detergent been used normally and kind of give impact on operation..." [B2-CPM]			

Triggered factor of failure	Implications on operational capability	Project A	Project B	Project C	Project D	Project E
Understanding on real life operational technicalities and constraints in design to owner specification	**Complex design not buildable**	<u>detail design was only look good on the drawing but was not buildable by the builder</u> "… these are construction related issues, quality control on site…it will be design related in terms of the detailing. Sometimes you may get such a detail come back from the designer which looks good, but actually when you give it to somebody to try and build out on the site you can't build what they've drawn." [A14-CPE]	"No. It's not a surprise at all. I knew about that. We said that from day one. That silt would always be a problem. And they [supplier] assured us silt would not be a problem. But we've always known it's going to be a problem." [B18-CAMAIN]	<u>Designer are not getting the same learning</u> " so [owner] make the decisions but the designer develops it and says, 'What do you think?' And they struggle, because they don't deliver the job, they don't get the learning we're getting." [C9-CONPM] <u>Different perception on quality</u> "... to an architect who likes design; "this is horrific, you need music, you need pictures.. you need.." so this is the answer when your conversation around, what is the appropriate level of fixtures and fittings for the walkway. So we looked at number of options...." [C3-CPM]		<u>Operational issues was not consulted with the early involve designer/ making more design complex</u> "so at that time there wasn't a designer on board" "we were doing design, then we gave the design to a supplier to deliver. ."[E12-CATM] <u>Operational team had to trust on the design as they not involve early</u> " it wasn't expected by us, engine operation definitely didn't expect that they were going to get a new runway with cracks in it and the designers assumption was that it wouldn't happen…"[E6-CPM]
	Design not reflecting operation technical and environment.		<u>The system was not designed in the way it should have to deal with the waste</u> "…you're left with pretty clear liquid coming out. So maybe that was in the design ... [or] we didn't design it in the way we should have. We should have designed it into an interceptor way of dealing with waste. "[B18-CAMAIN]	<u>Designer was being specified on product selection thus has no opportunity to select a product</u> "... [owner] has own design standards, [so] they specify that it is, what it needs to look like, and also products that you're not allowed to use… If that information was available within those standards then a designer wouldn't select it. So all the time you've got a set of parameters for a designer, he has the opportunity to select that product. It may not be the best		"…so this wasn't designed by [owner] in our team, this was done by an external company..." [E12-CATM] **<u>Scope not suitable to operations condition increases maintenance cost</u>** "it's become an ongoing maintenance issue with attached costs, because of, in this case, not reduced scope, but not expanding the scope to suit the ground conditions that we found during the works." [E16-CATM]

				product but he has the opportunity to select it." [C8-CONQM] <u>the benefits of the hindsight not realis e</u> "I'd imagine it would have been heavily design-related in terms of aesthetics. I imagine it would have been aesthetics over function, because all of us have said numerous times that with the benefit of hindsight I think all of us would have just polished the floor." [C10-CQM]		Designer does not reflex on the operational impact "...it was a perception by the designers that at the time that we didn't need to do anything to treat those joints...because we we're just doing a thin layer on the top but … those joints have reflected upon and cause cracking in the surface …means the operation in there [will have] more maintenance than what they had originally planned to and we had a brand new runway." [E6-CPM]
	Operational issues not resolved/ hindered quality control	<u>Quality control is extremely difficult when you have a complex design which then poorly detailed and constructed</u> "The problem is the quality control to make sure, and making something watertight is extremely difficult... the issue there was that whether it be part of a design decision in terms of having so many holes and then poorly detailed and constructed sealing of those penetrations resulted in an issue where we've got a lot of water coming through the top slab into the underlying car park... that has multiple impacts."[A14-CPE]	" I think we had four or five different ideas out there who almost as reversal basis system [and]..., it has options, and [the supplier]and the designer took that and develop[to] skim design... variable solution was proposed but not worked…" [B2-CPM]			<u>Additional work has to be done</u> "as an indirect impact of poor design, poor planning, poor delivery, because we say a project is going to take one month to build, in effect, it takes six months to build. Well, one, it will cost more because you're spending more time on it, but, two, even from a smaller level, there's a significant amount of re-work that's going on, so in terms of the labour that it takes to do all the planning, the approvals, the design...will be a period where we've then got to do additional work... purely because it hasn't been delivered on time to plan." [E16-CATM]
Trusting on contractor	**Poor quality performance**	work was done regardless of the correct method or quality	"So we've always known that would be an issue.	"What didn't go so well was the application of that product. So…		Owner has limited project

expertise and resources		acquire "... because it was so late in the programme, they had pretty much laid the blacktop in the last week before [project].. opened, and it really was a bit of a stereotypical chuck-it-down regardless of what's the quality of the base layers … of manholes and whether they'd been done correctly or not; and the quality… thrown down in was just dire… an issues with poor quality of construction; there's numerous photographs in documented inspections… it's not going to be properly constructed…" [A1-[CPM] Was not done according to designer specified detail "In theory if it had been done to the detail provided by the designer it should have worked but it wasn't done, so the waterproofing detail for instance wasn't as the designer specified. It should have been the top hand which would have stop the water, the water wouldn't have been collected in the drainage system. No top hat detail so the water went down the hole." [A7-CPM] Contractor did not implement what is on the design "... no they held their hands down because the survey covered exactly what was	Because that was an issue we faced…" [B18-CMAIN] "... the complexity of readiness thing is what we now have to work out and the thing that we need to get. So main contractor or integrator if you like, did that bit.. individual elements of that plant em, witness- ary acting they should have, and I think that's where we have taken supplier to tell us so,to be very robust or there is in a specialist [to] all the quality treatment." [B2-CPM]	and I'm not sure… not entirely sure what the influences on that were. It may have been the short working window and the fact that things were trafficked the very next day because it was a vinyl floor at the end of the day. But we found that there were issues with workmanship, so the application of that wasn't the best."[C8-CONQM] "I always had that feeling that it would gradually start to deteriorate over time, because the original installation, I was never very comfortable with the quality of the installation really. The corners were starting to lift and the edges were starting to lift quite early on in areas that were not impacted by the escalator delivery. So that told me that there was a problem with the installation really rather than just the external issues." [C10-CQM] "That was in relation to I think poor quality install, water ingress or the escalator issues." [C10-CQM]		engineers who attend site because of self-certify , owners are relying on contractor " With projects they're self-certified and managed by the contractor, so the DI, delivery integrators…[owner] do have project engineers who attend site to kind of keep a bit of a watching brief, but quite limited in terms of how many we have and what their role is and whether they can be everywhere at the same time. But in theory quality control and sign off sits with the DI under the contract which we have in place. They self-certify their work so we rely on them. "[E13-CDM]

		wrong and all of the things that went through, when you at what the fault was against the design, the design was clear and the intent was what they should have done was right problem is they didn't implement what should had been or what on the design." [A7-CPM] the right process was not follow during the construction process "…they knew that potentially there would be waterproofing there was a solution about how you do the waterproofing that should have mitigated that, but when we came to build it we didn't follow that process." [A14-CPE]				
	Different project goal lead to different quality expectation	Lack of quality in implementation, based on document "... if the delivery integrators are educated in getting sufficient resource probably, or knowing their responsibilities in actually undertaking that role, that's what they should be doing, the (contractor) quality manager was just dire. It was just paperwork and process based and spending their week putting trackers together…[they should].. go outside and have a look at something …they'd be too	As the project become more difficult, some elements have been de-scope when the early purposed of the facility then become unclear "… As they started coming through the project and got into the too difficult…We're trying de-scope them. The purpose of building the facility was because in a hot summers day, [it] will vent a lot of fuel on the taxi ways. And we would go behind and sweep up	**Contractor could not interfere because the supply chain was procured and the supplier was specified** "Hindsight is a wonderful thing and maybe if that had been thought through better we would have put our hand up and said, this isn't the best solution for that location. The fact that there was … you know, the supply chain were procured, they were the right, they were the approved installer of that product. They were… you know, they had their usual control plans in place. The method statements, risk	"I mean, I have the two-week period after we went live. We had a third party called out this. So, the process been, if there's a fault with asset, they called the maintenance guy... if this guys couldn't solve and actually was different brand… However, because they are all the same, but if that was a brand they couldn't sort it out,... they will call Thyssen and I have Thyssen on standby for 24/7 for fortnight"[D4-CPM]	"Quite often it will be maybe the project engineers who work for Heathrow who may come across the issue. They may be checking the quality of the work on site and pick up something which they're not happy with...review some of the test data, whether that be for concrete acute strengths and things like that which they'll check, and if that comes back with low results then ... look to pick up those issues with the DI...So, quite often a lot of the issues get flagged up more by owner's project engineers than

		happy to just sit in the office in admin roles…"[A1-CPM] Builders build everywhere and they have limited knowledge on airport operation; pm's are heavily relies on specialist "So I was the Delivery Project Manager…] [who knew] ...operations need, ... what to build, because obviously you've got builders and builders build anywhere and they've got a limited knowledge and understanding of airport operations, as do project managers as a whole as well, when you're working on an airport you do heavily rely on the specialists and operational team to tell you what's acceptable and what's not acceptable..." [A1-CPM] same designs and specifications were duplicated with appointing the same contractor thus repeating the problem "Everybody forgets or they say,"We'll do another, oh well we've got a design already for a multi-storey car park. You like [multi-story car park], we'll give you another… or you like multi-storey car park 5…then [they repeat] exactly, same design, same specification and then you get the same issues."[A14-CPE]	the fuel and suck the fuel up… Hence a lot of disposal costs for the product." [B18-CAMAIN] The benefit of the treatment plant has cause a neglecting in terms of it operational side of using the system "And I think at some point we've got carried away with the benefits of a treatment plant, neglecting the operational side of using the treatment plant. And I think there was that shift of focus." [B18-CAMAIN]	assessment, everything was planned." [C8-CONQM] **Quality manager was not involved during the risk review instead was done by other team** "…we have our own team as you know, I have my own team and we do our own risk-based discussions on projects and where we think we need to pay attention. [but] when there is the risk review of the project I'm never involved." [C8-CONQM] **Quality was the least important in the pecking order** "We're forth on the pecking order of importance… we'll we're probably fifth now actually. Safety, programme, cost, environmental, quality…"[C8-CONQM] "People don't like change, they don't like different products. It's very hard to combat because they were involved early and the guys that came early were the ones who wanted to be involved, but the ones later were the ones who didn't want to be and they're the ones that caused the issues."[C9-CONPM] **Quality manager was not involved during the risk review instead was done by other team** "…we have our own team as you know, I have	**project team are de-scoping the project according to their values and project aim without collaborative decision** -" "The problem is when you've got a company with departments [they]... are making decisions for their own goals, not for the overall...[when]they're supposed to tie up with the top…"[D15-CAM]	maybe the DI's quality managers...which is sad because it should be flagged up by the DI's and self-certified." [E13-CDM] **Failure is not a major issue although it is not to the standard and quality because, as it can still be use** "At the end of the day it's not a major issue; it's not to the standard or quality that would be expected, and actually it should be nice and flat, and there is a potential for a reduction in the life of that area, and that piece of asphalt. But actually at the moment it's not breaking up, its still fine, it just looks a bit funny, and you wouldn't notice it unless you were in a vehicle or got out, which not many people do, so we don't have to worry about that."[E5-CPM]

		"We at Heathrow have a policy, process, whatever you want to call it, whereby it's very much more self-certification by our first tier contractors. So, we select contractors who have got good quality processes so that they can actually then self-certify to say they've done the work in the right way; rather than having a really large project management structure. We've tried to be more of a owner than an active project manager." [A11-CCOM]		my own team and we do our own risk-based discussions on projects and where we think we need to pay attention. [but] when there is the risk review of the project I'm never involved." [C8-CONQM] **Difficult to manage quality as it Involved different expertise** "…because the way things cut up was different contractors doing different parts… the walkways weren't one single person. It was numerous, what it meant was this that the urgency of the project to get approval and go through…" [C4CPM]		
	Unresolved quality issues	"... then obviously the maintenance because while this weren't wired correctly the maintenance again you can't do proper maintenance on them because they did not operate as they should have done." [A7-CPM] "Water going through and getting into the service trades which carry all of the electrical cables, the comms cables, starts to corrode, so then you have issues in terms of having to maintain that on a much shorter lifespan because they weren't designed to have water dripping or sitting in it. So, there are issues in terms of that [also] may have issues in terms of failure in the electrical or	"It's not a surprise at all. I knew about that. We said that from day one. That silt would always be a problem. And they assured us silt would not be a problem. But we've always known it's going to be a problem." [B18-CMAIN]	"...When they provided a different product…engineers had to go through a training exercise …providing detailed training, not just familiarisation… it's a different conveyer altogether, you've got to show them. It's like having a new car and talking to a mechanic, he's got to learn how to maintain it."[C9-CONPM]	Limited time to develop proper relationship in proactive solutions "...[we] offered him early site of the escalator when it came to the building. Site has been connected together, ready for been covered up with the rest of the building worked. And once it was uncovered, frequent site visits to watch it be built and commissioned, tested… They were very forthcoming, attending those sessions... that relationship between those two companies would just kind of develop and they would work hand in hand with each other, but they	"We haven't fixed it, it's still there. We were supposed to, we haven't gone back to it yet. We're waiting for operations to kick up a fuss. We haven't really got the facility to be able to go and fix it now so it's a bit late for it." [E16-CATM] " it can have a real cost on them, and ... I think was never really fully understood ... in terms of grooves Marshall Asphalt, because the grooves themselves obviously caused quite a lot of rubber to be stripped off the tyres and it is amazing how much it builds up in quick time.[and]... because you've just put the surface in, the use of high pressure water...takes away all the

		comms cables because of the water..." [A14-CPE] "... we're going back to projects to try and get that resolved. But again it's what you can see, and with self-certification there's a lot which we can't see. " [A14-CPE]			didn't quite do that."[D4-CPM] Contractor would like to have the ability to stop the project when its fail to investigate, fix and thus learning from on site "I would have liked to have seen the project have the ability to stop when the problem first occurred and fully investigate why it's happened. I would also like the team to have had the ability to… influence that product selection.to try and eliminate that. And learning from on site, "[C8-CONQM]	fines... you end up with a much more open texture much earlier ... so it overall deteriorates the surface..." [E12-CATM]
Technical competency on-site operations	**Need new technology**		earlier funding for research and do prototype would cost as much as developing the system now " Yeah.. so that first stage, the option stage , if we did that in a longer period of time you would have probably throw each of those in them against budget and on time. So to actually go fund research and do prototype would have been quite a challenged I think..[because] for this things coming out committing to the company, you could have			The issues were fixed by the maintenance team until it get apparent then only it will get people form development to look and develop it "… from a maintenance perspective, we've done an initial repair because it looked like it was failing, and then it became apparent that there was a bigger issue there. So, with that I then went back to the project manager and said, "I think we have an issue, I think it's a build issue…"[E13-CDM]

			paid that money and develop a prototype that is as much as develop now the thing." [B2-CPM]			
	Non-compliance to regulation	Technical expert expertise was pale into insignificant due to critical time of completion "… so you'd have a technical engineer come out and look at the blacktop, and you'd have a technical engineer who'd come out and look at the drainage; whereas a field engineer, or clerk of works role, tends to be a bit more of a master of all; probably where work fell down a little bit was where the technical experts or technical team would critique something, but because of the nature of the schedule, would almost pale into insignificance because "yeah whatever we've got to get it done." [A1-CPM] Small working window when doing construction within live operation "because when you're building an (Project A) next to a taxiway and you want to put a crane up, [make sure]... line of sight isn't interfering with actual operations,[so]... lot of considerations there, with the piling rig in particular, that's quite challenging,... they do have issues with them, and you have to look at the probability of a piling rig going over, [which]...you could only pile	fully operational readiness is not achievable because the system to take the soil out is not workable "So we should have gone live probably about 2 years ago (2014). And it was ready, but..fully operation readiness ... the early trials and to get in operation using it...isn't getting in expect[so] this system that take the soil out... didn't have the level of its workability.." [B2-CPM]			the resurfacing the runway does not giving what operation is expecting as it had more problem "So that obviously did improve it, but obviously what we expected and what we hoped is that once the resurfacing had been done, we'd have a really nice runway that was giving us really good surface friction, but in actual fact, we still had big problems because of this issue. ."[E12-CATM] the new material has looked a lot worse than it was "and they're two slightly different problems, because obviously one was on the new material and one was on existing material, and it's just the fact that new material alongside, it suddenly showed up that actually it looked a lot worse than what it was, and especially in certain lights"[E12-CATM

		within certain working windows...as you know you do get catastrophic failure..." [A1-CPM]				
	Insufficient technical knowledge	Technical expert expertise was pale into insignificant "we had [numbers of] technical team [who] come out and review things ; whereas a field engineer, or clerk of works role, tends to be a bit more of a master of all; …the technical team would critique something, but because of the nature of the schedule, would almost pale into insignificance because "yeah whatever we've got to get it done." [A1-CPM] Operational issues was not understood by the project team "I don't know whether it was a design issue or whether or not it was a workmanship issue... I'm assuming it was only picked up at the very end of the actual project. It wasn't picked up at the time because if it had been picked up …[contractor] or [owner] would have said, "Hold on a second, we've got a problem. You need to sort out the waterproofing now rather than having to spend all of the money to actually strip everything off and come back and redo it". [A11-CCOM] " In the fact it's been leaking	"But what is interesting is we don't do the design ourselves. In anything. We didn't do the design not even in [other] project. However, this particular one is so different from what we do that we have no expertise at all. Now that's where I'm thinking, if we were to start again, I cannot see what we could have done differently." [B18-CAMAIN] Need other capability to innovate "Where actually you can have a research team to actually create something better. And you can be the first airport… imagine if you can manage this. You can have a better reputation on sustainability airport or whatever you're called…Definitely… but the reason why, I think, we don't do the first off is because it's so difficult. "[B18-CAMAIN*]*	Innovation with owner are not wide-ranging and only if contractor was involved early they probably get the opportunity to influence but it would be fortunate if it is to be accepted "… the opportunities for innovation within (owner)... are not that wide-ranging. There are some [but] you need to be involved early as the project team..[where] had drawings developed, a scheme designed, specification, floor chosen, conveyor provider chosen. Your opportunities are limited, unless the provider turns up like this, and says, 'Actually, we've thought about it and we can do this for you,' but you're not buying that as a service, you're fortunate if it comes along, almost..[and] provide 'Actually, if you looked at like this,' and you can give someone an opportunity to give you a better answer."[C9-CONPM]	Technical knowledge was not put in early considerations "… I asked for everything I could think of and got everything that I could think of, told everyone that was of importance what I thought and why. And then afterwards they almost acted like that didn't happen, which I found a bit disappointing to be honest. Then they start questioning and ..then when it goes wrong [they're] like, 'that didn't happen'". ."[D15-CAM] Operation are the one who suffering at the end to have to operate in unfinished building site "And the ones that suffer are us in the operation that have got all this temporary stuff everywhere, people trying to operate around, essentially, a worksite that's never quite finished. So that's the end-game, the bit that affects us, is having to work around or operate in and around building sites and unfinished works. ."[D15-CAM]	Different knowledge lead to different expectations "Otherwise there's no knowledge...[say] we've actually set the scope to say want a widget, so we've asked for a widget and we ideally get a widget at the end. Sometimes people say, 'We're going to deliver you something,' and it might be a different department, so we like to to say that we can influence the design to make sure that if they're going to give us a widget, it is compliant with our airfield requirements...[where]they delivered you something but have not realised the benefits." [E16-CATM] Owner has limited project engineers who attend site because of self-certify , owners are relying on contractor " With projects they're self-certified and managed by the contractor, so the DI, delivery integrators…[owner] do have project engineers who attend site to kind of keep a bit of a watching brief, but quite limited in terms of how many we have and what their role is and whether they can be

		so the previous guy tried to resolve it in a number of ways but we never really got to the cause of the issues.” [A7-CPM]			People want a binary answer in short time to fixing the issue and thus disregard the intelligence behind the work; led to non-appreciation of quality " Yeah, and almost want binary black and white answers. And people don’t appreciate that sometimes you’ve got trial and error, you can’t necessarily simulate faults. It’s easy saying, “Why did item x stop working for three hours and cause all this disruption?” if you can’t simulate that and prove why – people want to hear a binary answer within a couple of hours of what it was, and you can’t do that. If you’re being honest that’s not always possible. People don’t appreciate that; they put it down to, “Oh bloody engineers um-ing and ah-ing, can’t give me a straight answer”. Well, that’s not true. I think there’s not an appreciation for quality of many things these days. People just kind of want action. They disregard the intelligence behind it I think." [D15-CAM]	everywhere at the same time. But in theory quality control and sign off sits with the DI under the contract which we have in place. They self-certify their work so we rely on them. "[E13-CDM] Owner was only expecting to relies on contractor to deliver the project but it can’t be do without having the knowledge on it and thus becoming more contractor resource to ensure contractor are delivering towards the regulations "Yeah, exactly, so we expect to basically just give them our problem and they come up with a great solution for us at a great cost and just deliver it without us even knowing that they’re there. That’s kind of our expectation. And my experience of it is they say, ‘You can’t just give us all this stuff and no knowledge.’ So where I find myself now is more and more in that world where I’m constantly being asked for, ‘Who do I need to speak to for this and what would I need to do about that?’ so you end up being more of a contractor resource...where I’m trying to make sure they’re delivering from an ... a regulation point of view."[E12-CATM]

Triggered factor of failure	Implications on owner capability to operate	Project A	Project B	Project C	Project D	Project E
Technical aspect for operations	**Technical knowledge not transferred**	PM took over the project because it was not in a good state " I took it over because it wasn't in a good state, it was behind program and there were some quality issues." "All of the things where people has taken their bonuses and sort of run for the hills and said it were all working…" [A7-CPM]	Involved many different PM"…You know what? It's quicker telling me who the PM wasn't… There's been a lot of PMs." [B18-CMAIN] People left but the understanding was not transferred "…so my involvement was quite early on, in terms of understanding what the actual scope of the work was going to be, so some early workshops. The guy's left now and I can't recall his name off the top of my head…" people keep on changing thus difficult to find a way in reducing cost "...they are people changing and we also got different barn on that where opex is really under sweetening. And having to find ways of reducing … is you know can't be defined,.." [B2-CPM] Attention is needed elsewhere "So for the last year, year and a half, [other PM] has been looking after the sweeper tip project…Because I've changed to a different role.	Operations need to know how to maintain the asset "...When they provided a different product…engineers had to go through a training exercise [to] not just familiarisation… it's a different conveyer altogether, you've got to show them…he's got to learn how to maintain it."[C9-CONPM] Contractor experience does not take as learning "Yeah, and I've seen it all too frequently, when we are the guardians – and it sounds like we're banging our own drums – but we are your guardians of this stuff, because we're saying, 'We've seen it before, and if you do that, we'll be back in six years to do it again.' And they go, 'Oh, well, we can't afford ...' It's a hard decision to make. And then sometimes we get railroaded and get told, 'You're just a builder and do what we tell you. Here's the price, go and do it.' But if you come and say, 'I told you so,' it doesn't help, and, in fact, it annoys people."[C9-CONPM]	Blame culture to avoid failure responsibility "But I think that's a bit of a blame culture thing…But denying things for other reasons I don't personally think is very acceptable." the actual impact of that was relatively little." [D15-CAM] **putting the right requirement in the contract with operation involvement** "... that was some good learning where they said to me, "What did you want last time you didn't get because they were like that in contracts where we have to give it to you in contract?" So, I put a long list of requirements in their contract as asset manager, and we started the process of going through the product selection. And with my knowledge of what I'd seen and some other people we had factory visits, site acceptance tests, and we made the best decision we could." [D15-CAM] Operational consideration was not consider but OI was questioned back "… I asked for everything I could think of and got	PM not involved in early decision "I joined [when] the runway project was already basically in the process of being kicked off so all pre-g3 pre work was being done design was being completed and I was part of the tender review for the project as a whole and at the time I was working on a sub-section … it was an extra piece probably of another project that we then put into that to deliver it at the same time. ""[E5-CPM] "I came to the project after the previous project manager had been thrown and the task was to get it back on track and deliver to the time scale that were required.." [E6-CPM] The decision was made to do exactly as the scope that were design four years before that led to 112 crack after a year of completion "The design was done based upon a survey which was completed three or four years before

			So, my attention is needed elsewhere now. He has picked up all of that. ..They can't resolve that problem. They've found a lot of design faults in the design of it" [B18-CAMAIN]		everything that I could think of, told everyone that was of importance what I thought and why. And then afterwards they almost acted like that didn't happen, which I found a bit disappointing to be honest. Then they start questioning and …then when it goes wrong [they're] like, 'that didn't happen'". ."[D15-CAM]	construction started, so the design stated...owner approved the design, that said, 'Let's just do a top course.' So on the southern runway, when we were very conscious of cost, the decision was made to do exactly as the scope was done, and within a year, you started to see some underlying causes coming through, i.e., these 112 reflective cracks that came through, which we had to go back and do stuff in." [E16-CATM]
	Unclear on quality issues root cause	<u>cause was not really understood although attempt to resolved has been made previously</u> " In the fact it's been leaking so the previous guy tried to resolve it in a number of ways but we never really got to the cause of the issues." [A7-CPM]	<u>Avoiding responsibility on QI</u> "and some people…were saying, "No, we didn't. That was never intended". [B18-CMAIN]		<u>Maintenance get difficult with non involvement of product selection</u> "…if there's a fault with asset, they called the maintenance guy... these guys couldn't solve and actually was different brand… "[D4-CPM]	The reduce of asset life cannot be quantified makes a difficult decision "we can't quantify, obviously we can quantity the maintenance/intervention costs, but what we can't quantify at this stage is will it reduce the asset life of that runway. So instead of resurfacing in 15 years' time, will we be resurfacing in ten years' time? .."[E16-CATM] cracking is obviously a quality issues that was due to lots old joints underneath the runway -"... since the runway been in a operation... now we have had some cracking

						along the runway which is obviously due to a quality issue...I think I haven't really been part of a lot of discussion as to how that one kind of panned out and what the route cause of it is but as I kind of understood it we got a lot of... old joints underneath the runway. "[E6-CPM]
	Uncertainty on project scope		<u>Confused on the project scope</u> "…And people will tell you it doesn't. I can assure you, I was one of the original concepts on this…the first people involved. [we] wrote the scope, we sent…"[B18-CMAIN]			
Learning not captured on project	Different contract model impedes long-term learning	<u>Lesson learnt at the end of project was then forgotten</u> "I think what used to happen was that you may get a lessons learnt session at the end of a project, which was useful, but then after that meeting where did that go? It just got filed away." [A14-CPE]	<u>Avoiding responsibilities to learn</u> "We need to get someone that has experience with it ..Yeah… We want other people to have the problems and we learn from the mistakes."[B18-CAMAIN]	<u>COQ failure if captured provides greater benefits in early intervention to prevention</u> "Hindsight is a wonderful thing and maybe if that had been thought through better we would have put our hand up and said, this isn't the best solution for that location." [C8-CONQM] <u>information on success was not available</u> "Well that was very successful…that passenger conveyor was easy to maintain and delivered… [but] I don't know about that because we don't get to see that information.." [C8-CONQM]		<u>No flexibility in delivering project which prevented the learning</u> "as we've identified here, with hindsight, there are always going to be issues and bits and pieces. There needs to be a certain amount of flexibility within any project when it comes to the delivery phase, and that's the bit that is often quite a struggle. ."[E12-CATM] <u>Different contract model influence project delivery thus long-term learning can't be made</u> "two different contracted

						models,... That has a big influence. So every time the regulator says, ‘You are going to deliver that’ and we create a new model, we are kind of resetting, so, in a way, we cannot learn long-term." [E16-CATM]
	Full benefits of project not realised			<u>Project complete on time, but reputational damaged with poor quality</u> “The project was handed over on time, and it went operational, so the benefit was realised. It's more frustration, I think, and embarrassment, I suppose, where operation go down there and they see there's something else bubbling and something lifting, and there are concerns around safety and all this sort of stuff." [C10-CQM] **Contractor willing to influence to interrupt and fix the problem** “I would have liked to have seen the project have the ability to stop when the problem first occurred and fully investigate why it’s happened. I would also like the team to have had the ability to… influence that product selection.to try and eliminate that. And learning from on site, "[C8-CONQM] <u>Project success was not remembered as it was shadowed</u>	<u>People are keeping their reputations thus not share the learning</u> “... people don’t like talking about it..[even] it was from the people [that] heavily involved in it…they got very defensive about it, because obviously they’d spent a hell of a lot of money and made a poor decision. So, company wise people don’t like tarnishing their name.” [D15-CAM] different expertise has different value judgement “There was a discussion about how do we make a sensible decision and pitch them against each other for their individual value. And I think they probably kind of do that, but a lot of it is still opinion because it’s easier to give an opinion rather than set people off to work and find it out.” [D15-CAM]	<u>Project governance influence the poor quality</u> "…you might have finished a bit of works early, which is poor quality, poor planning, so you’ve not realised the full benefits, because you might not be able to use that asset... So there’s this whole unwritten resource, impact, loss of benefits, indirect benefits, indirect impact, indirect cost, indirect administration, around poor planning time and reworks, which I see as a quality issue around the project governance." [E16-CATM] the issues has becoming an ongoing maintenance issues due to not expanding the scope to suit the ground condition "it’s become an ongoing maintenance issue with attached costs, because of, in this case, not reduced

				by other issue "One of the things that we have found in this project is, although it had some successes, nobody remembers them. They only remember the floor, which is interesting." [C10-CQM] “So it's interesting that the operation known about the floor and the additional cost of opex to fix the unclear tiles whereas what they haven’t done is they haven’t realised benefits of the conveyors and lighting." [C3-CPM]		scope, but not expanding the scope to suit the ground conditions that we found during the works." [E16-CATM] the runway has been closed numbers of time although it was built for 25year "because we only built it eight years ago and it’s failed, so we had to close it a number of times, even though it had a 25-year design life." [E16-CATM]
	Quality issues repeated	COQ were acknowledged but issues were still repeated to another project "Yeah, what you find is something which we kind of touched on before, we replicate the same issues so we don’t learn. One of the big issues which we have with multi-storey car parks are the expansion joints…it’s an issue we have on pretty much all of our multi-storey car parks. And it feels like we know it’s an issue, we then moan about it and have to pay to undertake maintenance works to try and stop water getting through them, but each time we’ve built a new car park we have the same issue. "[A14-CPE] same designs and				Project need to learn at the beginning to avoid failure "it was not actually the fact that we did the lessons learnt at the end of the southern, it was the fact that we did the lessons learnt at the beginning of the northern; that made the difference..[and] is actually where they were two projects they were two projects doing exactly the same thing, basically one finished and the other one started, so actually it was a linear process...whereas with a multi-storey car park you build one now and the next one you may build maybe in three years, five years’ time.So, everybody forgets about it."[E13-CDM]

		specifications were duplicated with appointing the same contractor “Everybody forgets or they say,”We’ll do another, oh well we’ve got a design already for a multi-storey car park. You like [multi-story car park], we’ll give you another… or you like multi-storey car park 5…then [they repeat] exactly, same design, same specification and then you get the same issues.”[A14-CPE]				Quality issues were prevented before repeat to another project bring success "... there was an element of learning which came out of the southern runway...both runways were meant to have the same remediation…With northern they were a little bit more proactive... of how they recorded [and] identified [then] implement the crack repairs. On the southern it was slightly different... and that makes a big difference…” [E13-CDM] “…it seems to have proved relatively successful….Yes, same supplier, So, that’s the kind of cracks on northern and southern..”[E13-CDM] "In respect of the N we did more work, learning from the south, mainly because we thought that the North was in a worse state, but actually we took a different approach on the North than we did on the South, and as a result of that it’s in a better state. "[E5-CPM]

APPENDIX 4

Appendix 4: Extract examples of the need for integrated capabilities in failure mitigation.

Why need-integrated capabilities in failure mitigation	Project A	Project B	Project C	Project D	Project E
Operational failure was not acknowledged, and measured	Focused on operational readiness/ reputational impact - *" It would have still happened; and the reason being, the Queen's coming." [A1-CPM]* *"We could turn around and say, "We need to go and spend half a million pounds at multi-storey car park one to keep it in service" only to find that actually it then gets knocked down in a year and a half's time. The question is, is that money well spent?" [A14PE]* *"This is something in as much as I don't think it can be quantified…and that is something which we talk an awful lot about and we do actually use this as a kind of key card in terms of quality, in terms of reputation…but very, very difficult to put a cost against it" [A14PE]*		Interrelated to other complex operations - *"…because that end date doesn't move, you will eventually end up with quality issues that will impact operations and nobody has any real influence over them. They don't know...not even the owner I think... because there's a much bigger picture." [C8-CONQM]* Controlling contractor work performance - *"I changed the way that we paid them, so that there was more money held, retained, from their fix price contract until they got the final bit of commissioning done… we are holding on to indicate money..[and] … didn't get their final fee until… All the works been completed …So...it wasn't as if any department can close the projects, but they also had the best interest until the handed the job. "[C3-CPM]* *"because the way things cut up was different contractors doing different parts ... The walkways weren't one single person. It was numerous. what it meant was this that the urgency of the project to get approval and go through, [and]*	Project worked through indemnity losing the value - *"you continually attract ... for people to just keep up project live from financial reporting, processing payment because [supplier] will be paid every week… Every month. So, you need indemnity, for a year and the project could be close down in the right time." [D4-CPM]* *Collaborative decision is hard to achieve as people does not see the actual lost/ saving - " The problem is when you've got a company with departments [they]... are making decisions for their own goals, not for the overall...[when]they're supposed to tie up with the top ....They won't go, "Let's de-scope everything by 10% and then take the quality down from perfect to a little bit less than perfect but across the field" because that's complicated to do... against every single type of asset you're buying…That's complicated and people don't do that here. I've never seen that happen."* [D15-CAM]	

			it led to us having a triggered payment... "[C3-CPM] Governs by complex interrelations (system of system) - *"Well generally the installation programmes are tight… and there's lots of drivers for that. The [owner] has lots of reasons why they need things to be operational at certain times and they're generally… a piece of work is generally part of a much bigger picture. So… our piece of work may have enabled some other things to happen …that were critical …so that end date never moves." [C8-CONQM]*		
Operational failure costs were only realised at operations	*"so 18 months after [project] finished, we started to see this issue's; bubbles appearing and the deck actually crack.."... then obviously the maintenance because while this weren't wired correctly the maintenance again you can't do proper maintenance on them because they did not operate as they should have done." [A1CPM] "* Project life is uncertain *"One of the big issues which we have here is knowing what <u>design life we require</u>, and that links into master planning, and master planning is a little bit uncertain..." [A14PE]*		COQf help to visualised the benefits of either saving or failure, thus promoting the learning - *"So it's interesting that the operation known about the floor and the additional cost of opex to fix the unclear tiles whereas what they haven't done is they haven't realised benefits of the conveyors and lighting."(C4CPM)* *"as an indirect impact of poor design, poor planning, poor delivery, because we say a project is going to take one month to build, in effect, it takes six months to build. Well, one, it will cost more because you're spending more time on it, but, two, even from a smaller*	Measuring COQF provides clearer view on the benefits of the project - *" I think probably part of that, though, needs to be really clearly identified what the benefits are, what the purpose of this project is, and the reasons they're spending hundreds of millions isn't just to get a shiny, new building, and that's part of it."* [D15-CAM]	There is an saving to other operations costs - *"the capital cost of the project was increased to do the extra crack treatment; but effectively the increased benefit we get from doing the extra crack treatment is a reduction in maintenance, reduction in whole lifecycle costs etc…"[E12-CATM]* Operational failure can be predicted - **"***runway cracking is one way is a hidden defect but became apparent over time"* [E6CPM]

			level, there's a significant amount of re-work that's going on, so in terms of the labour that it takes to do all the planning, the approvals, the design. Every time that we do a project we write to the CAA for approval...will be a period where we've then got to do additional work... purely because it hasn't been delivered on time to plan." (CAIR1)		
To improve quality management within project team	*"...the quality management needs to be so strong within the builder, and that's the bit that's falling down because the quality management in (main contractor) isn't strong, it's desktop exercises, they rely on the site managers to say that it's good enough. The quality manager doesn't put his boots on and go and look at stuff on-site, it's all paperwork, desktop, make sure that the templates are filled in, that the process is followed and the eventual delivery of it, it's all process based."[A1CPM]* *"... it's my opinion ..., if you have a project manager who good at managing project then that's where his expertise is, if you have somebody who leads a*				Identifying the failure will provide more flexibility for the project to stop and change- *"as we've identified here, <u>with hindsight, there are always going to be issues and bits and pieces</u>. There needs to be a certain amount of flexibility within any project when it comes to the delivery phase, and that's the bit that is often quite a struggle. People talk about changed management, but nobody ever seems to want to go through changed management... representing the operating world, the people that get left with <u>it after the projects gone, it seems to me that common</u>*

	project to understand whether it be civil work or labor work, life safety or whatever it is. That person is going to have a better understanding otherwise what your dependent on is people part of your team, people providing you without assurance that is the right quality…"[A7CPM]				*sense goes out of the window sometimes and 'We'll just deliver this because that's what I've been told to deliver by somebody,' when they were looking at something three years ago and made the best decision they could then!".* As a performance indicator or lagging indicator - **"** *I think from a QMS perspective, if you look at what advantages QMS gives you, even from this model, from looking forward to your planning use, if you're using consistent processes, if you're providing consistent information, if you're asking people to quote against works in a consistent method, ... so you've almost got an element of performance indicators to demonstrate that this is a lagging indicator that shows us that we are consistently below where we need to be or we're consistently- Whether that's a cost element..."*

How failure could be mitigated					
Long-term relationship	Owner and contractor long term relationship helps in incentivised contractor to fixed the issues - *"... But equally [the contractor] are an organisation that have worked with [us-owner] for many years. They were part of the joint venture ...for us and they are more than interested in supporting us on [other project]…So, they know as an organisation that they need to sort this out. To just walk away … wouldn't be a sensible position for them to be in." [A11-CCOM]*	*"…also the long term contract with the treatment company, so monitoring the system remotely and how they would do their long term maintenance. So we did do that whole lifecycle cost of the project. [B2CPM]*			

Integrating capabilities	There is a need to integrate with specialist and operation team - *"… when you're working on an [infrastructure projects] you do heavily rely on the specialists and operational team to tell you what's acceptable and what's not acceptable..." [A1CPM]* Project need integrations between different organisations - *"People build projects. People who want to build a successful project and want to work together with the other members of the project team will build a successful project. One person cannot do it on their own…" [A11COM]*	There is a need to include operational knowledge *"…we needed to get the engineering team to look at how they would maintain [and]… like engineering and operations [to determine] how much time they have to spend on it …" [B2-CPM]* Early involvement of the designer with consideration on operational need provides better understanding on the drawings - *"Designers need to get down to site with your tape and measure it.." "Designer need to spend time with the operation/ user to understand how it can be function, not only to transfer information into drawings.."[B18CMAIN]*	Integrating operational capability help smoothen operational delivery - *"…and what I did on this job is actually brought the operation in to do that. So, it was the engineers that were checking the cars, it was the engineers were agree testing procedure. Which made it easier…" (C4CPM)* *"through the job that <u>I have lot of movement of operational team</u>. And I managed to secure lead engineer in about end of 2010 and who then stayed with me until the end of the job. " (C4CPM)*	Early involvement for different stakeholders to better understand the project - *"...[we] offered him early site of the escalator when it came to the building. Site has been connected together, ready for been covered up with the rest of the building worked. And once it was uncovered, frequent site visits to watch it be built and commissioned, tested… They were very forthcoming, attending those sessions…."*[C3-CPM]	"*Getting the scope right is key to quality of cost, quality of finish". (E12CAIR)*
Front end management that include technical expertise	*"Something which should have been targeted better was construction on the front end, the schedule management; we took quite a "you're the builder, you're the professional, let us know if you've got any problems" approach to things; whereas there's a few different owner models for how to manage contractors; especially in a heavy asset orientated environment, so for example [to have] field engineers; ... but that model is completely different to what we do ... we don't really have the technical team to do*	Aligning quality through contract - *"...but. pretty more contract less... well actually there is some sort of planning that we can keep the sub-supplier on board. [through]...warranty bases actually…so there is a basis at the back there were you actually should have." [B2CPM]*		Front end planning that involve different stakeholder to mitigate the risk - *"…It was critical because they had to open a hole in the runway and drop it in and close it before the first aircraft landed in the morning. So everything had to go exactly to plan. So there was a lot of planning work went into that and it was deemed to be very successful; lots of back-slapping..." "And lots of meetings, planning it, lots of detail, lots of reviews, independent people coming in – all of the stakeholders*	Learning that was captured from on project and implemented at the beginning of project make greater impact - **"***it was not actually the fact that <u>we did the lessons learnt at the end of the southern, it was the fact that we did the lessons learnt at the beginning of the northern</u>; that made the difference..[and] is actually where they were two projects they were two projects doing exactly the same thing, basically one finished and the other one started, so*

	inspections or anything like that" [A1CPM] *"...understanding how long the assets are going to be there for to inform the right decision in terms of whether it be a short-term intervention or a long-term intervention, and quite often we're guessing that. So, that has big cost implications…" [A14PE]* *"... what we do ...[is] actually is reducing the design life because it maybe more cost effective to actually deliver something which will perform for five years or ten years rather than 15, and say after five or ten we'll come back and do another intervention. But if you get that wrong, either in terms of quality what's been delivered or actually under-delivering, that can cost you an awful lot...." [A14PE]*			*involved…, everybody involved and the mitigation plans that were put in place meant that piece of work did…it's about identifying what the risks are and putting the right level of mitigation in place "[C8CONQM)* *"The whole driver around that piece of work was the risk. It was the risk to not doing it properly. We could not close the runway and the only way to access that… to do that piece of work was to put a hole in the runway. So that <u>risk drove all the behaviours</u> to plan this piece of work to the nth degree. (3-C8CONQM)*	*actually it was a linear process...whereas with a multi-storey car park you build one now and the next one you may build maybe in three years, five years' time. So, everybody forgets about it. " (*E12CAIR) *)*
Collaborative work environment			help in realisation of the benefits - *"it's all about team for me. The legacy is that, I grabbed everybody, operation, security, engineering, (contractor and suppliers)… And we were all in creative environment, we were all in together. If I fail, security couldn't operate properly. If they were failing, there's no blame culture."* C3-CPM]		Provide proactive action on dealings with the problem - *"... we spent another half a million on the southern, whereas to probably do it as we go along might have cost us a quarter of a million pounds on the northern. <u>So dealing with the problem at the time, so getting the scope right was the right thing to do</u>."*[E13-CDM]