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MINIMISATION OF REWORK IN UK HOUSING CONSTRUCTION: CONTRIBUTION OF SUBCONTRACTORS

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ABSTRACT

The housing supply chain includes a plethora of privately owned trades, and a high level of fragmentation is driven by a significant number of micro businesses in the UK housing construction. The construction industry has been recognised as one of the major industries with a high level of waste and rework, particularly among different contributors in housing construction. Rework is an endemic and chronic issue and has been recognised as a symptom that has afflicted the workflow process and the productivity in housing construction projects in the UK. Traditionally, the root cause of rework in the housing supply chain has been identified as a poor performance of subcontractors. However, there is very limited research into the elimination of rework in the housing supply chain. Subcontractors play an important role in delivering successful projects. There has been less attention paid to the importance role of subcontractors in housing supply chain, given the high level of fragmentation associated with the large number of subcontractors in housing development projects. The research method is based on a literature review, semi-structured interview, and questionnaire survey. A pragmatic sequential exploratory approach (i.e., the qualitative research followed by quantitative investigation) was used to address the research questions. For the qualitative research a semi-structured interview was carried-out to gauge industry experts' perspectives and understanding of the root causes of rework. A quantitative research method, using a questionnaire survey, was employed from wide range of practitioners within housing development projects. The finding of the study suggests and highlights the importance role of subcontractors for rework minimisation in housing construction projects. Also, several key findings that have emerged from the study include cooperative working to foster trust among subcontractors, collaboration improvement among practitioners, creating incentive mechanism, and learning mechanism, improving site management team, different strategies to minimise rework, employing offsite manufacturing techniques, using digital tools, and adopting communication tools to improve collaboration and minimise rework onsite. To help subcontractors achieve a sustainable rework minimisation practice, a best framework has been developed based on the findings from the study and evaluated by employing a focus group. The content of the study can be used by practitioners who are involved in housing development projects.

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Table of Contents

List of Figures

Lists of Tables

ABBREVIATION

ANN	Artificial Neural Networks
ACO	Ant Colony Optimisation
CBR	Case Based Reasoning
JIT	Just in Time
HSC	Housing Supply Chain
LC	Lean Construction
MMC	Modern Method of Construction
MMR	Mixed Method Research
OCV	Original Contract Value
RA	Regression Analysis
RM	Rework Minimisation
RMF	Rework Minimisation Framework
SC	Supply Chain
SCM	Supply Chain Management
TQM	Total Quality Management

INTRODUCTION

1.1 Background

The construction industry is one of the UK's largest sectors, with an output of £110Bn and a 7% contribution GDP in 2018 (ONS, 2018). The housing construction sector's contribution was reported as approximately £44Bn per annum - equivalent to 40% of the total construction market share (ONS, 2009). The construction industry is a major employer, consisting of 280,000 firms providing almost 2.93 million jobs and turning-over £370Bn (HM Government, 2018; ONS, 2009). However, for the past 50 years' studies show that the construction industry has been struggling with low productivity, a high level of waste and rework generation, poor quality of products and high output costs.

The UK construction industry in general, and the housing supply chain in particular has often been criticised for being wasteful and generating high levels of rework, with low productivity, poor quality and high level of risk with small profit margins (Egan, 1998; Booke et al., 2004; Cai et al., 2007; Pan & Hon, 2020; Fulford, 2018; Arashpour et al., 2014). The root cause of these issues has been attributed to housing supply chain's fragmented characteristic. For example, on a typical housing construction project, between 70% to 90% of construction work value is subcontracted to smaller companies and specialist firms (Cai et al., 2007). Data from the Office for ONS (2009) revealed that out of the 250,000 construction firms registered in the UK in 2014, only 2.1% employed more than 25 people. This illustrates the level reliance the UK construction industry has on a large number of subcontractors, which are often SMEs.

In recent years, the UK government has emphasised strategies and policies towards the improvement of housing construction sector in response to increasing market demand. Issues in the construction sector, highlighted by Farmer's report (Farmer, 2016), include structural fragmentation (such as a poorly integrated supply chain, a large number of Small Medium Enterprises (SMEs), and an increase in the number of self-employed). Other issues include low productivity, leadership fragmentation (e.g., lack of interdependence between industry and clients, general fragmentation of the industry's main representatives), lack of predictability (e.g., cost overrun, and quality of products), workforce composition and size (such as ageing workforce, and decrease in the number of new entrants), high level of rework, and a lack of collaborative and cooperative culture.

Contractors, in the rush to complete housing projects, can compromise quality of the building. This suggests that remedial work could be avoided though is largely overlooked in higher profit margin (Sommerville, 2007). Consistently, (Baker, 2012) on UK housing supply, stated that contractors aim is not geared to deliver a high-quality standard product to secure their future projects and reputation or expand their market share in the sector. This has resulted in high level of rework occurrence in housing development projects.

Several recommendations for reduction of rework have been proposed within literature as an on-going priority for the UK housing industry. In particular, training and trades, standardisation processed and product, strong collaboration among different contributors, predefined quality criteria and learning from previous rework (Taggart et al., 2014; Hopkin et al., 2016); Love et al., 2015b). However, none of these elements can eliminate rework from the entire housing supply chain – and a holistic approach with effective subcontractor collaboration on construction sites could prevent rework generation. This research investigates the root causes of rework in housing construction projects and identifies the gaps in the current knowledge.

1.2 Problem Statement

1.2.1 Inadequate and Low-Quality Housing in the UK

There is a considerable shortfall in the number of dwellings available in the UK, which puts house builders under pressure to deliver upward of 250,000 housing units a year to meet increasing demand (Holmans, 2013; Hopkin, 2016; Hashemi, 2017). In the last 8 years, an average of 134,000 houses was built per annum, though the supply rate of houses has declined since 2007, from 188,450 to 114,670 (Hopkin, 2016; NHBC, 2011) It is argued that one of the main reasons of housing delivery decline in the UK is the withdrawal of local councils from the production of housing in the late 1970s (KPMG and Shelter, 2014). The consequence of local council withdrawal has further escalated the pressure on private house builders to close the gap.

According to the Office for National Statistics (ONS, 2018), housing demand is projected to grow each year due to population increase, demographic changes, and adoptability, while the supply has been performing poorly and falling behind (RTPI, 2013). In addition, house prices in the UK have increased rapidly since the 1980s (RTPI, 2013). RTPI., (2013) stated that some 77% of people in the UK believe that it is harder for them to rent or to buy houses than it was for previous generations, and 90% argue that it will be harder still for the next generation. The experience of the last two decades suggests that the level of demand for new houses over the next 10 years will not be met by piecemeal incremental developments (RTPI, 2013).

The number of completed new houses increased by 8.8% to 178,800 in England in 2019 in compared with 2018 (ONS, 2018). In 2016, there were around 27.7 million residential dwellings in the UK – of which 23.7 million were in England, 1.4 million in Wales and 2.6 million in Scotland (ONS, 2018). In 2015, the government set out an ambitious strategic vision to deliver 1 million new, additional net housing stock, expected to be delivered in 2020. In 2017/2018, England increased the number of housing units by 222,190 – where conversion and change of use also added to the increased dwelling stock. New builds have accounted for less of the net total in recent years, whereas change of asset use from non-residential to residential property has become more common, increasing by 65% between 2013 to 2015, with a continued rise over the subsequent years.

The UK housing supply chain has often been criticised for the poor-quality dwellings (Pan et al., 2008). While other countries, such as Germany, have had significant progress in producing large scale green buildings and zero carbon emission buildings, the UK is struggling to deploy sustainable and energy-efficient construction practices in housing projects (Gröndahl and Gates, 2010). This suggests that the UK faces a significant challenge in providing affordable quality houses required now and in the future. A fundamental shift and innovative ideas are necessary to meet the increasing demand of affordable and quality housing in the UK (Rodionova, 2016; Kollewe, 2017).

Zero carbon requirements from the UK government have also increased the pressure on the UK housing industry (UK government, 2012). This policy resulted in tougher building regulations (DCLG, 2013) , in which house builders need to incorporate new technologies into buildings to attain compliance (Lees and Sexton, 2014). A review of the literature suggests that the pressures the UK housing industry is encountering have had an adverse effect on build quality and, consequently, the level of rework has increased in the housing construction stage (Hopkin et al., 2014). A survey conducted by the Home Builders Federation found that more than 93% of home occupiers experienced and reported rework and defects within their newly built houses, a statistic that has increased two years in a row (HBF, 2015).

The problem of poor supply and quality has successfully been tackled by automobile manufacturing industries. In the early 1990s, Toyota developed a systematic method entitled ‘Lean’ for waste minimisation within their manufacturing system to improve the productivity and quality (Koskela 1992). Lean implementation emphasises the importance of optimizing workflow through strategic operational procedures while minimising waste and being adaptable. The ‘Lean’ concept has been transferred to the construction industry from manufacturing principles, first by Koskela (1992). Koskela (1992) termed the concept as ‘Lean Construction (LC)’. However, there have been debates about the application of Lean thinking in the construction industry, which is discussed in the next section.

1.2.2 Lean Thinking in Construction Industry

Lean thinking aims to increase value in every production process stage. Although the construction industry is different from manufacturing, industrialised housing construction provides the closest analogy to automobile production (Winch, 2003). Industrialised housing can be compared with automobile manufacturing considering their similarities in production strategies (Gann, 1996; Barlow et al., 2003; Woudhuysen and Abely, 2004). Its distinctive features, including controllable production flow, high production volume and large inventory of work in process, make the application of Lean thinking favourable for the housing supply chain (Yu et al., 2009). Upon introducing the Lean concept to the construction industry, there were many attempts to implement LC and eliminate ‘waste’ and add ‘values’ to projects. There was an indication from the Lean Institute UK that Lean operation in construction could revolutionise construction through affordable housing units with high quality builds.

Ogunbiyi et al. (2013) highlighted several benefits associated with the implementation of LC. They showed that benefits, such as improved corporate image and sustainable competitive advantage, improved process flow and productivity, improvement in environmental quality and increased compliance with customer’s expectations, can be achieved following the adoption LC. Their study also identified several areas of linkage between LC and sustainability, such as waste reduction, environmental management, value maximisation, and health and safety improvement among others (Ogunbiyi et al., 2013). However, during the last two decades, there has been a lack of clarity within the construction industry surrounding the concept of LC. The majority of the industry has failed to implement it and, despite some great achievements, it has not been prevalent in construction practice (Koskela et al., 2012; Bolviken and Koskela, 2016).

Salem et al. (2006), compared the manufacturing and construction industries to find out why Lean production theories and practices do not fully fit the construction industry. They highlighted three main features of construction industry that distinguish it from manufacturing: onsite production, one-of-a-kind projects, and complexity (Salem et al., 2006). However, they concluded that, although many LC tools and elements are still in an embryonic state, LC techniques are gaining popularity because they can affect the bottom line of projects. More specifically, Mossman (2009) noted that one of the main reasons why Lean thinking has not been successfully implemented in the UK, is fragmentation. Sub-contracting and fragmentation in construction mean that there is little motivation for project teams to learn together, as it is unlikely that they will work together again.

The construction industry has a large supply chain and is characterised by high levels of fragmentation. Harris (2013) demonstrated that for a typical large housing project (within a range of £20 to £25 million) the main contractor may be directly managing around 70 small enterprises as subcontracts. For a regional project, the subcontract size may be even smaller. This indicated the scale of fragmentation and subcontracting in the industry, which also confirms the extensive engagement of SMEs in housing supply chain in the UK as subcontractors. Subcontracting strategies are widely used by many companies in the construction industry to reduce the construction process and eliminate or reduce costs (Ohnuma et al., 2000). However, this fragmentation and subcontracting can work as a barrier to LC deployment (Mossman, 2009). This research will examine the potential of LC for rework minimisation in the housing supply chain among subcontractors in this study from practitioners' point of view.

There have been attempts by some clients to create opportunities for Lean implementation for SMEs as subcontractors through partnering agreements, but these generally only involve the major players (Mossman, 2009). To conduct a LC deployment, research is needed beyond some specific LC techniques. As a result, the research is not promising that LC can be applied through different contributors in the housing supply chain.

The construction industry in general, including housing, is among the most wasteful industries worldwide (Aziz and Hafez, 2013). The term 'waste' is commonly defined as 'anything that is not required to create value for the customer/client or end-user' (Sarhan and Fox, 2013) One of the major 'wastes' which needs to be minimised in housing construction projects is 'rework'. The term 'rework' describes work that must be done a second time and affects both project cost and schedule. Construction sites are complex environments where multiple subcontractors and suppliers work simultaneously and often with different business objectives. In such environments, the likelihood of errors is high. The cost of rework in construction projects has been estimated to be up to 12% of the contract value, which can be a large amount of the revenue (Burati et al., 1992; Love and Edwards, 2005). This is discussed further in the next section.

1.2.3 Cost of Rework in Construction Projects

Almost all existing cost estimates for rework are expressed as a percentage of the total project cost (Taggart et al., 2014). Studies by Love and Li (2000), Rogge et al. (2001), Love et al. (2004) and Hwang et al. (2009) suggest that rework costs range from 2-6% during construction with an additional 3-5% during the maintenance period. Love and Edwards (2005) suggest that many costs are hidden in the process, and this could well range up to 25%. Problems, defects, and faults are often generated in one part of the process, but not detected until some later stage, tending to multiply the cost (Koskela et al., 2006).

The cost of rework in poorly managed projects can be as high as 25% of contract value and 10% of the total project cost (Love and Li, 2000; Barber et al., 2000). Thus, if a 10% rework value is applied to the annual turnover of the UK construction projects, the cost of rework can be estimated to be £11Bn per annum. This estimate confirms that rework reduction could save the UK economy billions.

Rework in construction industries can be observed globally, such as in Australia (Love et al., 1999) , China (Kumaraswamy and Dissanayaka, 2003), and Chile (Serpell et al., 2002). These countries are experiencing a similar percentage of additional costs due to rework (Sommerville, 2007). In Australia, for instance, it is estimated that the direct cost of rework in construction is greater than 10% of project cost, which is equivalent to $4.3 billion per annum for the entire national construction projects (Love and Li, 2000). Similarly, the USA based Construction Industry Institute has projected the loss due to rework to be as high as US $15Bn per year just for industrial construction projects (Rogge et al., 2001).

Egan's (1998) Rethinking Construction report, highlights that a 20% annual reduction in the number of defects at handover is required to drive sustained improvement. Love and Edwards (2004) showed that earlier work on rework might result in less cost (i.e., values between 3% to 15% of a projects contract value). Barber et al. (2000) suggested that rework cost might be as high as 23% of a contract value. Simpeh et al. (2015) on the other hand found that the total rework costs could have a high variation with a range from 0% to 25%.

1.2.4 Root Causes of Rework

Traditionally, the sources and causes of construction rework have mostly been considered to be the responsibility of the main contractors (Love and Li, 2000; Love and Edward, 2005; Love et al., 2009), though this might be a simplistic view of a complex problem. Some of the rework problems handed to site operatives are beyond the contractors' control. The project designer, product manufacturer, contractor and subcontractors, and processes, such as procurement, materials handling, and site construction practices, all contribute to rework generation.

The focus in most of the housing construction practices is on fixing the problem (i.e., the fault in particular dwelling) at the end of the construction and before handing over to the client. However, if the source of the problem is not examined and the cause is not identified, there is no guarantee that the problem will not be repeated in the next project. There are limited studies on the identification of the sources and causes of rework in construction projects in general and particularly in the housing supply chain (Taggart, 2014).

Shammas-Toma et al. (1996) classified the defects are usually occurred during housing construction but are caused due to other factors such as; during planning, or at the design process or at the point of material/component production. Josephson and Hammarlund (1999) noted that operatives must have the necessary knowledge and motivation for correct execution of each task. Josephson and Hammarlund (1999) highlighted those contractual pressures, in terms of cost and time, late involvement of end users and delays in decision-making by clients to be factors that contribute to higher defect levels. Vrijhoef and Koskela (2000) and Love et al. (2009) indicated a lack of supply chain coordination as one of the prominent factors causing defects.

1.3 Gaps in the Knowledge

1.3.1 Rework Within the Entire Housing Supply Chain

There is a plethora of research on construction rework, but limited evidence of how rework is generated in housing construction projects (Seidler, 2013; Hwang et al., 2014; Kakitahi et al., 2013; Taggart et al., 2014; Jingmond and Agren, 2015 and Love et al., 2018). Rework is produced by the actions of the entire housing supply chain through design, manufacturing, construction, distribution, refurbishment, and demolition. Rework caused by various actors in the supply chain is different in terms of amount, cause, composition, and level of integration. Each actor plays a role in reaching the minimum rework, but the actions and their relative contribution may vary in accordance with their ability to deliver. Significant reductions of rework can be possible if they are properly assessed and managed among practitioners in the housing supply chain.

The level of rework generated in a project is inevitably influenced by the attitude of the key players (Faniran and Caban, 1998). As clients set the standards of quality to which the project team must comply, it has been argued that clients usually have the greatest influence over rework minimization practices. However, efforts towards rework minimization will not be successful if those downstream the supply chain do not buy-in to effective rework minimization strategies (Dainty and Brooke, 2004; Teo and Loosemore, 2001). Within this argument, the fragmented and unstructured nature of the construction industry might be seen as a significant barrier to embedding the culture of rework minimization practice in the housing supply chain.

London (2008) identified a deeper level of complexity in the construction industry. He argued that, although subcontractors may not be working with the same suppliers or customers on every project, they typically are located within a cluster of professional networks, which develop and are maintained over several years. Thus, there is an indication that there are indeed long-term relationships among the various actors of the supply chain who have various degrees of influence over each other in their attitudes and behavior towards the adoption of efficient rework minimization strategies. Therefore, it is important to gain deeper knowledge of how this takes place throughout the supply chain, specific to the housing sector.

1.3.2 Current Practice in Minimisation of Rework

Previous research on construction rework reduction and rework avoidance in construction projects have identified the following key practices for construction organisations seeking to minimise rework:

- Rework reduction by using various measures at the early stages of the design process, including standardisation and dimensional coordination, limitation of design modifications and provision of detailed designs (Poon, 2007).
- The use of prefabricated products to reduce rework generation on site, which consequently contributes to cost savings and higher quality (Love et al., 2004; Zhang et al., 2005).

Researchers have concluded that there is a gap between theory and the practical implementation of the suggested practices for rework minimisation by construction firms. Lingard et al. (2000) suggested that the attitude of being 'resistant to change' as a part of the common culture of the construction industry, which is a major barrier to effective implementation of rework minimisation practices. The study by Teo and Loosemore (2001), indicated that the unique nature of each project, the fragmented characteristic of the project organisations and poor coordination and integration among various participants, are the main barriers for successful rework minimisation. A review of the literature indicates that many barriers to efficient rework minimisation revolve around underlying behavioural and structural characteristics of the construction supply chain in general, and SMEs as subcontractors (Taggart et al., 2014; Tezel, 2017).

1.3.3 Engagement of SMEs as Subcontractors in Housing Supply Chain

Fragmentation and subcontracting act as an obstacle to the deployment of rework minimization in the construction industry (Asefeso, 2014; Taggart et al., 2014). It has been observed that, fragmentation and subcontracting in housing construction hinder the incentives for project participants to efficiently practice rework minimization towards producing affordable quality houses (Asefeso, 2014). In practice, subcontractors view the main contractor as their 'customer' and they have little concern for the ultimate project customer and other subcontractors with whom they interact (Karim et al., 2006). Defects often go unnoticed or are not communicated because of lack of integration with other subcontractors. Consequently, the impact of late defect detection can be multiplied as projects move forward (Koskela, et al., 2006).

SMEs are the largest group in the construction supply chain (Morton and Ross, 2008), engaging as subcontractors in housing projects. However, the engagement with subcontractors for rework reduction and a possible LC method has been limited to date. It has been reported that only large companies, which are in the top 1% of companies by size in the UK, have taken the LC pathway (Tezel et al., 2017). Some of the general arguments regarding the lack of LC deployments and rework minimization in smaller-sized enterprises (across construction industry in general) have been found as follows:

1. As an impeding factor for partnering for LC, there is a prevalent lack of trust between SMEs and their larger clients (Briscoe et al., 2001).
2. There is a lack of spare resources for SMEs to invest in innovation (Alves et al., 2009).
3. Efficient LC deployments should integrate SMEs into the process of rework reduction, to eventually reduce the transaction costs of the entire industry, and; not only the main contractor (Miller et al., 2002).
4. Large clients need to actively support SMEs regarding know-how and resources to develop capabilities in innovative approaches (Ferng and Price, 2005).
5. Generally, there is a lack of belief regarding the mutual benefits from LC and supply chain integration practices (Dainty et al., 2001).

The exploration of rework minimisation in SMEs is limited in construction, having not been discussed from the supply chain integration perspective. Beyond generic remarks, the lack of sector-specific analyses (such as, housing, railways, and highways) of rework minimisation in SMEs is even more notable, which represents one of the main justifications of this proposal. Currently, there is no sector-specific study to assess implementation of rework minimisation within the housing supply chain. Such a study can clarify the barriers for an efficient rework minimisation practice in the housing industry and suggest how it can be improved to produce affordable quality houses.

1.4 Research Questions

Rework can be generated in any process or stage of a construction project. Various practice guidelines and policies on minimising rework have been tried by a few organisations worldwide. Several key approaches for rework minimisation have also been presented by scholars and experts (e.g., Taggart et al., 2014), with a focus on the strategies of rework minimisation. The significance of evaluating and monitoring the effectiveness and outcomes of the rework minimisation practices is largely neglected. While previous studies have revealed the importance of organisational attitudes and behaviours in the implementation of rework minimisation practice, there is still limited research investigating on the critical role that SMEs as subcontractors play within the supply chain on influencing the attitudes and perceptions towards rework minimisation. Given the context rework can arise at any stage of the housing construction process, from design to operation, collaboration and cooperation between subcontractors and other supply chain contributors is critical for achieving an integrated approach on rework minimisation practice in the housing supply chain. This study therefore investigated the following detailed research questions:

1. What are the causes and sources of rework in the housing supply chain?
2. What is the current condition of rework minimization practice used by subcontractors within the UK housing supply chain?
3. What should be the way forward to minimize rework across the subcontractors in the UK housing supply chain?

SMEs often constitute the largest group in the construction supply chain. However, rework minimisation approaches have rarely focused on SMEs to date with sector-level analyses being even scarcer. For an extended dissemination and rework minimisation practice across housing supply chain, it is essential to gain a better understanding of the issue from the SMEs' point of view.

1.5 Aim and Objectives

The aim of the current research is to develop a strategic framework for rework minimisation practice in the UK housing supply chain. The objectives of the study are:

1. To explore the sources and the causes of rework in housing supply chain.

2. To investigate barriers and current practices for rework minimisation in the housing supply chain from a subcontractors' perspective.
3. To identify appropriate remedial action, and strategies for rework minimisation practice
4. To Suggest future direction for rework minimisation practice through development of strategic framework and lessons learnt in the housing supply chain.

A key research outcome would be to assist the UK construction industry in avoiding and reducing rework in the housing supply chain, which would also decrease the cost of housing development. This would be a step forward in increasing the much-needed production of affordable housing by the UK construction industry.

1.6 Original Contribution to Knowledge

Research interest in rework minimisation has been increasing in the UK construction industry. Given the increasing costs and time-overrun projects due to rework occurrence, innovative approaches to reduce and/or avoid rework throughout the collaboration of contributors in the housing supply chain is urgently required. This study is well placed to make a significant contribution towards the rework minimisation practice in the housing supply chain.

Subcontractors constitute the largest group in construction supply chain. However, to date, rework minimisation practices have rarely focused on subcontractors, with sector-level analyses even scarcer. For an extended dissemination and deployment of rework minimisation practices across the housing supply chain it is essential to gain a better understanding of the issue from the subcontractors' point of view.

Rework minimisation framework development will impact on carbon emission reduction, boost production, enhance sustainable construction, and fast track project delivery time. Other contributions from the framework are including cost saving, risk minimisation and possible superior quality of product delivery. The research contribution on knowledge was viewed from the standpoint of poor construction work culture, materials, and other resources wastage. In summary, the study contribution to knowledge can also be viewed from sustainability, improvement to working culture in construction, enhanced workforce, better quality of construction deliverables, cost, and timely project delivery.

Finally, the study specifically contributed to housing, construction production and subcontractors' management body of knowledge.

This research aimed to understand the current condition, and future direction of rework minimisation in the UK housing supply chain, taking a mixed methods approach. Through experts' perspective, the researcher aimed to obtain a complete understanding of current rework minimisation practices among different contributors in the housing supply chain. Interview findings were validated using statistical analysis of a survey study, which helped rank the relevance of each current condition point (the second research question) and the importance of each future direction (the third research question) from different supply chain actors' perspectives (such as; subcontractors tier 1s, and tier 2s) for prioritisation. The research developed a strategic framework among subcontractors for the minimisation of rework practice. This can help the housing industry to improve productivity and reduce cost of production, and a higher quality housing. The research contributed to the improvement of collaborative working culture among subcontractors, improving communication, transparency, and trust in the UK housing supply chain.

1.7 Structure of the Thesis

The thesis comprises 7 chapters. A summary of each of the chapters are detailed below and the structure of the thesis is illustrated in Figure 1.3.

Chapter 1 Introduction of the Research

Chapter one presents an overview of the research. The chapter describes the problem statement and gaps in the knowledge. The research questions, the aim and objectives of the thesis are identified and the contribution to the knowledge is explained.

Chapter 2 Literature Review

This chapter presents the critical literature review on rework in housing construction. The chapter defines rework and identifies the root causes of rework in construction. The chapter also investigates possible emerging technologies that can help to minimise rework in the housing supply chain.

Chapter 3 Research Methodology

This chapter details the research design and contains the methodological approach of the research. The chapter covers the research philosophy, strategies, and approaches that were identified for the research. A mixed sequential method is identified and explained in more detail. Details of data collection and analyses techniques adopted for the research are provided.

Chapter 4 Qualitative Data Analysis

The chapter details the in-depth methods adopted for the data analysis of the research. It explains the data collection process and coding of the data, and data analysis and the development of themes and sub-themes.

Chapter 5 Quantitative Data Analysis and Discussion of Results

Chapter 5 presents the outcome of the questionnaire. The chapter covers background of the survey's respondents and their experience within the housing sector. SPSS software was used for data analysis from the questionnaire. The chapter presents a discussion of the findings of the research and the developing themes of within the context of literature.

Chapter 6 Framework Development and Validation

This chapter provides the development of framework stages for rework minimisation in the housing supply chain. The chapter describes the structure of the framework and steps to develop the framework and its key components. This chapter also present the rework minimisation framework (RMF) validation process and results emanating from the validation focus group interview. The chapter further provides a summary of improvement measures for rework minimisation and guidance for practitioners to implement the rework minimisation framework.

Chapter 7 Conclusions and Recommendations

The final chapter provides a summary of the study and the steps taken throughout the studies to obtain the objectives of the research. This concluding chapter also highlights the contributions of the study, limitations, and further research.

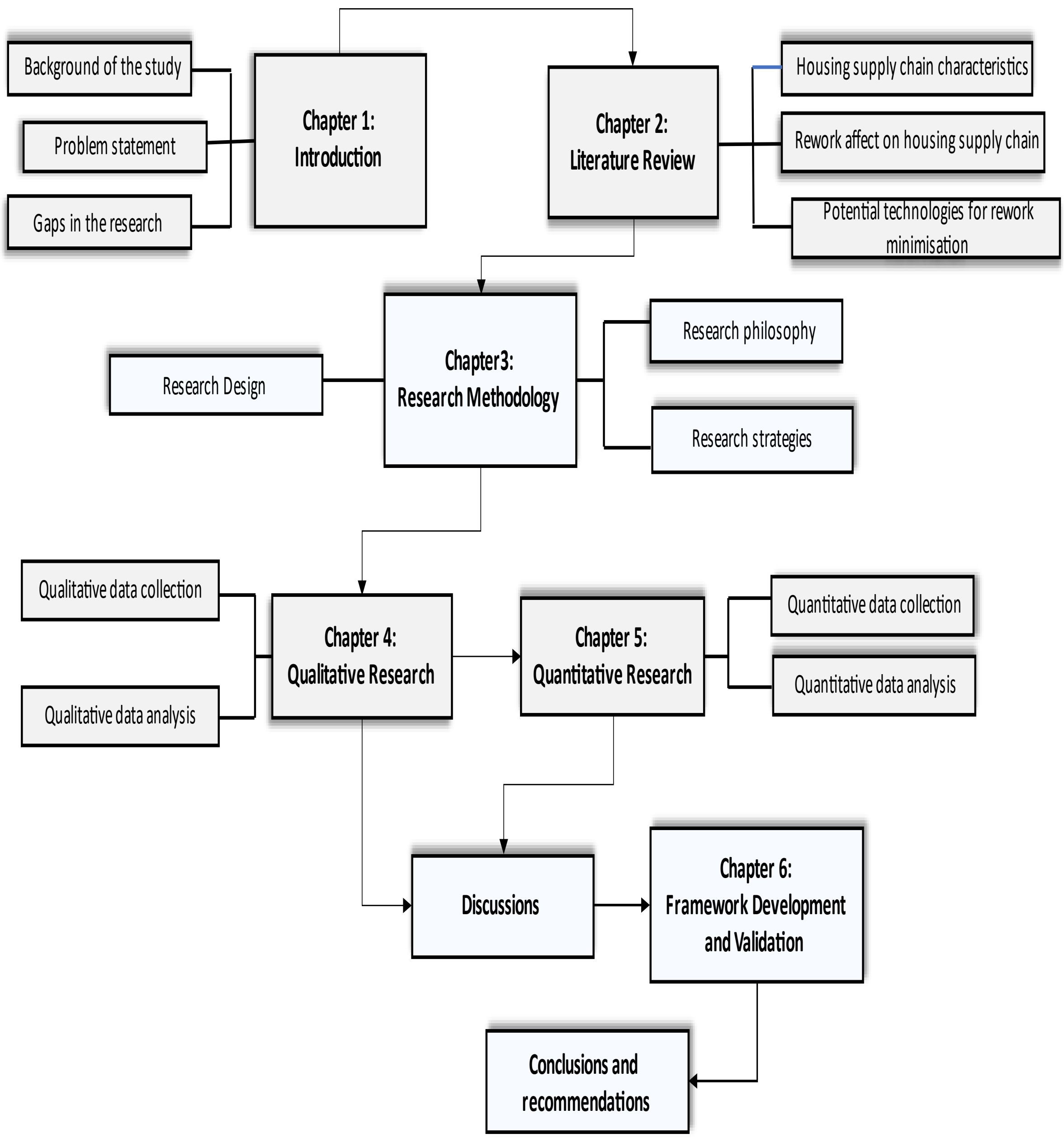


Figure 0.1 The structure of thesis

1.8 Chapter Summary

This chapter presented the introduction to the study, its rationale, the research background, aim and objectives, and the structure of the thesis. The chapter discussed the problem statement and research gaps and provided some information on how minimise rework in housing supply chain in the UK. The chapter discussed the steps taken to achieve the aim of the research through the objectives, research questions, and the justification of the research. The next chapter presents the review of literature.

LITERATURE REVIEW

2.1 Importance Challenges, and Characteristics of Housing Industry

2.1.1 Introduction

Housing has certain peculiarities that have contributed to the heterogeneous characteristics of housing construction projects. For example, one-of-a-kind production, the temporary organisation, high levels of fragmentation, large number of small and specialise trades, the length of production cycle and an uncertainty around housing market. Geographic constraints and the availability of existing infrastructure, and market factors relating to housing demand fluctuation have impacted the development of housing projects. In housing projects, the client usually plays the most crucial role in achieving integration of the supply chain (SC) to deliver a successful project (Briscoe et al., 2004).

Harvey (2017) stated that the term "flexibilization" illustrates the downsizing of firms and the outsourcing of activities. The increasing number of subcontractors is facilitated through client diversification, technological complexity, and intense competitive environment among different subcontractors. Consequently, construction operations began to be organised through an "extended chain of vertical subcontractors", changing the focus of the responsibility of main contractors to management and coordination of different subcontractors (Green, 2011).

The fragmented nature of the housing sector is characterised by a short-term relationship among different subcontractors working from project to project. The temporary relationship per project may hinder fostering a long-term relationship with different contributors. However, some attempts to forge a collaborative and cooperative working culture among the SC contributors has been made to minimise rework and improve the quality of housing. However, is still difficult to succeed in fostering a collaborative culture in housing construction (Koskela et al., 2006). One of the reasons is a culture of resistance to change among different parties in housing sector. It is essential to emphasise the importance of cultivating a culture of collaborative and cooperative working among different contributors in the housing SC. Collaboration itself can lead to more innovative ideas for reduction of rework in the housing SC.

Manseau and Shields (2005) stated that, "productivity level in housing construction is still relatively low in comparison to other industries". Another study, by Koskela and Vrijhoef and

Koskela (2000), discussed the performance of construction and cited Winch (2003) and Gann (1996) to support their statement that “the performance of the construction industry in terms of productivity, quality and product functionality has been poor compared to other industries for the past decades’.

The UK housing market has been experiencing inadequate housing supply, exacerbated by a strong growth in demand over the past few decades. A report conducted by Rosenberg et al. (2012) at the institute for Public Policy Research (IPPR), projected a housing shortage of approximately 750,000 homes by 2020. A problem which will have a particularly adverse effect among the younger generation and other low-income groups who are experiencing difficulties getting onto the housing ladder.

Several factors have contributed to the shortage of housing, including lack of investment from both public and private sectors, market prices, financial volatility and economic fluctuations, land and regulatory regime, and government strategic schemes especially ‘Help to Buy’ and ‘New Homes Bonus’. However, the underlying problem for the acute shortage of housing has been identified in the supply of housing (Baker, 2012; Bramley and Leishman, 2005; Cladera and Johnsson, 2013; Hilber, 2015; Anacker, 2019). Housing SC plays a critical role in delivering successful housing projects, however, is criticised for low productivity, high cost of production, and poor quality. Such factors have resulted in a high rework occurrence.

Housing and land have always foundational to both power and wealth distribution (Clapham, 2018). Houses are complex tangible assets that can have a very unique structure. Houses have different aspects compared to other forms of construction, such as railways, highways, and so forth. These aspects can be political, contractual and/or social (Clapham, 2005). Each house has a particular fixed location, and this can be a home having many different elements of identity and meaning, which are attached to the more functional aspects of a house (Clapham, 2005); Clapham, 2018). A house is a necessity and foundation for life, and there is extensive evidence regarding the importance of the home environment in influencing the educational achievement and health of family members (Cladera and Johnsson, 2013; (Clapham, 2005).

2.1.2 Planning and Regulation

Governments have different types of mechanisms for intervening in housing supply. Planning restriction has been a major obstacle for developers. Bramley (1994) identified that planning has caused housing prices to increase and creates barriers to the housing ladder. Several authors, such as Evans (1991), Cheshire and Sheppard (2004) and Glasser et al. (2008), have argued that the overall restriction of land supply regulation will lead to higher prices and densities because of growth controls and general planning restriction. Whitehead and Williams (2012) discussed that several proposed planning applications have been deserted because of the removal of output targets for local authorities. The Barker Review pinpointed planning as the primary cause of housing supply (Baker, 2012). Since 2003, the housing policy has changed the trajectory of its emphasis to housing supply and affordability issues, as encapsulated in the Barker review (Baker, 2012). Despite government approval, it has not addressed the supply and affordability of housing. Setting regulations is one of the ways that governments can control housing supply, by setting the limits of action by private companies and individuals and can institutionalise social practice in the housing market. An example of such practice includes the regulations set for the private rented sector, which can control housing rent, constrain the activities of letting agents and provide tenure security to tenants (Campbell et al., 2000; Clapham, 2015; 2018). The inherent pressure of housing supply, including the array of government objectives, with an increase in local political tensions, have made regulatory systems complex and uncertain. However, regulatory systems can be used to support the provision of affordable housing by shifting away from public sector ownership and allocation towards more market-based systems (Whitehead and Williams, 2012).

The impact of housing policies may differ between individuals and groups. For instance, a policy may provide financial support to a house builder and increase their profits, but it may not result in more houses being built, and so may not be helpful for those trying to purchase a house. Some policies may lead to an increase in the price of existing houses, which helps established homeowners, but may hinder those looking to buy (Clapham, 2018). Housing supply has been a ‘prominent part of the devolution story’ and a site of much policy innovation in the UK context (Gibb, 1999) In 2003, Chancellor Gordon Brown tried to understand UK housing supply by establishing two enquires; one into housing finance and the other one into housing supply, with emphasis on the role of planning system.

2.1.3 Influence of Procurement Methods on Rework Occurrence in Housing Supply Chain

To satisfy the requirement of time (completion of time or earlier), several non-traditional procurement methods have emerged in the construction industry – where design and construction schedules are compressed and the construction stage begins before the final design is complete (Hanna, 1999). This results in a degree of overlapping (concurrency) activities undertaken at construction sites, which in turn increases the complexity of projects. However, Hoedemaker (2017) discussed that there is a limit to the number of activities that can be concurrently conducted. Due to the complexity of concurrent project communication and co-ordination (Love and Li, 2000a) the probability of rework occurrence and increase in time and cost significantly increases.

Love et al. (1999) stated that a procurement method is an organisational system that assigns specific duties and authorities to people and organisations and defines relationships of different factors in a construction project. The procurement method implicitly allocates risk between parties (Love et., 2018). As a result, CIDA (1995) stated that the cost of rework varies with a chosen procurement method to deliver a construction project. Due to the uncoupling of design and construction processes, the risk of rework generation is exacerbated with poor communication, defined as a result of utilising traditional lump sum (TLS) procurement methods (Banwell et al., 1964). Love (2002) examined 161 construction projects and concluded that there is no significant difference between procurement methods and project types associated with rework costs. He identified the total mean project rework cost to be 12% of the original contract value (OCV) and is comprised of direct and indirect costs at 6.4% and 5.6%, respectively (Love, 2002). However, refurbishments and renovation projects have been considered to have tendency of higher rework costs than new build projects because of the uncertainty and complexity of the tasks.

Typically, the issues associated with concurrent activities are exacerbated by time pressure, particularly in the event of rework occurrence, which can accumulate when a project approaches the completion date. Given the context, non-traditional methods can be subject to the higher level of rework compared to traditional methods, particularly in the event of errors, omissions or change occurrence. In traditional methods, design and documentation are completed or largely completed, before the construction stage takes place – in theory minimising the level of rework attributed to design-related sources (Love, 2002).

Hughes et al. (2006) noted that procurement has become an increasingly complex in the construction sector. Hughes et al. (2006) and Gray and Flanagan (2009) both suggested a connection between the selected procurement and complexity of decision making, noting the possibility of costs associated with tendering, in which there is a tendency to increase multiple layers of subcontracting. The construction industry is becoming more aware of changes in current methods of delivering a project through rigorous partnering with the SC. There are some issues facing the construction industry. Particular threats to the productivity improvement of the housing SC processes are as follows:

- Design and construction separation
- Lack of integration among contributors
- Lack of communication
- Uncertainty of construction environment
- Unexpected change in clients' requirements and priorities
- The complexity of projects

The management and engagement of key stakeholders are recognised as crucial to foster a successful construction procurement (Walker and Rowlinson, 2000; Mathur, 2008).

A KPMG survey of construction project management in 2015 found that 90% of public sector building projects failed to come in on time and within budget (KPMG 2015). Choosing the most appropriate project delivery method and corresponding procurement strategy can set the stage for project success or failure.

The Latham report 'Constructing The Team' in 1994; identified inefficiencies and lack of trust among contractors and clients as prominent factors for improvement within construction industry. Egan report 'Rethinking Construction' in 1998', stated partnering is the crucial factor to ensure client's needs are at the heart of construction process. In the Egan (1998), he indicated that there is a "deep concern that the industry is under-achieving" and that "too many of the industry's clients are dissatisfied with its overall performance". With an aim of "eliminating rework and increasing value" the report makes specific reference to the need to "replace competitive tendering with long-term relationships based on clear measurement of performance and sustained improvement in quality and efficiency" (Egan, 1998).

The UK Government published the report 'Construction Deal' to address the sluggishness nature and poor productivity of the construction industry (HM Government 2018). The strategy aims to explore more options to drive procurement efficiency, reduction of construction costs, speed up the delivery of buildings, minimisation of rework and greenhouse gas emissions of building, the lack of collaboration and limited knowledge sharing across different contributors in the SC, and low vertical integration of the SC with high reliance on subcontracting. The aim of the strategy was to achieve a 33% cost reduction in construction, 50% shorter delivery time for new housing projects, 50% reduction in building green gas emission, and a 50% reduction in the trade gap among total exports and imports of construction products and materials.

(Walker 2009; Love 2002; Love and Edwards 2004) identified that there was no disparity among different procurement methods and the cost increases and schedule overruns experienced in building and civil infrastructure projects. Love (2002) found that GFA and the number of stories in building construction projects were not causes of rework costs.

2.2 Supply Chain Management

The evolutionary and concept of supply chain management (SCM) initially emerged in 1980s and subsequently flourished in the manufacturing industry with the aim of improving the productivity of workflow and add value to overall projects performance (Harland 1996; Oliver and Webber 1982). SCM initiative developed through the field of quality control and total quality management (TQM), and innovative approaches such as Just-In-Time (JIT), then integrated and become as part of Toyota Production System (Womack et al., 1990; Womack et al., 1990).

The term Supply Chain has defined by Christopher (2011, p. 13) as: "*the network of organisations that are involved through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer*".

Council of supply chain management professionals (CSCMP) defines SCM as: "supply chain management encompasses the planning, and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates both the management of supply and demand within, and across different entities. Supply chain management is a function of integration with responsibility to link major business functions and business processes in different companies into a cohesive and adhere to high performing business model. It includes all the logistics management activities stated about as well as manufacturing operations and it drives coordination of process and activities across marketing sales product design finance and information technology."

While SCM includes information sharing, cooperation, risk sharing, customer service focuses on developing trust, commitment, vision, interdependence, identifying the leader of the supply chain, and the support of management team, it is important to become supply chain oriented before the adaptation of SCM (Tracey & Smith-Doerflein, 2001). The adaptation of the SCM philosophy include improved customer value and satisfaction, lowering cost, and cooperative advantages (Christopher, 2011; Tracey & Smith-Doerflein, 2001).

Christopher (2011) stated that the term supply chain (SC) has been extensively used in the housing construction industry. In recent years, there have been several attempts to better understand how to manage and improve construction supply chain (Wegelius-Lehtonen 1995; O'Brien 1998; Wegelius-Lehtonen 1995; Pahkala 1998; Naim et al. 1999; Vrijhoef and Koskela, 2000; Arbulu et al. 2003).

2.2.1 Construction Supply Chain

There has been plethora of research and attention since 1990s in supply chain management theories to understand and characterise the deficiencies and potentially provide a solution to improve the construction supply chain. In both Egan (1998) and Latham (1994) report, and construction 2025 report, investigated the current practice of underperforming and fragmented housing supply chain, Dubois and Gadde (2002) indicated a more integrated type of supply chain creating a collaborative agreements system between different contributors such as client, contractors, engineers, architects, and subcontractors. Cox and Townsend (2004) examined the relationship among supply chain management and market structure, i.e., the constrains and structural forces of the market, Agapiou (1998) proposed the "building merchants" providing supply chain for the building industry as an important player in the supply chain.

Another perspective for the root cause of poor productivity improvement has been recommended by Vrijhoef and Koskela (2000), in which noted that the management of interface between site activities and the supply chain, and they characterised the supply chain as:

- Converging at the construction site where the object is assembled from incoming materials
- Temporary producing one-off construction projects through repeated reconfiguration of project organisations separated from the design; and
- Typical make-to-order supply chain, with every project creating a new product or prototype

The construction industry has a large supply chain – accounting for around £124 billion of intermediate consumption in 2014 and almost all of which are sourced within the UK market (ONS, 2009). In another words, construction spending tends to stay domestically within the UK supply chain market.

Construction supply chain has a unique characteristic, fragmented, one of a kind products, temporary workplace, and site production, involvement of multiple stakeholders with varied criteria requirements, contractors, and subcontractors' relationships, and change inertia which preventing the improvement of workflow processes in the supply chain (Virjhoef and Koskela 2000; Segerstedt and Olofsson 2010; Behera et al., 2015). Over 90% of construction firms are categorised subcontractors and SMEs, and of those, some 83% employ no more than one person. The construction industry tends to rely on a high degree of subcontractors and has a high proportion number of self-employment, with over 40% of construction contracting jobs being self-employed. This makes the industry as a whole, highly flexible and responsive to changes in market conditions, however, the high degree of fragmentation have other consequences. Construction supply chain has a complex nature as several number of subcontractors are involved in the development of projects (Cox and Ireland 2004; O'Brien 1998). Figure 2.1 shows the complexity of a housing construction supply chain.

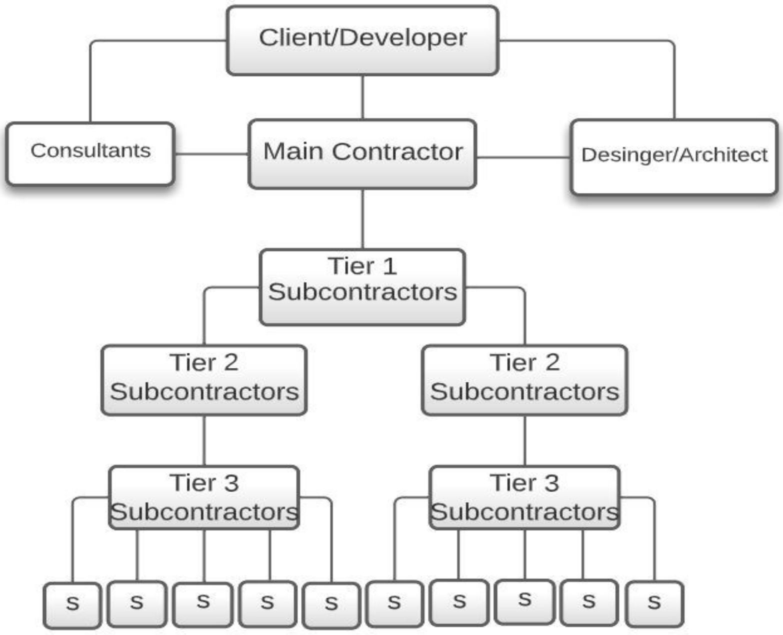


Figure 0.1 Construction supply chains, adapted for the research

Several scholars have recognised the importance of client's role in housing supply chain. Briscoe et al. (2004), identified client as the most vital actor in attaining integration in the supply chain. London (2008) adopted Lambert et al. (1998) model of the supply chain structure from an industrial organisation perspective and put the client organisation in the focal point. Virjhoef and De Ridder (2005) developed this concept further and discussed two strategies for integration, supplier driven integration and client driven integration.

However, yet, construction supply chain has not made the breakthrough to attempt replicate the potential benefits of supply chain management that gained from other industries particularly manufacturing industry (Akintoye et al., 2000; Love et al., 2004; Lonngren et al., 2020).

It is well understood that construction supply chain is not a real chain. However, merely a network of multiple organisations and relationships including clients, main contractors, architects, consultants, designers, subcontractors, and engineers in which adds the value, the flow of information, the flow of materials, services or products and the flow of funds among clients, contractors, designers, and subcontractors. Housing construction also is a multi-stage process, which includes conceptual design, activities, construction, maintenance, replacement, and demolition (Xue et al., 2007).

This requires a continuous workflow of material, machinery, and labour in each stage of construction projects. The complexity of information flow from one contributor to another such as consultant, designers, and architects, and above mentioned affects the supply chain coordination and workflow processes. Several scholars believe that paying more attention to the coordination of supply chain will have a significant effect both on time and cost overrun, productivity, and quality of end products (Agapiou et al., 1998; Akintoye et al., 2000). Virjhoef and Koskela (2000) stated the importance of communication and how lack of communication among contractors, subcontractors, suppliers, and architects can lead to time and cost overrun projects. This can result in rework occurrence, poor quality of products (Hwang et al., 2009; Virjhoef and Koskela, 2000) and impacts the level of productivity in construction industry (Josephson and Saukkoriipi, 2005).

2.2.2 Housing Supply Chain

The SC is the interconnected hierarchy of supply contracts necessary to procure a built asset. Managing the SC involves a comprehensive understanding of the breakdown and traceability of products and services, organisations, logistics, people, activities, information, and resources that transform raw materials into a finished product that is fit for purpose. The housing SC characteristics include temporary organisations, geographical location constraints, and one of kind products. In the SC of housing projects, clients play a leadership role in achieving the integration of SC (Brisco et al., 2004)

Generally, the UK construction industry, and particularly the housing SC, has a large number of privately owned companies within the SC – the UK housing SC is embedded with a high level of fragmentation, where 90% of firms are SMEs and of those, 83% employed up to 5 people and 40% of construction contracting jobs being self-employed. High level of fragmentation in housing SC is likely to be driven by a relatively large number of micro businesses in the UK housing SC (BIS, 2013).

Typically, SMEs house builders are involved in building units with three or more bedrooms, rather than a large block of units or small houses (NHBC, 2012). SMEs are more concerned about developing a reputation in local sites – particularly those that would not be viable for high-volume operations. Small-scale builders promote bespoke new home environments and carry the philosophy throughout the projects, highlighting their strategy of developing houses with individual features – a buyer who prefers a one-of-a-kind product and is willing to pay a premium for it, is less inclined to purchase property on a very large development (NHBC, 2012).

The success of a project in the construction housing industry is heavily dependent on SC capability both offsite and onsite. This capability is necessary for the efficiency and reduction of rework in the housing SC. This can promote the involvement of subcontractors from an early phase of the projects and foster a collaborative working culture to develop successful projects.

More than 85% of the building stock that will exist in the year 2050 is already built. Half of all dwellings in the UK are more than 50 years old, and a fifth are more than 100 years old (CIOB, 20103). Typically, buildings experience several refurbishments throughout their life, with a major refurbishment every 20 to 30 years (CIOB, 20103). These refurbishments and retrofits represent an opportunity to reduce carbon emissions through refreshing a building's fabric and services equipment.

SC theory indicates that value must be added to the process faster than cost. A process can be defined as a structured, measured set of activities designed to produce a specified output for a particular costumer or market. All organisations and sectors of industry use "processes" to deliver their businesses – more and more organisations are attempting to develop and improve their processes to perform more efficiently (Chen et al., 2015).

The collaboration within the housing SC is becoming increasingly critical to address fragmentation and foster a collaborative working culture and healthy competitiveness among subcontractors. SCM can be defined as an evolutionary and cumulative innovation (Saad et al., 2002) and it is the latest term compared to "partnering", which can be considered as a "strategic arrangement through contractors which are involved in a series of projects with the aim of lowering costs and improving efficiency" (Dainty et al., 2001; Harris and McCaffer 2001).

In Egan's report, some features aimed at improving collaboration of housing sector SCM were highlighted (Egan, 1998). These included development of suppliers and management of workload to improve suppliers' and company's performance, acquisition of suppliers through value-based sourcing and innovation (Egan, 1998). These characteristics highlight the importance of managing relationships with suppliers to improve a collaborative working culture for the success of projects.

Theoretically, SC implies a linear process, however, the housing SC there is limited linearity due to the large number of different contributors (e.g., client, designers, architects, contractors, consultants, and subcontractors). For the purpose of the study the chain starts from client and ends in subcontractors, more specifically focuses on subcontractors in the production phase. The fragmentated nature of housing SC has made the establishment of collaborative working environment challenging among different contributors.

The advantage of collaborative and cooperative working has been emphasised in literature (Cao and Zhang, 2005), however, there are some barriers to their implementation, such as different business objectives, lack of communication and temporary organisation. Cultivating a culture of collaborative working among contributors is important for reducing rework and improving the performance of the housing SC. In the housing SC, barriers to foster the full potential of collaborative working remain in place – SCM usually represents the most resource-intensive requirement for buyers and suppliers, and that causes difficulty to build a sustainable relationship with different players (Cox, 2004). The success of a collaborative and cooperative working culture plays an important role in delivering a sustainable project, other industries, particularly the automobile manufacturing industry, have invested heavily in SC improvement to minimise waste and rework (Soosay et al., 2008)

2.2.3 The Unique Characteristics Nature of Housing Supply Chain

Subcontracting plays a key role in delivering a successful housing development project. For almost every project, between 70 % to 90% of the construction project work value is given to subcontractors (BIS, 2013). Therefore, selecting the most appropriate subcontractors, and managing the SC relationship, are essential for delivering a successful housing construction project. Of 280,000 construction firms registered in the UK, only 2.1% employed more than 25 people and, as a consequence, most of these firms do not have sufficient resources to adopt modern principles of quality improvement, management and innovation (BIS, 2013). Despite the fact that up to 90% of construction project work value is subcontracted to small and specialised firms, there has been less attention paid among housing SC's collaboration (Dainty et al., 2001; Karim et al., 2006). The government construction strategy (GCS) stated that the industry is "highly fragmented with over 300,000 businesses (97.7% of which are SMEs) and that affected the performance of construction industry in terms of capacity to deliver value and that there has been a lack of investment in construction efficiency and growth opportunities" (Cabinet office 2011, p.5).

Subcontracting is at the lowest root of vertical integration in the industry and creates a bottleneck in the flow of information and innovation. It is argued that a more rigorous and integrated SC is in utmost need down the chain to subcontractors and suppliers, as housing construction development flows from one stage to another, from one subcontractor to second one (Briscoe and Dainty, 2005). However, a collaborative working culture is limited to client and main-contractor linkages, which ultimately restricts the ability of subcontractors to improve overall SC performance Dainty (2001).

Miller et al. (1999) indicated that a collaborative working environment will produce promised gains and therefore reduce costs if the subcontractors are fully integrated into the process. Moore and Dainty (2001) stated that there are cultural difficulties and resistance to change in professional practices in the housing sector that impede achieving the fully integration of subcontractors in housing construction. It is argued that adversarial relationships and mistrust emerge from competitive bidding (Kadefors, 2004; Wong et al., 2005) and that could be eliminated from price competition to a more collaborative procurement route between main contractors and subcontractors (Matthews et al., 2000; Thorpe et al., 2003).

In almost all industries, SC plays a significant role in successful product delivery (Taggart et al., 2014), and there is a meaningful integration among various chains. However, in the housing sector clients are the customer and normally have no influence over a SC, which is one of the unique characteristics of housing sector that distinguishes it from other SC industries. For instance, in infrastructure development projects, clients are service providers to the public and often have great influence over a project and are able to exercise considerable change upon the SC. Another prime example is commercial building, where clients are developers or operators of building and therefore have an active role in the co-ordination of SC.

Rework is a prominent factor among the housing SC (Love et al., 2010). The logistics of the housing SC tends to affect just-in-time delivery of material and products. This has an impact on the cost of a completed project and rework generation. The housing SC tends to rely on many subcontractors to reduce rework. The large proportion of the work process is usually undertaken by subcontractors and, as a consequence of fragmentation and lack of collaboration, generates a high level of rework within the cluster of housing SC.

2.2.4 The Fragmented Characteristic of Housing Subcontractors

Fragmentation has been broadly debated as a contributing factor to low productivity, poor value for money and average client satisfaction in the construction industry (Latham, 1994; Low and Zheng, 2018). The high propensity for the main contractor to involve subcontractors (Ofori and Lim, 2009) has further escalated the level of fragmentation in the industry. The intense competition in the construction industry further exacerbates the level of fragmentation, as actors become sceptical about sharing information. Distrust, lack of transparency and self-interest have significantly affected the level of rework occurrence in housing development projects (Morledge et al., 2009; Pheng and Zheng, 2018).

2.2.5 The Importance Role of Subcontractors in Housing Development Projects

In the UK's housing supply chain, SMEs have been chosen as short term subcontractors by the Tier 1 companies, often based on minimum price with fixed-priced contracts. Moreover, most of the time contact with the main clients for process improvement efforts and rework minimisation is shaped and directed by Tier 1 clients, and subcontractors have rarely been in direct contact with the main clients. Due to the nature of work, the subcontractors implement their on-site operations in short working windows to prevent delays in the project and disruptions in the supply chain. Given this context, one of the main strategic aims of clients is to efficiently implement rework minimisation strategies across the whole housing supply chain, primarily including all subcontractors. Therefore, it is essential to establish an efficient and practical framework for the housing supply chain by embarking on the role of subcontractors and their engagement in the rework minimisation practice. This can be achieved through a comprehensive study to understand the current and future directions of rework minimisation in SMEs as subcontractors in UK's housing supply chain.

The housing sector is characterised by a plethora of subcontractors – where some of contractors need to manage up to 70 subcontractors on a single housing construction project (Barawas et al., 2013). There is a long history of subcontracting in the UK housing construction industry, which has become more dominate and more widespread. Subcontractors perform about 90% of work value on construction projects (Akintan and Morledge, 2013), with SMEs and/or subcontractors driving UK economy. This is particularly true given the COVID-19 pandemic crisis, shortage of skilled labour, and political and economic climate, where the departure of the UK from the European Union may put the emphasis more on SMEs role as the driver of the construction industry (Prowle et al., 2017).

The latest report by 'Government Construction Strategy: 2016-2020' indicates that the industry was dominated by a significant number of SMEs with less than 50 employees. The number of SMEs with less than 50 employees increased to over 1,667,265, up from 972,000 since 2016, comprising almost 99% of businesses in the UK construction industry. The number of SMEs within the housing sector accounts for almost 53,645 businesses. The report indicates that the turnover for these businesses is around £185Bn a year – up from £172Bn in 2016. The total turnover for construction industry reached £296.8Bn in 2017, up from £271.9Bn in 2016.

On a housing construction project, responsibility and performance may cascade down the SC to the subcontractors, which are unknown to management at the top of the chain. Almost in every country, the construction industry relies heavily on the subcontractors' project model. For instance, in Australia, construction has the highest number of self-employed contractors and subcontractors of any industry, at 26% (ABS, 2018), and subcontractors are responsible for between 80% to 85% of all construction work value (Williams, 2005). In the UK construction industry, the number of SMEs and subcontractors are higher than in any other sector at 40% (Alwan, Jones & Holgate, 2017).

Generally, the Subcontractors task is to break-down activities, as well as alleviating project risks, to carry out intricate and complex activities. However, this is the simplistic view of understanding the important role of subcontractors in delivering successful projects. In the construction industry, the multi-layered subcontractor model is typically adopted to deliver a project (Ofori and Lim, 2009), where one subcontractor subcontracts different activities to a specialised subcontractor. This adds layers and fragmentation to housing construction projects and creates a hierarchy-based system of subcontracting relationship.

2.2.6 UK Housing Skills Shortage

The number of employees the UK construction industry decreased by 6% in 2019 to 1.28 million from 1.35 million in 2018 (ONS, 2009). This was the first decline in the construction industry since 2014, when the number of employees decreased by 0.1%, indicating that the shortage of skilled labour has negatively impacted the UK housing construction industry (ONS, 2009). However, for the past decade, the housing sector has played an important role to the growth of the housing projects, accounting around 34.1% of all new work in 2009 (ONS, 2009). Despite the decreasing share of employment in construction, the Southeast and London have 15.1% and 13.1% of the UK construction employment, respectively (ONS, 2009).

The shortage of skilled-labour in the construction industry is described as the number one challenge for house builders – skilled bricklayers, plumbers, and charted surveyors, plasters, carpenters, roofers, electricians are lacking. This means that the cost of labour has risen more than 6% in the past few years (ONS, 2009). The housing minister, Brandon Lewis, also regarded the shortage of skilled labour as the biggest challenge in housebuilding sector. The construction industry an intensive labour-dominated market. Leveraging emerging technologies and automation will enable us to develop innovative tools to enhance productivity of the craft workforce and transform the industry from current method of conventional towards more consistent, repeatable process with higher precision and quality.

A report by Business, Innovation and Skills (BIS, 2013) stated that 53% of construction employers have emphasised the shortage of skilled labour in construction industry (BIS, 2013). It has been argued that the UK construction labours are not rewarded (by the construction Skills Certification Schemes - CSCS) for their competencies or occupational qualifications.

2.2.7 Lack of Collaboration in the Housing Supply Chain

Karim et al. (2006) indicated that subcontractors usually perceived the main contractor as their “customer” and showed little concern for other subcontractors that work at the same time on the construction site. The lack of collaboration among subcontractors results in rework occurrence and unfinished tasks that lead to multiplying cost and schedule overrun. Such problems are often generated in one part of the process; however, these issues are not identified until at near to the end of projects, which tends to multiply the impact of the problem (Koskela et al., 2006).

An attitude of collaboration and effective communication among SC participants could provide a remedy for rework generation in the housing development process before moving on to the next stage of construction (Liker, 2004). Improvement can be attained, though would require effective ways to capture data, from which an improvement criterion can be developed (Lee and Amaral, 2002). Collaborative working can improve the workflow process among subcontractors’ contributions to prevent possible rework occurrence in the housing supply chain.

Manseau and Shields (2005) stated that, “productivity levels are still relatively low in comparison to other sectors”. Yet, effortless interaction among different players in different stages of the completion process with a broad spectrum of information in the construction industry is fragmented, poorly coordinated, not structured, difficult to find and complex. This usually leads to a rapid increase of unnecessary communication paths and copies of information, as each new party becomes engaged. This contributes to the risk of omission and rework occurrence (Eastman et al., 2011; 2013). Collaboration within the entire housing SC can prevent possible rework occurrence and drives an agenda of stopping and fixing issues as early in the process as possible (Liker, 2004).

2.3 Adversary Impact of Rework in Housing Construction Projects

2.3.1 Definition of Rework

There have been various attempts to define rework, such as; reference to quality deviation, quality failures, non-conformance and defects (Burati, Farrington, and Ledbetter 1992; Barber et al., 2000; Josephson et al., 2002). Similarly, words such as “rework”, “quality deviation”, “non-conformance”, quality failure, “error”, “snag”, “defect”, failure” are used interchangeably to describe imperfections in housing construction (Mills et al., 2010; Sommerville, 2007; Josephson et al., 2002; Love 2002; Gieorgiou et al., 1999). Love (2000) identified, various interpretations of rework, including quality deviations, non-conformance, defects, and quality failures. Love (2000) identified two main definitions of rework: “the process by which an item is made to conform to the original requirement by completion or correction” (Ashford, 1992) and “doing something at least one extra time due to non-conformance to requirements” (Construction Industry Development Agency, 1995). Love (2000) defined rework from a project standpoint as “unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time”. Robinson-Fayek (2004) defined rework from a construction perspective as “the total direct cost of re-doing work in the field regardless of the initiating cause”, which specifically excluded change orders and errors caused by off-site manufacturing. In this scenario, rework costs become a direct responsibility of the contractor and subcontractors (Love et al., 2009).

Rogge et al. (2001) defined rework as “activity in the field that has to be done more than once or activities that remove work previously installed as part of the project”. Fayek, et al. (2003) identified the cost of rework as the “total direct cost of redoing work in the field regardless of initiating cause”. Hwang et al. (2009) defined rework as “the process by which an item is made to conform to the original requirements by completing or correction.”

In housing construction, it has been common to use the term rework interchangeably with ‘defect’, however, these definitions can vary. Khan and Atkinson (1987) clearly distinguished a difference of failure and defects: “A failure is a departure from good practice, which may or may not be corrected before the completion of building. A defect, on the other hand, is a shortfall in performance which manifests itself once the building is operational”. However, Wardhana and Hadripriono (2003) defined failure “as incapacity of a constructed facility or its components to perform as specific in the design and construction requirements”. In housing construction, defect is the most common term used, although, there is no practical difference between rework and defect in housing construction domain (Davis et al., 1989).These words can be interpreted differently to different people, and lack of precise definition of the terms can lead to inaccurate and incomplete measurements, cost determinations, and possibly inappropriate strategies for reduction of rework (Mills et al., 2010). The term rework describes work that needs to be done for the second time. This results from a variety of errors in the construction stage and from unexpected changes to the work brief (Love and Edwards, 2004). Typically, errors are contractors’ and subcontractors’ responsibility.

Rework can be considered as international word, as it covers different concepts such as defects, non-conformities, cost associated with redoing an activity that incorporated incorrectly with additional or missing part and errors. The definition of rework by Love (2002) is adopted for the purpose of this research and is considered a synonym of defect and any activity that requires redoing.

2.3.2 Causes and Sources of Rework

Rework has been recognised as a symptom adversely affecting the workflow of the process and productivity of the UK housing industry, and in many other countries such as Australia (Love et al., 2004), China (Ye et al., 2015), Singapore (Hwang, Hao and Goh, 2014), Spain (Qui, Lee & Ingabire, 2021) and Canada (Robinson-Fayek, 2004; Taggart et al., 2014; Forcada et al., 2014). The housing construction industry is one of the major industries worldwide that is commonly recognised as having high levels of ‘rework’ (Aziz and Hafez, 2013). However, reduction of rework has not been a dominant strategy regarding improving productivity in the industry (Bolviken and Koskela, 2016). The elimination of rework is a key driver of improvement in many manufacturing industries, such as the automobile production industry. However, despite its great achievement in other sectors, it has not been as prevalent in the construction sector (Koskela et al., 2012).

The complexity of construction projects increases the level of rework occurrence at the construction site (Love et al., 2015a; Love and Edwards, 2012). Structured minimisation of rework and management practices are required to minimise project cost and prevent schedule delays (Love et al., 2015a; 2016a).

Traditionally, housing construction companies tend to rely on the practice of detecting rework during construction stage and inspections. This method only fixes the problem, while the root causes of rework remain hidden (Shammas-Toma et al., 1996). Elimination of the root causes of rework within the housing SC addresses long-term rework issues. Seymour et al. (1997) stated that subcontractors engaging in “fire-fighting”, which they perceive is an occasional rework, actually face chronic rework issues. Several different contributions reflect on the root causes of rework, and which usually lie deeper than a superficial blaming of construction operative and mangers (Khan and Atkinson, 1987).

Josephson et al. (2002) identified defects caused from design-related issues (20%), workmanship (20%), site production process (20%); material failure (17%); client issues (6%); and machinery failure (3%). A study by (Sommerville, 2007) and the work Building Research Establishment (BRE), identified defect causes in three broad categories; design issues (50%); issues during operation of construction (40%); and product failure (10%). Design errors are diverse in nature and in the adversity of their affect (Lopez et al., 2010; Taggart et al., 2014).

Two prominent causes of rework are suggested as (1) those that originate from problems in the production process, e.g., lack of information flow among SC participants, and (2) causes that emerge from outside the production process, which are beyond contract control, e.g., unilateral client change (Shewhart 1996; Love et al., 1999; Taggart et al., 2015; Love et al., 2018). From their study, they identified, 85% of all construction rework emanates from the former and only 15% from the latter (Love et al., 1997; Love et al., 1999; Taggart et al., 2015).

Josephson and Hammarlund (1999) studied seven major projects with rework causation incorporated and identified that motivation to deliver good work is inadequate for minimising rework. Operatives must also have necessary knowledge and information to implement the task with a high degree of precision. The authors also noted that several factors contributed to higher defect levels, including: (1) delay in decision-making by clients; (2) late involvement of end users; and (3) contractual pressures in terms of cost and time. On the other hand, they stated that a few simple characteristics tend to reduce rework affect; (1) stability in the client and design team composition; (2) previous experience of working with project participants; (3) supportive project management; leading to (4) higher motivation. Love et al. (2009) argued two root-cause factors of rework and defects; (1) problems in the production process, termed typical causes, such as poor information flow among SC participants, and (2) causes beyond the contractor's control, e.g., unexpected client changes. It is suggested that 85% of all construction rework emerges from poor information flow among SC participants, and only 15% from unilateral client changes (Love et al., 1997).

Love et al. (2009) established a list of 29 possible rework causes, which are loosely categorised as follows: 1. Scope changes; 2. Erroneous design/documentation; 3. Lack of quality management systems; and 4. Poor workmanship. Of these categories, several factors are prominent, including 1) misinterpretation of drawings and specifications; 2) use of superseded drawings and specifications in the SC; 3) poor or imprecise communication; 4) lack of SC coordination; 5) poor training and skill levels; and inadequate supervision (Chong and Low, 2014).

Managerial aspects may also be key in generating rework in housing SC (Love et al., 1999; 2002; 2010; Josephson et al., 2002; Love and Edwards, 2004). Client requirements for unexpected changes, design error and omission have a relatively greater cost impact compared to other factors (Hwang et al., 2009; 2014; Love and Edwards, 2003). Burati et al. (1992), Abdul-Rahman (1996), Love et al. (1999), and Kakitahi et al. (2009) suggested that when quality frameworks are in place, other managerial factors are considered to improve project governance and can eliminate rework in building projects.

A plethora of design deviations often arise due to errors and omissions contained in contract documentation (Crawshaw, 1976). Quality deviations can lead to product features, including the workflow of processes, hence, causing rework generation (Dale, 2003; Love et al., 2004).

Poor-quality documentation with designers and consultants is a severe problem on the construction site in generating rework (Crawshaw, 1976). Project characteristics have also been recognised as predictors of performance in construction works (Walker, 1994). These characteristics include construction costs, project duration, gross floor area (GFA), number of stories, building type, and procurement method (Love and Edwards 2004).

Recommendations for reduction of rework in the literature have been proposed as an on-going priority for UK housing industry, in particular, training and trades, standardisation processed and products, predefined quality criteria and learning from previous rework (Hopkin et al., 2015). However, none of these factors have ability to eliminate rework from the entire housing SC – and a holistic approach could apply among subcontractor's interaction for an effective collaboration on construction site.

It is argued that mandatory training and workshop requirements, resulting in a licence to conduct activities on construction sites could enhance the levels of workmanship to a desired quality and eliminate rework (Baiche et al., 2006). The potential adoption of standardised processes and products in the construction stage has been suggested as an effective solution to eradicate rework and defects (Hopkin et al., 2016). For instance, gas engineers in the UK are required to have a qualification and be on a register to legally work on boilers, fires, and other gas appliances (Gas safe, 2015). Despite mandatory qualifications and registration requirements for gas engineers, rework is still an issue, particularly in relation to boilers and flues (Hopkin et al., 2016).

Baiche et al. (2006) noted that the adoption standard details would potentially minimise the complexity and fragmentation of construction processes and improve familiarity of each stage and that leads to reduction of rework in construction environment. It is also, argued that learning from past rework occurrence can be a means for addressing the root causes of rework in construction stage. Macarulla et al. (2013) looked at house builders in Spain and noted that they can analyse their rework performance from past experiences to provide an understanding of the nature of rework occurrence and develop strategies to minimise it.

Auchterlounie (2009) looked at the UK housing industry and argued that it could follow a feedback system to enable developers to assess and measure performance and output. Roy et al. (2005) suggested re-examining and modifying the practice of working could minimise quality failures. Baiche et al. (2006) stated that continuous review, research, and feedback as a method of eliminating rework in the UK housing subcontractors. A report published by the NHBC Foundation (2011) suggested that an approach of recording and analysing rework data, feeding the outcomes of the analysis into the design and construction of a home to rectify procedures and that leads to improvement based on past learning experiences.

Defects may occur on projects on site because of design errors, poor supervision during construction stage, materials failure, and human errors. The Building Research Establishment (BRE) in the UK found that 35% of the defects are creates due to faulty construction. Some researchers identified the causes of the defects as:

a) Design-related factors

The absence of coordination in a design team in combination with design errors intensifies the causes of rework. Josephson and Hammarlund (1999) mentioned that the wellspring of design-related rework in construction is basically correspondence issues.

b) Client-related factors:

A lack of experience and information in design and the construction procedure can cause rework issues, the lack of client contribution; lacking preparation; poor correspondence with design specialists; and deficiencies in contract documentation. A poor correspondence stream between the client and designers can result in documentation errors and omissions occurrence.

c) Site management-related factors:

Ineffective use of quality management practices, poor coordination and planning of resources, lack of safety and failure to provide protection to construction worker, lack of experience and training and failure to rectify errors.

d) Subcontractor-related factors

Damage to other trades work due to carelessness, poor workmanship, unclear instructions to workers, inadequate supervisor/foreman tradesmen ratios, non-compliance with the specification, the shortage of skilled labour, low labour skill level and supervisors.

e) Contractor-related factors

The failure of numerous administrators to design work, speak with labourers and direct exercises sufficiently is, in a general sense, connected to expanding sums and costs of rework. The site administration group and subcontractors' task achievement is dependent upon the adequacy of the primary contractor's ability to arrange endeavours (Love and Li, 1999). Without a quality framework set-up, there is commonly a 10% cost increment on account of rework.

Different factors generating rework have been also categorised as follows:

• Setting-out errors: Errors can be created from misreading measurements on the working illustrations and working twisted Josephson and Hammarlund (1999).

• Disturbances in faulty arranging errors also can be created due to expanded deformities and poor workmanship, which may emerge because of high workload, and multitasking. Likewise, an unsettling influence in faculty arranging happens when staff are reallocated (Love, Mandal, and Li, 1999a).

• Failure to give assurance to workers can create errors due to an inability to ensure certain parts of a contract amid adjustment of workers (Barber et al., 2000).

Regarding the type of projects, Benson et al. (1988) suggested project type was an attribute rather than a causal factor and, hence, does not affect the project's overall performance. However, the National Economic Development Office and Naoum and Mustapha (1994) indicated that project type was associated with the level of complexity and, therefore, does affect project performance and cost of rework Hwang et al. (2009). Some type of projects, for instance refurbishment and renovation, have a tendency towards higher cost of rework compared to building projects, due to the higher degree of uncertainty and complexity (Love and Wyatt 1997).

Knowing the sources and causes of rework is vital for successful rework minimisation in the housing SC. Traditionally, the source and cause of construction rework have mostly been considered as the responsibility of the main contractors (Love and Li 2000, Love and Edward 2005, Love et al. 2009). However, this might be a simplistic view of a complex problem. Some of the rework problems handed to the site operatives are beyond the contractors' control. Project designer, product manufacturer, contractor and subcontractors, materials handling, procurement, and site construction practices all contribute to rework generation.

The outcome of a comprehensive literature review (Fayek et al. 2004; (Mossman, 2009); Love et al., 2010; and Arashpour et al., 2014) on the contributors and root causes of rework in construction projects is presented in Figure 2.2.

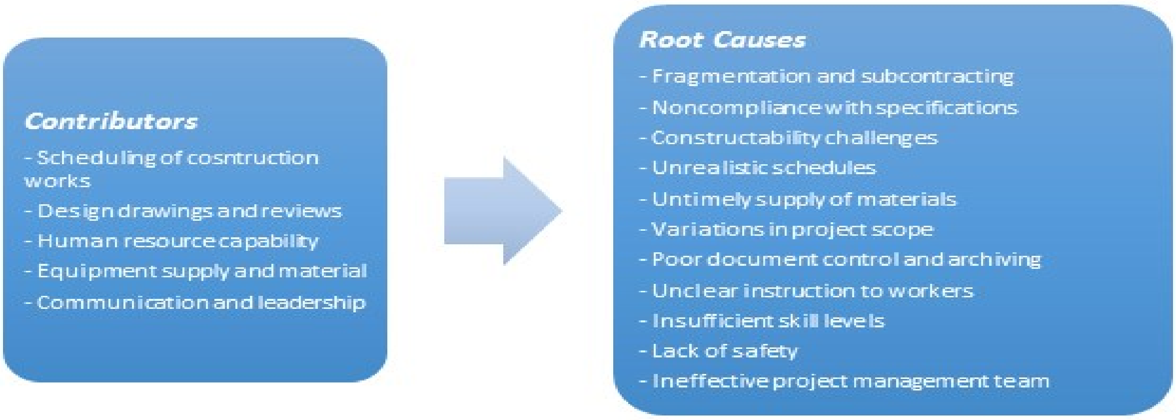


Figure 2.2 Contributors and root causes of rework in construction projects

Dissanayake et al. (2003) categorised rework components into five main causes:

1. Human resource capability
2. Engineering and reviews
3. Construction planning and scheduling
4. Material and equipment supply
5. Leadership and communication

Love (2002) and Love et al. (2005) classified rework into four major categories, defined as:

1. Change: A directed action altering the currently established requirements.
2. Error: Any item or activity in a system that is performed incorrectly resulting in a deviation. Errors are the result of incorrect construction methods and procedures and are human related.
3. Omission: Any part of a system including design, construction, and fabrication, that has been left out, resulting in a deviation.
4. Damage: Might be caused by employees, subcontractors, weather condition, or natural disasters.

Table 2.1 Root causes of rework during the design and construction

	Design	Construction
Change	• Lack of communication • Problem of interpretation • Bad design • Client's demand • Design change due to financial changes • Inaccurate design • Poor documentation	• Unsuitable materials • False information • Lack of communication • Poor project management • Client's demand • Construction method
Error	• Lack of co-ordination • Unsuitable design • Client's demand	• Poor project management • Personnel capabilities • Noncompliance of rule • Lack of skills • Poor workmanship • Damage by subcontractors • Faulty Manufacturing materials • Late delivery of material
Omission and Damage	• Missing design/drawings • Damaged drawings	• Machine breakdown • Unusual circumstances • Ground condition • Machinery breakdown

Possible rework occurrences in projects the during design and construction stages have been summarised in Table 2.1 from Mastenbroek's work in 2010. His study showed that Change is the dominant cause compared to the other indicators (i.e., Error, Omission and Damage).

Mastenbroek (2010) suggested that there should be further research on the level of contribution of each category in rework generation.

2.3.3 Cost of Rework in Housing Projects

Rework is a chronic issue in building projects and can have an adverse impact on costs and project duration (Hwang et al., 2009; Love et al., 2010; Forcada et al., 2014), safety (Love et al., 2015b), schedule (Burati et al., 1992; Love et al., 2010; 2015a), quality (Burati et al., 1992; Love et al., 2015b), and profitability (CII, 2001; Forcada et al., 2014). Love, 2002 found that rework contributed around 52% of the cost growth experienced in 161 Australian construction projects.

Burati et al. (1992) stated that the average direct cost of rework from nine fast-track industrial construction projects associated with rework, including re-design, repair, and replacement, to be 12% of the total project costs. Design changes, errors and omissions were found to be the cause of 8% of the total deviations incurred, on average, and 79% of total costs (Love et al., 2008). Burati, Farrington and Ledbetter (1992) noted that the figure of 12% only covered direct costs affecting the total projects' cost. Given the context, considering the indirect costs associated with delays, stress, lack of motivation, disruption, claims, and litigation, would all significantly increase the cost of rework. However, it is difficult, if not impossible to obtain data on the indirect costs (Love and Edwards, 2005). For instance, Bowersox, Carter and Monckza (1985) estimated the cost of rectifying a poor-quality product or service can be more than eight times its initial cost.

Typically, according to Love et al. (2010), rework contributes to 52% of the total growth of incurred costs and has a tendency towards time overrun by approximately 22% (Love 2002). However, rework data are usually hard to obtain, and lack of precise interpretation and definition of rework have led to vague data collection and quantification in the housing SC (Love and Smith 2003; VanDerVoorn et al., 2010).

Josephson and Hammarlund (1999) estimated the costs of rework on residential, industrial and commercial building projects, to be on average between 2% to 6% of the contract values. Similarly, Fayel et al. (2003) reported that a range of 2% to 12% on rework costs on residential building, and Love, Ki and Li (2000) stated direct costs of rework to be, on average, 3.15% of the contract value in residential buildings and 2.5% in industrial buildings. In another study by

Oyewobi et al. (2011) reported rework costs accounted for 5% of the completion cost of new buildings and 2.3% of the completion cost of refurbished buildings.

A study conducted by Love (2002) stated that, cost increase and schedule overruns were significantly correlated with direct rework costs, which has adverse impacts on overall residential buildings' construction budget (Palaneeswaran et al., 2007). Jafari et al. (1994) stated that larger projects incur lower quality failure costs. However, Hwang et al. (2009) identified that rework contributed most to projects with a cost range of $50 million to $100 million, although not to projects with a cost of above $100 million.

Love et al. (2004) identified a rework cost to range from 3% to 23%. Love et al. (1999) noted the cost of rework could range as high as 12% of total project cost. Rework is a chronic issue in different countries. Love and Smith 2003 stated that the Singapore Development Board recommended that around 5% and 10% of total project cost was wasted on rework costs. American studies indicate a figure of 5% for rework Hwang et al. (2009). Nielsen et al. (2009) identified that the cost of rework in Denmark construction considered a loss of around 10% of construction turnover. Studies conducted in Hong Kong, state that main contractors have no such interest in unearthing the precise cost of rework, as most activities conducted with subcontractors (Taggart et al., 2014).

Cost of rework in Danish construction industry estimated by Danish authorities around 1.7Bn Euros, which is almost 10% of the total annual production value (Koch et al., 2019). Rework occurrence has been adversely affecting the cost and schedule of projects across the globe such as Sweden (Josephson and Hammarlund 1996a; 1996b), Australia Love and Li 2000. Despite the effort to reduce rework, the aforementioned countries are experiencing the same level of rework and defects in housing projects (BEC 2016, Love et al., 2016). From micro perspective, rework is a cyclical occurrence and experience on the construction site (Koch and Jonsson 2015). It appears to be a practical including research gap in grasping the underlying reasons and root causes of rework occurrence in construction site (Koch et al., 2019).

Egan's (1998) Rethinking Construction report stated that a 20% annual reduction in the number of defects at handover is required as a driver of sustained improvement (Sommerville, 2007). The financial and economic impact of rework in construction varies widely per project, with costs of rework cases reaching up to 70% of the total project costs. Love and Edwards (2004) showed that earlier practice on rework can result in less cost (i.e., values between 3% to 15%

of a projects contract value). Barber et al. (2000) suggested that rework cost might be as high as 23% of a contract value. Simpeh et al. (2015), on the other hand, found that the total rework costs could have a high variation with a range from 0% to 75%.

Return visits are a typical process of completing rework. However, they are a very unproductive process, which result in multiple cost implications and have an impact on project time overrun. This results in extra expenditure on factors like travelling time, non-productive time, additional access, equipment and plant (Taggart et al., 2014). This phenomenon can be considered in terms of direct costs (specially associated with the defect) and indirect costs (associated with the return visit) (Love and Edwards, 2004). Love and Edwards (2004) indicated that indirect costs were 22.5 times than direct costs. Indirect costs are hard to obtain, however, once the projects progress to the end they can be estimated as a percentage.

Josephson et al. (2002) suggested that rework costs should be considered on three levels to obtain a comprehensive view:

- Direct cost: the cost of defect elimination for the defects found before or after handover.
- Checking costs: the costs of checks, inspections and return visits to complete defects.
- Prevention costs: the costs of preventative measures and the system.

There have been cases where the indirect costs of rework were reported to be 22 times greater than the direct costs Love and Edwards (2004).

Direct consequences of rework can lead to various overruns, such as:

1. Time delay, as rework takes time.
2. If work has been done incorrectly, which can be interpreted as non-productive time and labor poor performance and take extra time and labor's effort. Consequently, poor performance of labor can cause extra effort of both time and labor overruns.
3. Extra material, as often some parts of the work must be undertaken with new materials.
4. Cost overrun, the main indicator of rework occurrence. Materials cause costs to overrun the budget.

In addition to direct consequences of rework, there are also indirect costs (Love, 2002), which may be hidden and can be several times higher than the direct costs. Indirect costs of rework can include:

1. Client dissatisfaction
2. Inter-organizational conflict
3. Stress, fatigue and de-motivation within the organization and the workforce
4. Loss of future contracts
5. Poor moral
6. Reduced profit
7. Damage to professional feature

Considering rework as a 'waste' of material, time, and cost overrun, which can be associated with the lack of quality control and/or the lack of collaboration through design and construction processes. Providing effective strategies and suggesting efficient rework minimisation practices is essential within the housing supply chain.

2.3.4 Management of Construction Sites for Minimisation of Rework

There are limited studies on construction sites' rework (e.g., Love and Li 2000, Robinson-Fayek, 2004; Jaafari and Love, 2013; Forcada et al., 2014). Often contractors pay little attention to rework as it seems to be a natural function of operations (Moore 2012), and in some cases costs and incidents might be intentionally hidden (Ford and Sterman, 2003; Love et al., 2008).

Managing a construction site effectively will have a significant impact on the level of rework generated. Strong communication ability has been identified as the most important aspect of a subcontractor's performance, emphasising the importance of a managers' capability to combine knowledge, experience and soft skills. Effective team management, also viewed as an important factor on the improvement of performance in the housing construction industry (BIS, 2013).

A study conducted by (Love et al., 2008), revealed that 19,605 rework incidents occurred in 346 construction projects. This equates to a mean occurrence of 57 reworks per project, which occurred by contractors and subcontractors (Love et al., 2008). The literature suggests that one of the predominant elements causing rework is human error, which can happen from mistakes, or lack of knowledge, slips and lapses of attention, and omission (Love and Josephson et al. (2002); Love et al., 2016). However, many rework studies have been failed to identify the main cause of human underperformance, leading to errors and mistakes, and therefore how to prevent them (Ye et al., 2014; Fu et al., 2010; Jingmond and Agren 2015 and Love et al., 2016).

Phenomenological research by Love and his colleagues (Love et al., 2009; 2012) identified human errors, as follows:

- People often ignore most of the information around them
- Cultural differences escalate the probability of misinterpretation of the same event
- Problems commence when people's goal in the same organization start to diverge
- People break rules to make work more efficient
- People's decisions are a trade-off between the availability of time and information

Ford and Sterman (2003) gathered valuable insight and suggested, employees may disguise rework to avoid reporting incidents to managers. Ford and Sterman (2003) also stated that the practice of concealing mistakes is institutionalised in many organisations and is akin to making an "omission error".

Personnel capability and personal behaviour have been suggested as having a high effect on the reduction of rework, as they could influence the commitment of subcontractors on delivering a good quality task, pricing behaviour and reputation for future projects (BIS, 2013). Fostering better communication, trust and transparency on a construction site can improve collaboration among different subcontractors and prevent errors or mistakes that may lead to rework occurrence.

2.4 Exploring Automated Technologies for Reduction of Rework in the Housing Supply Chain

2.4.1 Introduction

Housing has been experiencing a significant occurrence of rework within the SC. Rework affects both the cost and schedule of projects due to complex environments, intricate activities, and the highly fragmented nature of the housing SC. The cluster of the SC generate data and share information with one another, which contributes to a multitude of challenges such as design errors and mistakes, document control, lack of communication and poor scheduling. As a result of rework, productivity and workflow of information in the construction SC has been affected and that causes projects overrun budget and scheduling. Automation in the construction SC with novel technological innovation, such as Robots, Offsite manufacturing, and AI, has the potential to improve housing productivity and change the trajectory of the traditional way of processing. Thiexplores current strategies of employing new technologies and the challenges involved in utilising automated technologies for minimisation of rework. The aim of this section to explore possible opportunities of employing new technologies and challenges involved in utilising automated technologies for minimising rework in the housing SC. A conceptual framework is developed to determine the suitability of various technologies to fully automate housing SC and facilitate the reduction of rework in construction housing SC.

The exponential growth of technology has created a new avenue of coordination, and communication to improve the productivity in the construction industry through the elimination of rework (Volk et al., 2014; Dave et al., 2016). The UK construction industry is characterised by the embedded attributes of a highly fragmented nature, and with multiple stakeholders, having different business interests and objectives. Reports by Egan (1998) and Latham (1994) indicate that fragmentation in the housing SC affects productivity and performance. Fragmentation in housing SC causes rework and affecting both cost and schedule of projects. There is a need for innovative approaches to improve the productivity and overall performance of the construction building industry through the reduction of rework.

The construction environment is embedded with an enormous amount of information, which plays a crucial role in successful project delivery. The flow of information has always been elusive or obsolete (Love et al., 2004; Volk et al., 2014; Chu et al., 2018). The quality of information significantly affects both costs and scheduling throughout projects. The fragmented nature of the construction SC leads to a rapid increase in the number of possible communication paths and number of copies of information, as each new contributor becomes engaged in the process. There is a risk of omission and errors in different copies held by different parties (Eastman et al., 2011; 2013). Egan (1998) and Latham (1994) both stated that the UK construction industry is described as ineffective, adversarial, fragmented nature and there is a need to improve the productivity level with an aid of innovative technologies.

The recent improvement of digitisation in construction has enabled project information to be more accessible among construction actors. With an increase in mobility, such as smart phones and tablets, convenient access to up-to-date digital building data from anywhere can be provided. However, to yield the benefits of such technologies in the housing SC, interpreting of the information is required by SMEs and subcontractors so they can conduct the meaningful tasks.

2.4.2 Industrialised Housing

There are different terminologies used for industrialised construction in the literature, such as off-site production (OSP) (Nadim and Goulding 2010); off-site manufacturing (OSM) (Hamson and Brandson 2004); prefab (Steinhardt et al., 2013a, Steinhardt et al., 2013b); modern methods of construction (MMC) (Rahman 2014); industrialised construction (Lewicki 1966) and modular construction (Modular) (Parrish 2012; Lawson & Blatt, 2014). Gibb and Isack (2003) introduced a hierarchical model to differentiate between the levels of industrialisation of construction works (Figure 2.2). Traditional construction is fully craft-based construction by workmanship in which all the processes happen on-site and involve *in situ* manufacturing and installation of prefabricated elements, such as doors, windows, pipes, bricks, tiles, etc. On-site prefabrication is the assembly of building components on-site which are then moved into position (components such as timber framing, handmade roof trusses and façade units). Off-site prefabrication is assembly of building components, such as air conditioning units or roof trusses, and then transporting them to site and assembling in place. Pods are pre-assembled units, such as toilets or bathrooms, manufactured off-site and then transported to the site to connect them to other building elements. Complete modular encompasses fully finished units that form a complete building structure (Goh and Loosemore 2017). Nevertheless, the manufactured modular housing has often been neglected, as the construction industry has a tendency to be slow in adopting new technologies.

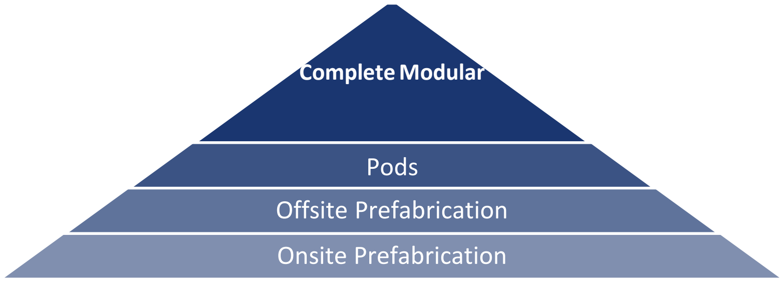


Figure 0.3 The industrialised construction hierarchy (Gibb and Isack, 2003)

Off-site technologies with a support of robots have enormous potential to reduce negative environmental impacts, increase the re-use of materials (Court et al., 2009; Chen et al., 2009), eliminate waste, minimise rework, reduce cost, and optimise performance and quality levels (Gann 1996; Egan, 1998; Gibb 1999; Lawson & Blatt, 2014). There are many advantages of robotics associated with manufactured housing over traditional construction methods, such as higher precision, more energy efficient to operate and cost efficiency. The consequence is shortening the completion process of building with higher quality. One of the significant benefits of fully automated off-site manufacturing in construction projects, is reducing human error (which results in rework generation), as well as avoiding the impact of adverse site conditions (i.e., weather) on the quality of the completed project. These aspects can significantly reduce rework generation and consequently prevent projects from cost and schedule overrun.

Jaillon and Poon (2008) found that manufactured housing can save up to 20% of time compared to on-site construction in Hong Kong construction projects. Gibb and Isack (2003), Blismas and Wakefield (2009) and Steinhardt et al. (2014a) highlighted numerous indirect benefits associated with off-site prefabrication due to reduced site preliminary costs, reduced site congestion and earlier income generation for clients. Gibb (1999), Court et al. (2009) and Chen et al. (2009) showed that off-site prefabrication can also reduce safety risks by around 35% due to less site congestion and moving operatives from a dangerous site environment to a controlled factory environment, with better working conditions.

Pan et al. (2008) surveyed the top 100 UK housing builders and identified that to attain high quality is the key motivator for utilising off-site prefabrication. Blismass et al. (2009) and Blismas and Wakefield (2009) found that off-site prefabrication could reduce the need for many trades that are in short supply, thus, it significantly improves workflow and integration, which results in elimination of rework within different SC windows. However, lack of SC capacity, lack of technology awareness; cultural perception; lack of business process model; high initial investment costs; incompatibility and inflexibility of design are the most challenging barriers for off-site manufacturing (Gibb, 1999; Chaing et al., 2006; Lu and Liska 2008; Loosemore, 2014; Rahman 2014; Goulding et al., 2015). For instance, in Hong Kong the Provisional Construction Industry Coordination Board has noted that high initial investment remains a significant obstacle to the adaptation of off-site prefabrication techniques and to unleashing the full potential of cost saving (Chaing et al., 2006; Goulding et al., 2015).

Lu and Liska (2008) identified that the inflexibility of design was a major issue for off-site prefabrication, because it requires an early design freeze. The finding was supported by (Rahman 2014) who highlighted that the main barriers to off-site prefabrication were cost and design incompatibility and flexibility issues. Logistics and transportation also have been major impediments to the adaptation to off-site prefabrication (Nadim and Goulding 2010).

The review of literature (Gann 1996; Gibb 1999; Blismass et al., 2009; Chaing et al., 2006; Lu and Liska 2008; Pan et al., 2008; Nadim and Goulding 2010; Rahman 2014) confirms that offsite manufacturing techniques play a crucial role in enabling industrialised construction. It can improve performance and deliver high-quality products and subsequently eliminate rework within the entire housing SC.

Optimised scheduling reduces costs and improved design through Building Information Modelling (BIM) can help in overcoming the disadvantages of off-site manufacturing. The precision and extensive modelled information in BIM can enable a better collaborative information and provide a high level of information integration. Improved design accuracy, with an aid of BIM, can ultimately eliminate all modification needs and design errors. The transportation of big components can be facilitated by improved design and logistics can be supported by optimised schedules. Having improved design and information accuracy, and with efficient collaboration between parties engaging in BIM, will lead to a shorter lead-time, and reduced costs in manufactured housing (Ezcan et al., 2013). The UK government makes explicit links between the BIM associated and off-site housing manufacturing. Availability of digital information will also enable more effective use of BIM within the housing SC.

To help off-site prefabrication with the inflexibility of design issues, advanced technologies, such as Digital Twin, can be helpful. A Digital Twin is a virtual copy of a physical construction component, bridging the physical and virtual world. Data is transmitted seamlessly, allowing the virtual copy to exist simultaneously with the physical component. In a construction project the Digital Twin can help overcome the disadvantages of off-site manufacturing assembly and quality issues. A fully robotically automated fabrication process in off-site manufacturing, with the support of a Digital Twin will enable digitised visualisation of a virtual replica of a physical subject on the factory floor. This can improve quality issues and monitor products' maintenance with installed chips. The Digital Twin can help eliminate all modification needs and design and human inaccurate prediction issue detection. This will lead to a shorter lead-time, improve the quality of products, minimise rework and reduce costs in fully automated manufactured housing.

2.4.3 3D Printing Technology in Construction

The application of advanced technologies, such as robotics and 3D printing, are being established in manufacturing and are continuously expanding into other industries specifically the construction industry. In construction, robotics has been progressing to reduce the time and cost associated with operations. Robots have the potential to attain productivity, efficiency, safety, and quality in construction projects (Ardiny, 2015).

3D printing technology has a tremendous potential to maximise the productivity in both offsite and onsite construction, to eliminate majority of reworks, address the inflexibility of design and undertake tasks with greater precision. 3D printing can also potentially support LC practices, in which continuous improvement can add value to each step of the process and consequently reduce defects.

Within the last decades the exponential growth of 3D printing, which could also be referred to as additive manufacturing in most industries, has become one of the fastest adaptable growing technologies. Many researchers have shown the merits of 3D printing in the field of aerospace and manufacturing in making the cost more affordable than ever before (Gibson et al., 2010; Huang et al., 2013; Vazei et al., 2013). It can be expected that 3D printing technology can increase the construction profitability by eliminating waste, reducing cost and accelerating the completion processes substantially (Conner et al., 2014; Thomas and Gilbert, 2014). Freedom of design and the ability to print complex structures with least waste, fast prototyping, the ability to transform manufacturing and SC processes are the main advantages of utilising 3D printing in construction projects.

The latest 3D printing technology developed for the construction industry is called counter crafting. It is an additive fabrication technology that uses computer control to exploit the superior surface-forming capability of towelling.

Despite many advantages of such technology, the uptake of 3D printing in construction industry has been limited and neglected compared to other industries, such as aerospace and automobile industry (Bogue, 2013). Nevertheless, employing 3D printing in the construction industry, and more specifically in the housing SC, has great potential to reduce construction waste and rework generation.

2.4.4 Virtual Reality and Augmented Reality Application at Construction Sites

Visualisation technology to involve client observing construction process

The design process has helped overcome most difficulties usually encountered during the construction of residential buildings. The involvement of the client at the construction stages can reduce rework generation greatly during residential building construction. The contractors benefit from this technique by knowing exactly what their client wants in time and making provision for them. There will not be any doubt in making choices and decisions on what material, equipment, colour, size, and design of the installed utility, for example, thus saving time and potential cost due to rework. The aim is to save costs associated with rework where the clients can watch how the construction is going on from the comfort of their own home. The contractor should ask the client, if necessary, how and by what margin they want certain sections of the building to look like. The numerous site visits can be stopped, and great success still achieved by using this simple technology Josephson et al. (2002).

Virtual Reality Technology Application to Construction Sites

Use of virtual reality in the construction of residential buildings can significantly reduce rework. Virtual reality replaces the real world with a simulated environment. In the construction of residential buildings, virtual reality can help to visualise and simulate how the occupants of the building are going to utilise the facilities when they move into the building before it is built. Before starting the construction, virtual reality can indicate errors and omissions, thereby eliminating rework at the early stages. Virtual reality for the construction industry has great potential overall, both for contractors making programs in building construction and for the third-party companies building virtual environments. Technology has helped to reduce the project documentation and the time it takes.

Augmented Reality Technology Application to Construction Sites

Augmented reality is a copied view of a physical environment supplemented by computer-generated images. The use of augmented reality technology in the construction of residential buildings is another way to prevent errors, doubt, and confusion. It helps staff to concentrate on the allocated task with less error.

Virtual reality replaces the real world with simulated environment to experience the unprecedented tasks. Comparing virtual reality and augmented reality we see that augmented reality takes what already exists in the real world and processes, while virtual reality replaces the real world with simulated environment. The major advantage of these technological tools is that reality images make you look at, or navigate, all project phases. It makes it easier to notice mistakes and errors in residential building construction for managing job sits and detects, mistakes, errors, and omission before they are generated (Whyte, 2010). The development of mobile technologies, smart phones and tablets is helping residential building construction companies to improve communication on sites. Identifying errors, mistakes, and omission is the prominent motivation among contributors to employ virtual reality for minimisation of rework in the housing SC.

Augmented reality (AR) is a copied view of a physical environment that is supplemented with computer-generated images. The use of AR technology in the construction of residential buildings is another way to prevent errors, doubts, and confusions. It helps the staff to concentrate on the allocated task with less error. The contextual awareness of AR systems enhances the process of information retrieval by providing a mechanism to filter data, information, and services, thereby removing redundant data and allowing the user to see only relevant information (Behzadan et al., 2008; Chu et al., 2018).

The potential application of AR in the housing SC is that tasks could be assessed by applying the following cognitive principles (Wang and Dunston 2006): information searching and accessing (Agarwala, 2014); attention allocation (Anumba et al., 2008); working memory (Aral et al., 2012); and spatial cognition. Building upon this research, Hou et al. (2013) and Nakanishi and Sato (2015) suggested that through an AR filtering mechanism a user might benefit from improved cognitive function, in which can enable workers to undertake assembly tasks more effectively by reducing cognitive loading through improved working memory capacity. This can result in user ability to reduce rework through interpreting and retrieve information precisely. However, AR's applicability and employability in the housing SC remain limited due to problems surrounding its portability, functionality, and its capabilities to send data to workers' platforms (Wang et al., 2013; Chi et al., 2013).

2.4.5 Robotics Help in Rework Reduction

The application of robotics is well advanced in manufacturing and is continuously expanding into other industries including the construction industry. In construction, robotics has been progressing well to reduce time and costs associate with operation, as robots have the potential to attain productivity in construction performance, efficiency, safety, and quality (Ardiny et al., 2015).

The housing construction process is comprised of iterative stages. At construction sites, the degree of automation is relatively low, the final assembly of building components are heavily reliant on humans, and automation processes have been inconsistent between design and construction. The most impact robotics systems have had on the housing construction industry has been in off-site fabrication, which is making a component of construction using robots in a controlled environment. Construction sites are highly hazardous environments, with highly fragmented tasks, which provides an infinite number of opportunities to improve the performance of construction industry via automation. In recent years, robots have become more task-adaptable and seamlessly integrated with the process of a given task. This can improve the productivity and innovation adaption of the construction industry.

A review of the literature demonstrated that research on robotics for construction automation began in the 1980s. Ever since, general categories of construction robots are considered to fall into 3 classifications (Saidi et al., 2008), including: 1) teleoperated systems, in this instance; robots are under humans' control, 2) programmable construction machines, in which humans insert the specific programmed menu of function or giving the instruction of new function to robots, 3) intelligent systems, in which fully-autonomous robots accomplish a required set of activities without human intervention.

Research and development (R & D) in the utilisation of robotics in construction has led to an extensive range of different applications. Applications have included civil infrastructure and residential buildings, such as automation of road, concrete compaction, interior finishing and tunnel and bridge construction (Ardiny et al., 2015; Giftthaler et al., 2017). Housing SC consists of a defined set of number of sub-activities for example, handling, concreting, coating, measuring, and assembling. This will enable robots to conduct each task without causing rework generation to projects.

A few studies have analysed the subject of productivity and cost analysis in the construction robots. Skibniewski and Hendrickson (1988) stated that applying robotics for on-site surface finishing work, particularly for repetitive tasks, could be plausible from a technical performance and economic growth perspective. In a similar study, Najafi and Fu (1992) suggested that utilising robotics for straightforward and repetitive tasks in building construction is more economical than traditional methods.

Another study compared the level of productivity between robots to human in the function of time and cost and demonstrated a significant improvement in productivity by employing robots in building construction (Slaughter, 1997). Castro-Lacouture et al. (2007) found the productivity of concrete paving improved 22% when using robotics as compared to traditional approaches.

An experimental study conducted by Hack and Lauer (2015) on a fully automated process of robotically built metal mesh mold wall as concrete reinforcement. In their study a robot implemented a three-dimensional mesh, where steel mesh functions as a stay-in-place formwork. The protrusion rate of the concrete properties controlled through the mesh and the surface roughness of wall (Kumar et al., 2015; De Soto, 2018). The main objective of the mesh mold wall is the bespoke fabrication of free form steel meshes, which form both mold and reinforcement to enable a waste-free production of a customised, reinforced-concrete wall structure (Hack et al., 2015; Kumar et al., 2015). The result of the study illustrated the possibilities of raising the degree of automation using robotics for improved fabrication processes and optimising the efficiency of geometrically iterative, complex activities and consequently reduction of rework in housing SC.

Automation in construction in general and in the housing SC has the potential to add more independence to tasks conducted by humans and eventually eliminates rework occurrence and quality issues. As opposed to human, robots are capable of continuously controlling, monitoring the progress of construction process meticulously, which resulting in continuous improvement of the overall construction performance.

It can be suggested that, for elimination of rework at a construction site, mobile robots could be sent for monitoring the progress of work and for detection of errors and changes. Robots can detect human errors within each task after labours have completed daily tasks and then send data to the construction project manager. Robots can be controlled by a VR camera mounted on the robot. This method could monitor projects' progress continuously and eliminate all the possible rework occurrence and delay in the housing SC. One of the most basic repetitive tasks in housing construction sites is masonry walls. It is time consuming, labour intensive and cost inefficient, therefore, it is the most suitable activity to robots for. Recently, many companies have started to employ robotic automation for such a repetitive on-site activity. One company attempted to apply semi-automated masonry (SAM) for bricklaying, which was conducted by the BRONCO robot (Pritschow et al., 1996).

Also, robots can be used to make responsive intelligent decisions in reaction to immense sensory data input and intricate configurations in the construction environment due to material transportation and building activities. In order for robots to make informed decisions in a fragmented and unstructured construction site, with a high degree of uncertainty and unpredictability of physical interactions with construction material, more advanced strategical decision-making techniques and tools are needed.

2.4.6 Employment of Artificial Intelligence (AI) for Reduction of Rework

The prediction of rework in the housing SC has always been determined using a trial-and-error process, which has a tendency to escalate uncertainty within a project. Accurate prediction methods for the housing SC provides a remedy for the root causes of rework. Predominantly, contractors and subcontractors have very limited information regarding potential conflicts/errors at the start of a project, leading to rework generation during construction. Unambiguous prediction methods, such as AI, could prevent the occurrence of rework during a construction project and ultimately reduce the total cost of the project (Kim et al., 2014).

The application of AI in the housing SC could improve the predictability of projects' outcome accurately, before construction takes place (Lee et al., 2016; Nilsson and Nilsson 1998). This can address quality issues and detect human errors at the early stages of each task, before proceeding to the next stage. AI can be used as a consultant to subcontractors for enhancing the strategic decision-making and deploy the most optimised methods to eliminate rework and improve the quality of finished products in the housing SC.

AI can be used as a supplement to augment subcontractors' work. This can improve the performance of the fragmented nature of the construction industry and, particularly, the housing SC. However, there are obstacles to be considered, such as understanding the real phenomena of AI contribution, transparency, and trust among subcontractors to deliver a successful project. Each of these have been a considerable barrier to employing AI in the construction industry (Feng and Li, 2002).

Over the past few decades, a number of prediction models including artificial neural networks (ANN) and Ant Colony Optimisation (ACO) have been developed for estimating and predicting construction waste (including rework). Such ANN analysis is based on regression analysis (RA), case-based reasoning (CBR), and support vector machine (Finnie et al., 1997; Kim et al., 2004; Kim et al., 2005; Feng and Li, 2002; Kim et al., 2014; Bala et al., 2014; Lee et al., 2016). However, there is limited research on employing AI in the housing SC.

ANNs, or connectionist systems, are structures that have been modelled to imitate the learning process of the human brain (Salchenberger et al., 1992; Ding et al., 2013). The biological brain components consist of neurons that are connected to each other with synapses. It is a comparatively simple nonparametric technique that can capture the nonlinearity of any system characteristics and addresses complex problems by changing the degree of connections (Salchenberger et al., 1992). Recently, ANNs have been applied for cost estimation and prediction in construction projects (Murtala, 2011; Kim et al., 2014; Lee et al., 2002;). ANNs are designed to deal with complex problems, particularly with heterogenous information. As such, the construction industry has a heterogenous environment and ANNs can be used to achieve a high level of accuracy and reliable prediction to prevent rework occurrence in the housing SC.

2.5 Towards the Development of a Conceptual Framework on Emerging Technologies

The review of literature confirms that automation plays a crucial role in enabling digitised information of construction projects to be intelligently interpreted without human intervention. The emergence of advanced technologies, and their applications in the housing SC, can support sub-contractors to deliver a high-quality product by eliminating rework within the entire housing SC. Fully automated processes are crucial for the reduction of rework.

A conceptual framework is proposed in Table 2., which initially focuses on the construction stage of the housing SC, and the potential for improvement through automation. A key aspect of the conceptual framework is to identify and categorise the key requirements in terms of those that are critical, core and desirable. Table 2.1 explores the technologies used for automation with respect to these different requirements of the housing SC. The conceptual framework can be used to identify technologies most suitable to address a particular problem or to optimise the performance of each individual activity, which can result in the elimination of rework, and improvement of productivity of housing SC. For instance, one of the causes of rework in the housing SC is human error (Love and Edwards 2004; Love et al., 2016), which can be addressed with the support of robots, without human intervention, and offsite manufacturing techniques. Another distinct example is unexpected design errors and changes which happens as a consequence of unilateral client change (Love et al., 2009, Hwang et al., 2014; Love et al., 2016).

Table 0.2 The role of technologies to automate the characteristics of housing supply chain

	Requirement Characteristics	Off-site prefabrication	AI	Robotics	AR &VR
Critical	Dealing with errors and mistakes	X	X	X	X
	Design errors and changes	X	X	X	X
	Effective communication		X	X	X
	Management of change	X	X	X	
	Improvement of collaboration	X	X	X	X
	Transparency and trust		X		X
	Unrealistic scheduling	X	X		X

Core	Replacement of skilled shortage	X	X	X
	Poor document control and archiving	X	X	
	Damage by sub-contractors	X	X	X
Desirable	Construction method	X	X	X
	Faulty manufacturing material	X	X	X

The coordination of the housing SC is challenging due to the complexities of the production process. Some of the changes during the design and construction stages are inevitable due to errors, mistakes, untimely supply of material and unrealistic scheduling (Reason, 2000). Automation has the capacity to address many of these problems, as well as the catalogue of other challenges in the housing SC. Other challenges that automation technology may be able to assist with include skilled-worker shortages, document control and archiving, improvement of collaboration, and choosing appropriate construction methods to minimise the cost of changes, speed-up the process, and improve productivity. Automation has the potential to provide the most efficient way of predicting and dealing with the possibilities of change that might occur during housing production and can also provide an informed decision.

2.6 Summary of Chapter

This chapter investigated the root causes of rework, barriers to efforts to implement rework minimisation practice, the nature of the housing supply chain, and possible emerging technologies which can help to prevent and minimise rework in the housing supply chain. The review started with the sources and causes of rework in the housing supply chain. This examination revealed a number of factors causing rework occurrence in the housing supply chain, with subcontractors' crucial role to minimise rework in the housing supply chain. Some of these factors are: lack of subcontractor's involvement from early stage of projects, lack of collaborative and cooperative culture of working, fragmentation and subcontracting, unrealistic scheduling, poor workmanship, insufficient skill level and ineffective project management.

Throughout the review, emphasis was placed on the relationship of different practitioners and their contribution to rework minimisation practice in the housing supply chain. The review also considered different emerging technologies to help practitioners on rework minimisation practice. However, more emphasis has been placed on the level of collaboration and cooperation among different subcontractor on achieving rework minimisation practice in the housing supply chain. The next chapter discusses the research methodology of the research.

RESEARCH METHODOLOGY

3.1 Introduction

This chapter aims to identify the methodological approach of the research and outline the chosen methods for determining the extent to which the practice of reduction of rework in the

UK housing subcontractors. An essential aspect of scientific research is deciding how to conduct research, the most appropriate methods to collect the data, and synthesising the collected data to ensure the research aims and objectives are met. This chapter also justifies the choice of data collection method adopted and presents a discussion of the analysis used for the research.

There is a particular focus on subcontractors' contribution to the development of housing projects. This research is centered on housing subcontractors' collaboration on how to minimise rework among contributors, address the housing shortage, and provide solutions to the insufficient supply concerning high demand in the UK housing market. In doing so, the research adopts different methods and approaches which can provide answers to this problem. This varies from established procedures to more recent innovative strategies and solutions that this study can develop. This chapter describes the research philosophy that justifies and leads the research approach adopted, including the ethical consideration. This is followed by the ethical issues and approval guided by the LSBU's research ethics policy for ethical consideration in a research project. The chapter also sheds light on the broader research approach aligned to the current research project, followed by a discussion on qualitative and quantitative research methods. The data collection tools used in this research are also explained. This is followed by the description of the participants and the data analysis techniques adopted.

3.2 Research Philosophy

Holden and Lynch (2004) suggested for every researcher understanding some fundamental questions require essential consideration, such as "What to research" and "How to conduct the research". However, the purpose of these questions is to answer the question of "Why research is important?". the aim and objectives are established for the research answers the first question. However, a synthesis of the extent literature aided the choice of the research method. This helped to identify how to conduct the research more profoundly than just the practicalities, but something is more far-reaching, which is the philosophical solution that justifies the purpose of the study. Machamer (2004) considered the term "Philosophy of Science" as an area of the study that explains the exact way in which epistemology and ontology influence the process and structure of social research. Easterby-Smith et al. (2008) identified these points as helping to clarify research design which deals with the methods by which data are collected and analysed, the appreciation of the workability of designs, and knowing philosophy, which also helps to identify and creates designs that might be outside the researcher's previous experience. The knowledge of philosophy requires the researcher to make some core assumptions regarding two dimensions to the research, including the nature of science and the nature of the society (Holden and Lynch, 2004).

Some parameters describe beliefs, assumptions, perceptions, the nature of truth and reality and the knowledge of that reality. These parameters have a strong ability to influence how the research is undertaken from the beginning of the design through to the conclusions. Kothari (2004) noted that the discussion and understanding of these aspects of the study intend to help with nature and the aim of the research and ensure that the researcher's biases are identified, understood, exposed, and minimised the "Research Philosophy". (Holden and Lynch, 2004) claimed that it is essential to comprehend the philosophical stance that is the knowledge-centred, and it helps the researcher chooses the appropriateness of the methodology.

This research aims is to develop a strategic framework for rework minimisation practice in the UK housing supply chain. To achieve the aim and objectives, several methodologies are presented to the researcher for data collection which has been considered. Gittins (1997) argued that choosing the appropriate research methodology is essential, as it determines the research methods to be adopted. When selecting an appropriate research method, the two main factors that can be considered, are the specific research questions and the topic to be researched (Remenyi et al., 1998). While reviewing the research methods, Jobber (1991) argued that it is wrong to claim that one method is superior in abstract terms, as every method has its strengths and limitations.

In this research, the researcher has chosen to lean towards pragmatism (qualitative and quantitative methodology) as the most appropriate research philosophy. Figure 3.1 presents the research approach for the purpose of the study based on the concept of “research onion” adopted by Saunders et al., 2019). As previously discussed, the research is placed in a pragmatism philosophical stance, with a combination of inductive and deductive approaches employing mixed methods in a cross-sectional study in which they induce knowledge from the participants.

The purpose of mixed methods research (MMR) design is to attain data both from qualitative and quantitative research. The semi-structured interview was carried out to understand and probing the root causes of rework more in-depth from participants' perspective. Hence, a cross-sectioned questionnaire was conducted for this research. The quantitative research was designed and conducted based on the results of semi-structured interview to further provide rework minimisation practice in the housing supply chain.

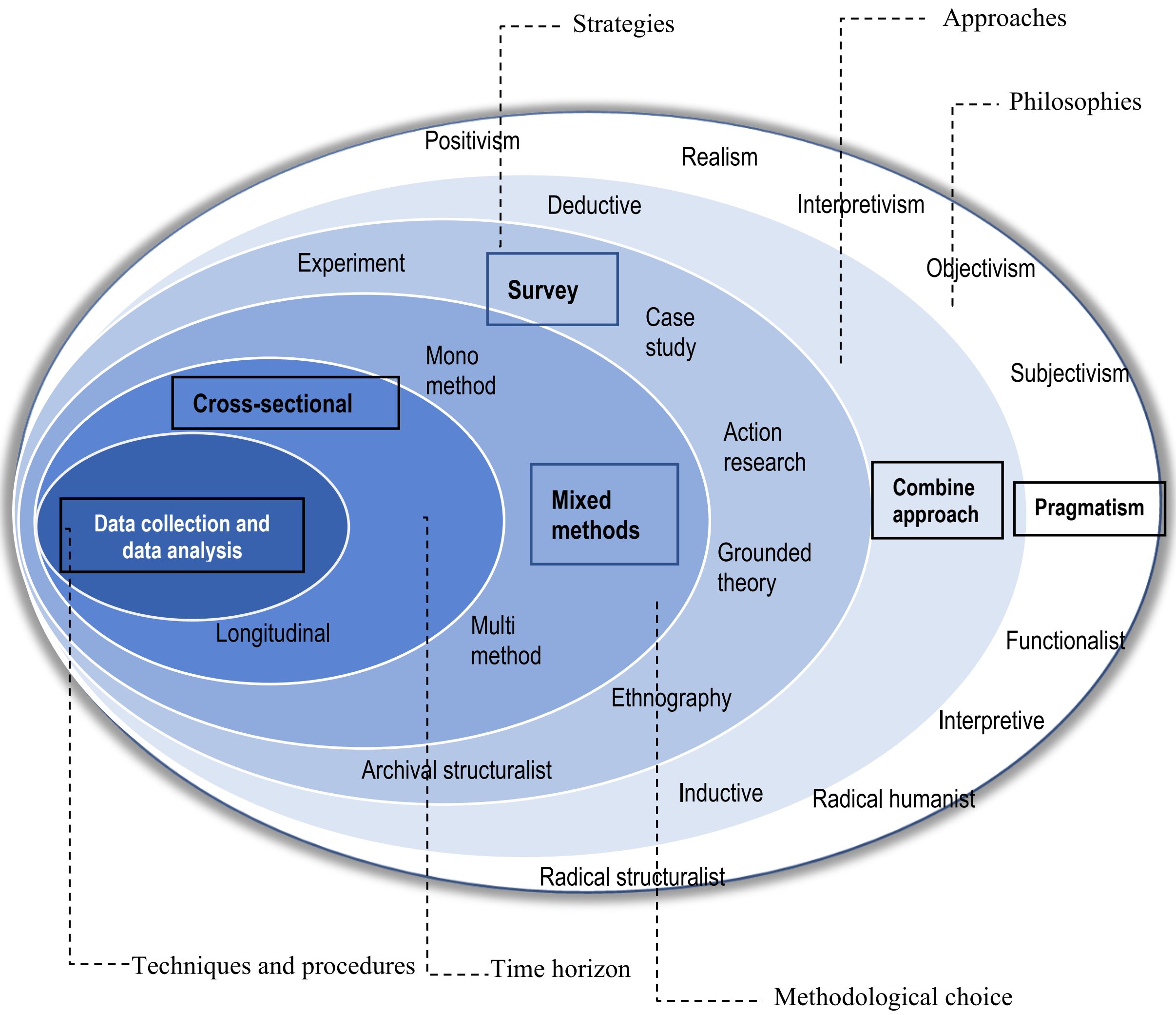


Figure 0.1 The research methodology based on the "research onion" (Saunders et al., 2019)

There are several research paradigms, which can be roughly categorised as either alternative paradigms (i.e., realism, interpretivism) or dominant paradigms (i.e., positivism) (Saunders et al., 2007). The default paradigm for the most scientific research is positivism. It assumes an ontological position: there is a true reality that is discovered using rigorous, empirical, and mostly quantitative study (Guba and Lincoln, 1994). The Positivists paradigm is not suited for this study for the fact that positivist researchers detach themselves from the research problem and are, hence, not able to interact with all the respondents deeply and subjectively as it is a key requirement for this study to understand the research problem in-depth from the practitioners' experience and their perspective (Yin, 1994). All the uniqueness of the organisational structure, construction projects, culture, and human resource motivation need a careful consideration for a better understanding of their influence on the performance of a project. Also, the research problem requires an investigation into the managerial, and supervisory practice of rework reduction in the UK housing subcontractors. As housing companies, subcontractors and experts are involved in construction projects which is experiencing constant changes, making it impossible to the study under the same circumstances as positivism requires and relies on facts. This is, however, not possible in this instance. Considering these essential facts, positivism as a scientific research paradigm is therefore deemed unsuitable for this study.

Similarly, this research adopted an interpretive approach which is the research philosophy for the qualitative study. This is because the interpretive approach allows for an in-depth perusal of the details of the situation and an attempt to understand the reality that perhaps influenced that situation. From the interpretive view, it is essential to explore the subjective meanings that motivate people's actions to understand the intention better. Furthermore, the research strategy applied for this study is the descriptive approach since it aims to collate first-hand information from multiple projects and their teams in different construction organisations. Although the epistemological position of this research leans towards interpretivism and deploys the qualitative strategy, combining it with some aspects of the quantitative strategy from positivism philosophy provides a richer outcome, as adopting just one paradigm may offer a limited window to the research (Mingers, 1997). This enabled the study to understand and analyse some quantifiable views, which are also important objectives of this study.

As a result, A sequential exploratory research method involving semi-structured interview and questionnaire survey was chosen for this study as it helps to neutralised biases characterised in any single methods or eliminate biases of several methods for a study. Multi-methodology is emerging as a popular research methodology where more than one research methodology is combined in whole or part within an intervention. Although Fellows and Liu (2008) emphasised that the established practice is that a research study must identify with a paradigm, multi methodology approach is attractive and possibly produces the best results in social science research, which can cover the complex nature of construction industry where qualitative and quantitative methods should be seen and applied complementarily rather than competitively and mutually exclusive (Dainty and Murray, 2007). Although this research was adopted a multi-methodological pluralism approach, greater emphasis will be placed on the quantitative strategy to the end. The blend will yield an improved result in this research study to determine how rework minimisation practice in the UK housing subcontractors can be achieved. Similarly, the proposed epistemological, philosophical position of the study leans towards "Interpretivism", whilst the ontological position leans towards "Constructivism". In terms of the axiological philosophical position, a stance leaning towards "Value-Free" (Creswell, 2014; Saunders et al., 2012) was followed. In the same vein, the methodological approach is pluralistic or multi-methodological. The nature of the study demands to employ both quantitative and qualitative research.

3.3 Ethical Consideration Risk and Data Management

The researcher complies with the guideline indicated by LSBU's research ethics policy for ethical consideration in the research project. The researcher needs to take ethical consideration into account and stimulate the integrity of the research to protect participants by building trust. In this way, data from people can be collected (Creswell, 2010). All considerations surround several criteria, such as the design of the research itself, the participants, and data collection and data analysis. This research is more concerned with the integrity of the study than any moral implications as there are no groups exposed to vulnerability. In addition to this, the researcher developed an informed consent form for participants to sign before engaging them in research (Creswell, 2010). The form acknowledges that the participant's right was protected. Factors of the form that were considered during the data collection (Sarantakos, 2005) are as follows:

1. Identification of the researcher
2. Identification of the sponsored institute
3. Identification of selected participants
4. Identification of the research purpose
5. Notation of the risks to the participant
6. Assurance that the participants can withdraw at any time

The research project followed appropriate procedures for collecting, handling, storing, transferring, and disposing of data. These procedures must comply with the University's requirements and legal data requirements and those of any data-relevant providers or funders. Expectations outlined the University's research data management policy were met. In addition, responsibilities set by the University's policy for research data management were also considered. Likewise, the data protection policy set by the University and guidelines for handling personal and companies' data were adhered to during the data collection and analysis. A comprehensive risk analysis was conducted for all the possible risks around the research project. For instance, for the availability of experts to participate in the research a large number of housing construction projects were nominated to assign experts for the research which was mitigated the issue of experts' availability.

As a critical principle, all responses from the experts remain confidential, including companies' and the participants' names. Access to the data was only available to the researcher and his supervisors. All personal data were coded or anonymised not to be linked to the companies who supplied it. The anonymized responses were stored separately from identifying details (such as companies' names, emails, addresses, etc.) in password-protected files. Although it is expected that experts wish their responses to be anonymized, in cases where some companies wish to be named, their wishes were also considered.

The participants' responses were kept confidential and only available to the researcher involved in the study. According to the ethical considerations of the university, data documentation was kept in a locked desk and cabinet. In other words, no papers related to data collection or analysis were left on desks or tables as unauthorised people might have access to them. Electronics files were also being kept on a removable data stick and an external hard memory locked, and the data were sorted in a password-protected computer. All related passwords were kept secure and secret and were changed regularly. These passwords were available to the researcher involved in the study based on the university policies. To minimize the risk of mishandling, all the information was handled in one place rather than being duplicated and held in various places.

Responses of the surveys were also kept for an appropriate time after the end of the PhD research based on the suggestion and policy of the university. Once survey data is no longer required, it will be disposed of securely and sensitively. As suggested by the data management policy, any disks which have held confidential information is better to be destroyed rather than erasing them. Also, data on paper should be shredded.

3.4 Research Method

A mixed method research is adopted for completing this research project. This involves the qualitative and quantitative form of research. Quantitative research stresses quantification in data collection and examination. It takes a deductible way to connect theory and research, and stress is kept on the confirmation of hypotheses. The quantitative research method integrates the norms and practices of the natural scientific model and positivism. It views the social phenomenon as an outer objective truth (Cooper et al., 2006). On the opposite side, a qualitative approach stresses words and contexts despite quantification in data acquisition (Opdenakker, 2006). It focuses on an initial approach in the connection between hypothesis and research and the spotlight is settled on the development of speculations. The process of quantitative and qualitative research is further summarised in Figures 3.2 and 3.3.

Figure 0.2 The Process of Quantitative research (Graue, 2015)

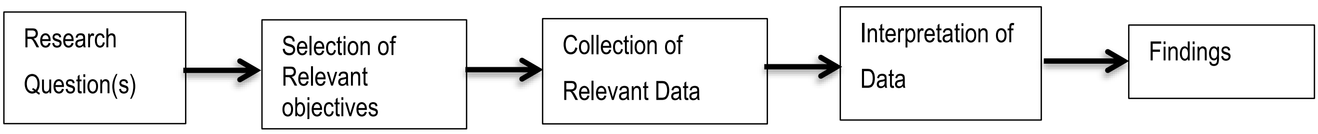


Figure 0.3 Process of Qualitative Research

An early definition of mixed methods came from authors in evaluation (Greene1997; Caracelli and Graham, 1997). In this study, the mixed-method designs are defined as those that include at least one qualitative method (designed to collect words) and one quantitative method (designed to collect numbers), where neither type of method is inherently linked to any particular inquiry paradigm. Tashakkori and Teddlie (1998) defined mixed methods as combining "qualitative and quantitative approaches in the methodology of a study".

MMR has evolved to the point where it is a separate methodological orientation with its worldview, vocabulary, and techniques" (Tashakkori & Teddlie, 2003).

Creswell and Clark (2007) defined the mixed method of research as a research design with philosophical assumptions and methods of enquiry. As a methodology, it involves philosophical assumptions that guide the collection and analysis and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analysing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of qualitative (exploratory) and quantitative (descriptive, experimental) approaches, in combination, provides a better understanding of research problems than either approach alone.

In MMR, the researcher:

- Collects and analyses persuasively and rigorously both qualitative and quantitative data (based on research questions);
- Mixes (or integrates or links) the two forms of data concurrently by combining them (or merging them), or sequentially by having one build on the other, and in a way that gives priority to one or both;
- Uses these procedures in a single study or multiple phases of a program of study;
- Frames these procedures within philosophical worldviews and a theoretical lens; and
- Combines the procedures into specific research designs that direct the plan for conducting the study.

MMR is a type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for breadth and depth of understanding and corroboration.

Greene (2007) also stated that mixed methods were an orientation toward looking at the social world that actively invites researcher to participate in dialogue about multiple ways of seeing and hearing, various ways of making sense of the social world, and multiple standpoints on what is important and to be valued and cherished.

MMR has four different major types based on the form of data collection, which is done either concurrently or sequentially: triangulation design, embedded design, explanatory design, and exploratory design (Creswell & Clark, 2007). A sequential exploratory mixed-method approach involving interviews (as the core component) and a comprehensive survey questionnaire (as the supplemental component) is suggested to identify the current condition parameters and future direction for rework minimisation factors at the housing supply chain. For this study, the exploratory design or exploratory sequential design, first, the qualitative data as the core component is collected and analysed. Then, the researcher uses the results to form variables, instruments, and intervention. After that, quantitative data as the additional component is collected and analysed based on variables, instruments, and intervention from the core component. The quantitative data is collected from varying and generalised conclusions from the qualitative data. Finally, the researcher interprets how quantitative results provide new and fine results.

Mixed-method research has been defined as a philosophically underpinned model of inquiry combining qualitative and quantitative models of research so that evidence may be mixed, and knowledge is increased in a more meaningful manner than either model could achieve alone (Creswell & Clark, 2007). This method of inquiry is most suited to achieve the research aim and objectives. As the researcher tried to understand the causes and sources of rework occurrence from experts' perspective who are actively engaged in day-to-day activities in the housing supply chain. Following a literature review, several contributors (ranging from contractors, architectures, engineers, site managers, supervisors, and subcontractors) from the UK housing supply chain were interviewed face-to-face. Companies with up to £50 million annual turnover were considered as SMEs (Tezel et al., 2017). Overall, the research approach adopted in this research project is briefly summarised in Figure 3.4.

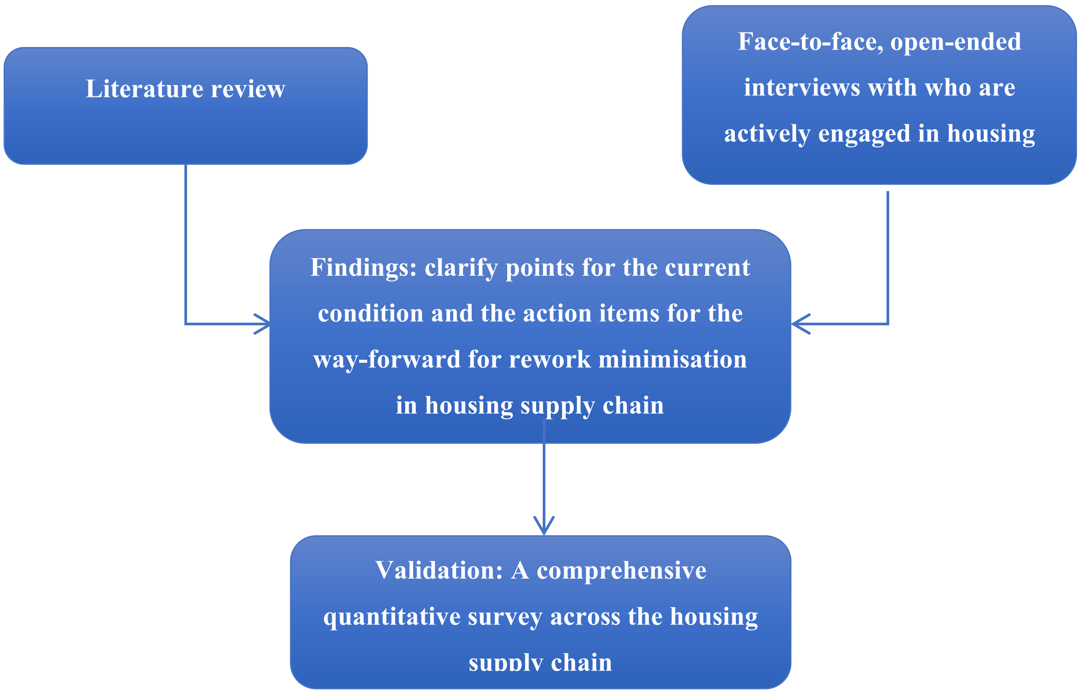


Figure 0.4 Illustration of Research Approach Adopted in Research Project

3.5 Review of Literature

A literature review was conducted to build up knowledge of the problem, first in the area of housing supply chains focusing on collaborative working practices and secondly in construction rework and defects. The supply chain literature is expected to be extensive and the defects literature more modest. More specifically, the current practices of rework minimisation implemented by SMEs in housing construction companies in the UK and the barriers have not also been investigated in literature review. Considering the limited research on rework minimisation in the housing supply chain in the UK, the objective of next phase of study is to explore, define, and understand the underlying causes and factors associated with rework occurrence in the housing supply chain among different subcontractors those who are actively engaged in day-to-day activities in housing construction projects.

3.6 Qualitative Research Interviews

3.6.1 Definition and History

Interviews are recognised as the most widely method in qualitative research (Bryman, 2006). However, there are other methods to be conducted for a qualitative study such as focus group, case studies and observations, with each have advantages and disadvantages, nevertheless, interviews are a great method when there is an exploratory or explanatory element to the research (Pojasek, 2005). Considering the exploratory and explanatory nature of the proposed questions of the research – interviews were chosen as the method to understand the phenomena of the problem and capture the qualitative aspects of the research. A semi structured interviews were designed for the purpose of the research to gather the information (Miles and Huberman, 1994).

Interviews can be explained as a meeting of people face to face, especially for consultation. However, a qualitative research interview is defined as a non-leading interview focusing on personal experiences which builds rapport with the interviewee. Charles Booth is the individual generally credited as the first to develop a social survey that relied on interviewing. In 1886 Booth embarked on a comprehensive survey of the economic and social conditions of the people of London, published as the *Life and Labour of the People of* London (2008).

The main characteristics of the qualitative research interview at early ages (i.e., the 1920s) were:

- Interviews began within a positivist social-science tradition.
- The interview was established to secure information.
- Participants were viewed as "informants" seen to possess the knowledge to inform a fact-finding mission.

In the 1940s and 1950s, information gathering roles became formalised. There was still an emphasis on questions being asked identically each time for each respondent. This was based on a view that data obtained would have greater validity and less bias (standardised instruments).

In the 1960s and 1970s, there was a movement from standardisation to discovery. Standardisation is seen to be associated with hypothesis-based, positivist research. However, a move away from this began by greater emphasis on interaction within an interview and dynamic interaction between interviewer and interviewee. As highlighted by Taylor & Bogdan (1989, p. 77): *"...the interviewer role entails not merely obtaining answers but learning what questions to ask and how to ask them"*.

In the 1990s, a separate qualitative strand of interviewing which was different to "robotic" standard survey interviewing, evolved.

As mentioned earlier, considering the limited research on rework minimisation in the housing supply chain, the objective of this phase was to explore, define and understand the underlying causes and factors of "rework" among different contributors who are actively engaged in day-today tasks of housing construction development projects. This was a critical phase of this study as it laid a solid foundation for the rest of the research to carry on.

3.6.2 The importance Interview

The researcher perspective for an interview is that "I interview because I am interested in other people's stories" (Seidman 2006, p.7). Stories or experiences are a way of knowing. Telling a story is meaning making (people select formative details, reflect on them, give them order, and make sense of them). Therefore, interviewing requires an interest in other people's stories/experiences.

Qualitative research interviews involve gathering facts and information about participants not to form advice or treatment plans. Through qualitative research interviews, the researcher elicits stories and learns about events, meanings, emotions and experiences, and relationships, not discussing internal states and processing sources.

3.6.3 Challenges to Qualitative Research Interview

Despite the advantages of a qualitative research interview, there are challenges to implementing a successful interview study. Some of those are:

- Can be time-consuming
- Generates a large amount of data

- Can be costly if the researchers hire an expert to professionally transcribe the interviews
- Can be challenging depending on the participants and depending on the topic for discussion
- Need to think carefully about design and sampling to answer the research question/s

In addition, some major ethical issues might be raised. Issues include privacy, informed consent, identification of participants, deception (survey interview that followed), confidentiality and anonymity, the researcher's safety, and benefits versus risks. Fortunately, most of the issues mentioned earlier are commonly covered in ethics applications at most research organizations. Four ethical tensions in a qualitative study design can be mentioned (NHMRC, 2007), including:

- **Generalizability**: question of sufficient detail
- **Sample Size & Saturation:** question of aims of study
- **Validity**: participant numbers and findings
- **Reliability:** is the project biased due to subjective nature (question of "authenticity")

It should be appreciated that qualitative research seeks to generate data about human experiences and understand complex processes/experiences by investigating how people make sense of and interpret experiences.

Research engagement is not passive. In a qualitative research interview, participants risk intrusion, distress, and misrepresentation, resulting in the research being regarded as suspicious and researchers being mistrusted. However, motivations to participate may include economic gains, altruism, expression of satisfaction or citizenship, activism and assistance, and some find participation therapeutic.

Another critical issue in a qualitative research interview is how much data is required. It should be noted that, this is not a procedural question in qualitative research. Interview data provides the primary raw material but how much the researcher need depends on what we want to make with it (Baker & Edwards, 2012). Therefore, the amount of required data is linked to the research purpose.

The concept of sample size in qualitative research is linked with "saturation" (originally linked with grounded theory studies). Saturation can be used to justify a small sample with "thin" data. As highlighted by Marshall et al. (2013): *"Saturation is the key to excellent qualitative work...but there are no published guidelines or tests of adequacy for estimating a sample size to reach saturation*".

Some general figures for sample size in a qualitative research interview can be as follows (Denzin & Lincoln, 2011; Marshall et al. (2013):

- Grounded theory studies – 20 to 30 to 50 interviews
- Phenomenological studies – 6 to 8 to 10

There are no rationales provided for these figures. However, they can be based on as many experts suggest them in a qualitative research interview.

There should be a proportional sampling framework and the approaches should be purposeful and convenient with maximum variation.

Internal and external constraints affecting the sample size in a qualitative research interview can be time, the scale of the project, funding and resources, experience with qualitative interviewing and access to research participants.

3.6.4 Semi-Structured Interviews

After the review of literature, semi-structured interview questions were designed to understand the underlying causes and the nature of "rework" among different contributors in the UK housing supply chain. As there was a need to explore the responses from the selected participants. Semi-structured interviews applied to understand the relationship between variables, in particular those revealed through a descriptive study (Saunders et al., 2019). Therefore, it was expected that semi-structured interviews can assist to establish the relationship between practitioners and rework occurrence in housing development projects.

The first section of the interview was focused on the background and the experience of each participant involved in housing construction projects. Section two tried to understand the root cause of rework among subcontractors in the housing supply chain. There was limited information in the literature review, particularly on housing construction developments. In section 2 the focus was on the causes and sources of rework. Section 3 of questions are around current strategies, and practices subcontractors or SMEs might take to prevent rework generation. Sections 4 and 5 focused on the barriers to implementing a rework minimisation strategy and future directions for avoiding rework occurrences. The interview questions which have a total of five sections used in the face-to-face interview are provided in Appendix 1.

3.6.5 Interview Sampling Strategy

The primary advantages of open-ended interviews are that they can provide more detailed information on a subject matter than survey studies and their potential to reveal rich insights for exploratory research (Berg, 2004).

Once the nature of the interview questions was chosen, the next step was to determine the sampling strategy of the interviews. Bryman (2016) suggested in qualitative research there are always two approaches for sampling strategy namely probability and non-probably or random sampling. For the purpose of the research random selection of participants were impossible as the researcher selectively recruited participants as the demographic of each participant were critical to serve the purpose of the interviews. A sequential sampling strategy was applied to select participants. (Teddlie and Yu, 2007).

The interviewees were identified under a purposive sampling strategy from managers actively engaged with rework minimisation in housing construction projects. Interviewees who have roles in housing supply chain (from clients to Subcontractors) invited to participate in the research. This is to capture a more complete picture of the issue across the entire supply chain, an important aspect of interview reliability (Shao and Müller, 2011).

To further increase interview reliability and validity, supervisors and peers were reviewed the interview protocol. The data and the analysis were linked to the existing literature as much as possible (Miles and Huberman, 1994; Shao and Müller, 2011).

There is no such a “gold standard” which could calculate the number of certain participants to interview (Luborsky and Rubinstein, 1995), however, the rule of thumb is to attain saturation (Baker and Edwards, 2012). For this study, considering the constraints of time and cost, the process of interview was continued till a level of saturation was achieved in each category of responses. Theoretical saturation applied that there is not necessary to continue with data collection regarding each category, instead the researcher should follow on with the other objectives of the research such as testing of the hypotheses (Bryman, 2016). Guest et al. (2006) stated that number of 12 interviews of a homogenous group is required to reach a saturation level. Overall, a total number of 17 interviewees were conducted across different stakeholders in the UK housing construction industry over a course of 6 months (October 2019 to March 2020).

The attempt was to follow the time allocation of 30 to 45 minutes for each participant during the interview. Each interview was recorded on a digital audio device and then transcribed and interpolated into the NVivo software for coding and data analysis. The demographic details of the participants of the interviews are shown in Table 3.2. After the literature review and analysis of the interviews, points for the current rework minimisation conditions and practices in the SMEs and required actions for the way forward were identified and will be discussed in Chapter 4.

As the research was focused on subcontractors and SMEs in the UK housing construction, the researcher identified potential companies who are categorised under SMEs and/or subcontractors in the UK construction industry. The definition of SMEs according to the UK government, a micro company has less than 10 employees and annual turnover under 2 million Euro, small company is one that has a turnover > 10 million Euro, and up to 50 employees. A medium-sized company has a turnover of up to 50m Euro and equal and less than 250 employees.

Table 0.1 Demographic details of participants (Interviews)

Stakeholders	Size	Interview(s)
Supply chain stakeholders		
Developer A	Medium	Director
Developer B	Medium	Project manager
Developer C	Small	Head of projects
Developer D	Micro	Client
Architect / Consultant A	Medium	Senior Consultant
Architect / Consultant B	Small	Consultant
Architect / Consultant C	Small	Senior consultant

Main contractor A	Medium	Head of engineering
Main contractor B	Micro	Engineering
Main contractor C	Medium	Supervisor
Main contractor D	Small	Project manager
Subcontractor A	Small	Procurement
Subcontractor B	Small	manager
Subcontractor C	Micro	Head of quality
Subcontractor D	Micro	Operations manager
Subcontractor E	Small	Supervisor
Subcontractor F	Small	Technical manager
		Mechanical manager
Total	**17**	

3.6.6 The Process of Interview

Concerns associated with operationalisation and validity of the statements (how statements/concepts are represented and measured) were mitigated by implementing pilot interviews before the main round of interviews conducted. A total of three pilot studies carried out to minimise the bias of the design instrument, clarity of each question, test the recording device, and assess the required time for the interview, where the participants chosen from construction management researchers at the School of the Built Environment and Architecture at the London South Bank University. This helped the researcher to have a practice session prior moving into the main interview series.

After carrying out research to identify prospective participants – a follow-up dissemination of three documents was conducted: an interview schedule, participant information sheet and consent form (Appendix 1). All the documents were sent by email to all selected interviewees a week earlier to allow participants to prepare for the interview questions. This allows to achieve a wealth of information relevant to the questions (Fowler, 20002) and as comprehensive an understanding as possible of the current issues with the housing supply chain.

The interview schedule comprised: aim, interview agenda, and all questions to be raised during the interview; participants information sheet, which induced the contact information of the researcher and the university address, a brief background of the research and other information such as; for example; how the interview will be carried out , the duration of interview, recording device and ethical consideration pertinent to interviewees, and gathered information during the interview such as; confidentiality how the information will be treated after data collection procedure. A sign off from both the research investigator and interviewee to agree upon to fulfil the London South Bank University Ethic committee requirements.

The structure of interview questions adopted to facilitate the discussion of the topic in which the perspective of the interviewees was critical. Therefore, further probing questions were posed to interviewees (Hannabuss, 1996). Probing questions explored concurrent issues from the comprehensive literature review, and interviewees. With a permission of each interviewee, each interview was recorded digitally as it helped the researcher to ensure the accuracy of data and objectivity in recording of participants (Hannabuss, 1996; Fellows and Liu, 2008).

All participants were interviewed face-to-face at the office of the interviewees. Each interview lasted 45 minutes, as the researcher attempted to follow the time allocation. All the interviewees were digitally recorded with a recording device and notes were taken during each interview. After each interview – the interview transcribed and transferred into NVivo software programme for data analysis. Overall, 17 interviews were carried out over 6 months. Figure 3.5 illustrates the process of an interview.

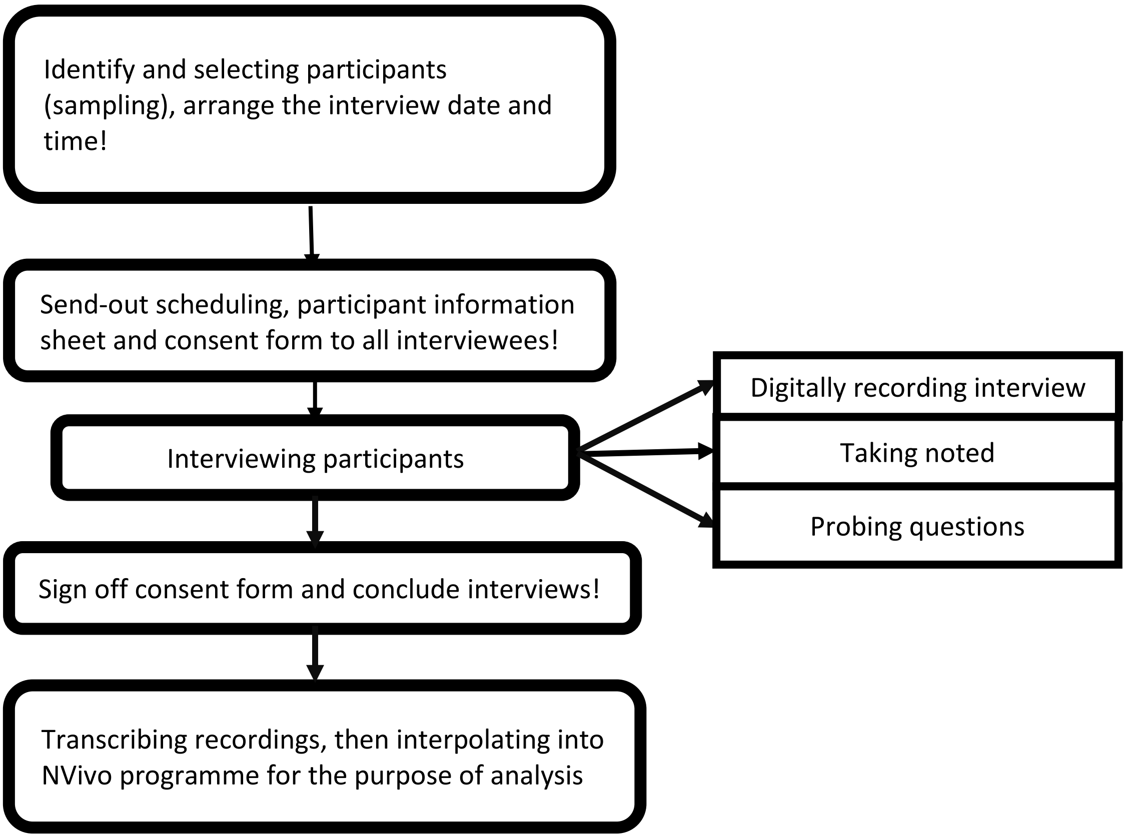


Figure 0.5 The process of interview steps

3.6.7 Data Analysis of Interview

After transcribing each interview and importing into NVivo software for data analysis - each identified meaningful theme emerged from the software. The next chapter will be discussed the analysis of data more in details.

3.7 Quantitative Research, Questionnaire

To validate, prioritise and perform further analyses on the interviews, a questionnaire survey was designed. A questionnaire is a very cost-effective method, which will cover a large number of respondents and consequently has a higher generalisability of the results (Oyedele, 2013). The questionnaire design first was validated through a pilot study of the respondents to assess the flow, relevance, the degree of depth, the clarity of language, and length (will be discussed more in detail in Chapter 5). After evaluating the questionnaire on a small sample, necessary adjustments and minor modifications were made before it was used in the actual data collection.

The questionnaire was distributed among practitioners across the supply chain. The questions for the questionnaire focus on:

- Root Causes of rework
- Current practices for rework minimization
- Barriers to implement rework minimization strategies
- Strategies for future actions by housing supply chain actors

The target participants of the questionnaire were a wide range of developers, contractors, subcontractors, engineers, and architects with experience of working within UK housing supply chain. However, higher number of participants (e.g., 100) is desired for this quantitative stage.

After the first draft of the questionnaire, a pilot study was conducted. Through the pilot study the level of ease at which respondents were able to complete the questionnaire was tested. The clarity of the language, the appropriateness and the logic of the questions, the layout, the degree of depth, the ease of navigation and user friendliness of the whole questionnaire were examined through the pilot study. Furthermore, there was a chance in the pilot study to ask the respondents if there were other statements beyond the draft questionnaire.

Last version of the questionnaire was sent to about 268 participants, and 108 responses were received, then the data was collected accordingly. Any questionnaire without a signed consent was rejected and not included in the data analysis. Similarly, any questionnaire in which less than 50% of questions were not answered were excluded from data analysis. This was done based on the fact, which mean score based on less than 50% of items is not considered as valid. The final questionnaire used in the data collection is provided in the Appendix at the end of the thesis.

3.7.1 Sampling Strategy

The target participants of the questionnaire were a wide range of contractors, subcontractors, site engineers, supervisors, and skilled workers with experience of working within the UK housing supply chain. This will be discussed more in detail in Chapter 5.

3.7.2 Participants

To collect the opinion of the experts for the quantitative part of the research, contractors, architectures, construction managers, site managers, supervisors, subcontractors, and skilled workers working who are actively engaged in the UK housing supply chain were chosen to send out the questionnaire for data collection. The participants were not aware of who else is participating in the survey. This is to prevent any potential bias of the research. The researcher tried to quantify the total number of small house builders and subcontractors in the context of UK housing sector. However, there are a large number of small privately owned companies whose employees are less than 4 people and were not registered in the UK housing sector. It is important to note that the construction industry compared to other industries has an extensive number of supply chain engaged in the development of housing projects. The UK construction industry comprises almost 300,000 companies involved with site preparation, construction, improvement, repair, installation, and services, and the sector employees 2.2 million of people to which contribute 7.5% of the UK employment ration (ONS, 2009). Table 3.3 presents data from Office National Statistics related to the number of private house builders and specialised trades within the context of UK housing sector. The number includes some of the companies which were temporarily inactive. The total number of registered specialised trade account for 121,005 in 2009 (ONS, 2009).

Table 0.2 Number of house builders based on different trades

Size of firm by number of employees	House builders	Subcontractors (specialist trades)									All trades
		Demolition	Roofing	Plumbing	Plastering	M&E	Floor & wall covering	Painting	Glazing	Other work including completion	
1	9,012	545	2,812	10,924	**1,453**	**11,078**	**2,455**	**2,877**	**1,378**	**14,516**	
2 to 3	9,651	317	2,342	8,468	1,110	8,261	1,882	2,343	1,618	5,833	
4 to 7	5,701	209	1,440	4,203	605	4,876	922	1,294	1,049	2,148	
8 to 13	1,922	120	489	1,523	190	1,997	346	454	391	1,165	
14 to 24	779	99	308	747	70	1,089	171	229	130	362	
25 to 34	219	37	80	219	33	340	36	80	23	369	
35 to 59	239	46	81	203	19	285	31	77	25	103	
60 to 79	81	12	12	64	6	68	5	18	5	93	
80 to 114	59	11		47	6	59	5	13	5	101	
115 to 299	87	12	11	47	-	68	-	10	5	32	
300 to 599	26	12	9	-	-	17	-	10	5	7	
600 to 1199	9	12	-	-	-	7	-	-	-	12	
1200 and over	6	-	-	10	-	7	-	-	-	12	
Total	27,791	1,406	7,584	26,454	3,492	28,155	5,852	7,395	4,623	36,043	**121,004**

As part of this research, the data were collected through a total of 108 questionnaires. There are different statistical methods through which the sample size can be validated. However, the sample size increases when the population size increases. If the sample size is calculated based on the population size, then it is easy to generalise the research findings. The common equations normally used for the size of the estimation are provided in equations 3.2, 3.3 and 3.4.

$$Sample\ Size = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1+\left(\frac{z^2 \times p(1-p)}{e^2 N}\right)}$$ …………….. Equation 3.2

Where;

N = Population Size

e = Margin of error

z = z-score

"e" which is the margin of error is noted in percentage, for calculation this is converted into decimal form (for example, if the margin of error is considered as 3%, then in equation 3.2 it will be used as 0.03).

The z-score is the number of standard deviations a given proportion is away from the mean. The z-score can be obtained from table 3.2. In some cases, the sample size calculated by these equations could not be helpful or even not adoptable. For instance, the population is the 'population of China'; then the sample size calculated through these equations will be very large and thus could not be achieved.

Table 0.3 Z-Score for Different Confidence Level

Required Confidence Percentage	**z-score**
80.0%	1.28
85.0%	1.44
90.0%	1.65
95.0%	1.96
99.0%	2.58

Similarly, a simpler formula for sample calculation was suggested by Yamane and Sato (1967) as shown in equation 3.3.

Where;

n = size of the sample

N = size of population

e = precision level

For instance, equation 3.3 is used to determine a sample size (n) considering the population size (N) of 100,000, and the level of precision (e) as 5%, thus the value of sample size (n) will be 399 participants.

Finally, the equation developed by Green (1991) is indicated in equation 3.4.

N > 50 + 8p ……………………Equation 3.4

Where;

N = Sample Size

p = number of predictors.

Using the above equation and considering the questionnaire which aims to target at least 100 responses, the p-value can be 5 or 6. Thus the sample size can be as under:

For p = 5

> 50 + 8x5 = 90 < 100; thus, can be acceptable

For p = 6

> 50 + 8x6 = 98 < 100; thus, can be acceptable

Thus, in both cases, the sample size is valid. However, the actual responses collected in this part of the research were, however, 108 which is higher than the sample size calculated in the equation 3.4.

Regarding sample size for the interviews, many studies indicate that have used a smaller number of interviews than the number used in this research. Mason (2010) also, in his research entitled "Sample Size and Saturation in Ph.D. Studies Using Qualitative Interviews," reported the result of five hundred and sixty studies and noted that the most common sample size in these studies was 20. While 20 is more than 17 interviews, this research project is based not only on the interviews but also on the questionnaire. Therefore, the sample size for the interviews is justified.

3.8 Data Analysis

After the data collection, there are four stages of data analysis in MMR studies. The first one is preparing data (i.e., data management, tidying up the data, data cleaning, cataloguing), which for qualitative phase, is organising data and transcription of the interviews and for the quantitative phase is coding data and assigning numeric values and recording data to prepare computer analysis (Maxwell, 2013). Once tidying up was completed, the masses of accumulated data will be well organised and more manageable.

The second stage is reviewing and exploring data (i.e., chunking or crunching), which for the qualitative phase is reading data and codes as well as developing qualitative codes using NVivo software and for the quantitative phase is descriptive analysis, looking for trends and distributions (Creswell, 2007, 2005; Creswell & Clark, 2011).

The third stage is analysing data, which for the quantitative phase involves coding data and assigning labels, grouping the data, looking for related themes, and using statistical software. For the quantitative phase, the third stage is to use appropriate statistical tests, using statistical software such as 'statistical package for social sciences (SPSS)', and recording of confidence intervals (Denzin, 2012; Riazi, 2016).

In the qualitative phase of the current study, the data have already been chunked since semi-structured interviews were used. The researcher transcribed all interview audio. Then, the coding process was initiated through NVivo software. Coding can be done on hard copy by hand or by using text management NVivo software that block text with codes and export the blocked text to compare instances and cases. In this research study, the coding will be done on NVivo software.

"Structural Coding generally results in the identification of large segments of text on broad topics; these segments can then form the basis for an in-depth analysis within or across topics" (MacQueen et al., 2008, p. 125). Namey et al. (2008) suggest "determining frequencies on the basis of the number of individual participants who mention a particular theme, rather than the total number of times a theme appear in the text […] a code frequency report can help identify which themes, ideas, or domains were common and which rarely occurred" (p. 143).

The fourth stage is representing the data or as named by some scholars' data display'. For the quantitative phase we need to represent the results in tables, graphs, and figures, while for the qualitative we present the findings in discussion or text form, figures and visuals might be used to represent themes.

Onwuegbuzie and Teddlie (2003) contend that either the visual display of qualitative and quantitative data might be "so compelling that data interpretation can immediately begin without advancing to the other data analysis stages", or the visual display of these data may lead to further types of analyses. The qualitative and quantitative data will then be compared to assess similarities and differences between the two datasets. The researcher can then investigate the commonalities and differences across the factors from the quantitative data to those derived from thematic groups of the qualitative data as suggested by Greene (2007). This stage might lead to new and unexpected perspectives or insights (Caracelli & Greene, 1997).

The content analysis technique was adopted to examine comments written in the last section of the questionnaire. Graneheim and Lundman (2004) guidelines were used for content analysis. Based on this method the meaning units which have the same central meaning, from the comments section were organised from most common to least common. Content analysis is a data analysis technique that is applied to make replicable and valid inferences by defining and coding textual materials. A qualitative data can be translated into quantitative data through a systematic examination of data such as documents, oral communication, and graphics. Although this approach of research has been used widely in the social sciences, only recently has it become more common among organisational researchers. The content analysis technique is common now in organisational research because it permits researchers to find and evaluate the nuances of organisational behaviours, stakeholder feelings, and social tendency. It connects both the quantitative and qualitative research methods by playing the role of a bridge. At one aspect, the content analysis permits researchers to evaluate socio-cognitive and perceptual constructs which are hard to examine through usual quantitative research methods. Similarly, at the same time, it gives a chance to the researchers to collect large samples which are typically hard to adopt in purely qualitative research.

Finally, the results obtained from the previous stages are used to support interpretations, inferences, and conclusions. The fifth or the last step is to merge the results of the two data sets (i.e., data integration) and make sure that "all data are integrated into a coherent whole" (Onwuegbuzie & Teddlie, 2003, p. 377) which can then be located in discussion and consideration of other, similar, research and the particular findings and contributions of this study can be made explicit. As this research has an exploratory sequential design, the researcher first analyses the qualitative phase data and then interprets how quantitative results provide new and better results. The steps mentioned above in the proposed methodology seek three main goals. The first goal is to reduce and organise data into a manageable form. The second is to help assess patterns of connections, trends, and interrelationships in the data and identify any differences. The third is to produce results that should validate and support other researchers' conclusions and inferences (Greene, 2007).

3.9 Framework Development and Validation

After the review of literature, the researcher proposed a framework for reduction of rework in the housing supply chain The framework will be developed and enhanced after the findings of semi-structured interviews and the research questionnaire survey. The outcome recommended a wide gap in developing a mechanism for rework minimisation practice in the housing supply chain. The initial concept for rework minimisation framework development was established based on the principle of critical literature review findings. The characteristics and causes and sources have been identified according to the literature review and the framework will be verified through qualitative and then quantitative research findings. The first version of the framework is proposed in Figure 3.6.

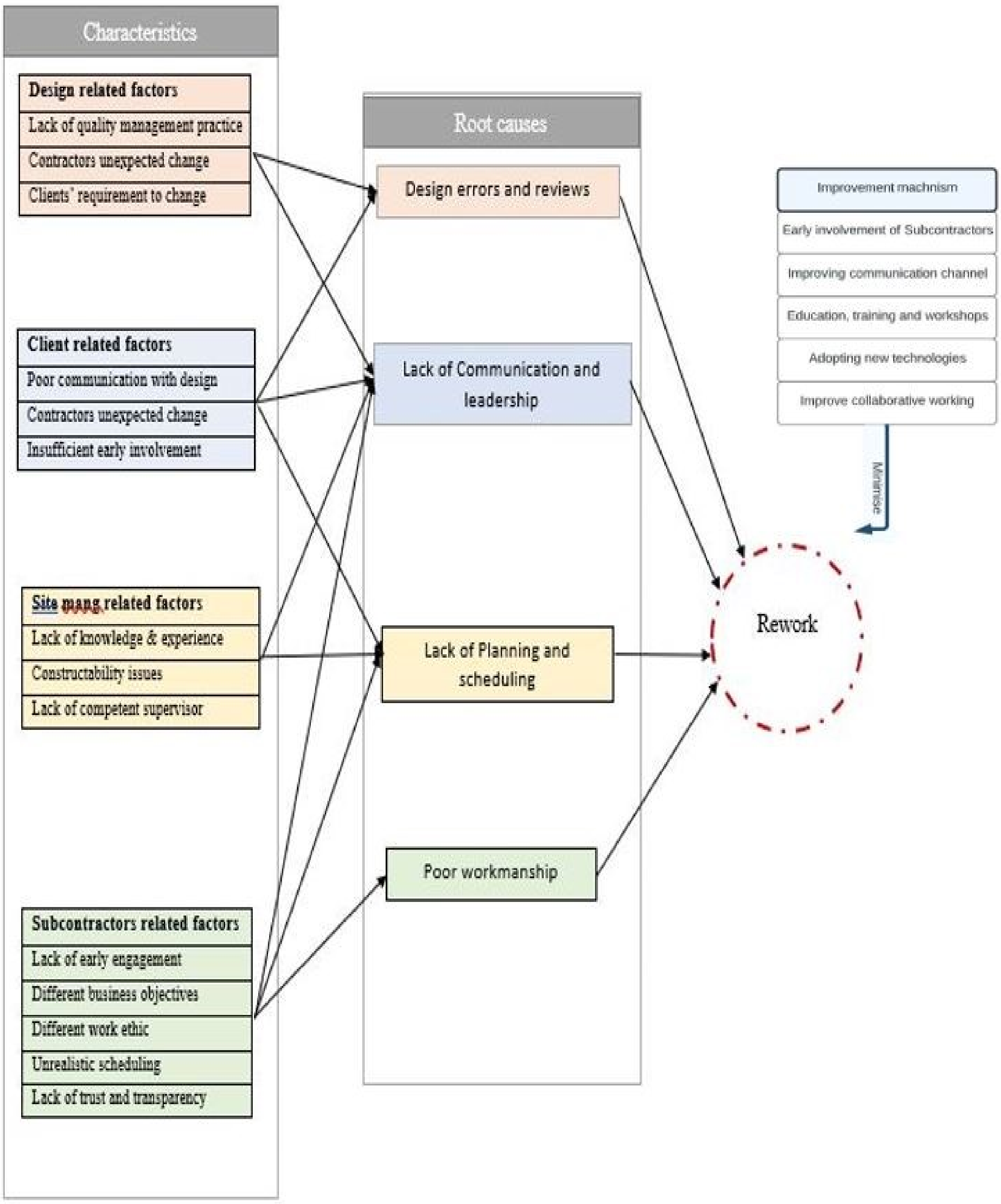


Figure 0.6 The proposed rework minimisation framework in housing supply chain

3.9.1 Rework Minimisation Framework Development Method and Design

The design of the framework structure was developed on the problem-solving methodology principle. The problem-solving methodology often adopted to identify the causes pertaining to a phenomenon and explore means of improving causes (Straker, 1995; Serpell et al., 2002). The key approaches that were constructed to the problem-solving methodology were, 1) run diagnostic of current causes, 2) an identification of barriers and improvement measures for discovered causes for rework minimisation, and 3) future direction for rework minimisation for future projects in the housing supply chain. These tree key factors of problem-solving methodology were used to develop the rework minimisation framework development for this study. Chapter 6 will be discussed the framework more in details.

3.9.2 Rework Minimisation Framework Development Validation Method

Validation is to ensure the credibility and strengthening confidence of the research's findings (Patton, 2008). The purpose of validation is to enhance understanding and explanation (Cronbach, 1984). Messick (1989) noted that "validation is essentially a type of scientific inquiry, that the judgement of validity is an inductive summary of all available information, with problems of meaning and interpretation central to the processes" (Mishler, 1990, p. 418). Hence, these points recommended that validation is a process of judging and help to improve credibility, explanation and understanding the findings of research. Bernard (1994) stated that validation is the collective of judgemental scientific community about the validity of a specific concept and its measures. A similar perspective can be observed through the literature review through the lens of researcher's judgement to the phenomena in generating validity of the findings research (Lincln and Guba, 1994; Cronbach, 1984; Patton, 2008). The process of validity also can be achieved involving reviews from participants who respondent to the research at first place (Lincln and Guba, 1994; Patton, 2008). It allows the researcher to understand and learn the accuracy, fairness, and completeness of the outcome of research findings (Patton, 2008). Therefore, validation process refers to evaluation and judgement of the results of the research's final findings or developed instrument through the engagement of the research cohort community, experts in the particular field and study's respondents.

3.10 SUMMARY

This chapter aims to introduce the research methodology adopted in the research project to achieve its aims and objectives. The chapter briefly outlines the research project's aims and objectives, followed by a detailed discussion on the available research approach suitable for such a project. The research philosophy explained in section 3.2 of the chapter, which explains the rationale behind selecting a mixed research approach for this study. The professional institutions' ethical issues, approval, and guidelines also covered in the chapter. A detailed procedure for data security outlined in the chapter. The chapter also sheds light on the development of data collection tools and links these tools with the existing literature review. The structures of the interview questions and the questionnaire used in the quantitative research part also explained in this chapter. Apart from the history of qualitative research, section 3.6.3 explains the detailed challenges associated with the qualitative research interview. These challenges are associated with time, nature of data, cost, participants, nature of the question, and discussion. The focus of the questionnaire is 1). Root Causes of rework, 2). Current practices for rework minimization, 3). Barriers to implementing rework minimization strategies, and 4). Strategies for future actions by housing supply chain actors are described in detail. The respondents for the interviews and the questionnaire are highlighted in the chapter, which are a). managers, b). site engineers, c). technicians, and d). skilled workers. The chapter further provides justifications for conducting 17 interviews and the second phase of data collection through 267 questionnaires, of which 108 responses were received. The sample size used in this research is further explained in the light of different equations extracted from existing literature. The data analysis procedure for both qualitative and quantitative explained in detail.

Qualitative Data Analysis

4.1 Chapter Overview

This chapter presents the results of the qualitative study as part of the research. A pilot interview was conducted comprised of 3 interviews to assess the flow of the questions, clarity, and the required appropriate time for the main stage of interview. A total of 17 interviews were carried out with different contributors to housing construction developments, such as; directors, contractors, subcontractors, consultants, architects, project managers, and supervisors. A software programming tool, NVivo version 12 was conducted sort and code from the semi-structured interview data. The findings from the qualitative data analysis have been presented in this chapter.

4.2 Introduction

This chapter describes the outcome of the semi-structured exploratory interviews. The interviews conducted with wide range of experts who are actively engaged in day-to-day activities of housing construction projects, and these include; Project Director, Subcontractors, Contractors, Designers and Supervisors. According to Creswell (2014) qualitative research seeks to extract common meaning from the experiences of several experts. Moustakas (1994) stated that two types of data collection methods determine qualitative research are in-depth interviews and focus group interviews. For the purpose of this research semi structured interviews conducted to elicit participants' point of view of a phenomenon (Hancock et al., 1998). The research employed in-depth interview with participants, since in-depth interview enables participants to discuss freely their individual opinions based on their experiences (Creswell, 2014). This provides a deeper understating of a wide range of different perspectives. The semi-structured interviews were based on the result of comprehensive literature review to understand the phenomena of the research and underlying causes from experts' point of view.

The interviewees were chosen under a purposive sampling strategy from identified contributors who were actively engaged in day-to-day construction processes. Number of 3 interview pilot studies carried out to eliminate bias from the instrument and increase the validity and how statements or concepts are presented and measured. In addition to that, before running the main data collection - the instrument reviewed by supervisor(s) and peers to further increase the liability and validity of the interview prior moving into the main interview series. Overall, number of 17 semi structured interviews conducted from selected participants within the housing supply chain over a course of 5 months (From October 2019), with a time allocation of 45 minutes for each interview. However, the structure of interview adopted to facilitate the discussion around the topic and give more room to participants to express their perspectives as the view of interviewees was important with some probing questions to understand the occurrence of the issues. All interviews recorded with a digital device and notes were taken during each interview. After each interview, the audio recorded transcribed and then transferred into NVivo software programme Version 12 for the analysis of data. The four steps of qualitative research method summarised, and Figure 4.1 illustrates these steps carried out during the qualitative research method.

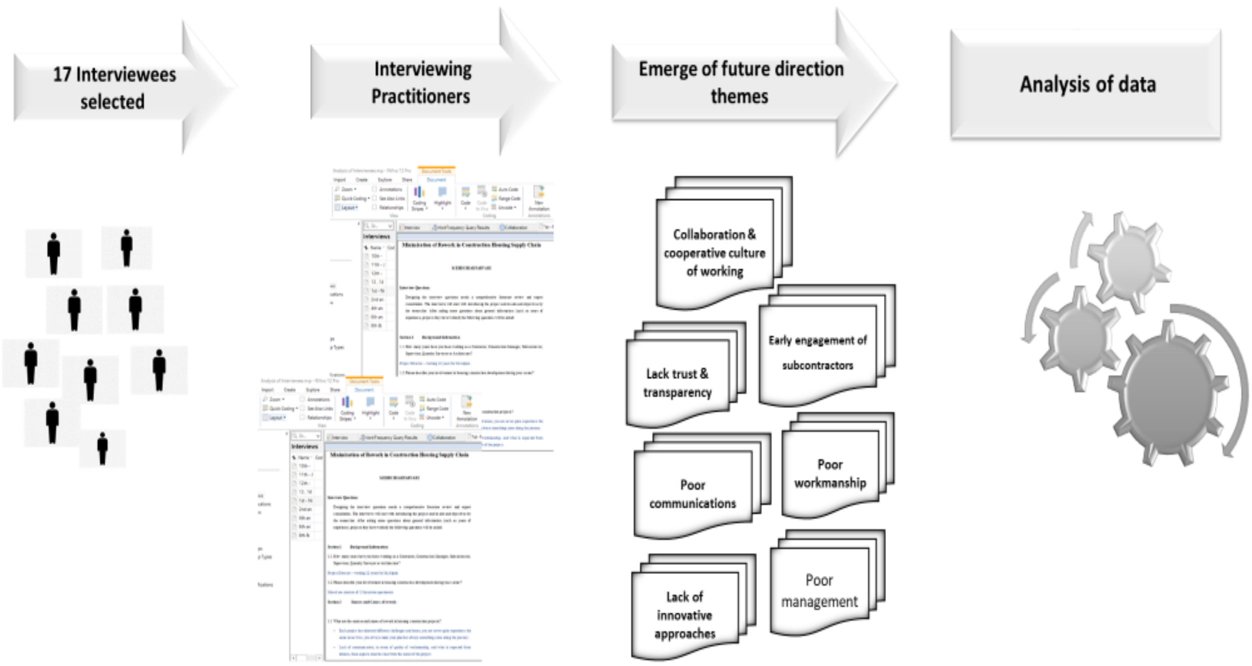


Figure 0.1 Four steps of qualitative research method summarised

4.3 Contributors background and profile

Number of subcontractors were identified for the purpose of the research. The key criteria for the selection of the participants include years of experience, position, and qualification within the housing sector. Therefore, the researcher identified these companies through the network of his supervisor(s) and conducting research to identify housing construction projects in London, particularly under the construction projects. Then, researcher visited to each one of ongoing housing projects to obtain information of identified contributors for the purpose of the research. These contributors were then contacted via email through their supervisors and PR of each company and asked for their participation in the research by providing the aims and objectives of the research. All participants for the research were interviewed face-to-face and their contacts kept for the second phase of data collection (questionnaire).

Table 4.1 illustrates the interviewees' profile comprising 17 interviews who contributed to participate in the interviews. The interviewees were chosen from wide range of different housing construction companies in the UK and sampling frame comprised of 7 categories including, Project director, Contractors (representing; C, O,P,Q), Subcontractors(representing; D,E,K,L,M), Supervisors, Designers(representing; B,F,G), and Engineers (representing; H,I). The distribution and the range of years of experience of the interviewees of the in-depth interviews are shown in Table 4.1.

Table 0.1 Interviewee background, sample size and categorised coded interviewees

Categories of participants	*No of participants*	*Years of experience*	*Coded Interviewees*
Project director	1	<25	A
Contractor	4	10 – 25	(C, O, P, Q) = Y
Subcontractor	5	15 – 35	(D, E, K, L, M) = X1
Supervisor	1	<25	N
Project Manager	1	<15	J
Architects and designer	3	20 – 25	(B, F, G) = Z
Engineer	2	<25	(H, I) = X2
Total	**17**		

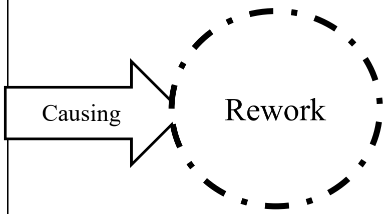
A set of semi-structured interview questions (Appendix.1) were also asked, see (chapter 3) from the interviewees, in addition to their career background and year of experience, and the extent of their contribution to the development of housing projects. The interviewees took around 45 minutes face-to-face, and all interviewees were based in London. Most interviewees held senior positions within their organisations, as shown in Table 4.1, and were involved in several housing construction projects. All contributors (17) had over 15 years of work experience in the construction industry and performed the diverse role in their professional careers.

4.4 Identifying themes

Once data analysis from interviews had progressed, the coded segments from NVivo software about each key node were reviewed, and key factors were gathered. NVivo helps to discover more from qualitative data, uncover richer insights and produce clearly articulated, defensible findings backed by rigorous evidence. The description of each interview is interpolated into the NVivo software, and based on the frequency of interviewees' analysis, 14 variables have emerged from the software; however**,** some eight of these themes are not significant to cause major rework generation in the housing supply chain. Albeit these variables cannot be ignored. Out of the total number of 14 themes (shown in table 4.2), 7 most frequent themes emerged (shown in table 4.3). The total themes are summarised as follows:

Table 0.2 Total number of variables based on NVivo software

Number of frequently emerged variables on NVivo software
Site managerial issues and lack of coordination among contributors
Lack of collaborative working
Lack of innovative approaches
Poor workmanship
Lack of trust and transparency among contractors and subcontractors
Early engagement of subcontractors
Lack of competent supervisors
Lack of coordination among stakeholders
Unclear instruction to labour
Shortage of skilled labour
Non-compliance with specification
Damage to other trades work due to carelessness
Different work ethic
Insufficient motivation



Out of aforementioned 15 themes, the seven most critical themes based on the frequency of interviewees' responses identified and emerged from the software. All 17 number of interviewees coded and categorised from A (1) to Q (17) to keep the information anonymous which are shown in table 4.3 including the 7 most important emerged themes. Each X represents the emphasis of each interviewee's responses on the importance of 7 listed below themes. For instance, all interviewees during the interview mentioned the importance of collaboration and co-operative working culture among subcontractors and that has been applied with X for elaboration from (A) interview to (Q) interview.

Table 0.3 The most significant emerged themes from interviewees' perspective

ID	Most significant themes	17 Coded Interviewees																
		A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*
1	Poor communication	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X
2	Lack of collaboration & cooperative working	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	Lack of innovative approaches	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	Poor workmanship	X	X	X			X	X	X	X					X	X	X	X
5	Lack of trust and transparency		X	X	X	X	X	X			X	X	X	X		X	X	X
6	Early engagement of subcontractors		X	X	X	X	X	X				X	X	X		X	X	X
7	Site managerial issues & lack of co-ordination among contributors	X	X	X			X	X	X	X	X				X	X		

4.5 Findings from interviews

4.5.1 Site Managerial Issues and Lack of Coordination Among Contributors

Managerial aspects are one of the key factors leading to rework in the housing supply chain. Love and Edwards (2004) suggested that managerial aspects are key component for generation of rework in housing supply chain. Client requirements for unexpected changes, design error and omission have a relatively greater cost impact compared to other factors (Hwang et al. 2009; Hwang et al., 2014; Love and Edwards, 2012).

One of the contractors (C) from contractor (Y) group argued *that "In most cases contractors and subcontractors are aware of issues on site and that because increase the cost for repair and return of the subcontractor including the short window timeframe for each activity - they tend to turn the blind eye on rework and defects issues, which multiplies problems once processes move forward on construction site".* The vast majority of participants (Y1, Z1, J and X1) took the view that having a good culture of cooperative way of working team on site with meticulous attention to detail. This can significantly impact on the levels of rework occurrence on housing construction site. Early engagement of stakeholders in projects can improve the decision-making process and eliminate bias from misinterpretation of exchanged data. This can result in less change as project continues to progress forward. For example, one of the experts (A) identified *that "Co-operative management set-up is key for success of delivering projects from both clients' and contractors' perspective, which requires effective communication skills and collaborative way of working for the progress of projects".* Also, the same expert noted that *"Informed decision-making among stakeholders is crucial to prevent the likelihood of rework occurrence in projects".*

4.5.2 Poor communication among subcontractors

All the interviewees (17 out of 17) agreed that ineffective communication significantly impacts the rework occurrence of housing development projects. They emphasized the importance of effective communication among different contributors in each stage of the construction process. More than half of the interviewees (11 out of 17) discussed the inadequacy of communication channels and digital tools affecting the level of communication and coordination in upstream and downstream projects, resulting in rework and quality.

One participant (P) mentioned *that "precisely understanding and defining the scope of work between different parties and keep communication channel open daily - prevents the misunderstanding of information and given task in which can significantly improve the workflow of process and minimise rework occurrence"*. Most of the interviewees suggested communication exchange in particular face-to-face interaction among different actors from early stage of projects will reduce the levels of rework generation. Interviewee (J) suggested that *"communication from early stage is very crucial among different parties and has to be done thoroughly particularly among designers, contractor, and subcontractors where they interface with one another to work together, however, often times the channel of communication and coordination does not really happen or limited only to clients and designers"*. This can help to drive the design and construction rework down which is affecting the quality and time overrun and cost overrun of projects. An expert (P) noted and argued that: *"lack of communication among different actors from the start of design to construction stage often leads to unintended errors and changes and causes rework generation, which requires a lot of new resources and materials - sometimes finding new supplier to provide new materials which often leads projects 'to overrun"*. The same participants went further and noted that "*poor communication with different trades usually affects the quality of workmanship – most of the time briefing doesn't well translated/understood among labourers which leads to rework generation, these aspects must be clear from the outset of projects by competent supervisors"*. However, the majority of interviewees discussed that the bigger the chain, the less effective communication become – and that requires daily communication with different parties who interact with and engage in day-to-day activities to reduce the level of fragmentation**.** Every participant agreed that ineffective communication and lack of coordination among subcontractors can cause rework occurrence.

One of interviewee (F) explained that in their current project "*the design and layout of the swimming pool has been changed five times as a result of client's requirement for change, because of insufficient client's experience and lack of understanding development of housing construction projects "*. From interviewees' perspective Table 4.4 presents a benefit of different mechanisms of running an effective communication in construction site among contributors.

Table 0.4 Measures for the improvement of communication in housing projects

Better communication and coordination among different contributors	
Daily interaction and frequent meetings	Improve the effectiveness of communication and coordination, also, reduces the delays of information for informed decision making Enhance coordination, progress of each task and reduces design changes
Workshops & Trainings	Improve the quality each trader and minimize the rework and defects Enhance the quality of projects Cultivate the culture of trust among subcontractors Foster a collaborative and cooperative way of working among different participants
Develop project specific gateway procedure and sign up	Setting-up key project portal as project progresses which improves the understanding of contributors what is required at which stage

4.5.3 Lack of collaboration among subcontractors' performance for reduction of rework

An attitude of co-operative and collaborative culture of working among subcontractors can provide a remedy for reduction of rework in housing development projects before moving to the next stage of construction. All interviewees (17 out of 17) indicated that collaboration is crucial to improve the performance of projects and prevent rework occurrence. It is argued that more rigours integrated supply chain is in utmost need down the chain to subcontractors and suppliers, as housing construction development flows from one stage to another, from one subcontractor to second one (Briscoe and Dainty, 2005). Majority of interviewees, mentioned that culture of competition should change towards more collaboration which will minimise rework generation and ultimately, improves the productivity of workflow in each stage of construction. One of the participants (A) mentioned *that "collaborating at the right time and that is all about the right people at the right time conducting right planning at the right time, also, it is important if something doesn't seem right it is imperative to address the issue and rework as quickly as possible rather than neglecting rework for the hope of it will be fixed later on"*. The same interviewee suggested that *"involving contractors and in particular* *subcontractors on board as early as possible, it gives enough time for a better collaboration, facilitates the idea of designer, and effective planning with players who are involved in and that reduces rework and errors on the site. Automobile industry is a perfect example to learn the collaboration from their supply chain integration".*

Majority of interviewees believe that efficient coordination among the chain is indispensable in elimination of rework within entire housing supply chain. Collaboration is one of the key factors in eliminating rework. One of the experts (J) noted "often *subcontractors view contractors as their client than part of a chain. Means that subcontractors usually try to keep the cost down with poor effort to maximise their profit, result in defects which sometimes are not detected until some later stage, resulting in multiple cost – this usually affects the level of collaboration among different actors who are working in construction site".*

Another expert (C) stated that *"most of bright ideas in construction stage comes from SMEs and subcontractors – they always have a solution to any problems, but traditionally they don't get any chance to be involved". "Normally what happens, once design is done, Quantity Surveyor (QS) measures it, contractor gives the price then employs subcontractors – and suddenly, subcontractors say that's the wrong way to carry work – then goes back to design team for modification and where rework start to leap".*

Early engagement of contractors and subcontractors right from the outset is vital to facilitate the design process and changes that may occur which will prevent rework generation on construction stage (Briscoe and Dainty, 2005).Table 4.5 shows the different characteristics and their impact on the level of rework when collaborative work is in place among different Micro businesses, SMEs and subcontractors on construction sites.

Table 0.5 Improvement of measures for better collaboration (Interviewees' perspectives)

Characteristics	Impact on reduction of rework
Early engagement of contractors and subcontractors	Improved buildability Early discussion opportunity with different parties which leads to less variations Reduces materials wastage Cultivating constructive working relationship will improve the workflow of processes
Time and cost	Tight budget and time impact on rework generation as contractors and subcontractors have to control unnecessary costs associated with material wastage
Working with integrated supply chain from early stage of projects	Clear understanding of different subcontractor's need which effectively reduces rework generation Minimising design changes and variations

4.5.4 Lack of innovative approaches

All interviewees (17 of17) agreed that the culture of resistance to change has been identified as one of the crucial factors affecting the adoption of new technologies and innovative strategies to improve the overall cost of production through minimisation of rework in housing supply chain. Also, they discussed lack of resources and lack of education and knowledge among subcontractors prevents the employment of innovative strategies. According to participants (X1, Z1), one of the reasons for apparent sluggish innovation in housing supply chain is the limited capacity of subcontractors' financial budgets to spend on research and development. One of the experts (A) discussed that *"Record of data and information is still based on hard copies for weekly update – where some part of information sometimes gets lost or forgotten to comply as a lack of digitisation"*. One of the experts (C), also stated that *"although sometimes Building Information Modelling (BIM) is employed in construction site, some contributors, particularly subcontractors still prefer co-ordinate and communicate on hardcopies, because of cultural resistance to change in construction, lack of training and lack* *of resources to invest in".* The expert continued (C) and added that *"BIM can provide a better service when is implemented in the right place, however, the problem is when you have a large number of subcontractors on site, things can get overwhelmed, and model don't pan out well".* However, the majority of the interviews discussed that emerging technologies and innovative strategies can only be applied to large organisations as they have resources to invest and educate employees.

Offsite manufacturing techniques can facilitate continuous workflow improvement in the manufacturing process and can be implemented throughout the housing supply chain to eliminate rework. Manufactured housing could minimise defects and errors that are caused by human in highly pressured with complex design in the construction environment.

An interviewee (B) suggested that *"using innovative materials that requires low maintenance it can redundant skilled labour for repair visit and ultimately eliminates rework".* He extended and mentioned that *"why don't we use materials that does not require maintenance or manufacture materials that need maintenance every 10 years or so. And why don't we have floors that don't need maintenance ".*One expert (C) noted that *" traditional contracting and the culture of resistance to change is one of the major barriers to prevent housing construction form innovative ideas and change"* another participant (Q) mentioned that " *the biggest single procurer is government – the government, public sector and local authorities want the cheapest price and shortest time to deliver a successful project and that causes rework occurrence, where by redefining the strategy we can achieve a better result. For instance, we can ask clients 'what is the budget we have to prepare for project delivery? Then based on the budget we can plan accordingly which can minimise the rework within the housing supply chain to deliver affordable products".*

Over half of the interviews lacked the deeper understanding of LC and how LC can help subcontractors for rework minimisation practice in the housing supply chain. Some of interviews (A, O, P) argued that it only Tier 1 construction companies are able to implement LC and make necessary adjustments within their organisations to cultivate the culture of lean thinking and cascade it down to the chain among SMEs and subcontractors in the housing supply chain. It takes considerable effort from SMEs and subcontractors to invest and educate employees to implement LC in the housing supply chain. Experts argued that the focus on the collaborative and cooperative working for rework minimisation practice among different contributors in the housing supply chain can have a significant return on the performance of projects and possible prevention of rework occurrence.

Investment in research and development R&D through different institutions can accelerate the rate of innovation in the housing supply chain – one of the promising methods is offsite manufacturing, which can reduce the cost of production significantly while improving the quality of products and shortening the completion time of projects with the potential to reduce negative environmental impacts and increase re-use of recycling materials.

4.5.5 Poor workmanship

The poor performance of labours on construction sites have been causing the level of productivity and the quality of housing development of projects. Almost all participants have discussed that the level of labours' performance and poor workmanship is considered to be one of the major issues causing rework in the housing construction industry. This has been causing rework occurrence to deliver a high-quality standard product for end users. A few of the experts (X1) has stated that *"quality of labour on site is declining rapidly due to lack of training and workshops, lack of knowledge, lack of experience, lack of competent supervision and less motivation among labours "another* expert discussed that *"the quality of repetitive tasks are varies and are inconsistent as a result of human error and that because of labours' carelessness or less motivation to conduct a good quality standard job".* One expert (A) suggested that "workshops *and training through different schemes can help to educate and train labours and demonstrates the clear way of conducting tasks more effectively to eliminate rework, he also added that one hand cannot clap but both hands can, bringing everyone for brainstorming can help to address problems from an early stage of construction – and improves the cooperative way of working among different subcontractors".*

Every interviewee discussed that running workshops and training for employees can significantly enhance the level of productivity among labours in which can prevent rework generation. One participant argued that *"experience is among the most important criteria to manage workforce and – with experience you need to have knowledge, and you have to nurture the knowledge by sending employees to workshops and training classes. This can result in the improvement of labours performance and the quality overall projects".* Competent employees on construction sites can monitor the progress of subcontractors and labours to prevent rework occurrence. Some of interviewees (X2) argued that many of labours do not understand the briefing well enough, which usually leads in occurrence of rework, therefore, workshops and training can enhance the understanding of labours in construction site.

4.5.6 Lack of trust and transparency among contractors and subcontractors

Another important issue causes rework in the housing supply chain is the lack of transparency and trust between contractor and subcontractor, which drives the level of rework. All participants (17 of 17) agreed that trust and transparency are the two crucial factors that need to be embedded in the construction industry – they mentioned that it is all about "trust." The fundamental lack of trust within the SME companies that form the industry's supply chains (Dainty et al., 2001) and the imbalance of power in short-term, adversarial contracted relationships, constrain effective supply chain management (SCM) before it can even begin. So, despite the best efforts to integrate supply chains, they remain problematic and fragmented.

One interviewee (C) mentioned "*creating incentives through different mechanism such as profit sharing among contractors and subcontractors can drive the productivity up and minimize rework – this can foster a better relationship for future collaboration in different projects"*. Using subcontractors as trade capital to provide fair incentives and rewards, to create a climate of sustainable and transparent collaboration. Yet, to do this the construction industry delivery system has to fundamentally shift to more innovative approaches.

Trust and transparency are the bedrock to collaborative and cooperative way of working where stakeholders' express different concerns and there is disparity in perceptions. Cultivating trust and transparency among subcontractors could create a robust partnership in future works – this will reduce the level of rework in housing construction projects and result a high quality delivered product.

It has been argued among participants (X1, Y1, J) that the supply chain of housing projects needs to follow the path and the strategy of automobile manufacturing supply chain where the elimination of rework has been a key drive to improve the level of productivity and quality of products.

Automobile industry is known for its significant supply chain integration and that can be duplicated in housing supply chain to eliminate rework and improve the workflow of process and productivity of housing. One of the experts noted that " we must be transparent in working together from the beginning, for instance, this is the budget we have and how we are going to implement it " another experts brought an example from Jaguar supply chain where the CEO had to reduce the supply chain from 2000 subcontractors to 200 and he mentioned that the strategy was that " *after 12 months of contract, then the price of product gone 10% down and said to subcontractors we must cut the production cost and give you the same contract and profit as a reward if subcontractors try to come up with an idea of bring the cost of production down as lower as possible".*

Establishing a close relationship with subcontractors is important to the success of project - cultivating a culture of trust and transparency among different subcontractors and trades can drive the level of productivity up through elimination of rework.

4.5.7 Early engagement of subcontractors from outset of projects

The overwhelming majority of participants agreed that contractors and subcontractor's involvement from the outset of projects will present an opportunity to enhance buildability and identify the possibility of rework occurrence. This can result in the prevention of rework occurrence during construction stage. Early engagement of contractors and subcontractors right from the outset of housing development projects is vital to facilitate the design process and changes that might occur and can prevent rework generation in construction stage.

Most of the interviewees (X1, Y1) discussed that the late involvement of key stakeholders particularly subcontractors from the early stage of design has a considerable impact on the level of rework generation. This can cause further issues along the chain such as poor decisions, poor buildability, lack of understandings, variations and rework occurrence. Participants expressed the view that contractor and subcontractor's involvement from the early stage of design can significantly impact on reduction of rework and holistically lead to resource efficiency. Further respondents mentioned that contractors and subcontractors who are engaged from the early stage of housing projects have the opportunity to mitigate the possibility of rework generation before construction take place, improve quality and, reduce design changes. They also held a perspective that lack of involvement of different parties would possibly create divergence among client's objectives, concept architects' design, contractors and subcontractors site operations. This was further elicited by vast majority of interviewees that lack of contractors' and subcontractor's involvement creates communication barrier with designer's decisions for prevention of possible further rework occurrence on construction stage. However, most of experts (X1, Y1, Z1, A and, Z2) criticised the fragmented nature of housing construction projects which has been affecting the level of rework generation. One of interviewee stated that an example to which partitions' design could be adjusted slightly higher or lower to reduce rework on plasterboards, however, if the design has already been completed that inevitably can be very late to rectify, and the only alternative is to consider the change for the design which will generate rework. However, several interviewees (Y1, J and Z1) highlighted some challenges associated with the engagement of a large number of subcontractors on site; these are including: careless about another's trade work due to a tight timeframe of work; failure to follow the right sequence of each task; an attitude that contractors are responsible for management of rework generation on site.

4.6 Discussion

From interview data analysis, construction sites are complex environment where multiple subcontractors and suppliers are all working at the same time often with different business objectives. In such environment the likelihood of errors and mistakes would occur along the supply chain cluster. The management of communication and information exchange process still heavily relied on traditional methods of paper transfer (Sommerville, 2007). This has caused a major barrier among different contributors to understand each other's activity and affects the workflow of processes.

Love and Edwards (2004) suggested that managerial aspects are key attributes for generation of rework in housing supply chain. Client requirements for unexpected changes, design error and omission have a relatively greater cost impact compared to other factors (Hwang et al. 2009; Love and Edwards 2012). Often lack of sufficient experience, precise information of detailed design and construction procedure onsite leads to rework generation that causes projects to overrun (Thunberg and Fredriksson 2018). Early engagement of contractors and subcontractors right from the outset of project's planning is vital to facilitate the design process and changes that may occur which will prevent rework generation on construction stage (Briscoe and Dainty, 2005). This will prevent rework occurrence in the construction process – clarifying responsibilities of different parties, setting quality standard and comprehend a clear set of well deliverables among contributors in the site.

Poor coordination between various contributors is one of the main obstacles for elimination of rework in practice. In housing construction projects, collaborative working is limited to client and main contractor linkages, and that ultimately, restricted the contribution of subcontractors to an improved supply chain overall performance (Dainty et al., 2001). Although the large amount of work is undertaken by multiple subcontractors, however, little attention has always been paid towards the challenges of their rework occurrence on site. From interview analysis it is well understood that the current rework reduction practices can be focused on the following:

- Assessing subcontractors' activities daily/weekly and their rework streams through supervisory channel
- Identifying responsibility of each subcontractor's own rework, defects and waste
- Applying appropriate strategies to eliminate rework among subcontractors' interaction on site

The productivity improvement in housing industry has lagged compared to those in other industries (Manseau and Shields, 2005). McKinsey (2020) analysis noted that the construction industry was among the least digested industries compare to the total economy across assets, usage and labour. Digitisation could address rework issues where different parties can revisit the quality of their activities and measure their performance. Automation can enable the industry to monitor each process daily in which the performance of labours and materials can be tracked in real time. This will enable an early diagnostic of the prospect of rework occurrence in construction stage. Workshops with other counterparts within the cluster of supply chain, before moving into the construction stage where they can brainstorm novel and innovative ideas for minimisation of rework.

From the findings collaborative and cooperative culture of working among supply chain is in utmost need particularly down the chain where there is less interaction and integration between different subcontractors. As housing construction development moves from one subcontractor to another. Miller et al. (1999) indicated that collaborative working methods will produce promised gains and minimise rework if the subcontractors are fully integrated into the process

Collaboration work is limited to client and main contractors' linkage. It has been suggested from a judgement of experts' perspective that often time bright ideas come from subcontractors – they always are capable of dealing with any issue that may occur along different construction stages.

It has been argued that adversarial relationships and mistrust emerge from competitive bidding (Kadefors, 2004; Wong et al., 2005) and this could be changed from price competition to more collaborative procurement route between main contractors and subcontractors (Matthews et al., 2000; Thorpe et al., 2003). It is also, important to establish a very close relationship with SMEs and subcontractors to create a climate where they can cultivate trust and transparency among different contributors - which could improve the workflow of processes and eliminate rework and, consequently imporves the productivity up.

4.7 Chapter Summary

The result of the interview was presented in the chapter. Qualitative data analysis techniques were employed for the purpose of the research using NVivo software programming tool. After carrying out the analysis, out of fifteen variables, seven most important themes emerged from the software. Then all 17 interviewees coded then categorised from A to Q to keep the identity of interviews anonymous which was shown table 4.2. The most 7 important variables have been discussed in the findings. The next chapter presents the analysis based on the quantitative data analysis of the research.

QUANTITATVE DATA ANALYSIS AND RESULTS

5.1 CHAPTER OVERVIEW

This chapter of the research presents the results of second phase (questionnaire) of data collection of the research from the UK housing supply chain. Overall, processes involved in quantitative data collection and analysis are presented in the chapter. The sampling size and technique were justified and explained, which is followed by the processes involved in designing the instrument for the quantitative research study. The approach to data collection and analysis are then justified and discussed before the findings of the statistical analysis are presented.

5.2 Sampling Size Technique and Population

For the generalizability of the research findings – sampling of professions was based on critical sampling technique (Creswell, 2010), which requires all contribution involved in housing development projects. For the purpose of the research, a purposive sampling, a non-probability sampling technique was used to the targeted population among different contribution of the UK housing supply chain. A purposive sampling strategy assured a reasonable representation of each stakeholder namely, developers, contractors, subcontractors, architects, and engineers from the UK housing sector.

Snowballing sampling technique also was employed to facilitate the process of data collection. The sampling approach was facilitated through the network of contacts and supervisors' connection with potential companies who are focused on the UK housing development projects.

5.3 The Design of Questionnaire Instrument

To assess the applicability and appropriateness of the research findings a quantitative analysis was conducted to serve the objectives of the research. The second phase of data collection (questionnaire) started with conducting a pilot study employing a preliminary questionnaire. The aim of employing questionnaire is to determine the applicability of previously identified characteristics (qualitative) and to explain the cause why it takes certain shape of explanatory (Buckingham and Saunders, 2004). The main consideration of such method is the ability to reach a wider audience in the field of housing construction sector, given the short period of time. Therefore, a questionnaire survey was carried out as a means of data collection from a wide number of participants in the short period of time (Baiche et al., 2006).

The initial draft of questionnaire covering the research questions were predominantly developed from the outcome of the first phase of the research - interview data analysis, discussed in Chapter 4, section 4.4 and 4.5. The insight from the literature review also enhanced the structure of the questionnaire. Number of factors affecting rework identified through literature review, and the first phase of data analysis (interviews) where the analysis incorporated to develop the second phase of data collection (questionnaire). The first phase of analysis helped to understand the causes and sources of rework occurrence from practitioners' perspective and their practical experiences more in-depth to develop the second phase of data collection to provide strategies and future direction for rework minimisation practice among different subcontractors. The following steps are consisting of four major sections.

5.3.1 Sections of The Questionnaire

The survey instrument comprised of four sections which are include:

SECTION A: PARTICUALR OF RESPONDENT INCLUDING CHARACTERISTICS OF HOUSING PROJECTS - The first part of the questionnaire consists of the background information of the participants. The respondents were informed of the nature of collected data for the academic purpose to obtain a high number of response rate. Also, the respondents assured for the confidentiality of all individual's responses that would be maintained after data collection. The first section captures about respondents' demographic such as the field of work, the title of career and years of experience. This would enable the researcher to identify the role of each participant within the housing sector.

SECTION B, C&D: BODY OF QUESTIONNAIRE – These three sections identify the root cause, the current practices and strategies, and future direction for the reduction of rework on housing supply chain. The respondents were asked to consider each of the factors and to rank the importance that is based on Likert scale. The section B is related to the characteristics of housing development projects with four questions. These questions are related to the type of projects, the type of procurement route, the project's original construction period and the project actual construction time. Section C of the questionnaire has eight questions related to causes and barriers to rework occurrence. The next part of the questionnaire is associated with several questions on current practices and strategies. There are three questions, and respondents have five options to record their responses. The next part of the questionnaire is linked with emerging technologies and future directions. This section has five questions, and the next section of the questionnaire has an open-ended question in which the participants are requested to provide additional comments regarding rework minimisation. The final section of the questionnaire aims to ask respondents if they are willing to receive a summary of the findings of the stud.

5.3.2 Measurement Scale

The respondents of the questionnaire were required to indicate the importance of the variables on a five-point Likert scale, from 1, where one represents 'Not at all' and 5 represents 'To a very great extent' and 'Strongly disagree' and 5 represents 'Strongly agree'. However, in section 1; questions from 1 to 7 is based on participants' background, types of projects, and time of the completion of projects with multiple choice questions. The questionnaire was developed into Qualtrics platform a web-based questionnaire platform to encourage easy to use and completion, reduce potential errors and to aid the analysis of data. The questionnaire design is shown in Appendix 2.

5.3.3 Pilot Study

The survey vetted through applying a pilot study. A pilot study was carried out within London South Bank University Construction management researchers at the school of the Built Environment and Architecture. The purpose of the pilot study was to assess the relevance, complexity, the degree of depth, the clarity of language, and length.

The pilot study was conducted to evaluate content validity, concurrent validity and construct validity (Croswell, 2014; Buckingham and Saunders, 2004), which are very important for the adequacy of data obtained through the design stage (Tashakkori and Teddlie, 2010). Number of different scholars have been suggested different range of sample sizes for the adequacy of conducting a pilot study. For example, Van Belle (2011) suggested number of 10 samples; Mooney and Duval (1993) recommended up to 30 participants in preliminary development stage, while Isaac and Michael (1995) argue that a sample size of 10 to 30 could be adequate.

Consequently, in this research, number of 16 pilot study was distributed to construction management researcher in the university, of which number of 12 questionnaires were obtained and tested including the feedback sheet. Number of four questions were further rectified and reworded to help enhance the clarity and are deemed information are rich for the study based on the feedback received from questionnaire.

Considering the comments received from pilot study, further enhanced the improvement of the final version of questionnaire. Furthermore, most of the respondents noted they had to spend approximately around 10 to 25 minutes to complete the survey. Pilot study helped to further determine the appropriate time required for a specific respondent to complete a survey at the main phase of data collection. The final version of the questionnaire is shown in Appendix 2.

5.4 Data Collection

After a comprehensive literature review and qualitative data analysis, number of variables relates to the reduction of rework on housing supply chain were identified the findings we discussed in chapter 4 (section 4.4 and 4.5). Then these variables structured into a survey by running a pilot study before the final instrument was developed and distributed. After reviewing and modifying the comments of the pilot study, the questionnaire distributed using e-mail to reach out the wider audience among different contributors in housing development projects.

5.5 Response Rate

A total of 267 questionnaires were distributed among the UK housing supply chain companies, such as; developers, contractors, subcontractors, engineers, architects, and subcontractors. All questionnaires were sent via email, and a follow-up email was processed for non-respondents at a fortnightly interval over 9 months due to the outbreak of unprecedented COVID - 19 pandemic.

After a series of follow-up emails, 116 responses were received, representing a response rate of 42.65%. Out of this response, 8 surveys failed preliminary analysis through incomplete information and unengaged responses, and they were eliminated from further analysis. After treatment of the missing value analysis, 108 questionnaires were imported into SPSS software for the analysis. A preliminary analysis was conducted based on the respondent's information in section A of the questionnaire to determine the dissemination of the respondents. All of them are from the housing sector shown in Table 1. The distribution of the 108 responses was used for data analysis. As shown in Table 5.1, the largest responses from the questionnaire are from developers, and subcontractors, with 40.40% and 26.26%, respectively. Developers are categorised as house builders with in-house of design and construction team. Contractors with 18.1%, CPM with 2.02%, 5.05% are architects, 4.04% belong to engineers, and 4.04% are other, including quantity surveyors. Also, it shows the category of each participant's percentages, including the number of questionnaires sent out to participants.

Table 0.1 Demographic of survey respondents

Variables	*Number*	*Percentage*
Total sent out questionnaire	267	100%
Total of submitted responses	116	42.65%
Discarded responses	8	6.7%
Number of usable responses	108	40.45%
Role /Title	Developers (N=44) Subcontractors (N=29)	41% 27%
	Contractor (N=20)	19%
	Architect (N=5)	5%
	Engineer (N= 4)	4%
	Others (N= 4) Construction project manager (N=2)	4% 2%
	0 – 5	3%
Years of experience (years)	5 -10	10%
	11 – 15	29%
	16 -20	31%
	21 – 25	16%
	Above 25	11%

5.7 Missing Value Analysis

Missing value analysis was carried out to assess each question to identify number of concerns caused with incomplete data. Missing value analysis is the process of statistical analysis in which can help to address issues are raised due to incomplete data which can affect the precision of statistical analysis (Hill, 1997). The process provides a methodical approach to treat incomplete data. It performs three key steps which are identification and description of the patterns in missing value of questionnaire, estimation of means and other descriptive statistical analysis and potential replacement of missing values with estimated values (Kang, 2013). The result of missing value analysis shown in Appendix 2 illustrates the number of missing data from questionnaire being less than 10%. Hence, the results of statistical analysis can be presented based on the measures of those non-missing values and therefore, the number of total questionnaire respondents remains at 108 (Table 5.1) based on the usable responses.

5.8 Analysis of Questionnaire Data

The statistical analysis was carried out on SPSS version 27 software for this research to establish the patterns of responses, and to make sure the suitability of gathered data for further analysis. To test normality contains two different hypothesis tests of normality (e.g., Kolmogorov-Smirnov and Shapiro-Wilk) were applied. Kolmogorov-Smirnov is a nonparametric test. It can be applied to test if the data come from a known, distribution not just the normal distribution. Null hypothesis was examined to test if the data come from the specified distribution; the alternative hypothesis is that the data do not come from the specified distribution. Shapiro-Wilk is a parametric test. The null hypothesis was examined to test if a variable was drawn from a normal distribution; its alternative hypothesis is that the sample was not represented from a normal distribution as shown (See appendix 5.1). To highlight, a sufficiently small p-value suggests, but does not provide evidence, that the data is not normally distributed. The Shapiro-Wilk test is very sensitive to insignificant variations in normality when the sample size is large that if sample size is very large, it is somewhat probable that the Shapiro-Wilk test may come back significant, just as if the deviations from normality are very small. Each variable explored using the data statistically tested and officially examined to be non-normal and; therefore, a nonparametric statistical analysis was adopted for the research.

In general, this study used other resources to support a claim of normality. After the tests of normality table, the Quantile-Quantile plot was tested. Q-Q plot contrasts the observed quantiles of the data with the quantiles that the result would expect to see if the data were normally. Q-Q Plot of each variable was also visually assessed to confirm normality of distribution, and nonnormality was confirmed along with the test statistics. Variables are approximately non-normally distributed; the points were from the line (See appendix 5.2).

Therefore, individually variable was explored using median for central tendency. measures of central tendency also were tested by finding the middle, or the average, of a dataset.

5.9 Factors Contribution on Minimisation of Rework in the Housing Supply Chain

This section has considered about factors that contribute on minimisation of rework in the supply chain. The questionnaire identifies the root causes of rework in housing supply chain – so the effective prevention strategies can be developed for future direction of rework minimisation. Table 5.3, Table 5.4, and Table 5.5 show the summary of descriptive statistics of questionnaire regarding barriers and causes of rework occurrence.

Table 5.3 Descriptive statistics of questionnaire about causes of rework and barriers

No	Causes of Rework and Barriers	Median	Range	Percentiles		
				25	50	75
Q7	Generally, subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation	2.00	3	2.00	2.00	3.00
Q8	Traditionally subcontractors must work on short windows on site. This hampers rework reduction efforts and generates rework	2.00	3	2.00	2.00	2.00
Q9	Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects	1.00	2	1.00	1.00	1.00
Q10	**Major barriers for minimization of rework practice**					
Q10.1	Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice. Please indicate to what extent the following are the main barriers of rework minimisation practice. - Fragmentation and subcontracting	1.00	2	1.00	1.00	1.00
Q10.2	Culture of resistance to change	1.00	1	1.00	1.00	1.00
Q10.3	Conventional way of construction	1.00	2	1.00	1.00	2.00
Q10.4	Short working window	1.00	2	1.00	1.00	2.00
Q11	**Different stages of housing construction process**					
Q11.1	Excavation	3.00	2	2.00	3.00	3.00
Q11.2	Frame construction	3.00	2	2.00	3.00	3.00
Q11.3	Plumbing and electrical HVAC	2.00	4	2.00	2.00	3.00
Q11.4	Drywall and interior fixture	5.00	4	5.00	5.00	5.00
Q11.5	Cladding installation	2.00	2	2.00	2.00	2.00

Q11.6	Fitting out and Flooring	5.00	3	5.00	5.00	5.00
Q12	**Design related factors**					
Q12.1	Contractors' requirements for change	1.00	1	1.00	1.00	1.00
Q12.2	Unexpected clients' change	1.00	2	1.00	1.00	1.00
Q12.3	Lack of quality management practice	1.00	2	1.00	1.00	2.00
Q12.4	Lack of coordination among contractors/subcontractors	1.00	1	1.00	1.00	1.00
Q13	**Client-related factors**					
Q13.1	Insufficient source of time and budget spent on the briefing process	2.00	2	1.00	2.00	2.00
Q13.2	Poor communication with design team	1.00	2	1.00	1.00	1.00
Q13.3	Lack of knowledge and experience of the design and construction process	1.00	1	1.00	1.00	1.00
Q13.4	Insufficient involvement of client from the outset of projects	2.00	2	1.00	2.00	3.00
Q14	**Subcontractors-related factors**					
Q14.1	Different business objectives	1.00	1	1.00	1.00	1.00
Q14.2	Unrealistic scheduling	1.00	2	1.00	1.00	1.00
Q14.3	Non-compliance with specification	1.00	2	1.00	1.00	2.00
Q14.4	Poor workmanship	1.00	1	1.00	1.00	1.00
Q14.5	Different work ethic	2.00	2	2.00	2.00	3.00
Q14.6	Late involvement of subcontractors from the beginning	1.00	1	1.00	1.00	1.00
Q14.7	Poor communication	1.00	1	1.00	1.00	1.00
Q14.8	Lack of trust and transparency	1.00	1	1.00	1.00	1.00
Q14.9	Insufficient motivation	1.00	2	1.00	1.00	1.00
Q14.10	Lack of collaborative and cooperative working	1.00	2	1.00	1.00	1.00
Q15	**Site management related factors**					
Q15.1	Lack of knowledge, experience, and training	1.00	2	1.00	1.00	2.00
Q15.2	Poor planning	1.00	2	1.00	1.00	1.00
Q15.3	Lack of cooperative working	1.00	1	1.00	1.00	1.00
Q15.4	Lack of competent supervisor	2.00	2	1.00	2.00	2.00

Table. 5.4 Descriptive statistics of questionnaire, learning mechanism, current practices, and strategies

No	Learning mechanism, Strategies and Future direction	Median	Range	Percentiles

				25	50	75
Q16.1	Trainings, seminars, and workshops	1.00	1	1.00	1.00	1.00
Q16.2	Research and development	1.00	2	1.00	1.00	2.00
Q16.3	Subcontractors daily process improvement without systematically labelling "rework minimisation strategies"	1.00	3	1.00	1.00	2.00
Q19.1	Culture of collaboration and cooperative working	5.00	5	5.00	5.00	5.00
Q19.2	Investment in new technologies and human resources	5.00	3	4.00	5.00	5.00
Q19.3	Training, seminars, and workshops	5.00	5	5.00	5.00	5.00
Q19.4	Early engagement of subcontractors from early stage	5.00	5	5.00	5.00	5.00
Q19.5	Create incentives among subcontractors	5.00	5	5.00	5.00	5.00

Table 5.5 Descriptive statistics of questionnaire, adaptation of new technologies

No	Adaptation of new technologies	Median	Range	Percentiles		
				25	50	75
Q20.1	Ability to rectify errors and mistakes	5.00	1	5.00	5.00	5.00
Q20.2	Reduction of design errors and changes	5.00	4	5.00	5.00	5.00
Q20.3	Realistic scheduling	5.00	1	5.00	5.00	5.00
Q20.4	Reduction in reliance on skilled labour	5.00	5	5.00	5.00	5.00
Q20.5	Effective document control and archiving	5.00	5	5.00	5.00	5.00
Q20.6	Improvement of transparency and trust	5.00	1	5.00	5.00	5.00
Q20.7	Improve collaborative and cooperative working	5.00	5	5.00	5.00	5.00
Q21	Digitisation of information and exchange of data	1.00	3	1.00	1.00	1.00
Q22	Adaptation of offsite manufacturing techniques	1.00	2	1.00	1.00	1.00
Q23	Employing innovative materials	1.00	3	1.00	1.00	1.00

5.10 Kruskal-Wallis H test

Kruskal-Wallis H test is a non-parametric test for multiple independent samples to determine whether there is a significant statistical difference between more than two independent respondent groups in regard to variables (Field, 2009). In the research study, the non-parametric test was adopted for this study to determine if there are view differences between the respondents in terms of their jobs, such as; developers, contractors, subcontractors, architects, and engineers. The value of the asymptotic significance level for most items for all questions was greater than 0.05.

The table (see appendix 5.3) states us what the dependent variable was ("which of the following distribution the company you are in); what the causes and barriers; "N", the number of participants in each survey; and the mean rank. The results of the Kruskal-Wallis H test are shown in Tables 5.4 to 5.7. Table 5.4 indicates that the result of the Kruskal-Wallis H test as a value of Chi-Square; how many are associated with it; and the significance level (p-value). A Kruskal-Wallis Test using a 0.05 significance level to determine if there is a statistically significant difference between the different types of companies. Factors that p-value of the test is less than 0.05, hence, we do not fail to reject the null hypothesis. The output for our major barriers for minimisation of rework practice of "conventional way of constructing "gives the p-value 0.0011, indicating that at least one of the traits is different from others, which we found a significant difference.

Table 5.4 Kruskal-Wallis H test against types of the companies

No	Causes of Rework and Barriers	df	X^2	P
Q7	Generally, subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation	6	6.110	0.411
Q8	Traditionally subcontractors must work on short windows on site. This hampers rework reduction efforts and generates rework	6	7.667	0.263
Q9	Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects	6	11.986	0.062
Q10	**Major barriers for minimisation of rework4 practice**			
Q10.1	Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice	6	18.716	0.005
Q10.2	Culture of resistance to change	6	5.575	0.472
Q10.3	Conventional way of construction	6	6.832	0.337
Q10.4	Short working window	6	13.282	0.039
Q11	**Various stages of housing construction4 process**			
Q11.1	Excavation	6	12.645	0.49
Q11.2	Frame construction	6	4.831	0.566
Q11.3	Plumbing and electrical HVAC	6	15.389	0.016
Q11.4	Drywall and interior fixture	6	16.307	0.012
Q11.5	Cladding installation	6	5.754	0.451

Q11.6	Fitting out and Flooring	6	5.515	0.480
Q12	**Design related factors4**			
Q12.1	Contractors' requirements for change	6	1.476	0.961
Q12.2	Unexpected clients' change	6	7.919	0.244
Q12.3	Lack of quality management p4ractice	6	6.494	0.370
Q12.4	Lack of coordination among contractors/subcontractors	6	15.530	0.017
Q13	**Client-related factors**			
Q13.1	Insufficient source of time and budget spent on the briefing process	6	4.118	0.661
Q13.2	Poor communication with design team	6	11.255	0.081
Q13.3	Lack of knowledge and experience of the design and construction process	6	6.629	0.356
Q13.4	Insufficient involvement of client from the outset of projects	6	12.327	0.055
Q13.5	Change during constrictor project	6	4.059	0.669
Q14	**Subcontractors-related factors**			
Q14.1	Different business objectives	6	13.177	0.040
Q14.2	Unrealistic scheduling	6	10.044	0.123
Q14.3	Non-compliance with specification	6	8.135	0.228
Q14.4	Poor workmanship	6	6.415	0.378
Q14.5	Different work ethic	6	5.818	0.444
Q14.6	Late involvement of subcontractors from the beginning	6	20.127	0.003
Q14.7	Poor communication	6	10.095	0.121
Q14.8	Lack of trust and transparency	6	4.763	0.575
Q14.9	Insufficient motivation	6	8.206	0.223
Q14.10	Lack of collaborative and cooperative working	6	9.041	0.171
Q15	**Site management related factors**			
Q15.1	Lack of knowledge, experience, and training	6	19.503	0.003
Q15.2	Poor planning	6	11.679	0.070
Q15.3	Lack of cooperative working	6	8.991	0.174
Q15.4	Lack of competent supervisor	6	6.140	0.408
No	**Learning mechanism, Strategies and Future direction**	**df**	**X^2**	**p**
Q16.1	Trainings, seminars and workshops	6	9.000	0.174

Q16.2	Research and development	6	11.802	0.067
Q16.3	Subcontractors daily process improvement without systematically labelling "rework minimisation strategies"	6	5.222	0.516
Q17	An important issue of direct parameter for Subcontractors to win future contracts at the moment	6	12.745	0.003
Q18	Doing process improvement in their daily activities, however, has not been systematically labelled as "rework minimization strategies"	6	4.737	0.578
Q19.1	Culture of collaboration and cooperative working	6	11.344	0.078
Q19.2	Investment in new technologies and human resources	6	5.658	0.463
Q19.3	Training, seminars, and workshops	6	2.419	0.877
Q19.4	Early engagement of subcontractors from early stage	6	21.466	0.002
Q19.5	Create incentives among subcontractors	6	7.103	0.311
No	**Adaptation of new technologies (automation / digitisation)**	**df**	**X^2**	**P**
Q20.1	Ability to rectify errors and mistakes	6	9.054	0.171
Q20.2	Reduction of design errors and changes	6	3.097	0.797
Q20.3	Realistic scheduling	6	6.513	0.368
Q20.4	Reduction in reliance on skilled labour	6	7.434	0.283
Q21.5	Document control and archiving	6	6.315	0.389
20.6	Improvement of transparency and trust	6	4.142	0.657
20.7	Improv collaborative and cooperative working	6	5.575	0.472
21	Digitisation of information and exchange of data among contributors	6	12.676	0.448
22	Adaptation of offsite manufacturing techniques	6	10.593	0.102
23	Employing low maintenance	6	7.069	0.314

For the majority of variables in Table 5.4 there are no significant differences in opinion between companies. However, there are the following variables Q(10.1;14.1;14.6;15.1;17, and19.4) with p <0.05 have a difference in opinion among different companies.

Table 5.5 Kruskal-Wallis H test against housing project type

No	Causes of Rework and Barriers	df	X^2	P
Q7	Generally, subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation	2	3.578	0.167
Q8	Traditionally subcontractors must work on short windows on site. This hampers rework reduction efforts and generates rework	2	1.878	0.391
Q9	Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects	2	3.765	0.152
Q10	**Major barriers for minimisation of rework4 practice**			
Q10.1	Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice	2	7.508	0.023
Q10.2	Culture of resistance to change	2	0.370	0.831
Q10.3	Conventional way of construction	2	0.996	0.608
Q10.4	Short working window	2	4.898	.086
Q11	**Various stages of housing construction4 process**			
Q11.1	Excavation	2	4.585	0.101
Q11.2	Frame construction	2	2.298	0.317
Q11.3	Plumbing and electrical HVAC	2	0.572	0.751
Q11.4	Drywall and interior fixture	2	5.755	0.056
Q11.5	Cladding installation	2	3.590	0.166
Q11.6	Fitting out and Flooring	2	1.871	0.392
Q12	**Design related factors4**			
Q12.1	Contractors' requirements for change	2	0.317	0.854
Q12.2	Unexpected clients' change	2	22.250	0.325
Q12.3	Lack of quality management p4ractice	2	5.43	0.063
Q12.4	Lack of coordination among contractors/subcontractors	2	6.999	0.300
Q13	**Client-related factors**			
Q13.1	Insufficient source of time and budget spent on the briefing process	2	7.143	0.028
Q13.2	Poor communication with design team	2	0.263	0.877
Q13.3	Lack of knowledge and experience of the design and construction process	2	1.259	0.533
Q13.4	Insufficient involvement of client from the outset of projects	2	1.374	0.503
Q13.5	Change during constrictor project	2	5.239	0.073
Q14	**Subcontractors-related factors**			
Q14.1	Different business objectives	2	5.825	0.054

Q14.2	Unrealistic scheduling	2	2.394	0.302
Q14.3	Non-compliance with specification	2	2.218	0.330
Q14.4	Poor workmanship	2	0.714	0.700
Q14.5	Different work ethic	2	4.409	0.110
Q14.6	Late involvement of subcontractors from the beginning	2	0.357	0.836
Q14.7	Poor communication	2	0.629	0.730
Q14.8	Lack of trust and transparency	2	0.955	0.620
Q14.9	Insufficient motivation	2	2.354	0.308
Q14.10	Lack of collaborative and cooperative working	2	0.247	0.884
Q15	**Site management related factors**			
Q15.1	Lack of knowledge, experience, and training	2	1.339	0.512
Q15.2	Poor planning	2	2.754	0.252
Q15.3	Lack of cooperative working	2	4.368	0.113
Q15.4	Lack of competent supervisor	2	1.566	0.457
No	**Learning mechanism, Strategies and Future direction**	**df**	X^2	***p***
Q16.1	Trainings, seminars and workshops	2	3.094	0.213
Q16.2	Research and development	2	0.606	0.739
Q16.3	Subcontractors daily process improvement without systematically labelling "rework minimisation strategies"	2	2.325	0.313
Q17	An important issue of direct parameter for Subcontractors to win future contracts at the moment	2	5.036	0.081
Q18	Doing process improvement in their daily activities, however, has not been systematically labelled as "rework minimization strategies"	2	4.737	0.578
Q19.1	Culture of collaboration and cooperative working	2	11.774	0.003
Q19.2	Investment in new technologies and human resources	2	1.566	0.457
Q19.3	Training, seminars, and workshops	2	0.306	0.858
Q19.4	Early engagement of subcontractors from early stage	2	16.034	0.000
Q19.5	Create incentives among subcontractors	2	5.310	0.070
No	**Adaptation of new technologies (automation / digitisation)**	**df**	X^2	***P***
Q20.1	Ability to rectify errors and mistakes	2	0.786	0.675
Q20.2	Reduction of design errors and changes	2	0.383	0.826
Q20.3	Realistic scheduling	2	0.266	0.875

Q20.4	Reduction in reliance on skilled labour	2	1.973	0.373
Q21.5	Document control and archiving	2	0.720	0.698
20.6	Improvement of transparency and trust	2	9.111	0.011
20.7	Improv collaborative and cooperative working	2	2.110	0.348
21	Digitisation of information and exchange of data among contributors	2	3.429	0.180
22	Adaptation of offsite manufacturing techniques	2	2.232	0.328
23	Employing low maintenance	2	4.391	0.111

Further, the majority of variables in Table 5.5 there are no significant differences in opinion between different types of projects. However, there are the following variables (Q10.1, Q13.1, ,Q19.1,Q19.4, and Q20.6) with $p < 0.05$ have a difference in opinion among different project type.

Table 5.6 Kruskal-Wallis H test against type of procurement

No	Causes of Rework and Barriers	df	X^2	*P*
Q7	Generally, subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation	3	2.961	0.398
Q8	Traditionally subcontractors must work on short windows on site. This hampers rework reduction efforts and generates rework	3	3.485	0.323
Q9	Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects	3	26.397	0.000
Q10	**Major barriers for minimisation of rework practice**			
Q10.1	Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice	3	21.492	0.000
Q10.2	Culture of resistance to change	3	16.143	0.001
Q10.3	Conventional way of construction	3	6.894	0.075
Q10.4	Short working window	3	4.480	0.214
Q11	**Various stages of housing construction4 process**			
Q11.1	Excavation	3	9.203	0.027
Q11.2	Frame construction	3	9.549	0.023
Q11.3	Plumbing and electrical HVAC	3	1.755	0.625

Q11.4	Drywall and interior fixture	3	14.284	0.003
Q11.5	Cladding installation	3	4.743	0.192
Q11.6	Fitting out and Flooring	3	13.004	0.050
Q12	**Design related factors4**			
Q12.1	Contractors' requirements for change	3	15.414	0.003
Q12.2	Unexpected clients' change	6	3.747	0.290
Q12.3	Lack of quality management p4ractice	3	3.047	0.384
Q12.4	Lack of coordination among contractors/subcontractors	3	3.112	0.375
Q13	**Client-related factors**			
Q13.1	Insufficient source of time and budget spent on the briefing process	3	12.087	0.007
Q13.2	Poor communication with design team	3	11.820	0.008
Q13.3	Lack of knowledge and experience of the design and construction process	3	5.161	0.160
Q13.4	Insufficient involvement of client from the outset of projects	3	21.594	0.000
Q13.5	Change during constrictor project	3	9.257	0.026
Q14	**Subcontractors-related factors**			
Q14.1	Different business objectives	3	12.939	0.005
Q14.2	Unrealistic scheduling	3	7.241	0.065
Q14.3	Non-compliance with specification	3	0.649	0.885
Q14.4	Poor workmanship	3	4.780	0.189
Q14.5	Different work ethic	3	2.758	0.430
Q14.6	Late involvement of subcontractors from the beginning	3	29.113	0.000
Q14.7	Poor communication	3	4.671	0.198
Q14.8	Lack of trust and transparency	3	0.048	0.997
Q14.9	Insufficient motivation	3	6.825	0.078
Q14.10	Lack of collaborative and cooperative working	3	15.087	0.002
Q15	**Site management related factors**			
Q15.1	Lack of knowledge, experience, and training	3	10.962	0.12
Q15.2	Poor planning	3	1.778	0.620
Q15.3	Lack of cooperative working	3	11.001	0.012
Q15.4	Lack of competent supervisor	3	0.867	0.833

No	Learning mechanism, Strategies and Future direction	df	X²	*p*
Q16.1	Trainings, seminars and workshops	3	28.206	0.000
Q16.2	Research and development	3	35.870	0.000
Q16.3	Subcontractors daily process improvement without systematically labelling "rework minimisation strategies"	3	27.234	0.000
Q17	An important issue of direct parameter for Subcontractors to win future contracts at the moment	3	10.786	0.013
Q18	Doing process improvement in their daily activities, however, has not been systematically labelled as "rework minimization strategies"	3	7.211	0.065
Q19.1	Culture of collaboration and cooperative working	3	3.980	0.264
Q19.2	Investment in new technologies and human resources	3	8.411	0.038
Q19.3	Training, seminars, and workshops	3	46.877	0.000
Q19.4	Early engagement of subcontractors from early stage	3	3.575	0.311
Q19.5	Create incentives among subcontractors	3	4.254	0.235
No	**Adaptation of new technologies (automation / digitisation)**	**df**	**X²**	***P***
Q20.1	Ability to rectify errors and mistakes	3	1.608	0.658
Q20.2	Reduction of design errors and changes	3	5.532	0.137
Q20.3	Realistic scheduling	3	7.221	0.065
Q20.4	Reduction in reliance on skilled labour	3	8.356	0.039
Q21.5	Document control and archiving	3	19.568	0.000
20.6	Improvement of transparency and trust	3	13.313	0.04
20.7	Improv collaborative and cooperative working	3	16.143	0.001
21	Digitisation of information and exchange of data among contributors	3	13.472	0.004
22	Adaptation of offsite manufacturing techniques	3	12.661	0.005
23	Employing low maintenance	3	13.828	0.003

Further there are variables in Table 5.6 with no significant differences in opinion concerning different procurement types. However, there are the following variables Q (10.1;10.2;12.1;13,2;13.4;14.1;14.6;14.10;16.1;16.2;16.3;19.3;19.4;21.5;20.6;20.7;21,and 23) with $p < 0.05$ have a difference in opinion between different type of procurement.

5.11 Chi Square Test

To determine whether there was a clear tendency in the respondents' point of view, a Chi-square (**X²**) test was performed to examine the significant in difference. As the main concern is whether the respondents were in agreement or disagreement with the question statement, the 5-point Likert scale were converted into a 3-point scale of 1= "Agree", 2= 'Neutral", 3= "Disagree". The original variables in SPSS with 5 response categories were transformed into new variables by combining the categories of "Strongly agree" and "Agree", "Disagree" and "Strongly disagree", and shown in Table 5.7.

Table5.7 Chi-square (X^2) test of questionnaire responses on variables

ID	Variables	Agree	Neutral	Disagree	X^2	df	*p*
Q7	Generally, subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation	60	40	8	41.167	2	0.000
Q8	Traditionally subcontractors must work on short windows on site. This hampers rework reduction efforts and generates rework	90	15	3	136.056	2	0.000
Q9	Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects	100	8	0	85.333	1	0.000
Q12.1	Contractors' requirements for changes	90	11	7	50.704	1	0.000
Q12.2	Unexpected clients' change	90	15	3	56.333	2	0.000
Q12.3	Lack of quality management p4ractice	85	13	10	59.259	1	0.000
Q12.4	Lack of coordination among contractors/subcontractors	90	8	10	45.333	2	0.000
Q13.1	Insufficient source of time and budget spent on the briefing process	88	12	8	14.815	1	0.000
Q13.2	Poor communication with design team	81	17	10	53.481	1	0.000
Q13.3	Lack of knowledge and experience of the design and construction process	81	18	9	498.000	1	0.000
Q13.4	Insufficient involvement of client from the outset of projects	72	26	10	14.815	1	0.000
Q13.5	Change during construction project	83	15	10	37.926	1	0.000
Q14.1	Different business objectives	101	4	3	48.000	2	0.000
Q14.2	Unrealistic scheduling	100	5	3	16.333	1	0.000
Q14.3	Non-compliance with specification	89	10	9	5.333	1	0.000
Q14.4	Poor workmanship	98	3	7	68.481	1	0.000
Q14.5	Different work ethic	74	8	26	29.037	1	0.000
Q14.6	Late involvement of subcontractors from the beginning	104	3	1	59.259	1	0.000
14.7	Poor communication	103	2	3	68.481	1	0.000

14.8	Lack of trust and transparency	95	6	7	45.370	1	0.000
14.9	Insufficient motivation	100	4	4	42.000	1	0.000
Q14.10	Lack of collaborative and cooperative working	101	4	3	50.704	1	0.000
Q16.1	Trainings, seminars and workshops	90	14	4	56.333	2	0.000
Q16.2	Research and development	92	10	6	65.841	1	0.016
Q16.3	Subcontractors daily process improvement without systematically labelling "rework minimisation strategies"	95	10	3	55.411	0	0.000
Q17	An important issue of direct parameter for Subcontractors to win future contracts at the moment	95	8	5	176.389	2	0.000
Q18	Doing process improvement in their daily activities, however, has not been systematically labelled as "rework minimization strategies"	99	6	3	176.167	2	0.000
Q21	Digitisation of information and exchange of data among contributors	80	18	10	96.972	2	0.000
Q22	Adaptation of offsite manufacturing techniques	91	10	7	164.093	2	0.000
Q23	Employing low maintenance	89	12	7	164.093	2	0.000

Most of the variables are agree, and this as proven the significant in opinion, however, some of these variables are not conclusive, and the results of the Chi-square (X^2) in the Table 5.7 confirmed that the differences in opinion are significant respondents on the three variables (p= 0.000). Chi-square (X^2) test was continued to be performed to examine the significance of difference in opinion for the rest of questionnaire variables. As the main concern is whether the respondents were in agreement or disagreement with the question statement, the 5-point Likert scale were converted into a 2-point scale of 1= "Not at all", 2= 'Related". The original variables in SPSS with 5 response categories were transformed into new variables by combining the categories of "Not at all" and "To a small extent", "To some extent", "To a good extent" and "To a great extent" and shown in Table 5.8.

Table5.8 Chi-square (X^2) test of questionnaire responses on variables

ID	Variables	Not at all	Related	X^2	df	p
Q10.1	Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice	85	23	62.259	1	0.000
Q10.2	Culture of resistance to change	100	8	85.333	1	0.000
Q10.3	Conventional way of construction	25	83	29.037	1	0.000
Q10.4	Short working window	87	28	20.593	1	0.000
Q11.1	Excavation	17	91	56.333	1	0.000

Q11.2	Frame construction	11	97	68.481	1	0.000
Q11.3	Plumbing and electrical HVAC	98	10	75.000	1	0.000
Q11.4	Drywall and interior fixture	88	20	53.481	2	0.000
Q11.5	Cladding installation	19	89	45.370	2	0.000
Q11.6	Fitting out and Flooring	80	28	20.370	1	0.000
Q19.1	Culture of collaboration and cooperative working	101	7	85.333	1	0.000
Q19.2	Investment in new technologies and human resources	86	22	40.333	1	0.000
Q19.3	Training, seminars, and workshops	103	5	88.925	1	0.000
Q19.4	Early engagement of subcontractors from early stage	100	8	80.832	1	0.000
Q19.5	Create incentives among subcontractors	30	78	20.645	1	0.000
Q20.1	Ability to rectify errors and mistakes	64	44	2.103	1	0.147
Q20.2	Reduction of design errors and changes	73	35	22.439	1	0.000
Q20.3	Realistic scheduling	94	14	52.570	1	0.000
Q20.4	Reduction in reliance on skilled labour	74	34	12.794	1	0.000
Q20.5	Document control and archiving	98	10	67.523	1	0.000
Q20.6	Improvement of transparency and trust	92	16	54.491	1	0.000
Q20.7	Improv collaborative and cooperative working	102	6	85.333	1	0.000

The results of the Chi-square $(\mathbf{X}^2)$ in the Table 5.8 proved that the differences in opinion are significant respondents on the two variables (p= 0.000). In summary, the result indicates that aforementioned factors in the Table 5.7 and 5.8 from respondents have impact on rework minimisation practice in the supply chain, and the survey views were consistent among various contributors. However, there are some factors that contribute to the occurrence of rework. There are also some inconclusive factors with significant larger than (p= 0.05) , and these factors are such as Q(20.1;16.2; and 10.4). Further, there are factors are not impacting the occurrence of rework in the supply chain and these factors are such as; Q (11.1;11.2; and 11.5) which have minimum impact on the occurrence of rework in the supply chain.

5.12 Data Validity and Reliability

The reliability and validity of the study established into the body of research methodology, applied during the course of study to reassure the methods employed and conclusions produced were reliable and valid. The validity of the content of the questionnaire was ensured throughout the literature review, interviews, and a pilot study survey. Assessing validity and reliability of the research both in qualitative and quantitative study is crucial in building confidence in the findings of the research. Validity determines the accuracy of the findings, and it measures the phenomenon which was intend (Gray, 2009). On the other hand, the reliability of the data determines the level of consistency of the research (Gibb, 2007). The validity of the questionnaire started with running a pilot study to assess the appropriateness of the questions, the length, and scale of the survey structure (Saunders, 2004). It is important that the questionnaire validity was assessed to which a sample could be generalised to a wider population.

Through a wider selection of respondents within the housing sector, attempts were made to ensure the reliability of data. Data from survey presents (shown in Figure 5.2) to which all respondents had ample of professional experience in the field of housing construction projects. Every respondent provided their background including name, designation, experience, and email address. Moreover, the diverse job positions of respondents in terms of the area of focus, years of experience operating departments, nature of jobs helps for the reliability related to the source of data. After data collection process, preliminary analysis was carried out such as missing value, and Kruskal-Wallis H analysis.

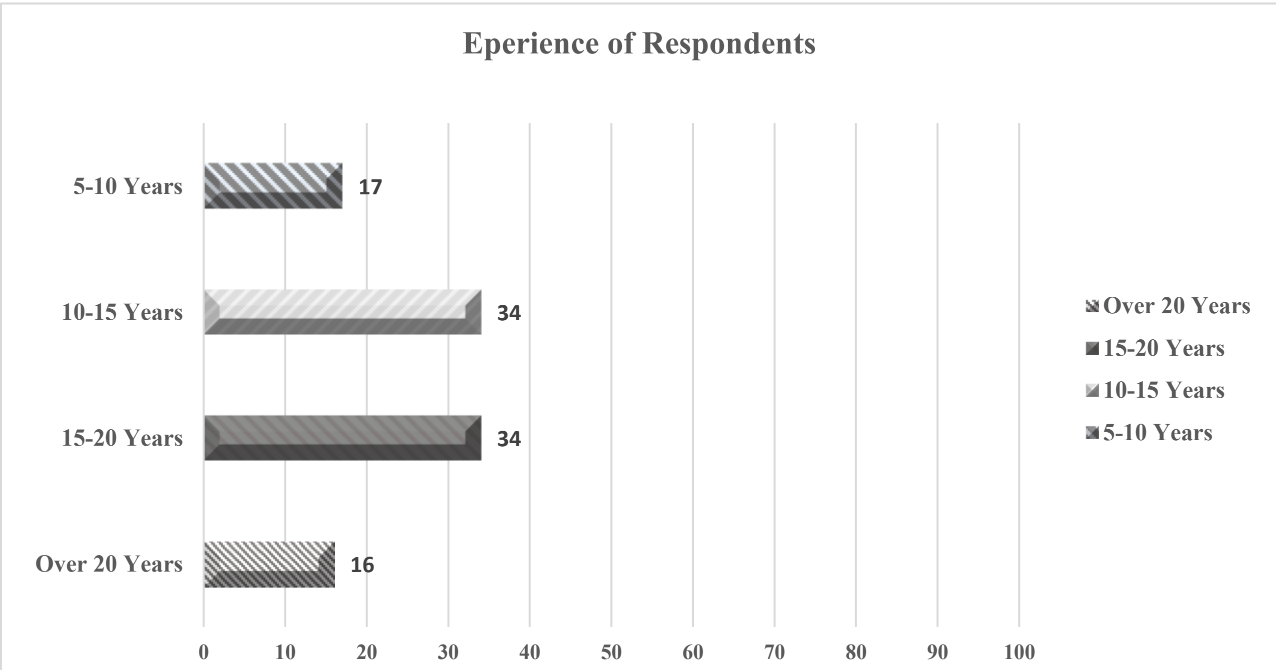


Figure 0.1 Respondents experience category

5.12 Findings and Discussion

5.12.1 Planning Site Activities

Effective site work planning among contributors noted as a key performance for rework minimisation. Managing and planning site activities is well understood as a strategic approach towards achieving the desired performance on constructions sites (Forster, 2017). Managing and planning work onsite is crucial for prevention of mistakes, errors, defects, which ultimately leads to rework. A careful assessment of specification during construction site planning can preclude unnecessary rework generation. Also, the study's respondents believed that having a dedicated role for rework manager onsite who is responsible to manage and provide strategies to potentially prevent rework occurrence. The commitment can be determined through setting a "rework minimisation strategy" which can help to avoid identified rework causing activities. Preparing rework scenarios plan through robust planning which can help to prevent the likelihood of rework causing activities from design stage of projects. The client's role also considered important, as clients have a profound influence in projects' criteria, as any changes without planning in advance and selecting the right team in place can cause rework along the production process. The finding of the research suggested robust planning can provide the capacity to deal with unexpected changes and uncertainties in different situations, such as; disagreement on quality, miscommunication, poor workmanship, and delays on projects, and if any issues or rework occurs then it can be quickly remedied as the planning the work can take risks and uncertainties out of the equation through the collective work of different contributors onsite.

5.12.2 Cooperative Working to Foster Trust (system-based trust through cooperative working)

The analysis of data showed that trust was a critical factor in few numbers of different scenarios from subcontractors' perspective. The fundamental lack of trust within subcontractors that form industry's supply chain (Dainty et al., 2001). and the imbalance of cooperative and power in short term, adversarial relationship constrains effective SCM before even to begin, despite the best effort to improve cooperative working among supply chain they still remain problematic and fragmented. Different work ethic and different business objectives among parties was considered crucial, as this can result in rework generation and impact on the quality of buildings. Level of Subcontractors' commitment to projects can also vary, with concerns that people can let other subcontractors down for multiple purposes, intentionally through the prioritisation of other work, poor workmanship, or unintentionally through mistakes and errors. Due to fragmented nature of housing sector, the research confirmed that cooperative working is necessary to build trust and driving rework down to zero. This can have consequences for whether subcontractors are willing to take responsibilities for the overall quality of projects. However, majority of the subcontractors would consider accepting responsibility, although this may be varied based on the level of trust and integrity among subcontractors. Osmani (2013) noted that industry's fragmented nature and lack of collaboration can impede the implementation of rework minimisation through cooperative working and trust. In a similar vein, Canadian National Inter-Professional Competency Framework (2010) recommended that achieving the best possible performance within a multi professional commitment, a good degree of collaboration and cooperative working among different contributors is utmost need.

5.12.3 Create Reward Mechanism System

The current study revealed that one of the factors which can contribute to rework minimisation is to create a reward system where this can motivate subcontractors for the delivery of high-quality work. As such, rework minimisation practice can be a key performance indicator. Adopting a profit share (Helm, 1968) among contributors based on the completion of projects. Using subcontractors as trade capital to provide fair rewards, to create a sustainable and transparent collaboration. Yet, to do this the construction industry delivery system has to fundamentally shift to more innovative approaches. Providing a reward mechanism among different parties onsite with a profit-sharing system based upon completion, tasks become focused on the final product rather than breaking the chain of subcontractor to only focus on assigned tasks with different business objectives. In this mechanism everyone's job become of similar value, as cooperative approach curbs fragmented culture of housing supply chain and provides a coherent crew amongst subcontractors onsite to work collectively for the success of projects. The way subcontractors interface together onsite becomes particularly important to conduct each and every activity with careful consideration to ensure all elements of the project is complied with standard quality.

5.12.4 Learning Mechanism Techniques

Learning mechanism techniques is one of the key factors which can improve collaborative working culture in the housing supply chain to minimise rework. The results suggest that having excellent construction knowledge among site teams in construction environment with iterative activities and chronological sequence of work can prevent error, defect, and damage to the previous completed job, therefore, this can reduce the likelihood of rework occurrence. Osmani et al. (2008) noted that understanding the root causes of rework it requires knowledge and training among site teams for reduction of rework. In reviewing literature, the importance of adopting appropriate learning mechanism system among contributors onsite can increase the awareness and knowledge of rework minimisation practice.

The erosion of mass labour employers and the prevalence of self-employed workers means that the responsibilities for training cascades to the supply chain, where there are the least available resources to undertake. Their retirement and lack of new entrant to the sector, makes skilled labour relatively scare (Hopkin et al., 2016). The significant proportion of the UK construction sector's workers are immigrants from different countries – the number is reaching around 35% of the workforce in London (The construction Index 2018).

It is important to understand RM requires training and running workshop for such every company has a way to ensure subcontractors have the relevant knowledge of understanding RM requirements and equipped with the required set of skills for RM practice onsite. Begum et al. (2007) stated that running workshops and training are essential component of strategies to achieve RM practice. Training and learning mechanism can run through site management teams onsite; and by e-learning platform among subcontractors.

Required training and workshop and obtaining license to conduct activities in construction site in which could enhance the levels of workmanship performance for a desired quality and that eliminates rework (Baiche et al., 2006). Knowledge of the whole construction process onsite and the sequence of work can assist in preventing certain form of rework occurrence. Comprehending construction activities and site layout can help to prevent the likelihood of rework. For example, having a knowledge of wall tiles and floor rendering in terms of which one comes first can reduce offcuts and similarly, to understand ceiling materials is fitted before wall rendering can also reduce large amount of rework onsite. Ample of training and workshops among site team can improve the knowledge in housing construction how to conduct activities, and site team efficient specifications is a crucial competence for driving rework minimisation culture in the housing supply chain.

5.12.5 Improved Collaborative Working Culture for Rework Minimisation

The findings of the research suggest that improved collaboration was identified as one of the most critical measures for reduction of rework. Improved collaboration for reduction of rework was ranked as one of the most significant factors in eliminating rework in the UK housing supply chain. This is not surprising since several studies suggested, for instance, Miller et al. (1999) indicated that collaborative working culture among subcontractors can achieve better outcome and reduce costs in construction projects.

The problem of poor supply chain management is well documented and include low productivity, inadequate site management, planning and execution which combine, and all repeatedly results in delays and cost overrun of projects (Thunberg and Fredriksson, 2018). Early involvement of contractors and subcontractors right from the outset of projects is vital to facilitate the design process and reduce design changes that might occur later which can prevent rework generation on construction sites (Briscoe and Dainty, 2005).

Results of the research strongly reported practice of cultural change in housing industry was essential to enhance the level of collaboration. Studies recommended that lack of collaboration among design team, contractors, and subcontractors is a key attribute that compromises profitability and performance of construction industry (Hughes et al., 2012).

Typically, clients commissioning a design team, which then involves consultant and engineer. As a result of heterogeneous and fragmented nature of housing sector, typically drawings are passed from one trade to another, without any collaboration. Then design documents passed to contractor who is responsible for executing actual job onsite. This usually results what considered in the industry as “over-the-wall-syndrome” meaning problems occurs when each contributor work independently towards the same goal with zero degree of collaboration. Therefore, this can result in late detection of defects and errors which can lead to cause rework. Evident suggests the major cause of rework occurrence are ineffective project communication and cooperation, and document delay (Osmani, 2012; Arain et al., 2004). This is the result of poor collaboration among contributors onsite. As such, rework minimisation practice requires to foster an effective communication, information sharing, effective project management onsite and early involvement of expertise (Hughes et al., 2012). This can result in resolving all inaccuracies, ambiguity that can occur before design completion, hence, preventing possible rework occurrence. In addition to that, collaborative and cooperative working culture can help to tackle constructability of design's issues among design and subcontractors' team which can otherwise affect rework occurrence onsite.

Usually, all parties onsite blaming each other for poor performance rather than working collectively to improve the overall performance of projects. The game of blaming behaviour is considered as one of the major factors causing to uncooperative working onsite which resulting rework generation (Henjewele, Fewings & Rwelamila, 2013). Contractors and subcontractors believe that designers are the cause of rework generation, while designers claiming that their work have nothing to do with rework occurrence (Osmani et al., 2008). This impedes the likelihood of collaborative working culture among contributors involved in the processes of housing development projects. However, the literature identified rework causes as design related issue are around 30% and considered to have a relatively greater impact on costs in housing construction projects (Josephson et al., 2002; Hwang et al., 2009, Hwang et al., 2014; Love and Edwards, 2012).

Considering heterogeneous nature of housing industry, fostering collaborative working culture is a key factor to achieve rework minimisation practice in housing supply chain.

Moore and Dainty (2001) stated that culture of resistance to change in housing construction environment can impedes achieving the fully integration of subcontractors in housing construction for a better collaboration. Cultivating a culture of collaboration and cooperative way of working among contributors on site can significantly impact to minimise rework occurrence. This can significantly impact on the levels of rework occurrence in housing construction site. Also, culture of competition should change towards more collaboration which can minimise rework generation and ultimately, improves the productivity of workflow in each stage of housing construction projects.

5.12.6 Ineffective Project Management Team (Competent and Qualified Supervisory

Evident suggest that one of the measures that causes rework occurrence is lack of competent project management team onsite. Project management team competencies, knowledge, and commitment was argued as a key driver for rework reduction. Teo and Loosemore (2001) noted that despite the comprehensive research and work in construction rework and strategies, there is a deep-rooted rework occurrence in construction projects because of poor performance among project management team. For instance, a penalty can be set for poor rework management performance, this can make rework minimisation practice an important performance indicator. For example, labelling *"Systematic Rework Minimisation Practice"* or achieving *"Zero Rework "*among contributors onsite can motivate contractors and subcontractors to treat rework minimisation practice, similarly as important as time and cost performance, which is crucial for the success of projects (Sanvido et al., 1992).

Typically, rework minimisation practice in housing construction given extremely limited consideration because there is not enough emphasis on the importance of site management role for rework minimisation in construction projects (Osmani, 2013). Usually, in construction projects, time, cost, and quality are significant indicators for the performance of assessing the success of construction projects (Sanvido et al., 1992). As such, site management team and other contributors invariably commit to the aforementioned key priorities which contributes for the measurement of their performance in housing projects. It has been well understood that contributors are not required for rework minimisation practice as a benchmark for the performance of construction projects. However, the practice of rework minimisation possesses attribute to improve time and cost of projects (BRE, 2008). A clear communication from management team onsite has a higher chance to have a good rework reduction performance.

5.12.7 Influence of Subcontractors' Expertise on Early Phase of Projects

As discussed earlier in the literature in a typical housing construction project, number of subcontractors can go up to hundreds or even more to deliver successful projects. Over 87% of the UK construction companies only employ five or less workers (ONS, 2019), and 40% of all workers are classified as self-employed (Rhodes, 2015). However, subcontractors and SMEs have always been neglected and less attention has been paid to their expertise and experience.

The success of housing construction projects is heavily dependent on supply chain capability both offsite and onsite and being responsive to unexpected changes. Therefore, the commitment and involvement of subcontractors from the early stage of housing projects are crucial to preclude rework occurrence in housing construction sites. However, generally, subcontractors have little to say or do not get involved at all from an early stage of projects. Questionnaire survey respondents strongly reported that subcontractors have a vast experience in carrying out iterative activities onsite housing construction projects. The benefit of such experience is that each subcontractor can capitalise on their experience and expertise while also helping to understand the key requirement of projects (Henjewele, Fewings & Rwelamila, 2013). Through holistic collaboration among designers and subcontractors there is tendency of preventing issues which can cause possible rework generation such as; including design errors, poor information sharing and constructability issues onsite construction (Hughes et al., 2012). The involvement of various contributors from early stage of projects can minimise all ambiguities, while experienced subcontractor can carefully assess the entire process to minimise rework. Ineffective communication, late or poor information sharing, errors and mistakes can be avoided, particularly, as collaborative working attitude characterised through improved cooperative and trust among different subcontractors.

The research result validated the importance of early subcontractors' involvement (ESI) and suggest that while subcontractors believed that their input is pivotal at design stage of housing projects to bring much certainty of constructability of projects and prevent likely rework occurrence; designers believed that they independently possess skillset required to prevent rework occurrence. However, evidence from literature suggests that design is about a third 33% of construction waste (Innes, 2004). The result of this research also suggests that ESI have positive influence on drawing quality, information flow, schedule performance (Song et al., 2009) Based on the differences on perception, this can be understood that housing construction industry is highly fragmented, and each contributor prefers to work independently. This can affect the ability of other parties to contribute on the development process, which in turn results in error and leads to cause the occurrence of rework. Arain et al., (2014) stated that lack of involvement of subcontractors from design stage of construction is responsible for error and subsequently causes rework in housing construction projects. Therefore, it highlighted the need to foster a cultural and behavioural change to a collaborative approach for rework minimisation practice to deliver sustainable housing construction projects.

5.12.8 Strategies Towards RM Practice

Approaches towards rework minimisation (RM) at the production processes ranged from the management of subcontractors, and the management style of educating labours during projects. Confirming the methods towards RM practice have a positive impact in housing construction projects, operational strategies were developed to transform the approaches to actions which lead to RM.

5.12.9 Driving Factors for Rework Minimisation

Previous studies indicated that rework has adverse impact on construction project performance (Love, 2002). The result from this study showed that in housing construction projects subcontractors have a vital role in prevention of rework. A careful consideration of factors revealed that the term 'Driving factors for Rework occurrence' aligns with the structure of this group.

Knowledge of construction process and sequence of work among site team and building operatives is important for mitigating rework generation, also, ensuring fewer changes during construction process has an effect on driving low rework occurrence. In a similar vein cultivating a culture of collaboration and effective communication among supply chain participants can provide a remedy for rework generation in housing development process before moving to the next stage of construction (Liker, 2004). The culture of collaborative working among subcontractors in the housing supply chain is key to achieve rework minimisation practice. Improvement can be attained; albeit necessitates effective ways of capturing and measuring data, from which improvement criterion can be determined (Lee and Amaral, 2002).

Collaboration within entire housing supply chain can prevent rework occurrence and drives agenda of stopping and fixing the issues as early in the process as possible (Liker, 2004). This necessitates management of a process that supports earlier rework prevention, detection of defects and dissemination of information and integrated approach to problem solving. However, it requires a stringent way of interpreting and capturing information on site, where rework minimisation improvement metrics can be determined. Therefore, the pressure the UK housing industry is encountering have an adverse effect in quality of buildings and consequently increasing the level of rework generation in different stage of housing construction (Hopkin et al., 2014). These would suggest that the UK faces a serious challenge in providing affordable quality houses that its residents need now and will need in the near future. A fundamental shift and innovative approaches towards affordable and quality dwellings is essential in meeting the challenges (Rodionova, 2016; Kollewe, 2017).

5.12.10 Systematic Rework Reduction

Th result showed that involving subcontractors and site team who are in better position to identify avenues in the design process for rework generation onsite. Previous studies suggested that there is no systematic rework minimisation among practitioners onsite and rework adversely affect the productivity and performance of projects (Love, 2002a), also, it impacts the cost and schedule overrun of projects (Love et al., 2010). Different practitioners onsite can realise that it is feasible to consider achieving a goal of "Zero rework", striving towards the ambitious goal can bring a several tangible benefits. This can result in increased of profit, reduction of cost and waste, improve the productivity and performance of projects and lead to a collaborative and cooperative way of working among subcontractors onsite (Leonard and Taggart, 2014).

5.12.11 Monitoring Rework Minimisation (daily improvement process)

Appropriate monitoring of rework minimisation has the potential to effectively impact on the result of rework generation on construction projects (Osmani et al., 2008), and this indicates the need to make an effort for rework minimisation in housing supply chain. Monitoring rework in housing construction identified to have advantages for several reasons, such as, for instance; it assists to understand how well contributors are carrying activities in terms of rework minimisation practice, helps to review the target of each party onsite, and supports to serve as a source of information for the prospect of future projects.

Learning and understanding rework minimisation can lessen effect of such rework generation and can improve the productivity and quality of housing projects. Viewing rework reduction as a continuous of process improvement than only a product of specific activities or behaviours, involve a collective contribution of housing supply chain spectrum and project management system to identify causes and interfaces which influence the reduction of rework practice. Given the complexity of housing supply chain characteristics the production of a housing projects can involve the learning process of activities through daily improvement among practitioners onsite to preclude rework generation (Lopez et al., 2010).

As one discussed in the first phase of data analysis that *"you can go up to a labour and tell them off for their work not being up to scratch, they would say you are just a bricklayer, you do your bit, and I will carry my job"*. It was argued that the need for monitoring activities on construction sites as part of ongoing process, and most respondents confirmed this can be conducted by someone who is qualified to carry the task.

Apart from a competent and qualified person for managing and monitoring rework minimisation process onsite among site team, particularly, collaborative competencies are essential for driving the performance of contributors for rework minimisation in housing supply chain.

5.12.12 Documenting and Recording Rework

The result of the study suggested that documentation and record of rework in each project can serve as a guideline to help prevent rework occurrence among subcontractors for future projects. Udawatta et al. (2015) noted that detailed documenting and recording rework plays a key role in reduction of rework in housing supply chain. Training and workshops on the development of RM documentation and the use of rework minimisation practice to prevent rework can be viewed as attempt to ensure practitioners pursue rework minimisation by documenting and recording rework in each project.

5.12.13 Change in Attitude Toward RM onsite

The results of this study reported that different subcontractors with various skills need to work together and cooperate in physical space and time to build a quality housing. The whole of a building as a product is definitely important than the sum of its parts, and that requires a shift in the attitude of sit team to work towards a shared goal rather than working independently for their assigned activity. However, attitude towards rework minimisation practice among practitioners in housing supply chain is gradually changing, the employment of different strategies such as incentives, particularly profit sharing with which can motivate practitioners onsite to manage rework occurrence has suggested crucial to be able to achieve rework minimisation in housing supply chain. Begum et al. (2007) suggested training and educating practitioners onsite can influence the attitude of different parties onsite in which can result in better understanding of rework minimisation practice. However, the attitude of site project management team was identified to have the most influence on the outcome of rework minimisation practice as they are responsible of driving site teams to prevent rework.

5.12.14 Type of Construction Methods

Technology advancement have enabled industrialisation and a shift towards offsite manufacturing approach. A more controlled environment to carry activities offsite has shown more valuable for the duration of COVID-19 pandemic. Research conducted by 2020 McKinsey reported that 40% of UK home builders are already investing in manufacturing facilities or considered in the future, for instance. The combination of lighter-weight materials and digital planning and production technologies can enable the housing construction to achieve higher quality of products which can result in rework minimisation.

5.12.15 Employment of Offsite Technique for Rework Minimisation

Another critical group for rework minimisation improvement in housing supply chain, according to the survey results, are innovative approaches and emerging technologies. The key variable contributing to reduction of rework is the element of manufactured building offsite, and carrying light work onsite, whereas number of issues causing rework such as design change, error, and poor workmanship was completely prevented. This can help to eliminate construction rework onsite (Poon et al., 2003), also, this can prevent time and cost overrun of construction projects**.** Off-site technologies with an aid of robotics have enormous potential to reduce negative environmental impacts, increase re-use of recycling materials (Court et al., 2009; Chen et al., 2009), reducing rework, cost reduction, and optimising the level of performance and the quality of products. The comprehensive review of literature (Gann 1996; Gibb 1999; Blismass et al., 2016; Chaing et al., 2006; Lu and Liska 2008; Pan et al., 2008; Nadim and Goulding 2010). Rahman (2014) confirms that digitisation of information is a crucial factor enabling industrialised construction to improve the performance and deliver high quality products and subsequently eliminate rework within entire housing sector.

However, there are different terms which has been used to describe industrialised housing, and discussed in Chapter 2 (section 2.3.2), factory built housing and other offsite techniques has been evident to minimise rework generated through with contributors' activities onsite (Lu, and Yuan, 2013). Frangopol & Liu (2007) stated the tendency of employing prefabricated techniques for rework minimisation has increased up to 84%. This illustrates that the employment of manufactured housing is necessary to minimise rework occurrence in construction sites generated by subcontractors.

5.12.16 Digital Delivery onsite for RM

The finding of the research reported that the employ of digital platforms can enhance several aspects of site management to minimise rework. This can allow information to communicate effectively onsite, and cope with onsite changes, for instance, on work overrun or delays on materials. The platform can manage and support the need for other parties and their work regarding the timeline of projects, quality and so on. A 2020 McKinsey study reported that the construction industry was among the least digitised sector in comparison to the total economy across assets, usage and labour. Understandably innovation is further hampered through risk aversion and limited margin. The use of digital tools in housing construction has primarily focused on project management, schedule management, facility management, and application of field reporting (Dong et al., 2009). Digital supply chain management can enable for better cooperative and collaboration, greater control of the value chain, and a shift toward more data driven decision making in the industry (McKinsey, 2020). Employing personal assistant can help different subcontractors onsite to monitor the progress and assess the quality of their jobs and rework management onsite in housing supply chain.

5.12.17 Lack of Communication Tools and Channels

Effective communication was perceived from findings of the research as one of key factors to build trust among subcontractors in order to preventing rework occurrence in housing construction projects. Also, this can help practitioners for their future work and job performance based on the completed jobs. Khalfan et al. (2007) noted that openness and transparent communication, reliance and delivery of outcomes is the most crucial factors which can influence the development of effective communication for rework minimisation practice in housing supply chain.

The management of communication and information exchange process still heavily relied on conventional methods of paper transfer (Craig and Sommerville, 2007). Miscommunications have an adverse effect on rework generation because rework occurs due to limited communication channel and cooperative among practitioners onsite, other reason includes the pressure of time to complete projects and improper communication channels and tools. Tam et al. (2007) highlighted the importance of effective communication and cooperative as a way to minimise rework generation.

5.12.18 Unclear Allocation of RM Responsibilities

The result of the research suggested that allocation of responsibilities for decision making has a significant impact on the level of rework occurrence in housing supply chain. Typically, subcontractors and contractors carry major responsibility for rework generation, while designers, clients, and other stakeholders has less responsibility towards rework generation. Also, it is clear that the implementation of rework minimisation practice mostly must be undertaken during the construction process by subcontractors and supervisors. A study by Greenwood et al. (2003) identified the need for communicating the responsibility for rework minimisation. Therefore, this raises the concern whether subcontractors are involved from early stage of projects and allow the execution of rework minimisation practice efficiently or designers and clients must also take more responsibility toward rework minimisation, as this study suggest that client and designers should also take responsibility of rework generation. The result of study appears to be consistent with Osmani et al. (2008) who confirmed that designers should take a major responsibility for rework generation in housing supply chain.

5.13 Chapter Summary

The quantitative research method was employed as a medium of data collection and then data analysis. The second phase of the data collection instrument designed a pilot study, and the final set of questionnaires was administered for the data collection process. Purposive sampling was used to disseminate the questionnaire, including the network of supervisors within the UK housing sector. A pilot study was conducted to test and enhance the questionnaire. Out of 267 questionnaires, 108 responses from a wide range of respondents were received, representing a response rate of 42.65%. To assess the applicability and reliability of the research findings, several preliminary data analyses were performed, such as missing value analysis and Kruskal-Wallis H test.

The variables grouped into different categories such as subcontractors' related factors, client's related factors, site management's related factors, major barriers for reduction of rework, technologies 'related factors, rework occurrence in a different stage of housing construction, learning mechanism for reduction of rework, future direction, characteristics for reduction of rework– leading for the establishment and evaluation of rework minimization on housing construction projects.

For the assurance of whether the respondents perceived the items in the same way – the Kruskal-Wallis H test was conducted on all items. Out of 61 variables on the questionnaire, there was variables which there were no significant difference in opinion. The result presents less than 1% of all the items, recommending that different job positions among participants do not affect their perceptions of the variables. This represents that the combination of all the questionnaire responses for further analysis doesn’t have such an impact on both the validity and reliability of the research findings. The analysis result revealed three critical categories in eliminating rework in the UK housing supply chain. These categories include reduced rework-related improved collaboration, rework occurrence-related driven factors, and Innovative approaches and new technologies. The summary of the findings and their significant which are related to rework minimisation in the housing supply chain shown in Figure 5.2.

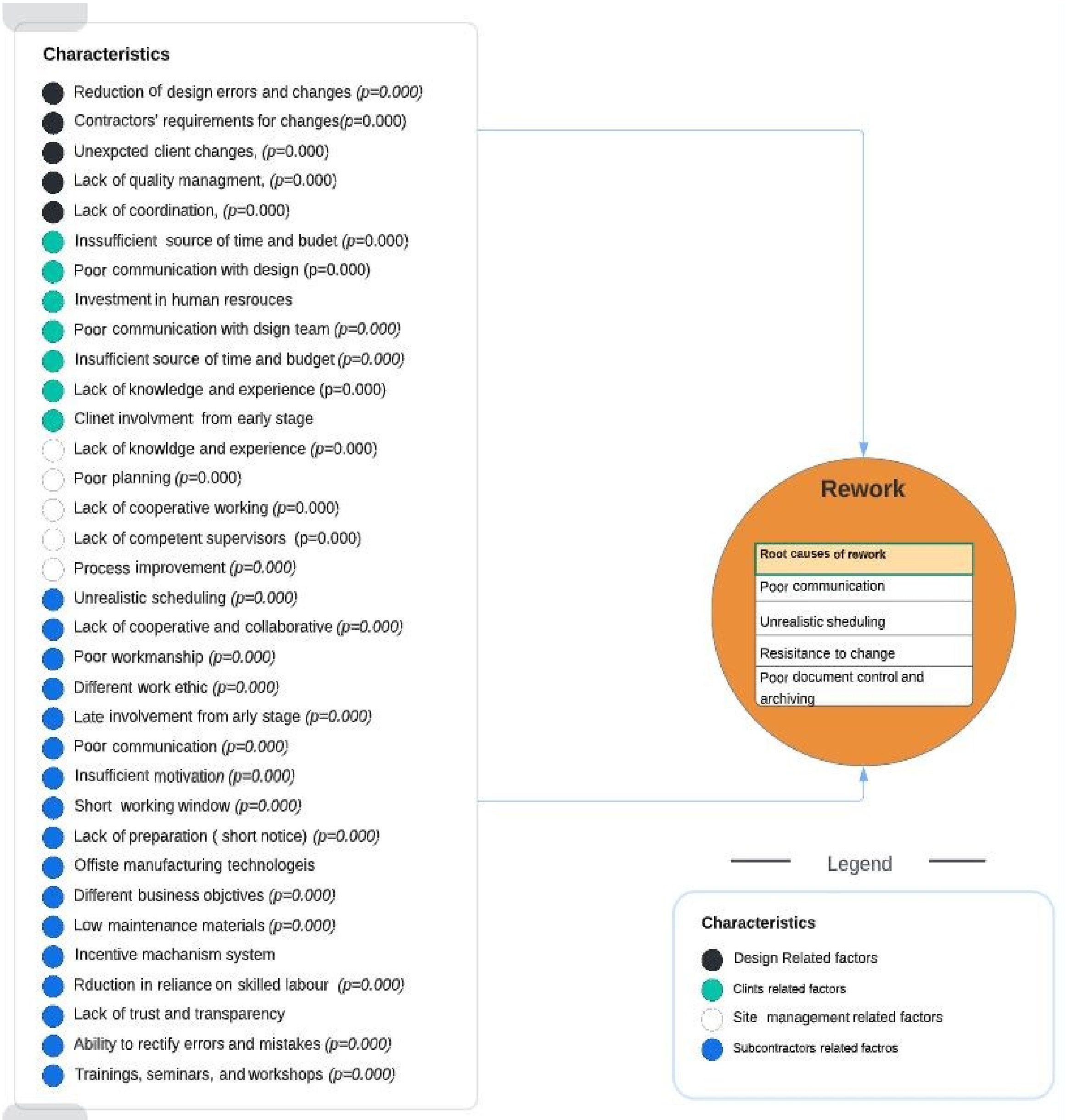


Figure 5.2 Rework framework based on the significant of related factors (p=0.000)

FRAMEWORK DEVELOPMENT and VALIDATION

6.1 CHAPTER OVERVIEW

This chapter is aimed to present the development and validation of the Rework Minimisation Framework (RMF) in the UK housing supply chain among subcontractors. The framework aims to attempt prevent possible rework occurrence, provide rework minimisation practice and direction for future projects in the housing supply chain. The following sections provide the RMF process based on the first version of RMF, which was proposed in chapter three, section 3.10. Further, the development was carried out based on the findings from the literature review, interview data analysis, and the second data analysis phase (questionnaire). The validation process of the framework evaluated in this chapter and key improvement measures emerged after the validation process – and critical action is presented step by step for the final version to improve the RMF and future direction for rework minimisation practice in the housing supply chain. The final version of the RMF proposed in this chapter to prevent rework occurrence among practitioners in the housing supply chain.

6.2 Aim of The Rework Minimisation Framework (RMF)

The proposed framework aims to prevent and minimise rework among subcontractors during housing construction projects. It is expected that the framework provides all the necessary steps among subcontractors to prevent potential rework occurrences and improve each activity during each stage of construction on site for future projects.

6.3 Structure of Rework Minimisation Framework Development Process

The first version of the rework minimisation framework (RMF) was developed after the review of literature and presented in Chapter Three (section 3.10). In retrospect of the literature, several factors causing rework in the housing supply chain were identified and proposed in Chapter Three. The framework development process continued to enhance after the data analysis carried out throughout the research, qualitative (interviews) and quantitative (questionnaire), respectively. Further, these factors were carefully assessed and clustered and are shown in Table 6.1.

Table 0.1 Stage of Framework development process improvement

Literature review results	Interview data analysis results	Questionnaire data analysis results
Communication and coordination between parties	Poor communication and coordination among subcontractors	Improved collaborative and cooperative working among subcontractors
Clients' early involvement from design stage	Subcontractors' engagement from early design stage	Improvement of Trust and Transparency
Subcontractors' fragmentation	Poor workmanship	Training and workshops Create incentive mechanism
Short working window onsite	Lack of collaboration and cooperative working	Innovative approaches
Incompetent supervisors	Ineffective Site management team	Unrealistic scheduling
		Documenting and recording rework

Development of RMF was carried out throughout the research after each stage of data analysis of the study. Primarily, after the first proposed version of rework minimisation framework in Chapter Three, the framework development process further continued from the results of both qualitative and quantitative data analysis of the research study. The second phase of data analysis applied to validate the data and yield the highest performance and presented in Figure 6.1. The red dots of the framework illustrates the first phase of the framework development and the blue dots represents the developed and complete version of the framework for rework minimisation practice in the housing supply chain.

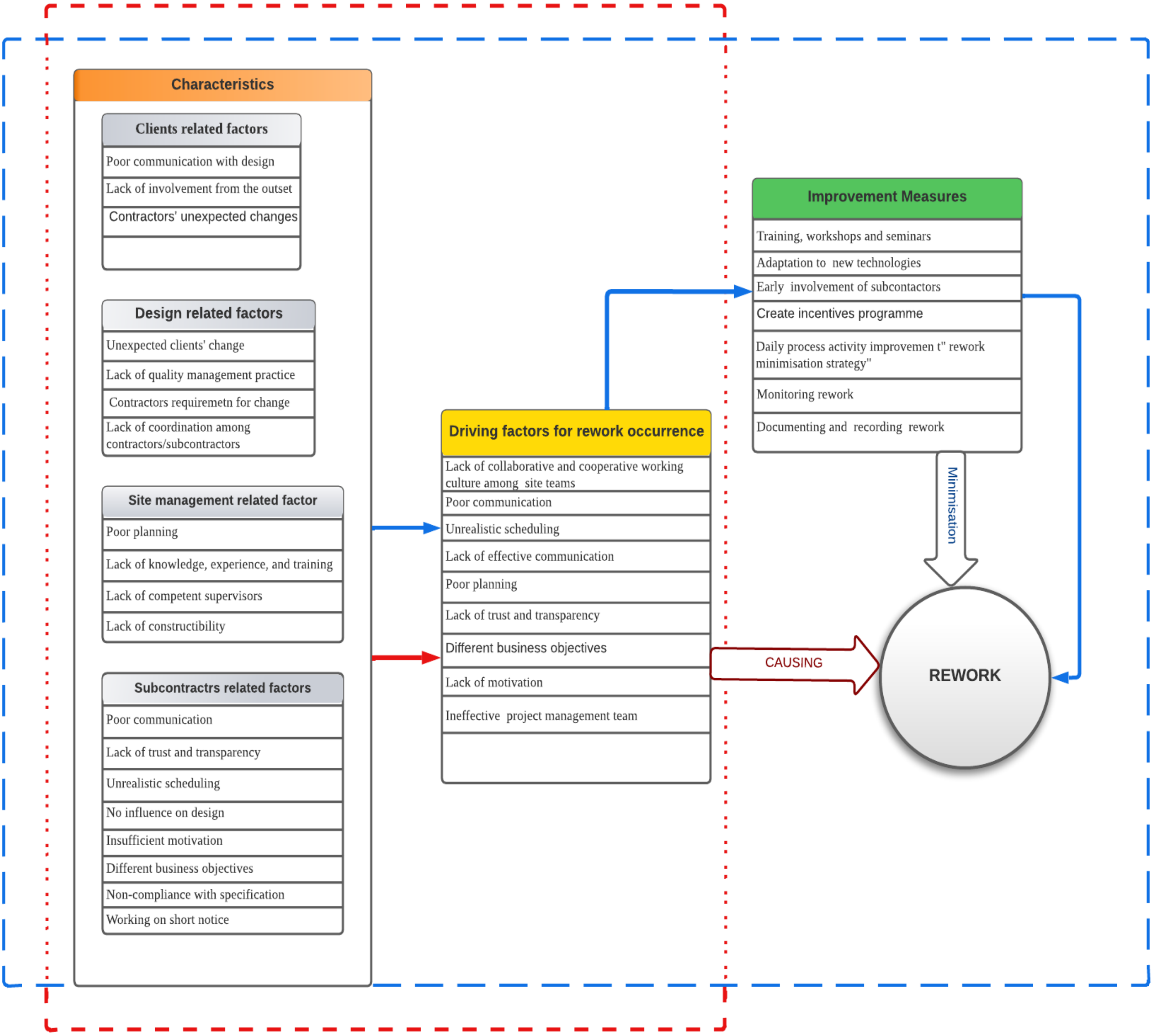


Figure 0.1 Rework minimisation framework for housing supply chain

The results of data analysis showed that training and educating practitioners onsite is crucial for preventing possible rework and rework minimisation practice in the housing supply chain. Subcontractors usually play a key role in delivery successful project, and therefore, the result of data reported that involving subcontractors from early stage of housing construction projects can prevent errors and/or mistakes that can lead to rework generation onsite. According to the data it is important to note that recording and documenting rework can have a positive impact on future projects and can improve the quality of buildings. One of the merit for improvement measure according to participants was to introduce incentive mechanism system among different subcontractors which can motivate site teams for rework minimisation practice.

6.4 Implementations of Framework for Practitioners

The most effective RMF for reduction of rework in housing supply chain has significant implementation to prevent and alleviate rework occurrence. To achieve the aim of framework – a guideline for the implementation has been presented which helps different contributors (subcontractors) minimise rework occurrence through the improvement of collaborative and cooperative working and make the most of the framework within their companies.

6.4.1 Implementation Measures for the Practice of Framework

To apply such a framework in practice, it is essential to foster a collaborative and cooperative working culture, involving the effort of different contributors onsite and making all the necessary and required adjustments based on the causes prevailing at the production level. Rework minimisation can be achieved when all parties have a shared goal and attitude towards an end-product to successfully achieve their objectives on site to deliver successful projects – and adhere to rework minimisation practice strategies. Therefore, achieving a sustainable rework minimisation practice is crucial to the system's quality or ranked measures at the project level and the extent to which this is followed on projects. A summary of the guideline for implementing the framework is presented in table 6.2.

Table 0.2 framework guideline for improvement measure on rework minimisation practice

Proposed improvement measures (subcontractors)	Implementation notes
Define project level rework minimisation vision	A perspicuous vision for rework minimisation should be defined and necessary measures put in place to pursue the aim.
Involve subcontractors at the design stage	Ensure subcontractors team is engaged early on at the design stage to assess the practicality of design and planning for rework minimisation
Set up and implement a rework minimisation strategy	Implement the strategy for rework minimisation onsite and educate the site team to make sure they fully comprehend the demand of rework minimisation for the project
Train and educate site team	Run workshops and seminar to influence rework minimisation at the project level
Institute a reward system – profit sharing	Institute a reward and incentive mechanism on site to persuade the team to improve the performance of projects
Monitor Performance and provide feedback to site team for their performance	Rework minimisation practice should be monitored and measure progress to identify rework causes where possible. And report and archive
Documentation and archiving	Review rework minimisation performance at the end of projects to identify the best practices and causes affecting rework occurrence on site. Document lessons and feed it back to managers

6.4.2 Recommendation based on the framework

The framework developed to be used in practice by practitioners on housing construction sites as part of the strategy and effort to successfully prevent and reduce rework in the housing supply chain. To obtain rework minimisation practice in housing supply chain, it requires an ability to understand the causes of rework and employ rework minimisation practice by fostering a holistic collaborative and cooperative working culture among practitioners on site. This requires subcontractors to pay attention to and prioritise rework minimisation practice, and make all the necessary adjustments to be able to adopt new strategies in which to carry their tasks on each stage of project. Rework minimisation practice demands a change in attitude to approach “systematic rework minimisation practice” and make it a key performance indicator within their agenda to improve the overall project performance.

6.4.3 Guide for implementing the best practice framework

Implementing the framework requires commitment and determination from different contributors in the housing supply chain to help make the necessary modifications to prevent and minimise rework occurrence. As identified throughout the research, rework minimisation practice can only be achieved when there collaborative and cooperative working system are in place and different contributors are adhered to in different stage of housing construction projects.

A clearly defined vision by client, designers and involving subcontractors can help different contributors in the housing supply chain with a specific aim to manage rework occurrence. This can be determined which types of drivers are the reason to achieve the aim. The next step after defining the vision for rework minimisation practice is to set detailed objectives for and which level of rework minimisation practice needs to be accomplished. Objectives can be established on a quarterly or yearly basis. These targets can be periodically reviewed to ensure contributors are aligned with objectives and are moving in the right direction. The review can be examined on the performance of each trade. The management team can be in charge of rework minimisation practice and determine approaches by setting objectives in meetings. Then these approaches can be articulated into workable strategies to prevent and minimise rework occurrence onsite. Determining strategies for rework minimisation as shown in Figure 6.2 can cover areas such as: planning for rework minimisation, a system or monitoring mechanism to ensure objectives are being met, training, workshops, and education, and documenting on rework minimisation practice.

During the housing construction projects, there should be a project specific vision for rework minimisation practice. However, all housing construction projects vary and might not share the same vision, project level vision should reflect as much as possible on rework minimisation practice. Due to the importance of subcontractor's role and the influence they are likely to have on rework minimisation, it is crucial to involve them as early as possible on projects. Planning should be made on rework minimisation practice and includes the rework stream channels, and the probable frequency of rework occurrence onsite and developing a strategy to manage them. Planning for rework minimisation can include monitoring different contributors' activities onsite to determine objectives are clearly defined and articulated and moving to achieve the shared goal. The next step is to implement rework minimisation strategies onsite. As part of this strategy, creating and running training, workshops, and seminars among subcontractors to improve the awareness and the importance of achieving systematic rework minimisation practice onsite. It is vital also, to institute a rework mechanism scheme among contributors onsite to ensure different subcontractors are complying with the goal and vision for rework minimisation.

Throughout the construction processes, the performance of rework minimisation practice should be measured to oversee the effectiveness of strategy onsite. This set for factors which are within the control of different contributors onsite and influence the performance of rework minimisation practice. These are approaches of rework minimisation manager towards rework; amount of planning at the initial stage of construction; attitude toward rework minimisation; level of rework minimisation knowledge; ability to identify avenues for rework occurrence; relationship among different subcontractors.

At the end of projects, the framework recommends that there should be a final revision based on the performance of rework minimisation to help to have a general overview of the level of collaboration among contributors onsite. All the lessons learnt from the review should then be documented and captured and report back into the management team for the possible necessary adjustment and improvement for in future projects.

6.5 Framework Development validation

6.5.1 Validation Aim and Objectives

The aim of the framework validation is to carefully evaluate the appropriateness, feasibility, adequacy, and make sure the framework was made to the highest level to contribute towards rework minimisation practice in the housing supply chain. Also, in addition for discussion of implementation strategy. For this purpose, the rational of validation framework is to meet the following objectives:

5. Improve the information flow, ease of use and clarity of the framework
6. Examine the practicality of the improvement measures; and
7. Identify a potential implementation strategy for practice

Some of the participants from previous data collection phases during this research were contacted to participate in validating the outcome of the framework. All these participants are experts in the housing sector and involved in the housing development projects, particularly who are experienced in the production process.

6.5.2 Validation Approach and Respondent's Demographic

The focus group was carried out to validate the framework development for this study. The process of validation comprised of two stages – first, a pilot study was carried out with seven construction researchers at London South Bank University to refine the framework upon the actual validation process. From the previous data collection phase, some respondents were contacted through email and phone calls to participate in the focus group. The participants were selected according to their experience level in the housing sector and availability. For the framework validation, a focus group was conducted with six participants engaged in daily activities in housing construction projects, such as contractors, engineers, site managers, subcontractors, and architects. The focus group was conducted online over Zoom due to COVID-19 restriction and the policy of working from home. The validation focus group was conducted with respondents aiming to refine the clarity and further examine the information flow and suitability of the proposed framework for rework minimisation and discuss the implementation strategy of the framework. The summary of the participants' backgrounds is presented in Table 6.3 below.

Table 0.3 Demographic of Participants in the Focus Group

Participants	Position	Years of experience
Participants 1 (I1)	Subcontractor	10-15 years
Participants 2 (I2)	Contractor	Over 20 years
Participants 3 (I3)	Architect	10 – 15 years
Participants 4 (I4)	Engineer	15 – 20 years
Participants 5 (I5)	Site manager	5 -10 years
Participants 6 (I6)	Subcontractor	Over 20 years

A set of key questions was prepared in advance to guide the discussion. The questions were constructed in which help to evaluate the framework development practice among subcontractors. The second version of the framework (section 6.1) presented to participants for recommendation. During the focus group, the interaction among participants was fostered in a constructive way to help enhance the practicality of the framework. Table 6.4 illustrates the agenda of the focus group.

Table 0.4 The Agenda for Focus Group

Agenda	
14:00 – 14:30	Introduction and instruction
14:30 – 15:30	Presenting proposed framework and discussion
15:30 – 16:30	Practice for the improvement of framework
16:30 – 16:45	Final remarks

6.6 Discussion of Validation Feedback

Feedback provided through validation framework process by participants and discussed in the following section under four main themes

I. Practicality and Usefulness of the framework
II. Feasibility of the recommendation
III. Completeness and adequacy of framework
IV. Recommendations for the improvement of framework

6.6.1 Practicality and Usefulness of the Framework

All participants had a same view that the RMFD presents a practical tool for rework minimisation practice in housing supply chain. Concerning the question about "to what extent the framework provided a structured, well-informed and holistic approach to rework minimisation in housing supply chain – all participants responded with yes and recommended it presents a very good basis for applying and planning for rework reduction. Two of the subcontractors suggested they are willing to adopt the RMF where one of the subcontractors made this remark:

"It is apparent that the framework can positively impact the daily process improvement onsite, it helps to reinforce reliability and improve trust and openness among subcontractors onsite to prevent potential rework generation onsite"

Participants (I1, I5 and I6) have suggested that they would combine some parts of the framework into their working strategy for rework minimisation practice. I2 mentioned that the framework can significantly help to planning activities onsite for rework management on housing construction projects, and then added:

"I found the last few parts of the framework very practical as a review at the end of each project to documents and capture the things we learn from the mistakes and feed that into the project manager will help in improving the level of performance onsite ".

Also, all of participants were expressed their support and recommended that this will have influence on the level of rework occurrence in housing construction projects.

6.6.2 Feasibility of the recommendation

Most of the participants' perspective on the RMFD was that it can interpret into the improved rework minimisation in housing supply chain. I1, I2 and I6 were a strong support for incentive and reward systems – as they had a same view and I2 added:

"We have been planning how to introduce a reward mechanism system to improve the performance of subcontractors onsite".

After the comment, the contractor invited two other subcontractors discussing how the system can be implemented on housing construction sites – and they recommended giving a percentage coupon and create profit sharing mechanisms where to share the profits of projects with subcontractors based on their performance and rework minimisation practice. Participants also were asked whether there might be any barriers which can hinder such implementation onsite, the general responses were that almost all projects, subcontractors are not involved from early stage of projects to apply their expertise to minimise rework generation and scheduling realistic planning for activities onsite.

6.6.3 Adequacy and Completeness of the Framework

All participants had a same view of the adequacy of the framework and all the sections of the framework have been covered the project cycle among different contributors onsite All respondent suggested the drivers for rework minimisation onsite among subcontractors captured all the necessary reasons why they manage rework minimisation and that recommended a large portion of work had been done to fully comprehend their process.

Both subcontractors and contractor found the insight from the influences on achieving rework minimisation in the housing supply chain appealing, and one of the subcontractors (I6) made a remark:

"Usually on each project we believe that everything managed and carefully covered, however, I can argue that there are certain factors that have been left behind – I believe that the framework is sensible to do so particularly the positive impact which can have on the outcome of rework minimisation practice onsite".

Similarly, the contractor continued the discussion and had a shred view of the adequacy of framework and further made a following comment:

"The suggestion that assurance of repeat jobs onsite impacts subcontractors' performance to manage rework occurrence and once different subcontractors are conducting activities in a particular and systematic way through the framework, will increase the attitude of collaboration among contributors "

The contractor went on further that from many years of experience on working and managing site teams, practitioners have come to understand and realise that most of the factors mentioned in the framework can easily lead to behavioural changes among contributors.

6.6.4 Recommendations for the Improvement of Framework

Participants were asked to suggest on how to improve the robustness of framework and its ability to have the most impact on rework minimisation practice. The perspective of the most participants on recommendation was that the overarching framework capturing the most important aspects of steps to take obtaining rework minimisation practice in housing supply chain. A few recommendations were also made, I3 mentioned on the following:

"*It can be more effective to have a system which could rate the subcontractors particularly on rework occurrence and help to maintain their responsibility of how to oversee the compliance for conducting rework minimisation strategy practice – which can be in practice for the selection process on future projects ".*

The site manager and the engineer added though the framework is covering all the necessary requirements for rework minimisation practice – it appears to have many sections and it may be challenging for site teams who do not have enough knowledge of rework minimisation practice within their activities and how to implement such a compliance to prevent rework occurrence.

In summary, the validation process proved the usefulness and practicality of the RMFD and serving an appropriate roadmap to implement rework minimisation practice in housing supply chain. Constructive feedbacks were given by practitioners on all the recommendation put forward based on the development of framework. Through validation process, it was identified that having the knowledge of rework minimisation practice is imperative to prevent rework occurrence onsite and this can be achieved with running workshops, and seminars for employees throughout year.

6.7 Final Version of the Framework

The last version of the framework is enhanced in light of the focus group's recommendations. The recommendation of participants was analysed and then summarised in Table 6.2, including the required actions for each suggestion. Therefore, the final version of the framework for reduction of rework in the housing supply chain was developed based on the causes, and barriers identified throughout the research. The final version has a profound influence on the prevention of rework occurrence and future direction for rework minimisation improvement measures presented in Figure 6.2.

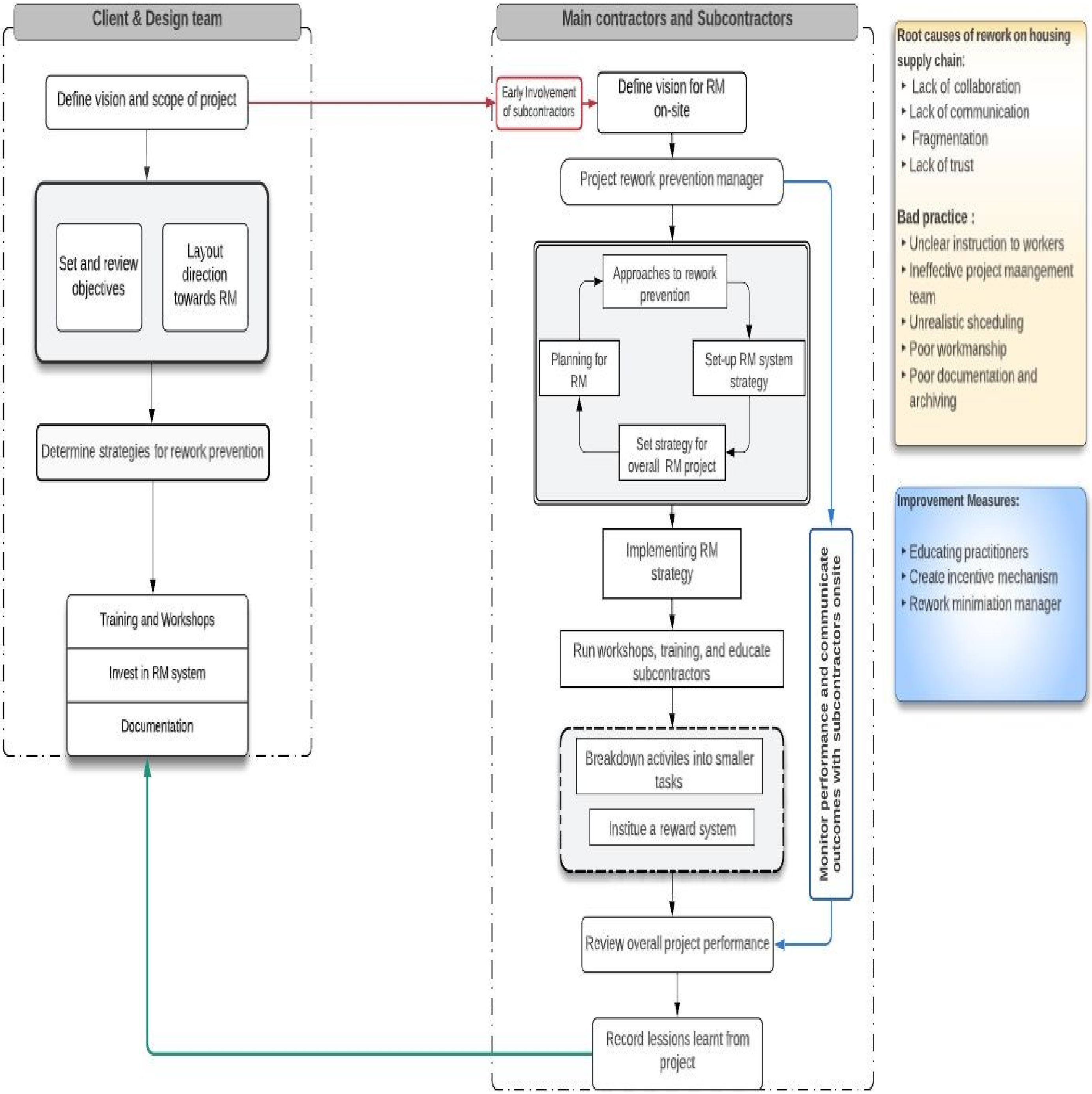


Figure 0.2 Rework minimisation model for housing supply

6.8 Chapter Summary

The chapter provides framework development and examines the framework development process for reducing rework in the housing supply chain. The chapter also presented a path to help construction companies implement the framework. Recommendations for improving the reduction of rework in the housing supply chain have been made as part of the framework. The overall validation of the framework developed from the respondents' point of view was positive regarding its information, clarity, appropriateness, flow, and practicability. The rework minimisation framework development RMF results demonstrated the robustness and practicality of the framework in the housing supply chain. The validation results also showed that the implementation of the proposed RMF has the potential to align with practitioners in the housing supply chain industry to help minimize and prevent rework on construction sites.

Moreover, the validation of results recommended that the presented context within the RMF has been broadly acknowledged among practitioners in which the employment of rework minimisation practice can be facilitated in the housing supply chain. Recommendations were made to improve the rework minimisation practice in housing construction projects. The usefulness and adequacy. The next chapter presents a conclusion, future recommendations, and contribution to the research knowledge.

CONCLUSION AND RECOMMENDATIONS

7.1 CHAPTER OVERVIEW

This chapter aims to present a summary of the research and future recommendation. The research has investigated and focused on reducing rework in the housing supply chain within the UK market dynamic. The study has resulted in several findings consolidated through the development of framework for possible rework preventions and minimisation of rework in the UK housing supply chain. The chapter provides a summary of the outcome of data collection and analysis. And presents the main conclusions and contributions include the limitation of the research and future research for this study.

7.2 Achievement of Research Objectives

The Objectives of research studies were accomplished through a robust research design and strategies, which are presented and discussed in Chapter Three. The research objectives are also presented in Chapter One, section 1.5. Four research objectives were developed to help achieve the aim of the research. The summary of research objectives, the methods employed in achieving all objectives, and the chapters containing the evidence of each objective achievement are presented in Table 7.1.

Table 0.1 Methods applied to achieve the objectives of research

Research Aim	Research Objectives	Methods of adopted to achieve each objective	Chapter Presented
The aim of the research is to develop a framework for rework minimisation practice in the UK housing supply chain	1. To explore the source and the causes of rework in housing supply chain.	Comprehensive Literature review on construction rework and the causes of rework enabled gain insights into the causes of rework occurrence in the UK housing supply chain. Identify and classify rework causes origin.	Chapter Two and Four
	2. To investigate barriers and current practices for reduction of rework within housing supply chain	Reviewed extant literature on rework causes, housing supply chain characteristics and subcontractors' dynamics, identified barriers for rework minimisation practice in the UK housing supply chain	Chapter Two and Four
	3. To identify appropriate remedial action for rework minimisation practice and development strategies for improvement action.	Based on the result of research and literature review, actions required for achieving rework minimisation practice were identified which then used in the development of framework for rework minimisation. The framework evaluated through questionnaire and focus group and obtained feedback from practitioners to provide direction and strategies among practitioners for rework minimisation practice in the housing supply chain.	Chapter Two, Four, Five, and Six

	8. To Suggest future direction for rework minimisation through strategic framework practice in the housing supply chain. 9.	Synthesised outcome of the review from data analysis applying questionnaire to develop a framework for subcontractors to reduce rework occurrence for future projects. The findings of the research provide necessary actions and strategies to prevent possible rework occurrence for future projects and rework minimisation practice among subcontractors in the housing supply chain.	Chapter Four, Five, and Six,

7.2.1 Fulfilment of the First Objective

The first objective was to assess the causes of rework in the housing supply chain. The literature review helped to gain insights into the sources and causes of rework occurrence in the UK housing supply chain. The literature review and interview findings on the rework occurrence in the housing supply chain illustrated that none of the previous studies had investigated the root causes of rework in the UK housing supply chain or to provide a systematic framework among practitioners for rework minimisation practice in the UK housing supply chain.

7.2.2 Fulfilment of the Second Objective

The second objective was to critically review and examine the barriers and current practices for rework minimisation in the UK housing supply chain. The literature review and interview findings both reported there is not yet a systematic rework minimisation practice in place within the housing supply chain. Poor communication, poor planning, and culture of resistance to change among subcontractors with different business objectives could be the most problematic in implementing rework minimisation practices in the housing supply chain. In contrast, collaborative and cooperative working culture has a high potential to prevent possible rework and minimise rework occurrence in the housing supply chain.

7.2.3 Fulfilment of the Third Objective

The third objective of the research was to develop a framework and the process was based on the key findings of the research. A sequential approach was adopted to identify the causes and provide a remedy for rework minimisation practice among practitioners in the housing supply chain. Therefore, the findings of literature review and interview (root causes of rework), and questionnaire (refined and key causes of rework and sub causes), and framework development and validation process, refinement and validation were contributed to fulfil the third objective.

7.2.4 Fulfilment of the Fourth Objective

The fourth objective of the research was to validate the developed framework. Thus, provide strategies and steps to prevent possible rework occurrence and rework minimisation practice among practitioners for future projects. The validation process was aimed at determining the clarity, the flow of information, appropriateness of framework and detailed contents, practicality of proposed rework minimisation practice framework and identify potential implementation actions and strategies for rework minimisation practice for future projects in the housing supply chain. To fulfil validation objectives, combination of questionnaire and focus group were taken into account. The overall feedback on validation objectives was positive, with several suggestions for improvement to the framework.

7.3 Research Contribution

Several numbers of contributions made as the outcome of this research is presented in the following sub sections, and these results have not been provided by other research.

Rework minimisation framework development will impact on carbon emission reduction, boost production, enhance sustainable construction, and fast track project delivery time. Other contributions from the framework are including cost saving, risk minimisation and possible superior quality of product delivery. The research contribution on knowledge was viewed from the standpoint of poor construction work culture, materials, and other resources wastage. In summary, the study contribution to knowledge can also be viewed from sustainability, improvement to working culture in construction, enhanced workforce, better quality of construction deliverables, cost, and timely project delivery.

Finally, the study specifically contributed to housing, construction production and subcontractors' management body of knowledge.

7.3.1 Theoretical Contribution

Arguably the research is the first comprehensive attempt to understand the root causes of rework and the impact of rework occurrence in the UK housing supply chain. Limited empirical studies exist surrounding the number of factors causing rework and adversely affecting rework generation in housing construction projects. However, the subject of rework minimisation in construction projects has widely been investigated on infrastructure projects. The research has particularly emphasised the influence of rework occurrence and its adverse impact on housing development projects among subcontractors in the UK housing supply chain. Therefore, contributes to bridging the research gap, findings from the research have presented a novel perspective and strategies on rework minimisation practice providing a direction for future projects in the housing supply chain. In addition, the research findings add to a body of literature on rework minimisation practice in the UK housing sector to enhance the productivity and quality of housing construction projects.

The study adopted pragmatism for its philosophical stance and employed a mixed methodology research strategy to achieve the research objectives. The current research contributes to the discussion surrounding the suitability of mixed methods research in housing construction projects. The outcome of the research findings was used to develop a practical framework to identify, prevent and navigate future directions for rework minimisation practice among subcontractors in the UK housing development projects. The framework has been intended to be applied as a practical guideline to preclude potential rework occurrence in a different stages of housing construction projects among practitioners.

Contribution to Practice

At the construction level, the research has identified several novelties within the production process. For example, a reward or incentive mechanism among contributors onsite, monitoring and recording rework occurrence, and prioritising rework minimisation practice onsite key performance indicators, which have not been discussed in previous supply chain studies, and therefore this adds to the novelty of the body of housing supply chain in the UK. Similarly, lack of training, workshops, and knowledge and ineffective communication tools emerged as a novel barrier to cause rework occurrence onsite. The absence of a systematic rework minimisation strategy among subcontractors has not been identified in all previous research on the UK housing projects.

Little has been known about rework causes associated with different contributors in the UK housing construction projects. This study has identified contributors' key drivers for rework occurrence in the housing supply chain. The research has contributed to comprehend other factors that can improve subcontractors' performance through rework minimisation practice onsite in the context of the UK housing sector. The study also provided several measures to prevent and eliminate future directions of rework occurrence.

The framework carried research findings together and attempts to diagnose the root cause of rework in housing construction site and provide remedy for relevant improvement measures and strategies for rework minimisation practice in the housing supply chain for future housing construction projects. The framework also provides the basis for rework minimisation in housing supply chain to diagnose the causes of rework and recommending potential measures to prevent the likelihood of rework generation onsite. Normally the housing construction companies manage the supply chain based on the perspective of each project in which exacerbate the level of rework occurrence and fragmentation; hence, it does not address supply chain problems. Therefore, also, the intention of the study is to manage the supply chain as production system in the housing supply chain. Thus, the framework contributes to rework minimisation, and the housing supply chain in the UK.

The contents of the framework reinforce the involvement and the backing of subcontractors from the outset of projects, effective communication and collaborative and cooperative working culture, and clear allocation and duties to comply with rework minimisation practice and enhanced rework monitoring and documentation for possible rework prevention for future projects.

7.4 Research Limitations

Managing rework occurrence in the construction industry, particularly in housing construction, requires extensive effort and collaboration within the whole housing supply chain among contributors such as clients, architects, consultants, contractors, engineers, and subcontractors. This is apparent that their decisions and actions directly impact the level of rework occurrence in the whole housing supply chain. The research findings are interpreted in line with the scope and limitations of the study. The data for this study was collected from UK housebuilders and subcontractors. However, the attempt was made to enhance generalisability through a probabilistic sampling of participants and critical sampling of respondents' roles. The study's findings cannot be generalized to other housing construction companies outside the UK. The study's qualitative and quantitative research collected data from the housing construction sector. As this study's research mainly focused on the UK housing sector, no attempt should be made to investigate strategies for rework minimisation in infrastructure projects. As such, there are variances in construction methods and materials employed in civil engineering projects compared with housing construction projects. Based on the limitation, the research outcome should only be interpreted as strategies (rework minimisation) for housing construction projects in the UK.

Despite the contributions of the research, the research has some limitations regarding its scope and data availability. One important limitation of the research is that this research was conducted in the context of UK housing construction. Given the context, an attempt was made to improve the generalisability of the questionnaire survey findings, though the research findings should not be generalized beyond the UK housing construction sector.

Another possible limitation of the study is that there was a chance that participants were doubtful to disclose some information regarding the current practices and strategies for rework minimisation practice and what constitutes rework occurrence concerning their company's policy. However, the effort was made to ensure that most participants completed and returned the questionnaire. All their responses will be managed confidentially, and there will be no adverse impact on their job/position in the company. It isn't easy to investigate the extent to which this was probable in obtaining the exact responses. The researcher also noticed several participants were reluctant to pronounce a complete view on certain issues (e.g., on rework minimisation strategy and current practices and the different management methods for reducing rework).

7.5 Further Research

The research accounts for its findings based on subjective respondents' perspectives. Therefore, the investigation showed the number of issues that need further research with empirical evidence. Precise quantification methods on rework occurrence applied to measure the actual level of rework occurrence in terms of required cost to remedy those occurred rework in housing construction activities onsite – this can allow additional insights into the relationship between subcontractors' activities and the level of rework and cost occurrence and in housing projects. There has been limited research that has tried to help determine the indirect costs of rework in housing construction projects. Therefore, the investigation into the costs and their impact on rework, specifically the indirect costs required to establish the hidden costs contained with guided rework minimisation practice.

Establishing a culture of collaborative and cooperative working among subcontractors has emerged as a relevant strategy to address issues that are liable for rework occurrence. Therefore, the research will suggest in-depth research to investigate paths of incorporating characteristics that can contribute to the collaborative and cooperative working culture in the UK housing development projects.

As previously mentioned in section 8.3, the research was conducted in the UK housing construction industry. Other studies can investigate the generalisability of its findings to different countries by collecting data from the housing construction industry and comparing it with this research. Also, as the research covers only housing construction projects, future research can navigate the investigation for rework minimisation practice in civil engineering projects.

7.6 CHAPTER SUMMARY

The last chapter discussed the stapes taken to attain the research objectives. The main conclusions and contribution of the research for rework minimisation in the UK housing supply chain were explained. Limitations and directions for further research of this study have all been demonstrated. The study offered empirical evidence of how rework minimisation can be achieved in housing construction projects through the contribution of different subcontractors in the housing supply chain. The framework of the study was demonstrated in Chapter Six to provide guidelines among practitioners onsite to minimise rework in the housing supply chain.

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Appendices

Appendix 1

Ethic Application Form

Ethics Application Form

When completing this form, please be aware that we want to process all ethics applications as quickly as possible. Please ensure you provide full details and consider ethical implications of your research fully before applying. If insufficient detail is provided, your application will be delayed while we clarify issues with you. Doctoral students should seek feedback on a draft of their submission from their supervisor before it is submitted. Junior researchers or those new to LSBU may also wish to consult with their School Committee or experienced colleagues, as procedures and standards can differ between institutions.

Project Title: Minimisation of Rework on housing supply chain **School: Architecture and the Built Environment**

Lead Applicant	Supervisors (Doctoral students only)
Name: MEHDI SHAHPARVARI **Email: SHAHPARM@LSBU.AC.UK**	**Name: Professor George Ofori** **Address: School of the Build Environment and Architecture, London South Bank University** **Email: Ofori4@lsbu.ac.uk**

	Name: Associate Professor Daniel Fong **Address: School of the Build Environment and Architecture, London South Bank University** **Email : Fong@lsbu.ac.uk**

Theoretical rationale (~500 words) *Please outline the rationale for your study, identifying the theoretical and / or practical need for the research and how initial hypothesis have been reached. THIS SECTION SHOULD NOT EXCEED 500 WORDS*
The UK construction industry contributes around £110Bn to the UK economy each year. However, the construction industry in particular, have often been criticised for the poor quality and performance of its products and the inadequacy of its production process. Housing construction is one of the major sectors with significant socio-economic impact and a key role to play to meet the increasing demand in the UK through the supply of adequate and cost-effective housing solutions. However, it is a sector that is commonly recognised as having high levels of waste. In which has been attributed to fragmentation of housing supply chain . For example, on a typical large housing project, the main contractor may be directly managing around 70 small enterprises as subcontracts. One approach to minimise waste in housing construction projects is to reduce rework by adopting lean thinking. Rework affects both cost and schedule throughout the project. Construction sites are complex environment where multiple subcontractors and suppliers are all working at the same time, often with different business objectives. In such environments, the likelihood of errors and mistakes would increase.

The cost of rework in construction projects has been estimated as high as 12% of the contract value, is estimated to be £11Bn per annum. This scale of waste illustrates the significance of tackling the root causes of rework in the housing supply chain to address socio-economic and policy challenges in the UK.

The elimination of waste has been essentially used as a key driver for improvement in the manufacturing industry. However, despite its great achievement it has not been as prevalent in the construction practice and literature. After introducing the lean concept to the construction industry, there were many attempts to implement LC across the industry to eliminate waste and add value to the projects. However, there has been a lack of clarity within the construction sector surrounding the concept of LC (LC).

The focus in housing construction practices is on fixing the problems at the end of the construction and before handing over to the client. However, if the source of problem is not examined well and the cause is not identified, there is no guarantee that the problem will not be repeated in the next project. This research focuses on identifying the nature, complexity and hypes of rework in housing projects to minimise waste and to add value to the housing supply chain. The study will examine factors that contributed to higher defects and rework such as; 1) procurement and contractual pressures in terms of cost, time and quality 2) role and involvement of end user and 3) causes of delays in decision making by clients, and its impact on projects 4) the supply chain and the sources of fragmentation.

Ethical guidelines

Please list the professional or association guidelines that you have read and intend t

See Appendix 4 of the Code of Practice for guidelines.

Participants *Who will be recruited and how? Are there any gatekeepers (e.g. people whose permission must be sought to access the participant population)? Is choice to participate likely to be a sensitive issue, and if so, what safeguards are in place? Is the population under study vulnerable (and if so, what steps will be taken to ensure population is protected?). Please attach representative copies of emails and posters which will be used during recruitment if you intend to use these.*
Operational managers, site managers and Supervisors who are actively engage in day-to-day tasks. I have made initial contacts with potential participants from different projects and companies. Target people are not vulnerable and focus of discussion will not be on sensitive issues (See Appendix A)

Recruitment *How will recruitment take place? Participants should usually receive an information sheet or similar prior to giving consent. Please use the following documents which are available from the Staff intranet Key Documents REI category and the PGR Moodle sites:* • Participant Information Sheet • Consent Sheet *Please confirm whether this is the case, and append for information about information sheets, and to see a specimen information sheet.*
Participant information sheet and consent sheet will be used (Appendix A)

Data types: *Which of the following data collection method(s) will you be using? (Please complete all applicable)*
<u>Secondary data / archival data</u>

For each source, please state how data will be collected, and from what sources. Please indicate if sources are anonymous at point of collection and whether they are currently password protected (e.g. are they in the public domain). (See Appendix 3 of Code of Practice)

<u>Surveys / scale based measures</u>

For each survey, please indicate the content of the instrument and, if the tool is already published, cite the source. How will survey data be collected? Please provide full copies in the appendix. Does permission for use of the instrument need to be gained, and if so, has it been?

Survey will focus on specific themes addressing the research objectives (See Appendix B)

<u>Non-intrusive physiological data (including blood pressure, kinematics, reaction time data, eye tracking, etc.)</u>

What data will be collected and how?

<u>Physiological materials / human tissue collection (incl. bloods and saliva)</u>

What materials will be collected and how? What Human Tissue Act issues do these present?

<u>Interviews / focus groups</u>

How will interviews be conducted? Please provide themes / indicative interview questions. Where will interviews take place?

Interview will focus on specific themes addressing the research objectives (see Appendix B). Additional documents will be collected from interviewees such as drawings, list of snagging /rework and defects from selected projects.

<u>Other forms of data / special procedures</u>

Please indicate what data will be collected and how. If any special ethical considerations arise from the data types you plan to collect, please comment on them here.

Timespan

What is the likely timespan of the recruitment and data collection phases of the proposed research? Data collection will commence when ethical approval is granted. The aiming is to commence the data collection phase on 15/12/2018 and should be concluded by the end of 31/06/2019.

(Each cell represent 1 month)

Start date	*1*	*2*	*3*	*4*	*5*	*6*
Interview Pilot Study (15/02/10)						
Interviews 17/05/19 to 17/12/19)						
Designing Questionnaire (01/09/20)						
Pilot Questionnaire 15/03/21 to 21/06/21)						
Questionnaire 21/08/21 to 21/12/21)						

Disclosure and Barring Service (formerly Criminal Records Bureau check)
Disclosure and Barring Service (formerly Criminal Records Bureau check) *Does the investigator or anyone else connected to the project require a DBS check? (If not, please indicate why) If a DBS check is required, UEP/School Ethics Coordinator will need to see a copy of the certificate before research commences.*
Not Applicable

Informed consent
Informed consent *Who will obtain informed consent and how? If you feel written consent is not required or impossible, please indicate why and how verbal consent will be obtained or what will be considered implied consent. If appropriate, what steps are going to be taken to ensure the decision to participate (or not) does not negatively impact participants? The University's standard participant consent and participation forms must be used.*
Inform consent will be used through letter of participations. (**Appendix A**)

Anonymity & data management
Anonymity & data management *What steps will be taken to ensure that data collected is anonymous or made anonymous? How will data be stored and when will they be destroyed? If stored electronically, what steps will be taken to secure the data? For additional information and advice please consult the University's Information Compliance Officer*

All responses form experts from the companies will remain confidential including companies name and participant's name. Access to data will be restricted to the researcher and his supervisor. All personal data will be coded or anonymised so it cannot be linked to the companies who supplied it. The anonymised responses will be stored separately from any identify details (such as companies names, emails, address, etc) in password protected files. Although it is expected that experts wish their responses to be anonymised, in cases where some companies wish to be named, their wishes will be taken into account.

Incentives *Will incentives beyond reasonable compensation for time and travel being used in the proposed research be offered to participants?*
No incentive offered.

Procedure *Please outline the procedure of your study step by step, beginning with the consent stage through to final debriefing. To expedite reviews it is important that the reviewers can understand exactly what your research involves so please be as clear as possible. If applicable, please make clear what the key independent and dependent variable(s) are and what the study design consists of.*
A mixed method (Qualitative – Quantitative) sequential exploratory approach involving interviews and a comprehensive survey questionnaire is chosen to meet the aim of identifying the current condition parameters and future direction for rework minimisation factors at housing supply chain. The interviewees will be identified under a purposive sampling strategy from operational managers, site managers and supervisors who are actively engaging with rework minimisation in housing projects. About 10 to 12 interviewees who have roles

in housing supply chain (from the client to subcontractors) will be invited. **This is to capture a more complete picture of the issue across the entire supply chain, which Is an important aspect for interview reliability. After collecting and analysing the data from interviews, quantitative part of the study will be implemented.**

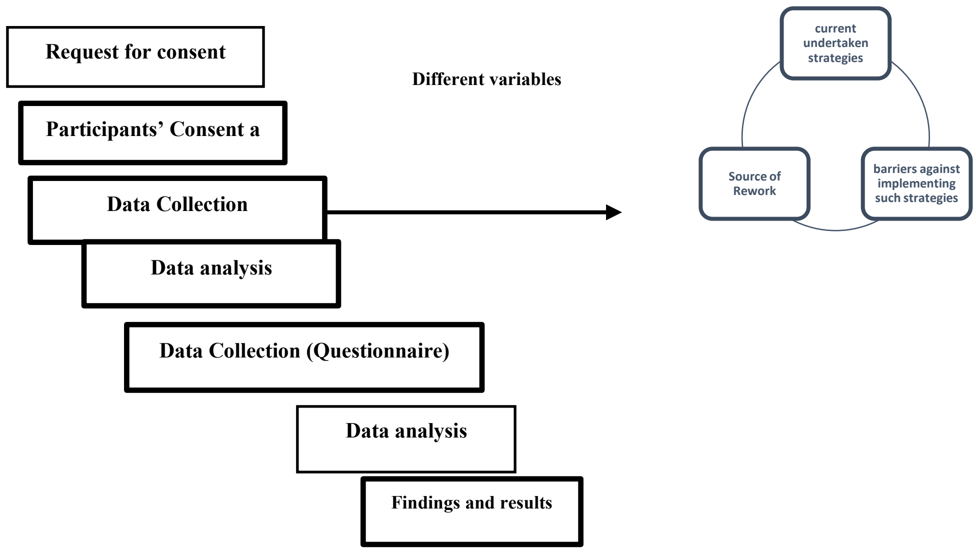
Quantitative study is to explore the relationship between particular variables. The identified points and actions resulted from the interviews will be turned into Likert- scale questions on a survey of multiple choice questions and will be distributed across the supply chain companies.
The questions for the questionnaire will be provided focusing on :

- Root causes of rework
- Current practices for minimisation of rework
- Barriers to implement minimisation of rework strategies
- Strategies for future actions by housing supply chain actors

After providing a first draft of the questionnaire, a pilot study will be conducted. Through the pilot study the level of ease at which respondents would be able to complete the questionnaire will be tested. The clarity of the language, the appropriateness and the logic of the questions, the layout, the degree of depth, the ease of navigating and user friendliness of the whole questionnaire will be examined though the pilot study. Furthermore, there would be a chance in the pilot study to ask the respondents if there are other questions/statements beyond the once in the draft questionnaire that should be included.

Finalised questionnaire will be sent to about 150 participants and data will be collected accordingly. To determine the internal consistency of the questionnaire, a Cronbach's alpha coefficient of reliability should be calculated when using Likert scale in a questionnaire. The aim here is to confirm whether the criteria and their associated Likert scale are actually measuring the construct they are intended to measure.

Cronbach's alpha coefficient should be between 0 and 1 and George and Mallery (2003) suggested a value of 0.7 or more for Cronbach's alpha coefficient.



<table>
<tr><td colspan="2">Risk
All research carries some degree of risk to participants. Please indicate (by ticking the box) which of the following risks may be entailed by your research and explain how they have been mitigated. Please 'X' all relevant risks in the associated tick box. NOTE: Most research contains some potential risk (even if minor), and failure to complete this section is a frequent cause of applications being returned without approval.</td></tr>
<tr><td>Please tick 'X' where applicable</td><td></td></tr>
</table>

	Use of environmentally toxic chemicals.
	Use of radioactive substances, ingestion of foods, fluids or drugs.
	Refraining from eating, drinking or usual medication.
	Contravention of legislation on any of: gender, race, human rights, data protection, obscenity.
	Potential psychological intrusion from questionnaires, interview schedules, observation techniques.
	Bodily contact.
	Sampling of human tissue or body fluids (including by venepuncture).
	Sensory deprivation.
	Defamation.
	Misunderstanding of social / cultural boundaries nudity; loss of dignity.
	Compromising professional boundaries with participants, students, or colleagues.
	Involves the study of terrorism or radicalisation or use of any information associated with such study.
	Other risk (please indicate what these consist of):
How will these risks be mitigated?	

Debriefing *When and how will participants be debriefed? If not, why is debriefing not required?*
Any doubt on data provided will be clarified/finalise with participants before utilisation.

Analysis *Although all forms of data analysis cannot be foreseen prior to data collection, please indicate what form of analysis is currently planned.*
For quantitative part of the research SPSS will be used to analyse the data. For qualitative part of the research, content analysis (NVIVO) will be used.

Collaborations *Does this research involve other organisations? If so, do they have their own ethical oversight requirements, or does working alongside them raise any ethical issues?*
No, the proposed research does not involve any other organisations as collaborators.

Training *Is any special training of investigators needed to complete this research, and if so, how will this be delivered?*
I have been attending research development workshops (Research design, systematic review, data collection, interview,)during the last sic months and it has been strengthen my analytical skills.

Beneficiaries *Are there any beneficiaries of the proposed research, if so, who are they and how will they benefit?*
Certainly, industry and housing supply chain in particular has a great opportunity to benefit form the outcome of the proposed research, in which could maximise their workflow and eliminate rework within entire housing supply chain

Appendix 1.2

Participants Information Sheet

London South Bank University
EST 1892

Designing the Participant Information Sheet - Guidance notes

The participant information sheet or recruitment leaflet/email should be dated, provide full contact details and location. It can be used as an integral part of a letter/email or in support of a separate invitation letter/email. This is a checklist of the areas that you should cover:

Open with the study title

The title should be simple and self-explanatory to a lay person

Follow with the reasons why the individual has been invited to participate in the research study.

'You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully'.

You should then ensure that all the points addressed in this guidance are covered in your participant information sheet:

The purpose of the study:

- The background and the aims of the study
- How long it will run for
- The overall outline and design of the study

Why they have been asked to participate

- The reasons the individual has been invited to participate
- The overall number of people that have been invited to participate

The voluntary nature of participation

'It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason'. Explain how to withdraw.

NOTE: If your study involved the recruitment of students you must explain that by choosing to either take part or not take part in the study will have no impact on their marks, assessment or future studies.

What will happen if the participant takes part and opting in

- The methods of data collection
- What the individual will be asked to do and the time involved
- How the participant can opt in for the study

Possible disadvantages/risks to participation

- Outline the disadvantages/risks or cost to the individual, including the time involved

Possible benefits to participation

- Outline any direct benefits to the individual and any other beneficial outcomes of the study, including furthering our understanding of the topic

Outline data collection and confidentiality

'All the information collected about you and other participants will be kept strictly confidential (subject to legal limitations).

Data generated by the study must be retained in accordance with the University's Code of Practice. All data generated in the course of the research must be kept securely in paper or electronic form for a period of 10 years after the completion of a research project.'

You must also inform the individual how their 'privacy and anonymity will be ensured in the collection, storage and publication of research material'

NOTE: If it is a condition of your research funding that the research data must be shared and stored in a repository, you must also explain how the data will be stored (for example with the UK Data Archive. See Appendix 3 in the Code of practice) and explain it will be anonymised.

What will happen to the results of the research study on completion

- What will happen with the results of the research once the study has been completed
- Will the results be used in your dissertation or thesis
- What degree will it be used for
- How sill the results be published
- How can the participant obtain a copy of the published research

Who is organising and funding the research

- You explain that you are conducting the research as a student or member of staff at London South Bank University
- Give your school and department name
- If appropriate, state the organisation that is funding the research (e.g. Research Council, Charity, Business, etc.)

Who has reviewed the study

- You can state that the research has been approved by the School or University, London South Bank University (as applicable).

Who to contact for further information

- You should give the individual a contact point for further information. This has to be the researcher's name and that of the study supervisor.
- You should state that if they have any concerns about the way in which the study has been conducted, they should contact the Head of Division and/or School Ethics Coordinator /University Ethics Panel on (contact details – phone number and/or email address).
-

Concluding the participant information sheet by

- Thanking the individual for taking time to read the information sheet
- The Researcher dating and signing the information sheet

Research Project Consent Form

Full title of Project: Minimisation of Rework on Housing Supply Chain

Name : Mehdi Shahparvari

Research Position: Doctoral Student

Contact details of researcher: Shahparm@lsbu.ac.uk

Taking part (please tick the box that applies)	**Yes**	**No**
I confirm that I have read and understood the information sheet/project brief and/or the student has explained the above study. I have had the opportunity to ask questions.	☐	☐
I understand that my participation is voluntary and that I am free to withdraw at any time, without providing a reason.	☐	☐
I agree to take part in the above study.	☐	☐

Use of my information (please tick the box that applies)	**Yes**	**No**
I understand my personal details such as phone number and address will not be revealed to people outside the project.	☐	☐
I understand that my data/words may be quoted in publications, reports, posters, web pages, and other research outputs.	☐	☐
I would like my real name to be used in the above.	☐	☐
I agree for the data I provide to be stored (after it has been anonymised) in a specialist data centre and I understand it may be used for future research.	☐	☐
Note for Principal Investigator/Supervisory team: Include statements below if appropriate, **or delete from the consent form**:		
I agree to the interview/….being audio recorded.	☐	☐
I agree to the interview/… being video recorded.	☐	☐

I agree to the use of anonymised quotes in publications.	☐	☐
I agree to assign the copyright I hold in any materials related to this project to ***[Name of researcher]***	☐	☐

Name of Participant Date Signature

Name of Researcher Date Signature

Project contact details for further information:

Project Supervisor/ Head of Division name:

Phone:

Email address:

Appendix 1.3

Interview Questions

Designing the interview questions needs a comprehensive literature review and expert consultation. The interviews were started with introducing the project and its aim and objectives by the researcher. After asking some questions about general information (such as years of experience, projects they have worked) the following questions were asked:

Section 1 Background Information

1.1 How many years have you been working as a Contractor, Construction Manager, Subcontractor, Supervisor, Quantity Surveyor or Architecture?

1.2 Please describe your involvement in housing construction development during your career?

Section 2 Sources and Causes of rework:

2.1 What are the sources and causes of rework in housing construction projects?

Section 3 Current Practice for rework minimisation:

3.1 How does your company measure and record rework?

3.2 What strategies are currently employed by your company to prevent/ reduce rework?

Section 4 Barriers for rework minimisation:

4.1 Are the barriers against implementing such strategies? If yes, what are those barriers?

Section 5 Future direction of rework minimisation:

5.1 What strategies can be implemented to better prevent rework generation in housing construction projects?

5.2 Which one of the strategies you suggested is more important and can contribute to rework reduction the most?

5.3 What type of technologies can apply to reduce rework in the construction stage? – and can be replaced by human to prevent unintended errors and mistakes.

5.4 What are the other crucial factors that create rework in housing supply chain? To add any constructive comments that I may have missed from the questions.

Appendix 2

Questionnaire Survey Documents

Dear Sir/Madam

RE: Questionnaire: Minimisation of rework in housing supply chain

The questionnaire is part of a doctoral research study that sought to develop a framework for minimisation of rework on housing supply chain (subcontractors and micro businesses). Your responses are critical to obtain a comprehensive understanding of these current issues in housing industry.

The aim of the questionnaire is to obtain information from UK construction practitioners to identify the root causes of rework in housing supply chain – so the effective prevention strategies can be developed for future direction of rework minimisation.

The questionnaire should take no longer than 15 minutes of completion. If you wish to be received findings of the research questionnaire, please tick the relevant section at the end of the questionnaire and I will forward a summary of findings in February 2021.

Thank you in advance for your support and help of conducting the research and I look forward to receiving the completed questionnaire.

Please note that the provided information will be treated confidential, and no information of individual respondent or organisation will be made public. The findings of your questionnaire and others will be used as one of the main data sets for my PhD research at London South Bank University.

Yours, Faithfully,

Appendix 2

Final Design of the Questionnaire:

Questionnaire Survey Documents

Dear Sir/Madam

RE: Questionnaire: Minimisation of rework in housing supply chain

The questionnaire is part of a doctoral research study that sought to develop a practical framework for minimisation of rework in housing supply chain (subcontractors and micro businesses). Your responses are critical to obtain a comprehensive understanding of these current issues in housing industry.

The aim of the questionnaire is to obtain information from UK construction practitioners to identify the root causes of rework in housing supply chain – so the effective prevention strategies can be developed for future direction of rework minimisation.

The questionnaire should take no longer than 15 minutes of completion. If you wish to be received findings of the research questionnaire please tick the relevant section at the end of the questionnaire and I will forward a summary of findings in February 2021.

Thank you in advance for your support and help of conducting the research and I look forward to receiving the completed questionnaire.

Please note that the provided information will be treated confidential and no information of individual respondent or organisation will be made public. The findings of your questionnaire and others will be used as one of the main data set for my PhD research at London South Bank University.

Yours, Faithfully,

Questionnaire – Rework minimisation in housing supply chain

The aim of the questionnaire is to collect views from the industry that help to develop a framework for rework occurrence in housing supply chain

Section A: Background of Participants and characteristics of housing development

1. Which of the following describes the company you are in?

a. Developer
b. Contractor
c. Subcontractor
d. Project Manager
e. Architect
f. Engineer
g. Other, please specify, ...

2. How long have you worked in the construction industry for?

a. 1 to 5 years
b. 5 to 10 years
c. 10 to 15 yeas
d. 15 to 20 years
e. over 20 year

3. What was the housing project type?

   a. New Build

   b. Refurbishment / Renovation

   c. Other, please specify............

4. What type of procurement method was implemented in the project?

   a. Traditional lump sum

   b. Design and build

   c. Construction management

   d. Turnkey

   e. Other, please specify ....

5. What was the project's original construction period?

6. What was the project's actual construction time?

SECTION B: CAUSES OF REWORK AND BARRIERS

7. Generally subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation.

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

8. Traditionally subcontractors have to work on short windows on site. This hampers rework reduction efforts and generate rework

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

9. Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects.

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

10. Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice. Please indicate to what extent the following are the main barrier of rework minimisation practice.

PLEASE USE THE FOLLOWING SCALE TO ANSWER THE QUESTION BELOW:

1 = Not at all **4 = To a good extent**

2 = To a small extent **5= To a great extent**

3 = To some extent

ID	Major barriers for minimisation of rework practice	Scale				
		1	2	3	4	5
1	Fragmentation and subcontracting					
2	Culture of 'resistance to change'					
3	Conventional way of building					
4	Short working window					

11. Rework can happen in different stage of housing construction. Please indicate to what extent the following stages causes a higher degree of rework generation.

PLEASE USE THE FOLLOWING SCALE TO ANSWER THE QUESTION BELOW:

1 = Not at all **4 = To a good extent**

2 = To a small extent **5= To a great extent**

3 = To some extent

ID	Construction process	Scale				
		1	2	3	4	5
1	Excavation					
2	Frame construction					
3	Plumbing and Electrical HVAC					
4	Drywall and interior fixtures					
5	Cladding installation					
6	Fitting out; flooring,					

12. Design related factors can be the cause of rework generation. Please indicate to what extent the following statements which you agree with.

PLEASE USE THE FOLLOWING SCALE TO ANSWER THE QUESTION BELOW:

1 = Strongly agree **4 = Disagree**

2 = Agree **5 = Strongly disagree**

3= Nether agree nor disagree

ID	Design related factors	Scale				
		1	2	3	4	5
1	Contractor’s unexpected change during construction phase					
2	Client’s requirement u change					
3	Lack of quality management practices					
4	Lack of coordination among contractors/ subcontractors					

13. Client-related factors can be the cause of rework. Please indicate to what extent the following statements which you agree with

PLEASE USE THE FOLLOWING SCALE TO ANSWER THE QUESTION BELOW:

1 = Strongly agree **4 = Disagree**

2 = Agree **5 = Strongly disagree**

3= Nether agree nor disagree

ID	Client-related factors	Scale				
		1	2	3	4	5
1	Insufficient source of time and budget spent on the briefing process					
2	Poor communication with design consultant					
3	Lack of knowledge and experience of the design and construction process					
4	Insufficient involvement of client from the outset of projects					
5	Contractor's unexpected change during construction phase					

14. Subcontractors-related factors can be the cause of rework. Please indicate to what extent the following statements which you agree with

ID	Subcontractors-related factors	Scale				
		1	2	3	4	5
1	Different business objectives					
2	Unrealistic scheduling					
3	Non-compliance with specification					
4	Poor workmanship					
5	Different work ethic					
6	Late involvement of subcontractors from the beginning of projects					
7	Poor communication					
8	Lack of trust and transparency					
9	Insufficient motivation					
10	Lack of collaborative and cooperative working					

15. Site management-related factors can be the cause of rework Please indicate to what extent the following statements which you agree with

ID	Site management related factors	Scale				
		1	**2**	**3**	**4**	**5**
1	Lack of knowledge, experience and training					
2	Poor planning					
3	Problems of constructability					
4	Lack of competent supervisor					

SECTION C: CURRENT PRACTICES & STRATEGIES

PLEASE USE THE FOLLOWING SCALE TO ANSWER THE QUESTION BELOW:

1 = Strongly agree **4 = Disagree**

2 = Agree **5 = Strongly disagree**

3= Nether agree nor disagree

16. Learning mechanism can improve the awareness of employees and result in reduction of rework. To what extent the following learning mechanisms are employed in your company?

ID	Learning mechanism	Scale				
		1	2	3	4	5
1	Training, seminars and workshops					
2	Research & Development					

3	Adaptation to new technologies					

17. Deployment of rework minimisation is an important issue of direct parameter for Subcontractors to win future contracts at the moment.

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

18. Subcontractors have been already doing process improvement in their daily activities, however, has not been systematically labelled as "rework minimisation strategies".

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

SECTION D: ADAPTATION OF NEW TECHNOLOGIES AND FUTURE DIRECTION

19. To what extent the following characteristics can significantly have impact on the future direction of rework reduction.

PLEASE USE THE FOLLOWING SCALE TO ANSWER THE QUESTION BELOW:

1= Not at all **4 = To a good extent**

2 = To a small extent **5= To a great extent**

3 = To some extent

ID	Characteristics	Scale				
		1	2	3	4	5
1	Culture of collaborative and co-operative working					
2	Investment in new technologies and human resources					
3	Training, seminars and workshops					
4	Early engagement of subcontractors from design stage					
5	Create incentives among contributors					

20. Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction?

ID	Requirement characteristics	Degree of importance				
		1	2	3	4	5
1	Ability to rectify errors and mistakes					
2	Reduction of design errors and changes					
3	Realistic scheduling					
4	Reduction in reliance on skilled workforce					
5	Effective document control and archiving					
6	Improvement of transparency and trust					
7	Improve collaborative and co-operative working					

21. Digitisation of information and exchange of data among contributors can help to understand the scope of work. This improves the communication to reduce fragmentation and prevent rework from early stage of construction.

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

22. Adaptation of Offsite manufacturing techniques on construction sites can significantly minimise human errors, site congestion and fill the gap of unskilled labour to reduce rework generation.

a. Strongly agree
b. Agree
c. Neither agree nor disagree
d. Disagree
e. Strongly disagree

23. Employing innovative materials which requires low maintenance and last longer, reduce return of repair for onsite construction and eliminates rework.

Employing innovative materials which requires low maintenance reduce skilled labour commute on site for return of repair, which can reduce rework.

a. Strongly agree
b. Agree

c. Neither agree nor disagree

d. Disagree

e. Strongly disagree

SECTION E: Further comments

24. Please use the space below to add any other comments or issues regarding the reduction of rework

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………
……………………………………………………………………………………………………

25. Would you like to receive a summary of the report findings? Please tick as appropriate.

Yes ☐

No ☐

Thank you for taking the time and effort in completing the questionnaire

Appendix 3

Quantitative study analysis results from SPSS:

Missing value analysis result:

Univariate Statistics

	N	Mean	Std. Deviation	Missing		No. of Extremes[a]	
				Count	Percent	Low	High
Q1	108	2.47	1.603	0	.0	0	9
Q2	108	3.32	1.109	0	.0	7	0
Q3	108	1.06	.283	0	.0	.	.
Q4	108	1.31	.716	0	.0	.	.
Q7	108	5.44	.714	0	.0	0	0
Q8	108	4.99	.677	0	.0	.	.
Q9	108	21.28	.561	0	.0	.	.
Q10_1	108	1.13	.364	0	.0	.	.
Q10_2	108	1.06	.230	0	.0	.	.
Q10_3	108	2.16	.787	0	.0	0	0
Q10_4	108	1.53	.618	0	.0	0	0
Q11_1	108	2.57	.726	0	.0	0	0
Q11_2	108	2.45	.675	0	.0	0	0
Q11_3	108	1.08	.278	0	.0	.	.
Q11_4	108	1.16	.391	0	.0	.	.
Q11_5	108	1.94	.534	0	.0	.	.
Q11_6	108	1.44	.517	0	.0	0	0
Q12_1	108	1.19	.456	0	.0	.	.
Q12_2	108	1.14	.347	0	.0	.	.
Q12_3	108	1.13	.337	0	.0	.	.
Q12_4	108	1.49	.538	0	.0	0	0
Q13_1	108	1.79	.612	0	.0	0	0
Q13_2	108	1.17	.421	0	.0	.	.

Q13_3	108	1.17	.374	0	.0	.	.
Q13_4	108	2.01	.803	0	.0	0	0
Q13_5	108	1.20	.405	0	.0	.	.
Q14_1	108	1.18	.406	0	.0	.	.
Q14_2	108	1.32	.508	0	.0	0	0
Q14_3	108	1.41	.530	0	.0	0	0
Q14_4	108	1.10	.304	0	.0	.	.
Q14_5	108	2.15	.783	0	.0	0	0
Q14_6	108	1.14	.373	0	.0	.	.
Q14_7	108	1.11	.344	0	.0	.	.
Q14_8	108	1.50	.521	0	.0	0	0
Q14_9	108	1.77	.621	0	.0	0	0
Q14_10	108	1.17	.399	0	.0	.	.
Q15_1	108	1.72	.734	0	.0	0	0
Q15_2	108	1.28	.470	0	.0	0	0
Q15_3	108	1.12	.354	0	.0	.	.
Q15_4	107	1.65	.551	1	.9	0	0
Q16_1	108	1.14	.347	0	.0	.	.
Q16_2	107	1.47	.649	1	.9	0	0
Q16_3	107	1.16	.415	1	.9	.	.
Q17	108	4.31	.621	0	.0	.	.
Q18	107	4.55	.676	1	.9	0	2
Q19_1	108	1.06	.230	0	.0	.	.
Q19_2	108	1.20	.427	0	.0	.	.
Q19_3	108	1.05	.211	0	.0	.	.
Q19_4	107	1.07	.248	1	.9	.	.
Q19_5	107	2.02	.765	1	.9	0	0
Q20_1	107	1.45	.536	1	.9	0	0
Q20_2	107	1.29	.495	1	.9	0	0
Q20_3	107	1.16	.392	1	.9	.	.
Q20_4	107	1.36	.536	1	.9	0	0
Q20_5	107	1.12	.381	1	.9	.	.
Q20_6	106	1.14	.350	2	1.9	.	.
Q20_7	108	1.06	.230	0	.0	.	.
Q21	106	13.26	.721	2	1.9	.	.
Q22	107	20.29	.714	1	.9	.	.
Q23	107	20.27	.667	1	.9	.	.
Q25	108	1.33	.474	0	.0	0	0

a. Number of cases outside the range (Q1 - 1.5*IQR, Q3 + 1.5*IQR).

Appendix: 3.1 – Test of normality

Questions (Q7 - Q62)	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Generally subcontractors start working on a short notice without sufficient preparation in advance for a project and this cause rework generation (Q7)	0.285	105	0.000	0.833	105	0.000
Traditionally subcontractors have to work on short windows on site. This hampers rework reduction efforts and generates rework (Q8)	0.347	105	0.000	0.743	105	0.000
Many reworks generate from the initial design stage of projects. However, generally subcontractors have a little influence with no involvement from early phase of projects (Q9)	0.47	105	0.000	0.536	105	0.000
Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice. Please indicate to what extent the following are the main barriers of rework minimisation practice. - Fragmentation and subcontracting (Q10-1)	0.517	105	0.000	0.395	105	0.000
Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice. Please indicate to what extent the following are the main barriers of rework minimisation practice. - Culture of resistance to change (Q10-2)	0.54	105	0.000	0.218	105	0.000
Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice. Please indicate to what extent the following are the main barriers of rework minimisation practice. - Short working windows (Q10-3	0.262	105	0.000	0.788	105	0.000
Housing industry is highly fragmented and experiencing some barriers which prevents the employment of rework minimisation practice. Please indicate to what extent the following are the main barriers of rework minimisation practice. - Conventional way of constructing(Q10-4)	0.338	105	0.000	0.726	105	0.000
Rework can happen in different stage of housing construction. Please indicate to what extent the following stages cause a higher degree of rework generation. – Excavation(Q11-1)	0.435	105	0.000	0.603	105	0.000
Rework can happen in different stage of housing construction. Please indicate to what extent the following stages cause a higher degree of rework generation. - Frame construction (Q11-2)	0.345	105	0.000	0.727	105	0.000

Rework can happen in different stage of housing construction. Please indicate to what extent the following stages cause a higher degree of rework generation. - Plumbing and electrical HVAC (Q11-3)	0.534	105	0.000	0.313	105	0.000
Rework can happen in different stage of housing construction. Please indicate to what extent the following stages cause a higher degree of rework generation. - Drywall and interior fixture (Q11-4)	0.507	105	0.000	0.443	105	0.000
Rework can happen in different stage of housing construction. Please indicate to what extent the following stages cause a higher degree of rework generation. - Cladding installation (Q11-5)	0.371	105	0.000	0.709	105	0.000
Rework can happen in different stage of housing construction. Please indicate to what extent the following stages cause a higher degree of rework generation. - Fitting out, flooring (Q11-6)	0.378	105	0.000	0.658	105	0.000
Design related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Unexpected client's change (Q12-1)	0.502	105	0.000	0.442	105	0.000
Design related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Contractors requirement of change (Q12-2)	0.519	105	0.000	0.401	105	0.000
Design related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Lack of coordination among contractors/ subcontractors (Q12-3)	0.522	105	0.000	0.385	105	0.000
Design related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Lack of quality management practice (Q12-4)	0.34	105	0.000	0.689	105	0.000
Client-related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Insufficient source of time and budget spent on the briefing process (Q13-1)	0.324	105	0.000	0.765	105	0.000
Client-related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Poor communication with design consultant (Q13-2)	0.508	105	0.000	0.428	105	0.000
Client-related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Lack of knowledge and experience of the design and construction process (Q13-3)	0.507	105	0.000	0.443	105	0.000

Client-related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Insufficient involvement of client from the outset of projects (Q13-4)	0.215	105	0.000	0.799	105	0.000
Client-related factors can be the cause of rework. Please indicate to what extent you are agree with the following statements. - Contractor's unexpected change during construction phase (Q13-5)	0.491	105	0.000	0.49	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Different business objectives (Q14-1)	0.503	105	0.000	0.457	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Unrealistic scheduling (Q14-2)	0.433	105	0.000	0.614	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Non-compliance with specification (Q14-3)	0.384	105	0.000	0.667	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Poor workmanship (Q14-4)	0.528	105	0.000	0.352	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Different work ethic (Q14-5)	0.251	105	0.000	0.794	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Late involvement of subcontractors from the beginning of projects (Q14-6)	0.517	105	0.000	0.395	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Poor communication (Q14-7)	0.524	105	0.000	0.359	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Lack of trust and transparency (Q14-8)	0.348	105	0.000	0.67	105	0.000
Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Insufficient motivation (Q14-9)	0.31	105	0.000	0.77	105	0.000

Subcontractors related factors can be the cause of rework. Please indicate to what extent you are agree with the following statement. - Lack of collaborative and cooperative working (Q14-10)	0.503	105	0.000	0.457	105	0.000
Site management related factors can be the cause of rework. Please indicate to what extent you agree with the following statements. - Lack of knowledge, experience and training (Q15-1)	0.284	105	0.000	0.778	105	0.000
Site management related factors can be the cause of rework. Please indicate to what extent you agree with the following statements. - Poor planning (Q15-2)	0.459	105	0.000	0.566	105	0.000
Site management related factors can be the cause of rework. Please indicate to what extent you agree with the following statements. - Lack of collaborative and cooperative working (Q15-3)	0.521	105	0.000	0.377	105	0.000
Site management related factors can be the cause of rework. Please indicate to what extent you agree with the following statements. - Lack of competent supervisor (Q15-4)	0.352	105	0.000	0.714	105	0.000
Learning mechanisms can improve the awareness of employees and result in reduction of rework. To what extent the following learning mechanisms are employed in your company? - Training, seminars and workshops (Q16-1)	0.519	105	0.000	0.401	105	0.000
Learning mechanisms can improve the awareness of employees and result in reduction of rework. To what extent the following learning mechanisms are employed in your company? - Research and development (Q16-2)	0.382	105	0.000	0.688	105	0.000
Learning mechanisms can improve the awareness of employees and result in reduction of rework. To what extent the following learning mechanisms are employed in your company? - Adaptation to new technologies (Q16-3)	0.508	105	0.000	0.428	105	0.000
Deployment of rework minimisation is an important issue of direct parameter for subcontractors to win future contract at the moment (Q17)	0.449	105	0.000	0.57	105	0.000
Subcontractors have been already doing process improvement in their daily activities, however, this has not been systematically labelled as " rework minimisation strategies "(Q18)	0.32	105	0.000	0.725	105	0.000

To what extent the following characteristics can significantly have impact on the future direction of rework minimisation. - Culture of collaboration and cooperative working (Q19-1)	0.54	105	0.000	0.218	105	0.000
To what extent the following characteristics can significantly have impact on the future direction of rework minimisation. - Investment in new technologies and human resources (Q19-2)	0.49	105	0.000	0.496	105	0.000
To what extent the following characteristics can significantly have impact on the future direction of rework minimisation. - Training, seminars and workshops (Q19-3)	0.54	105	0.000	0.218	105	0.000
To what extent the following characteristics can significantly have impact on the future direction of rework minimisation. - Early engagement of subcontractors from design stage (Q19-4)	0.54	105	0.000	0.245	105	0.000
To what extent the following characteristics can significantly have impact on the future direction of rework minimisation. - Create incentives among contributors (Q19-5)	0.205	105	0.000	0.807	105	0.000
Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Ability to rectify errors and mistakes (Q20-1)	0.364	105	0.000	0.68	105	0.000
Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Reduction of design errors and changes (Q20-2)	0.447	105	0.000	0.591	105	0.000
Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Realistic scheduling (Q20-3)	0.507	105	0.000	0.443	105	0.000
Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Reduction in reliance on skilled workforce (Q20-4)	0.42	105	0.000	0.633	105	0.000

Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Document control and archiving (Q20-5)	0.521	105	0.000	0.357	105	0.000
Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Improvement of transparency and trust (Q20-6)	0.515	105	0.000	0.416	105	0.000
Automation/digitisation can play an important role for reduction of rework. To what extent the following characteristics through automation can significantly have an impact on rework reduction? - Improve collaborative and cooperative working (Q20-7)	0.54	105	0.000	0.245	105	0.000
Digitisation of information and exchange of data among contributors can help to understand the scope of work. This improves the communication and prevent rework occurrence from early stage of construction (Q21)	0.34	105	0.000	0.439	105	0.000
Adaptation of offsite manufacturing techniques on construction sites can significantly minimise human errors, site congestion and fill the gap of unskilled labour to reduce rework generation (Q22)	0.445	105	0.000	0.583	105	0.000
Employing low maintenance materials	0.375	105	0.000	0.642	105	0.000

Appendix 3.2– Q-Q Plots

Figure 5.2

Q7

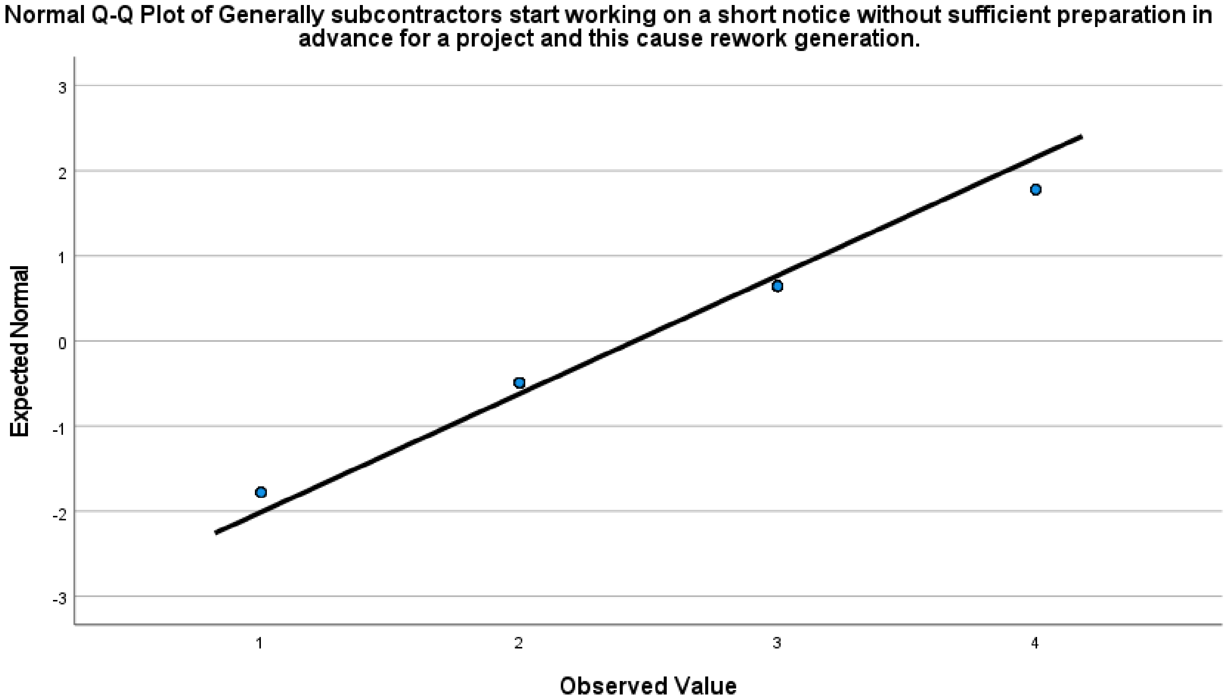


Figure5.3

Q8

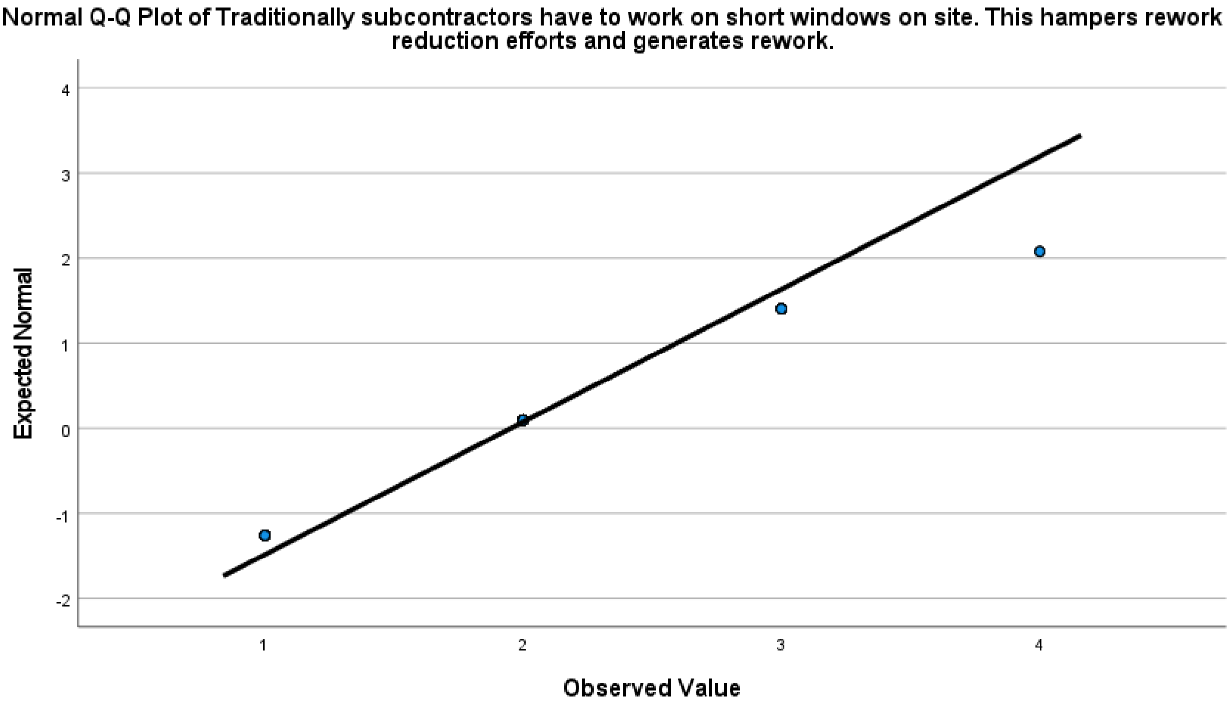


Figure 5.4

Q9

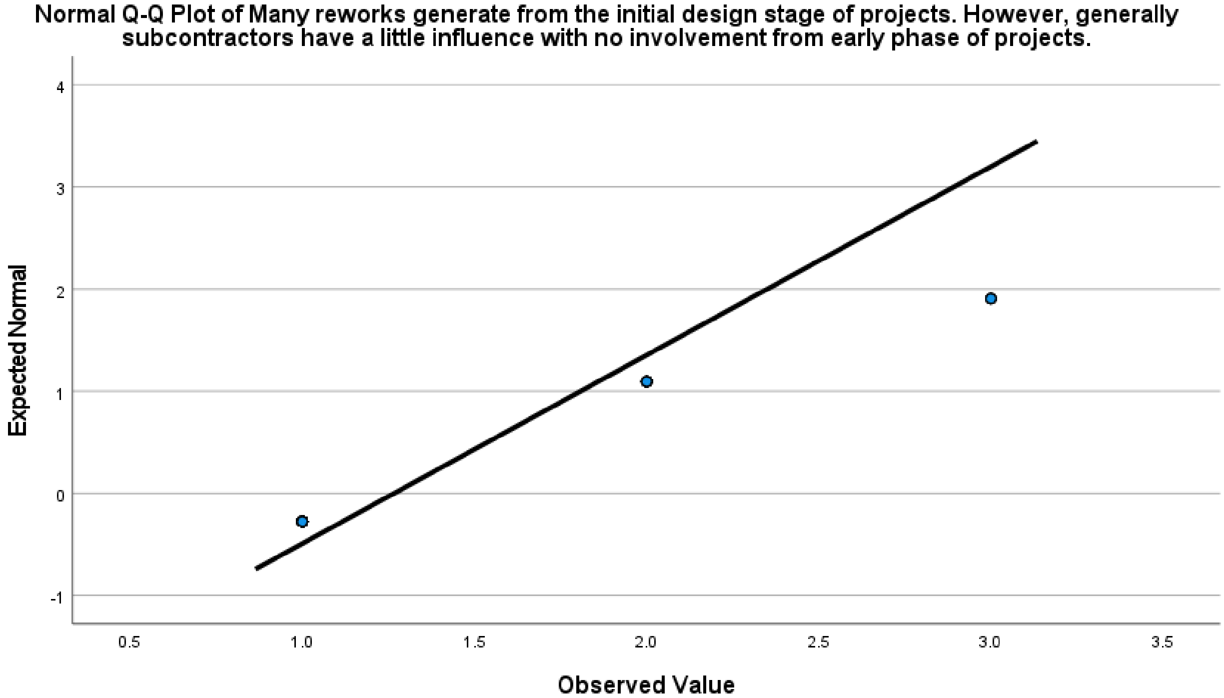


Figure 5.5
Q10-1

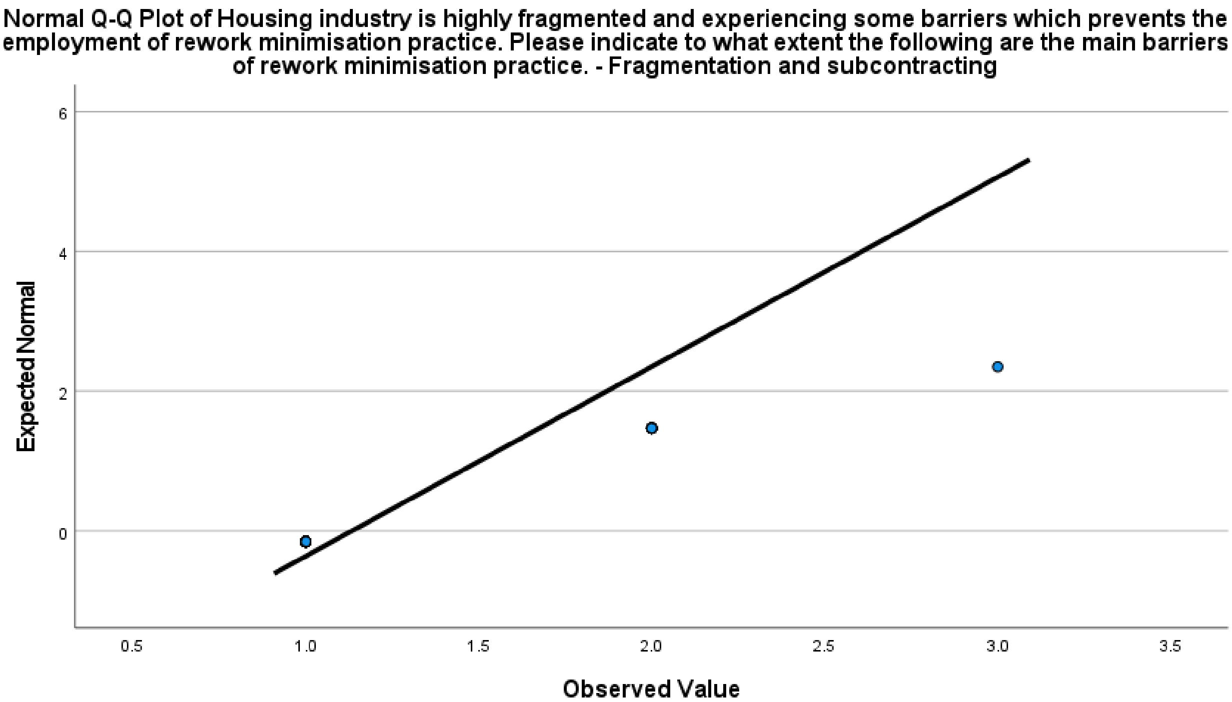


Figure 5.6

Q10-2

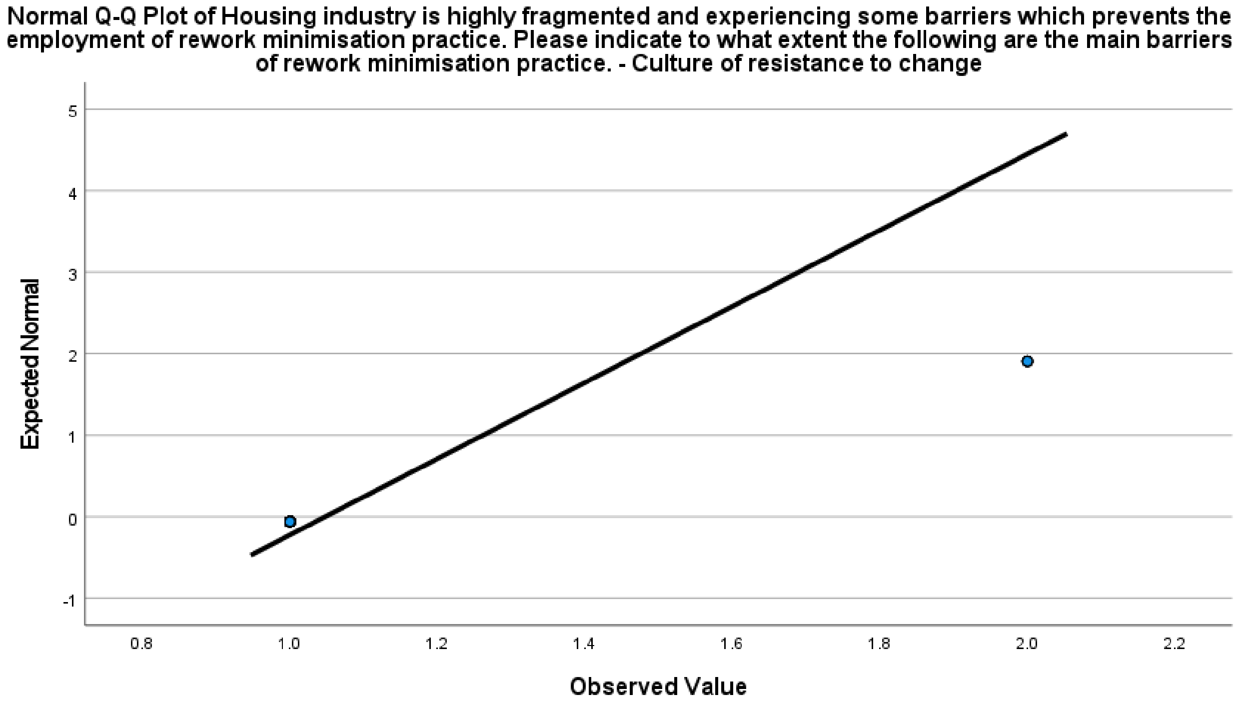


Figure 5.7

Q10-3

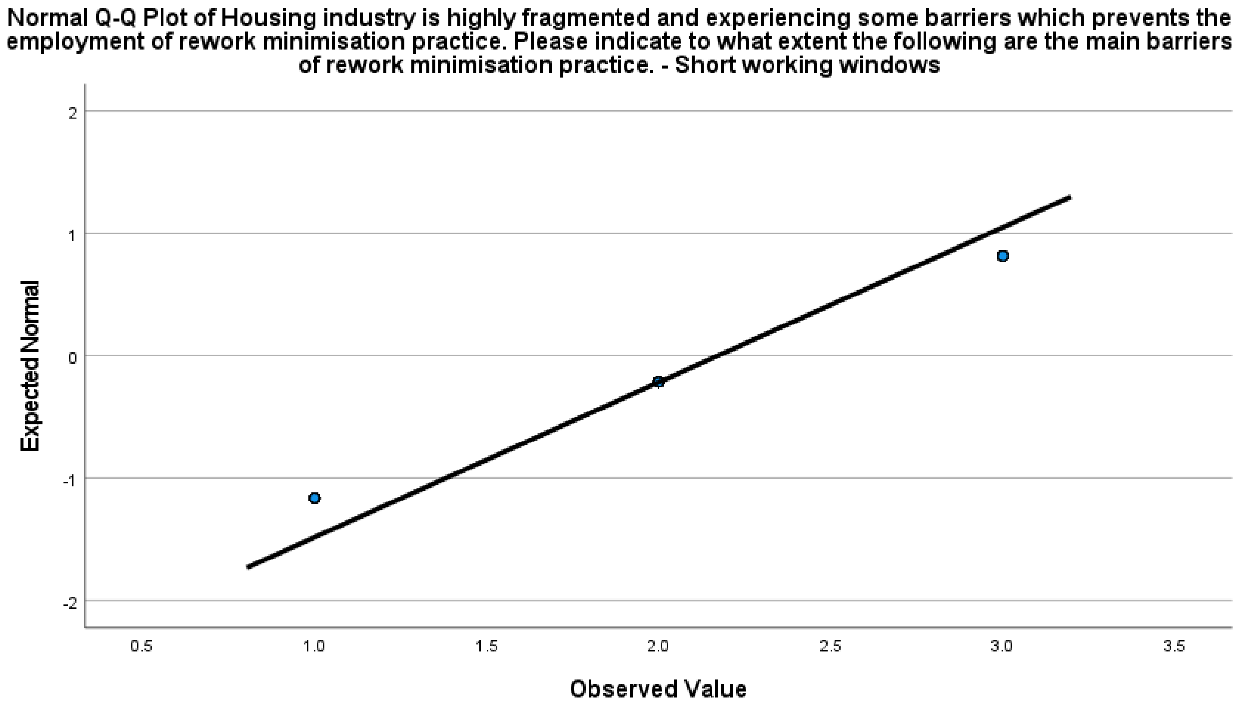


Figure 5.8

Q10-4

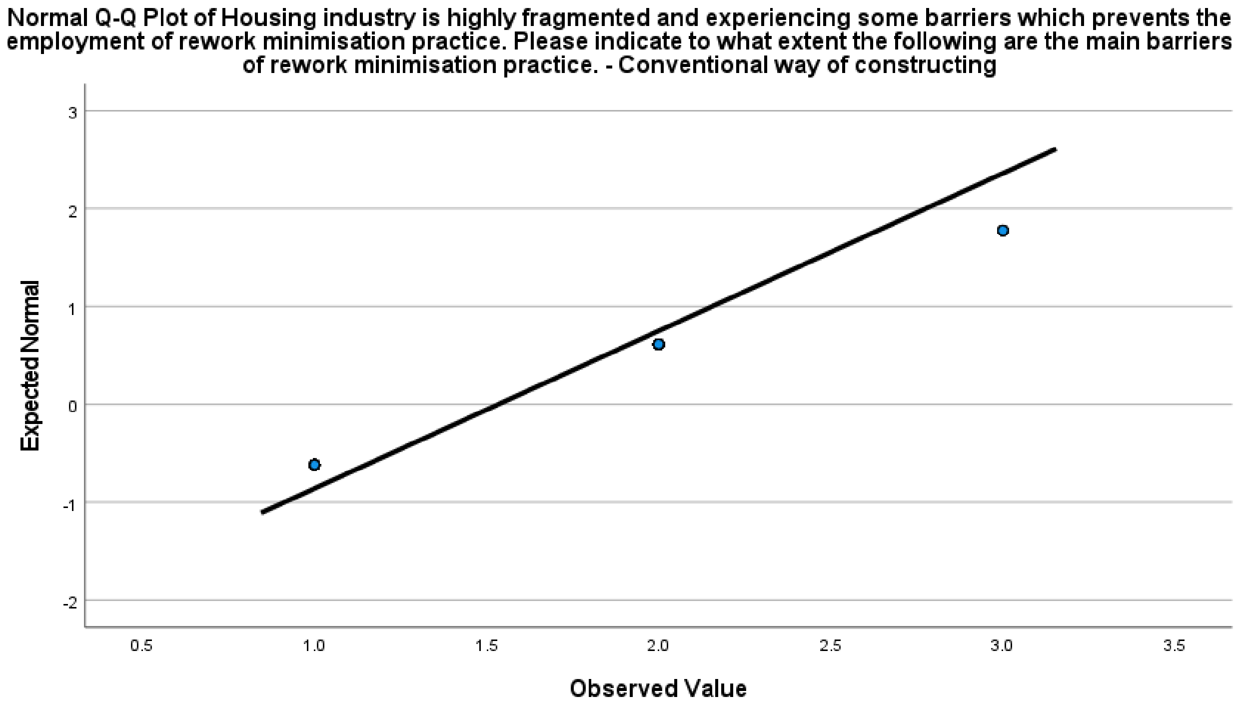
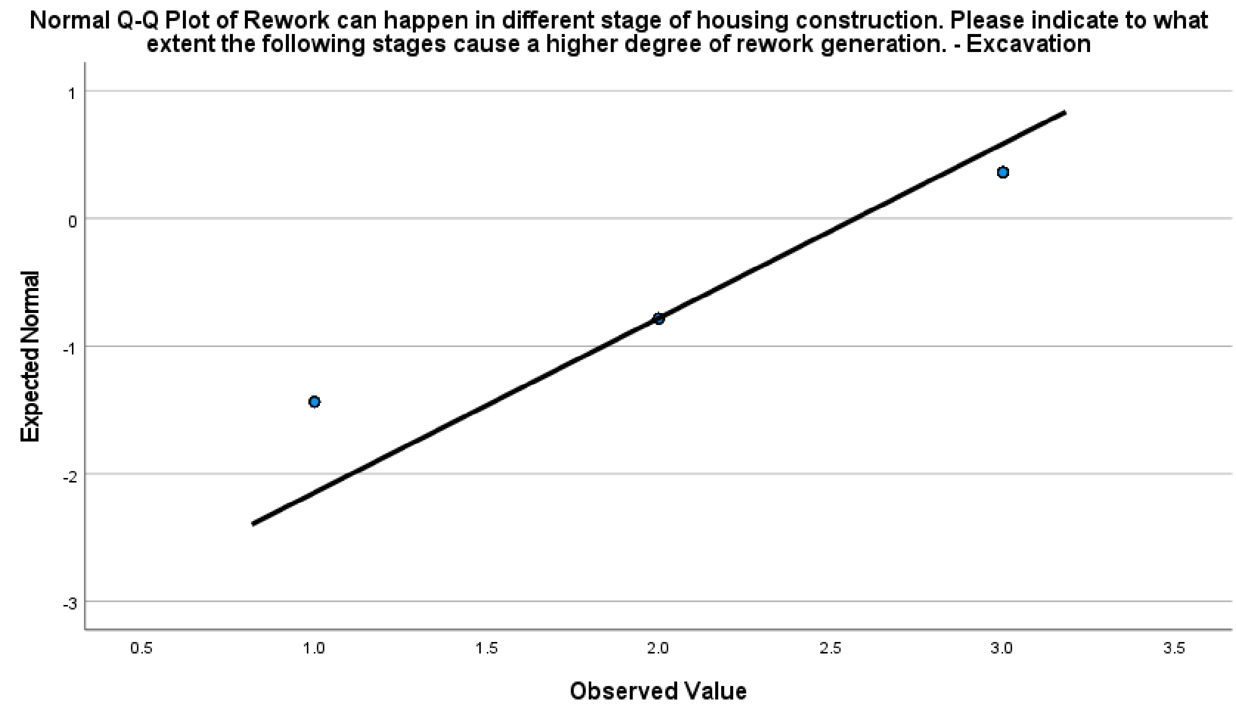


Figure 5.9

Q11-1



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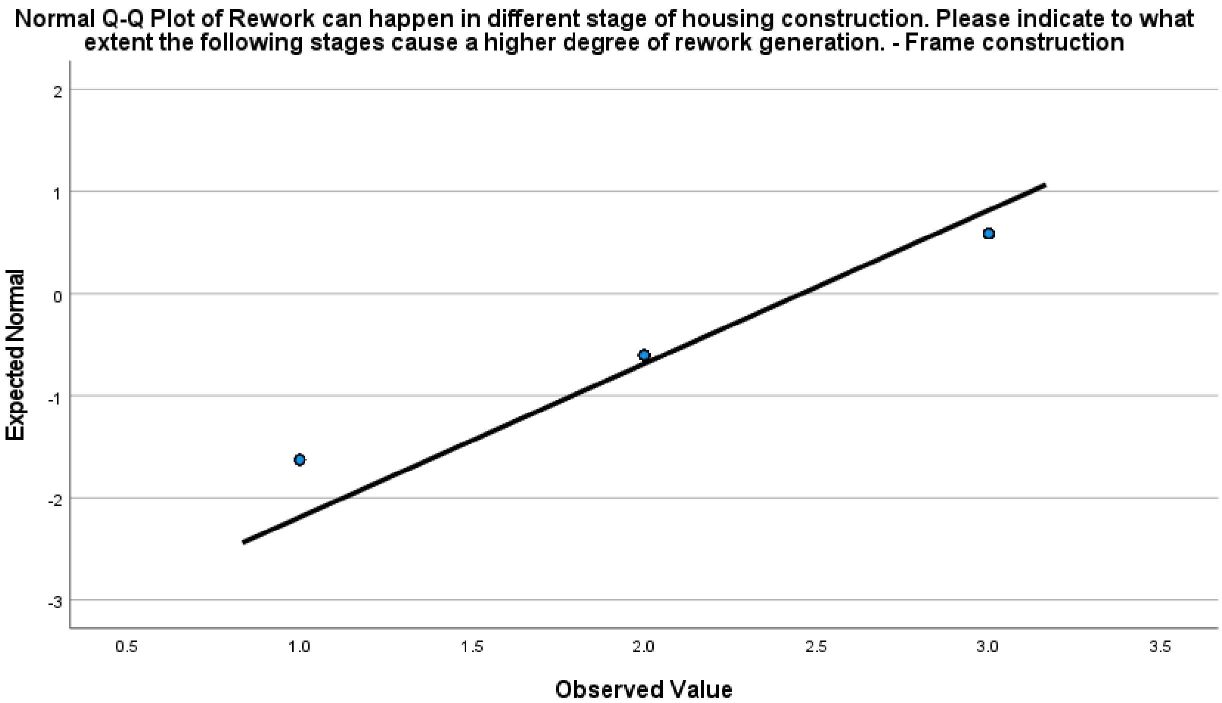

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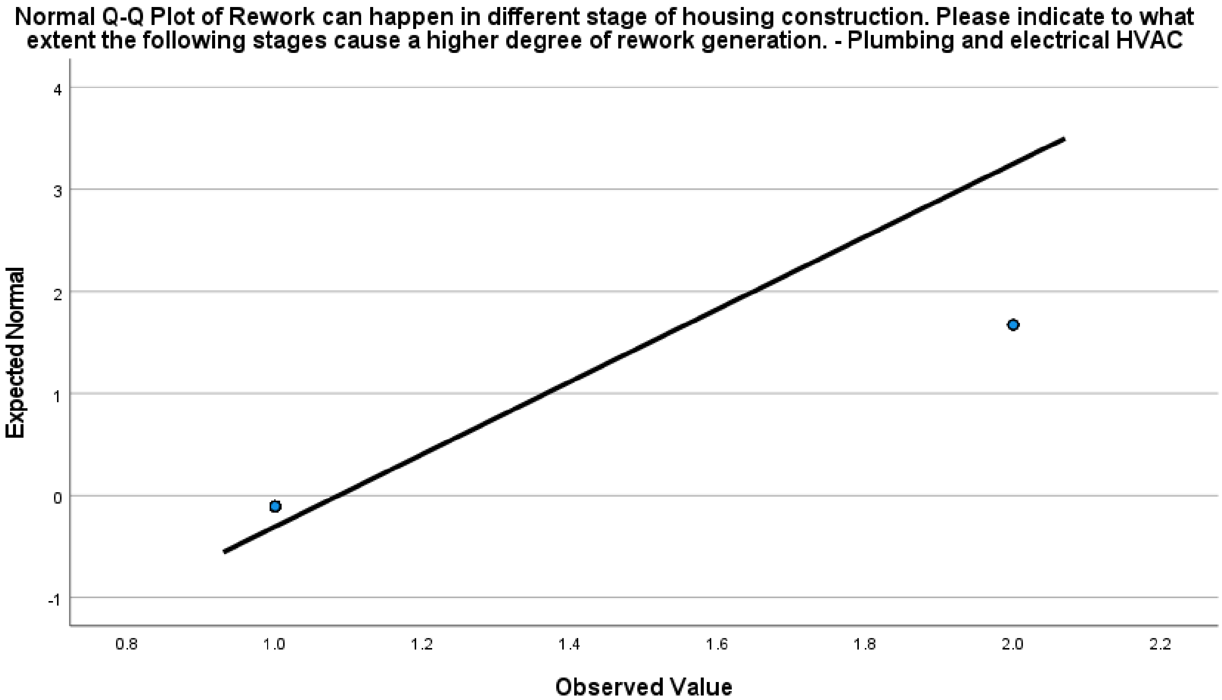
Q11-3



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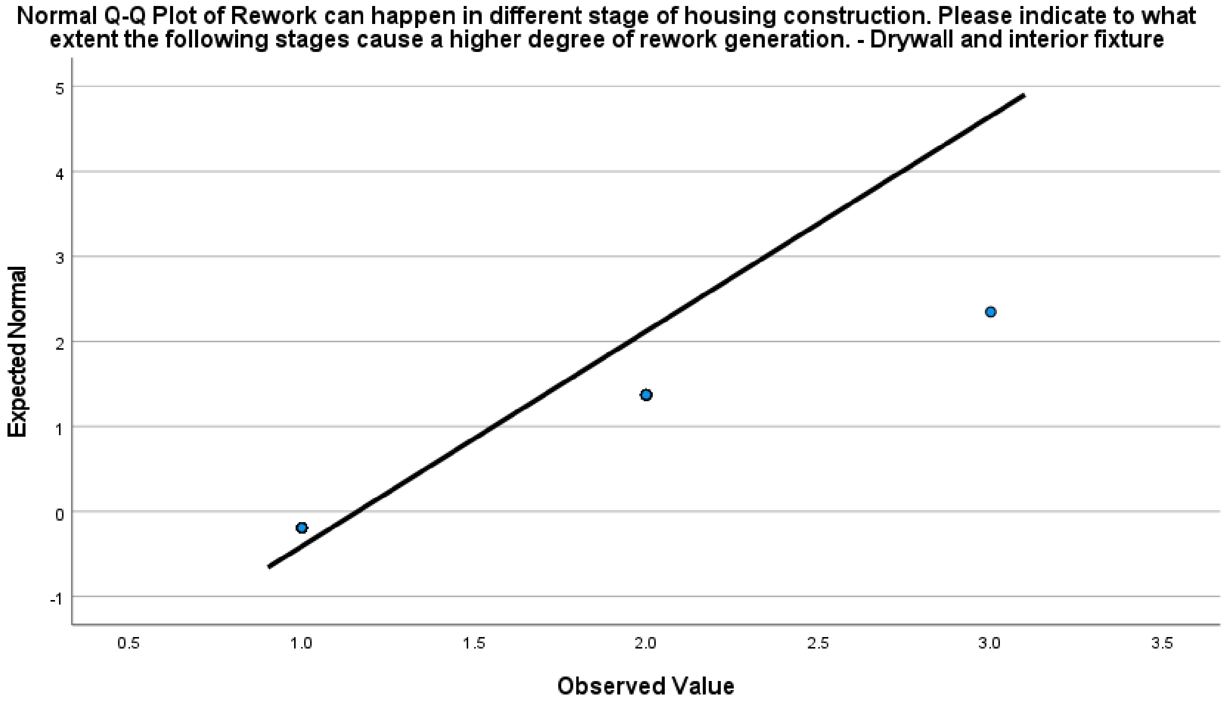

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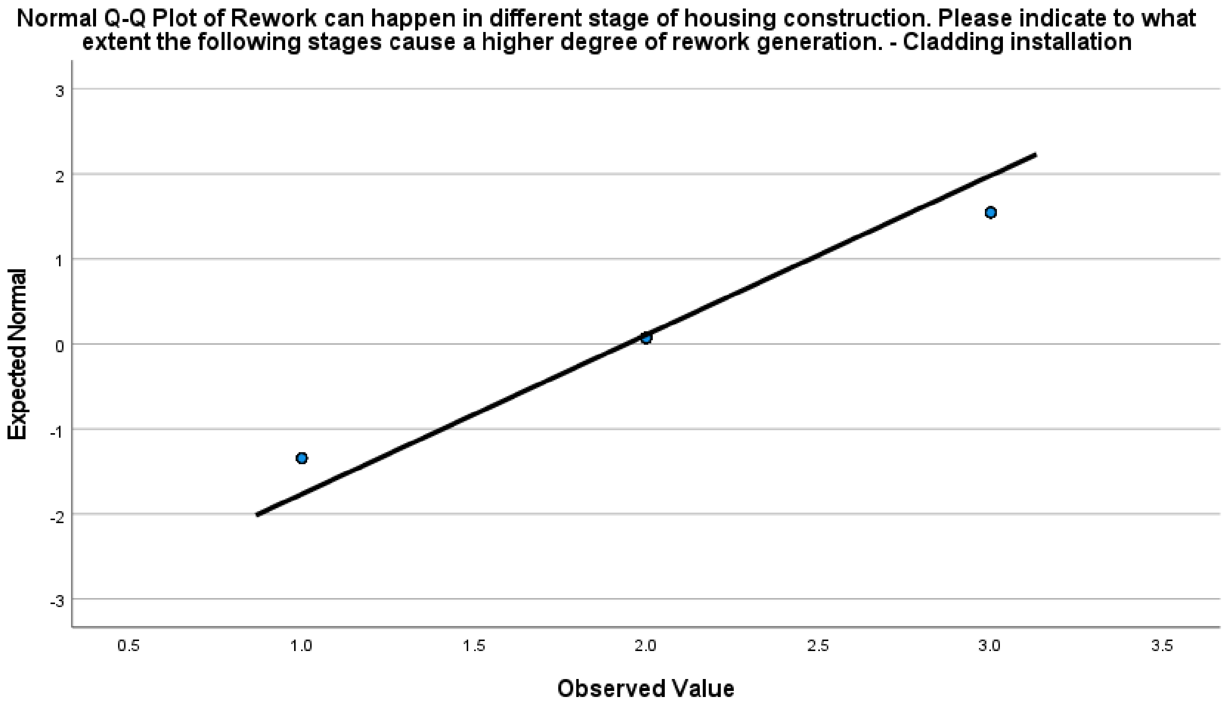
Q11-5



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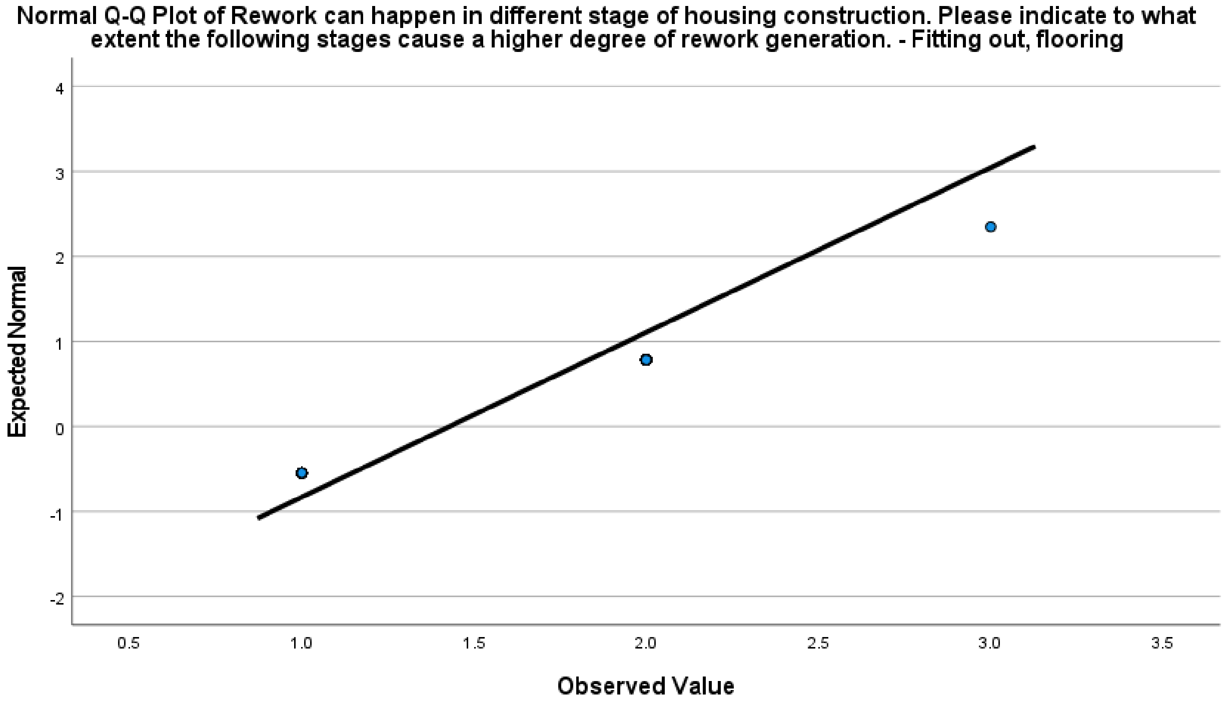
Q11-6



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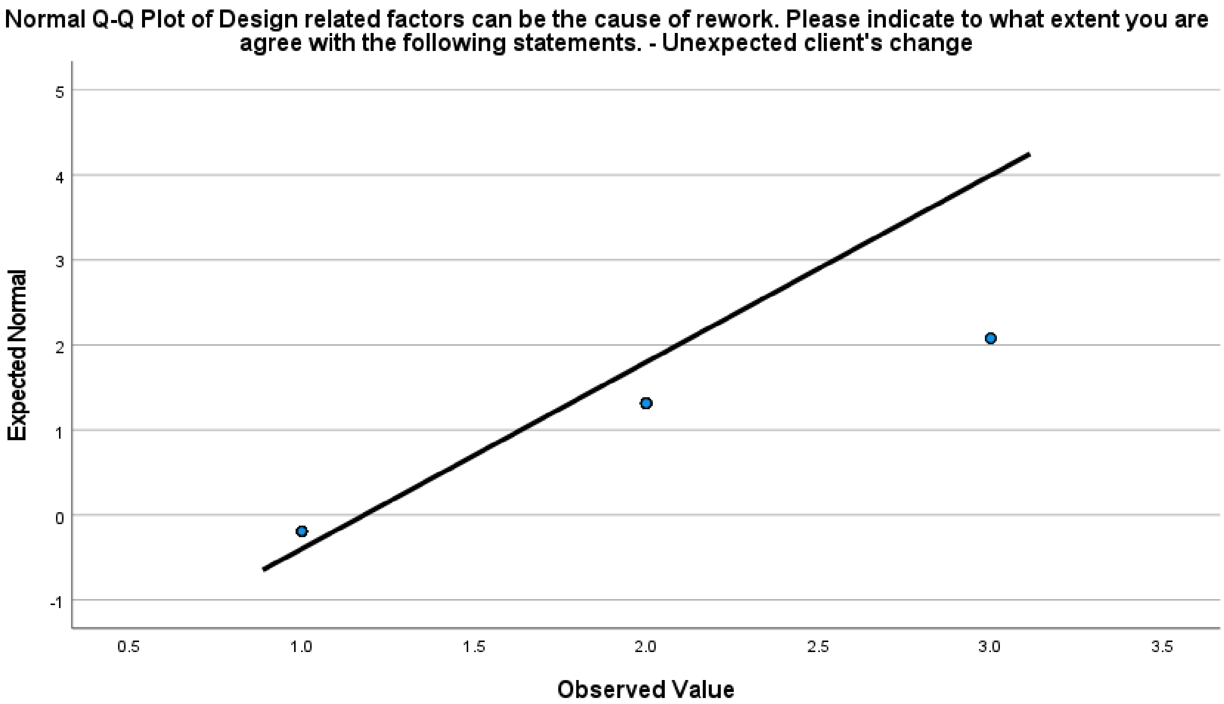

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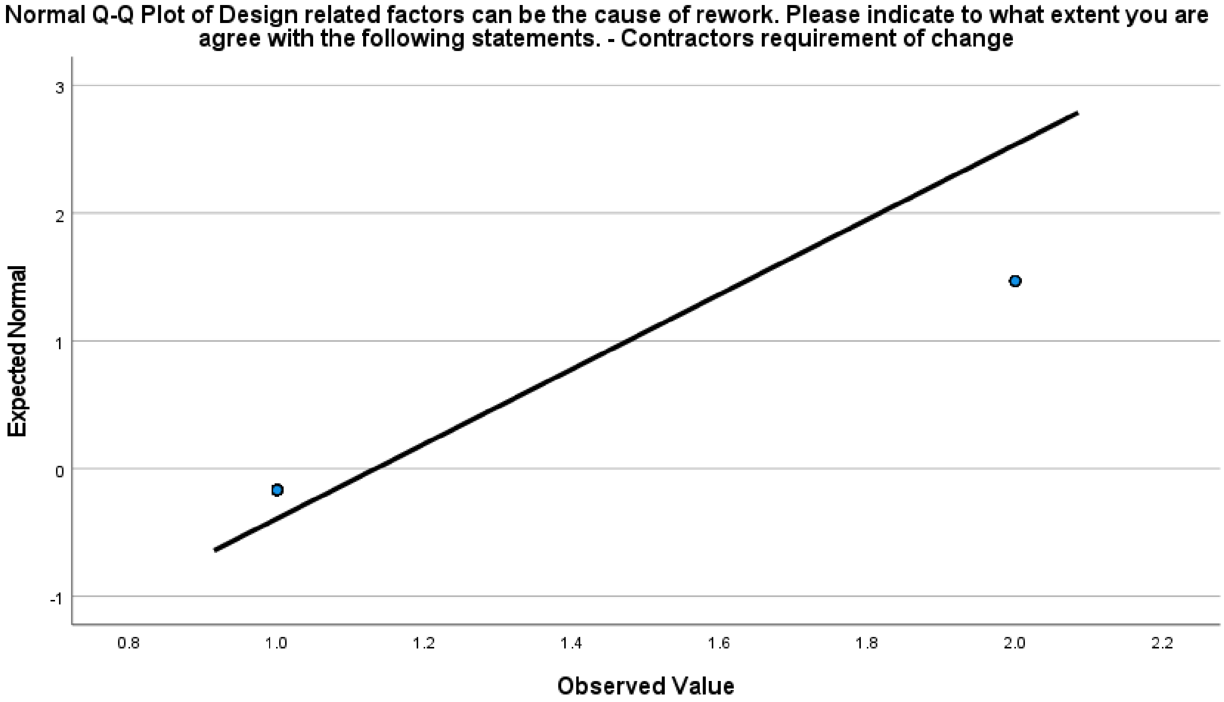

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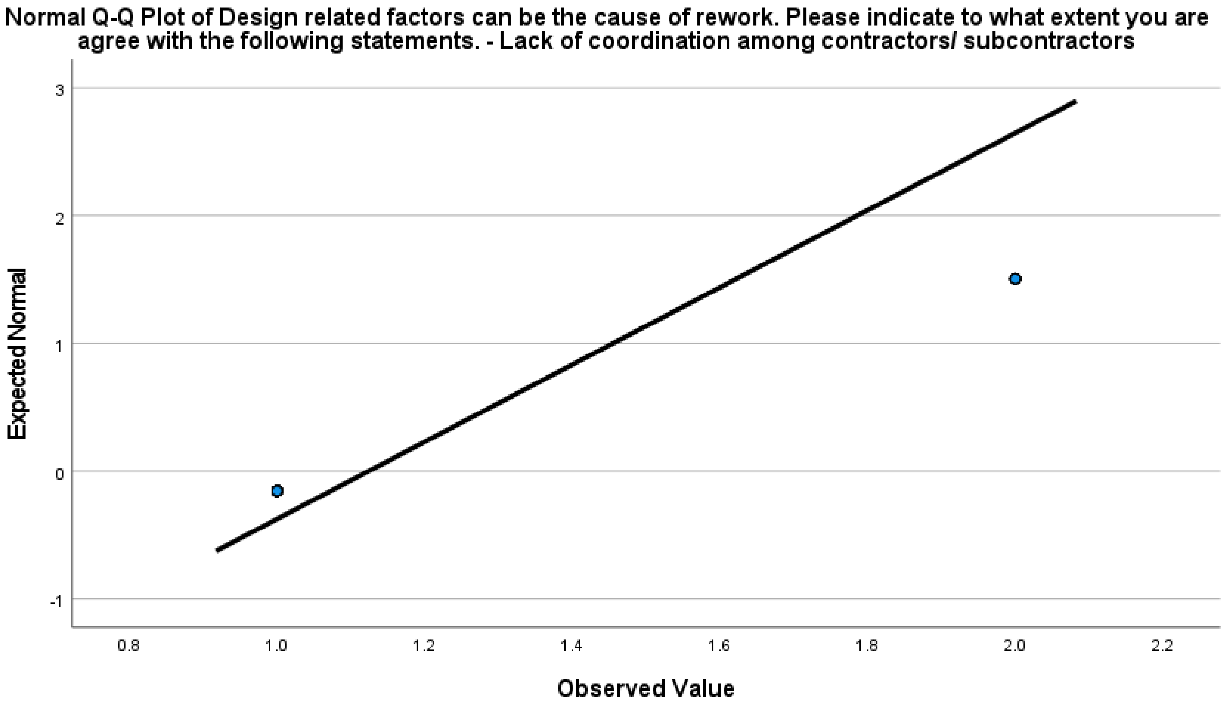

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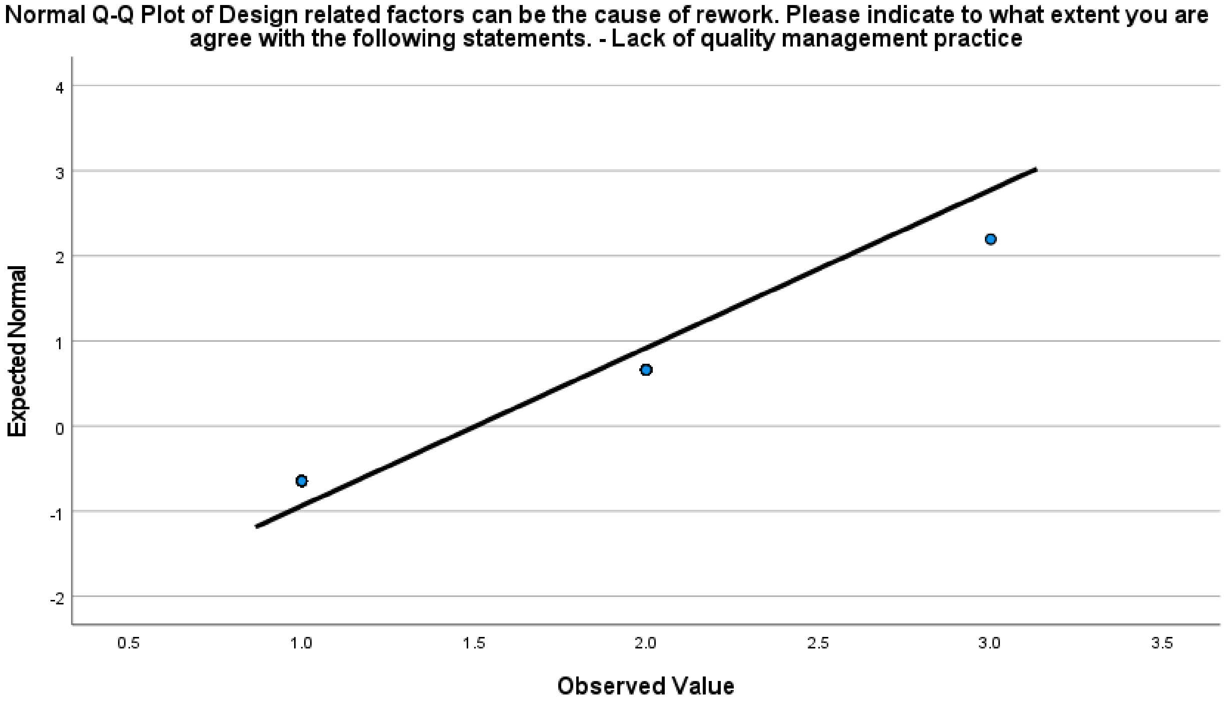
Q12-4



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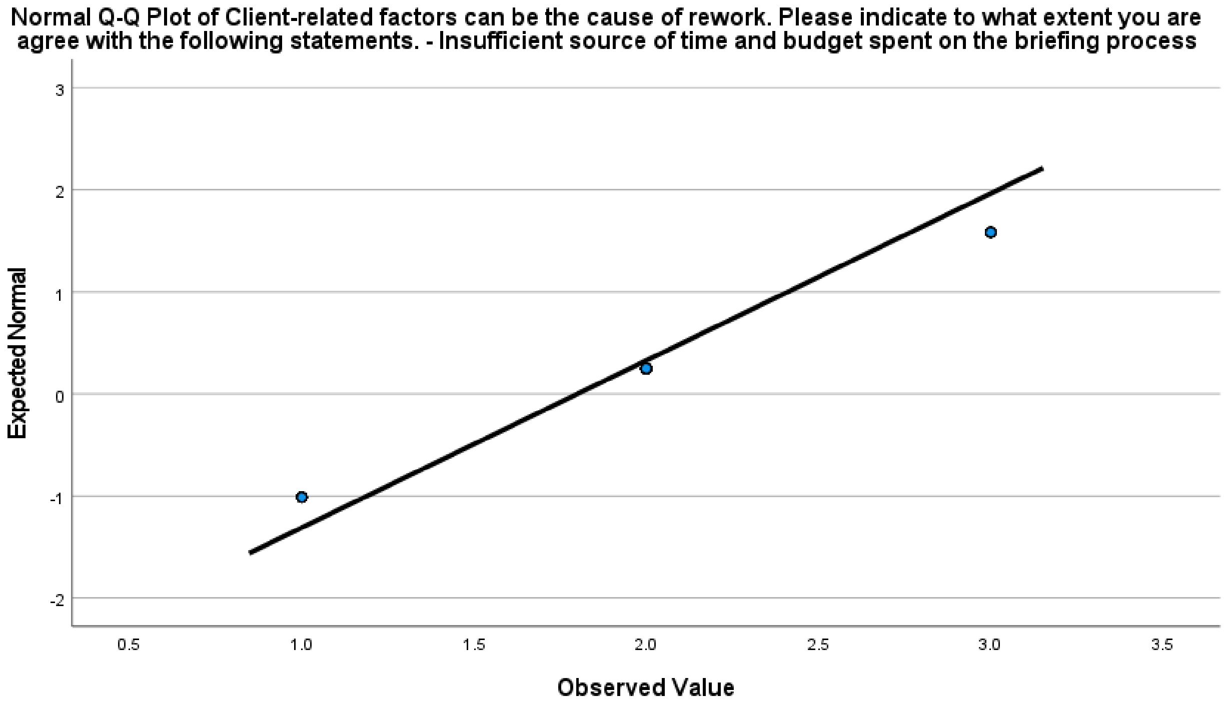
Q13-1



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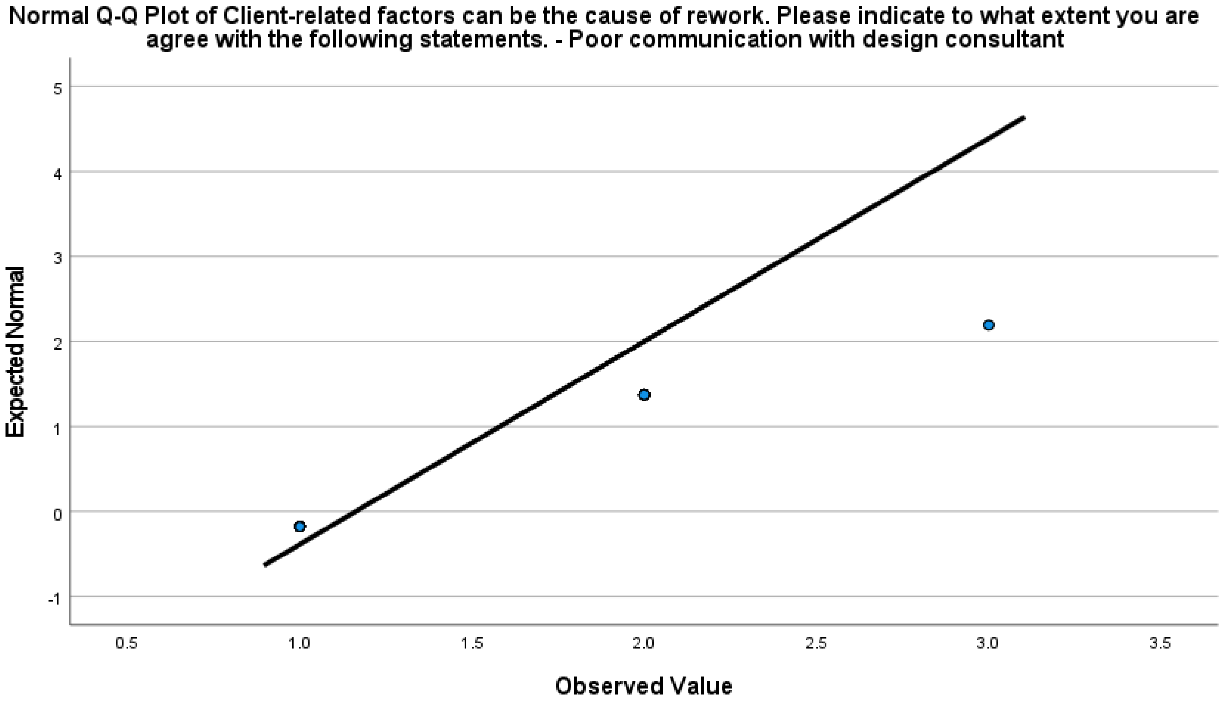
Q13-2



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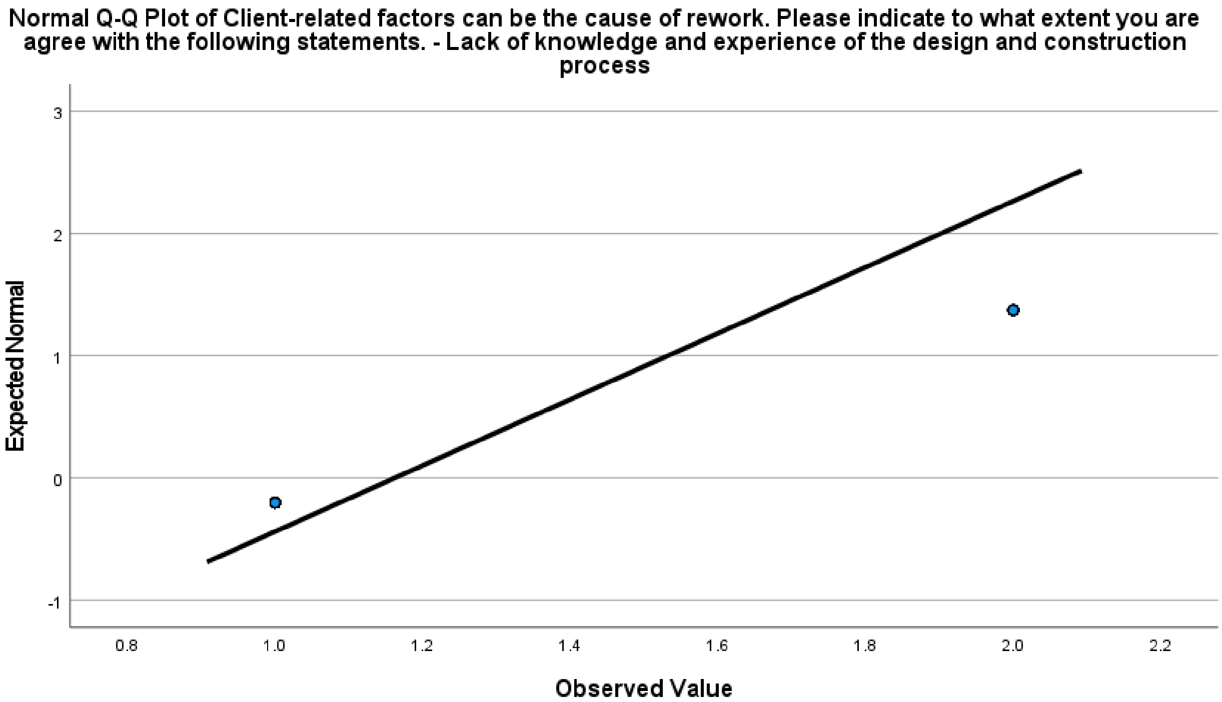
Q13-3



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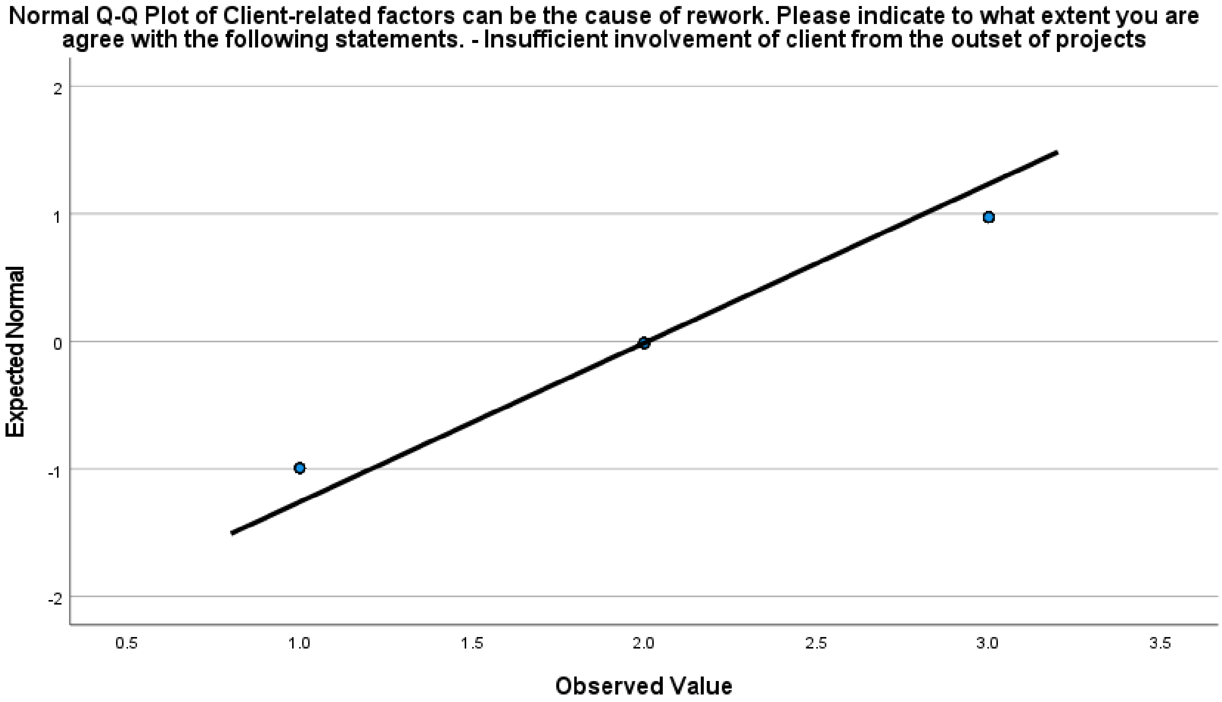

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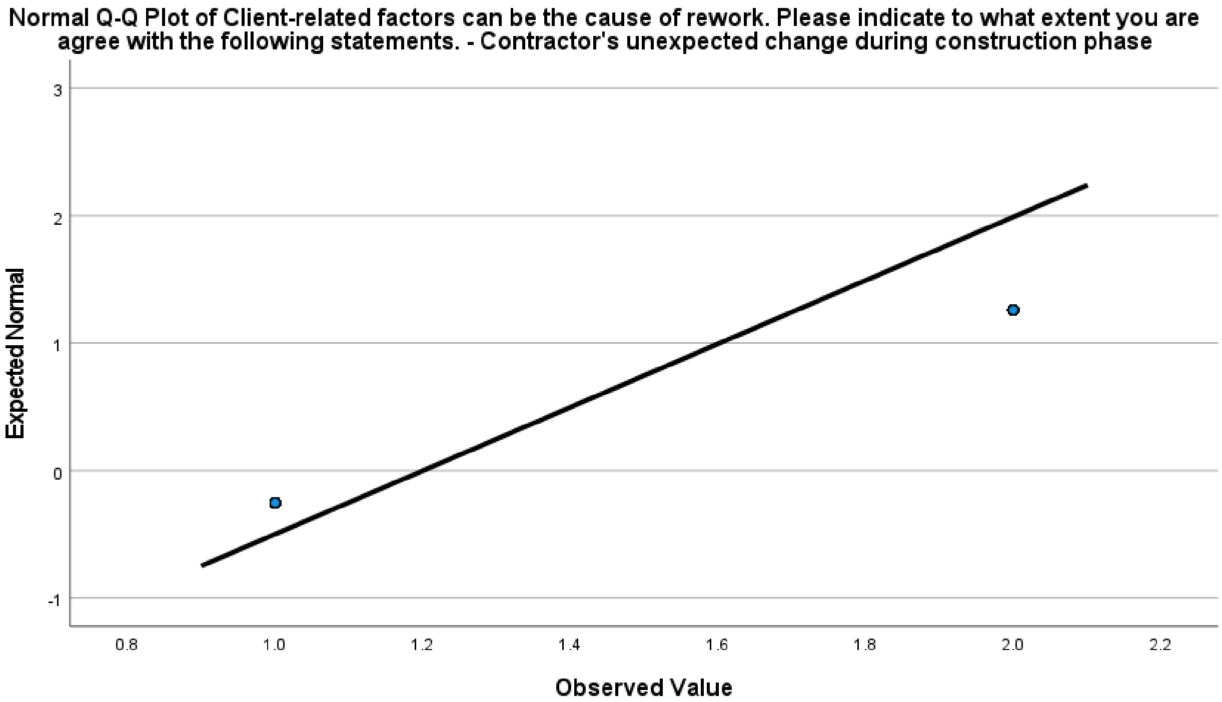

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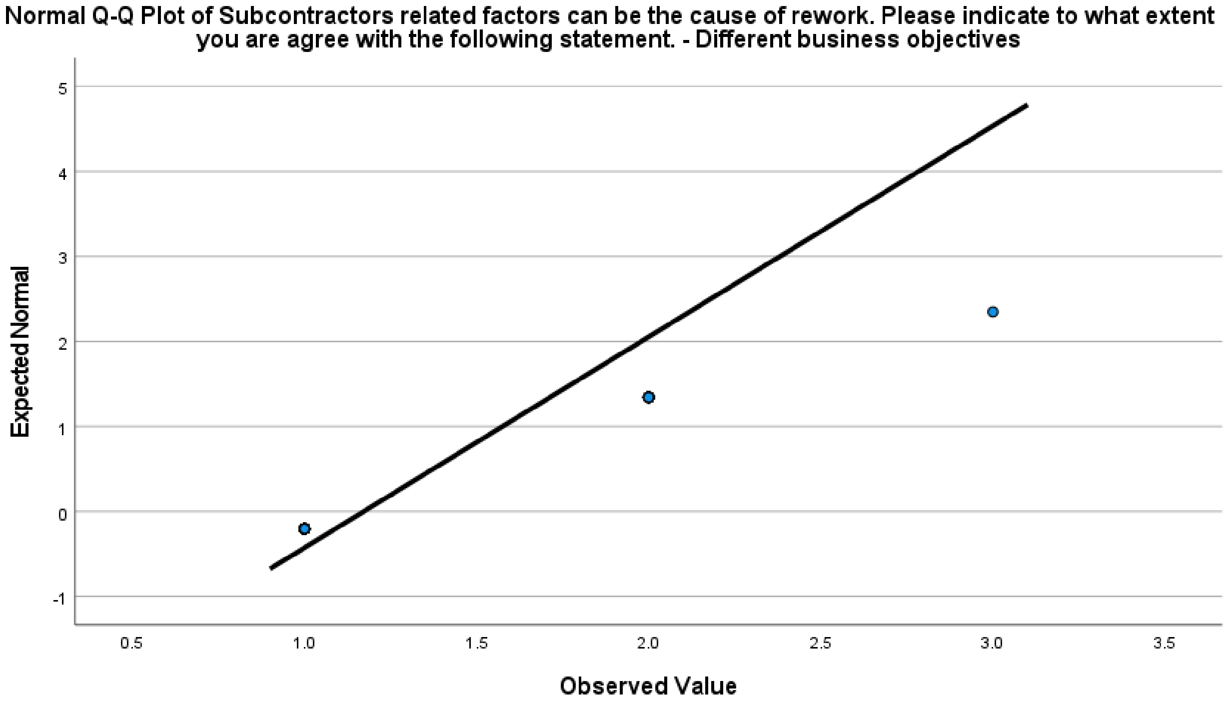

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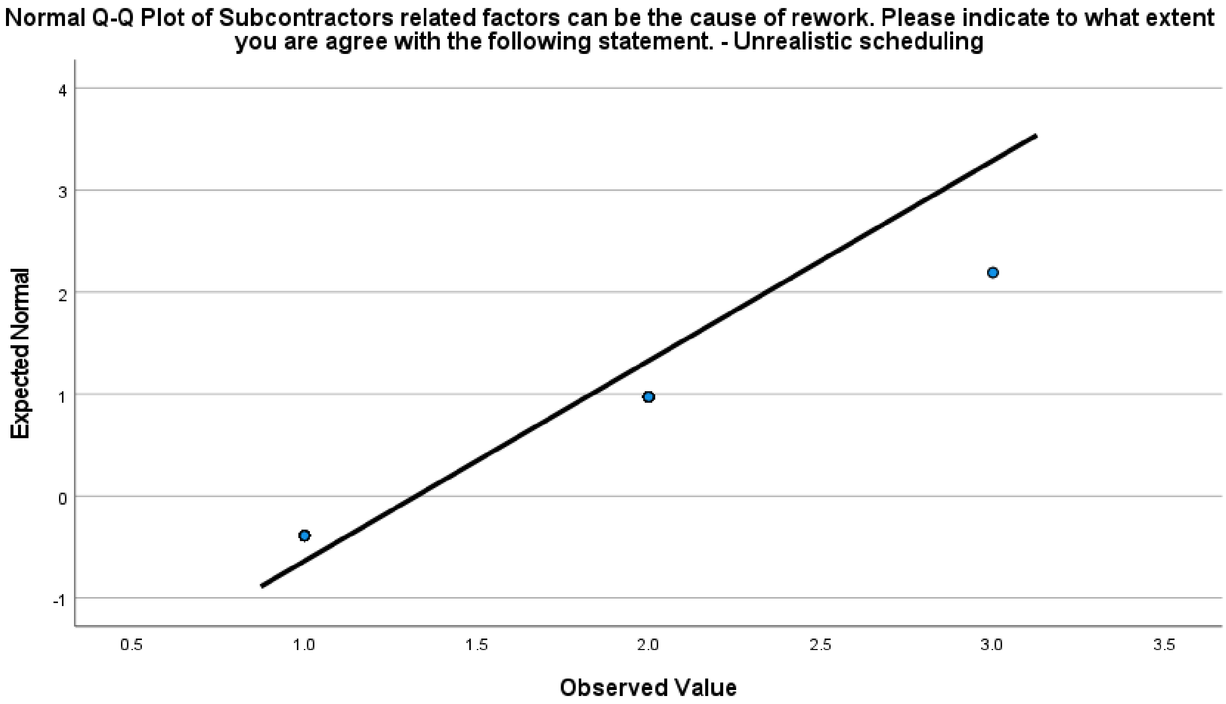

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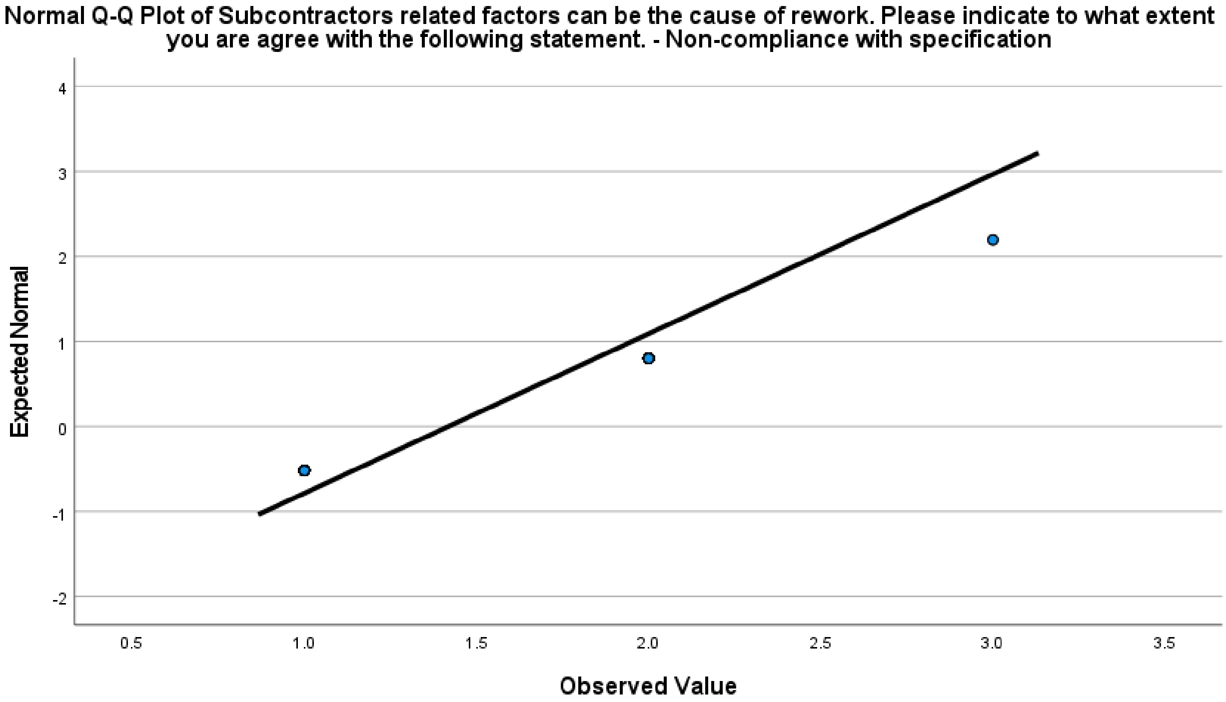

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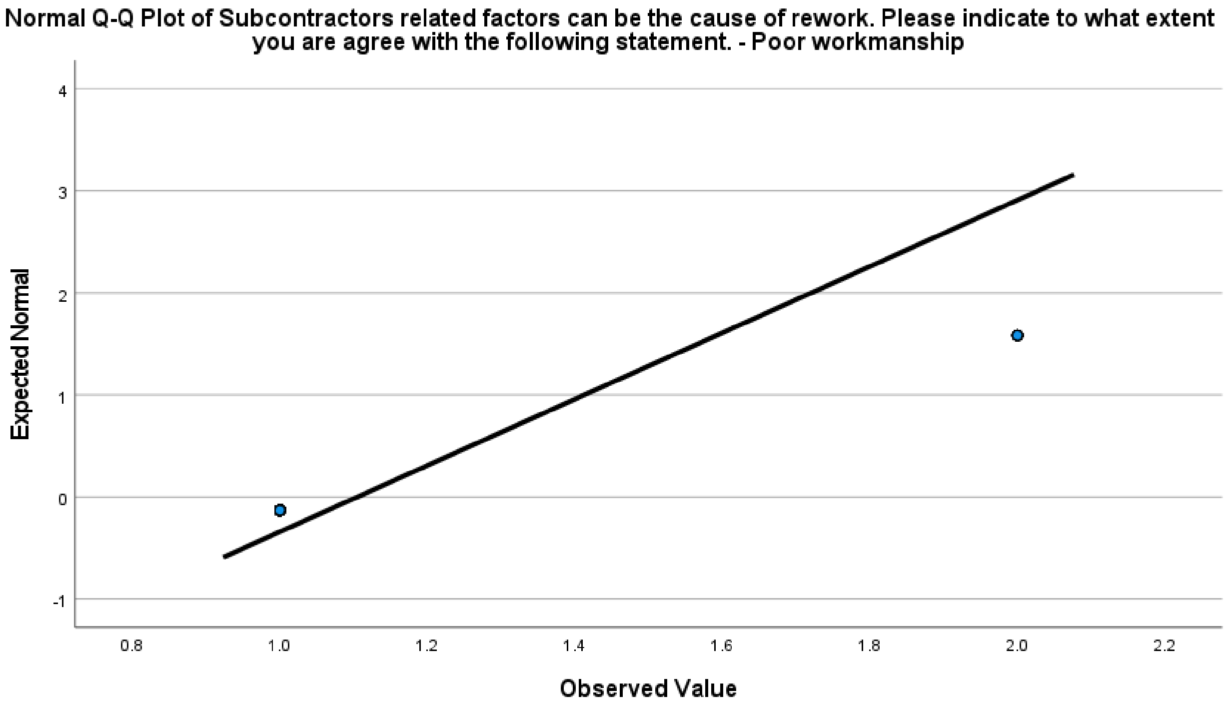

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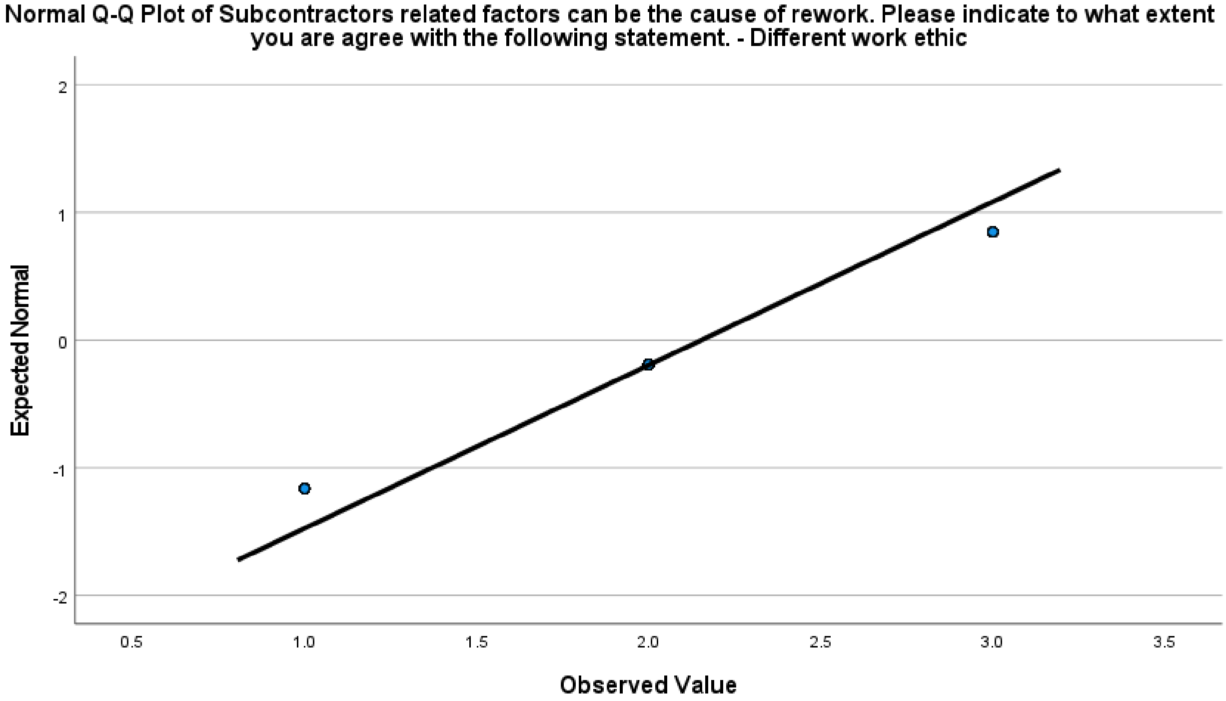

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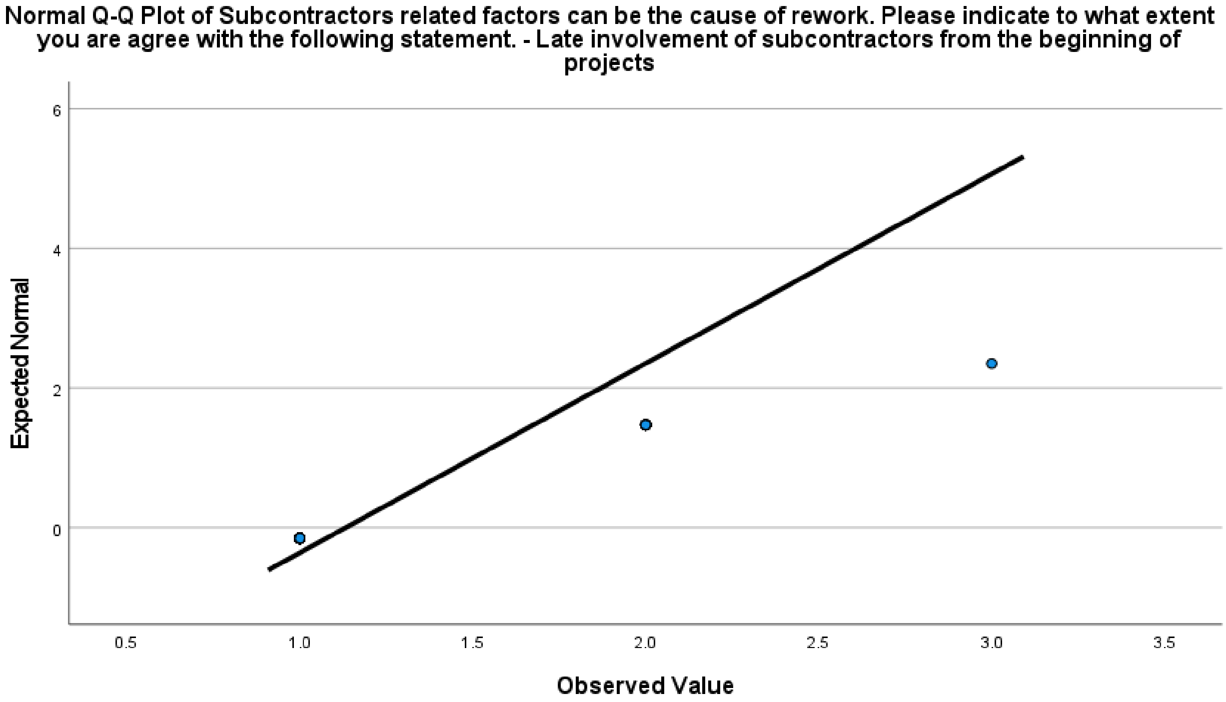
Q14-6



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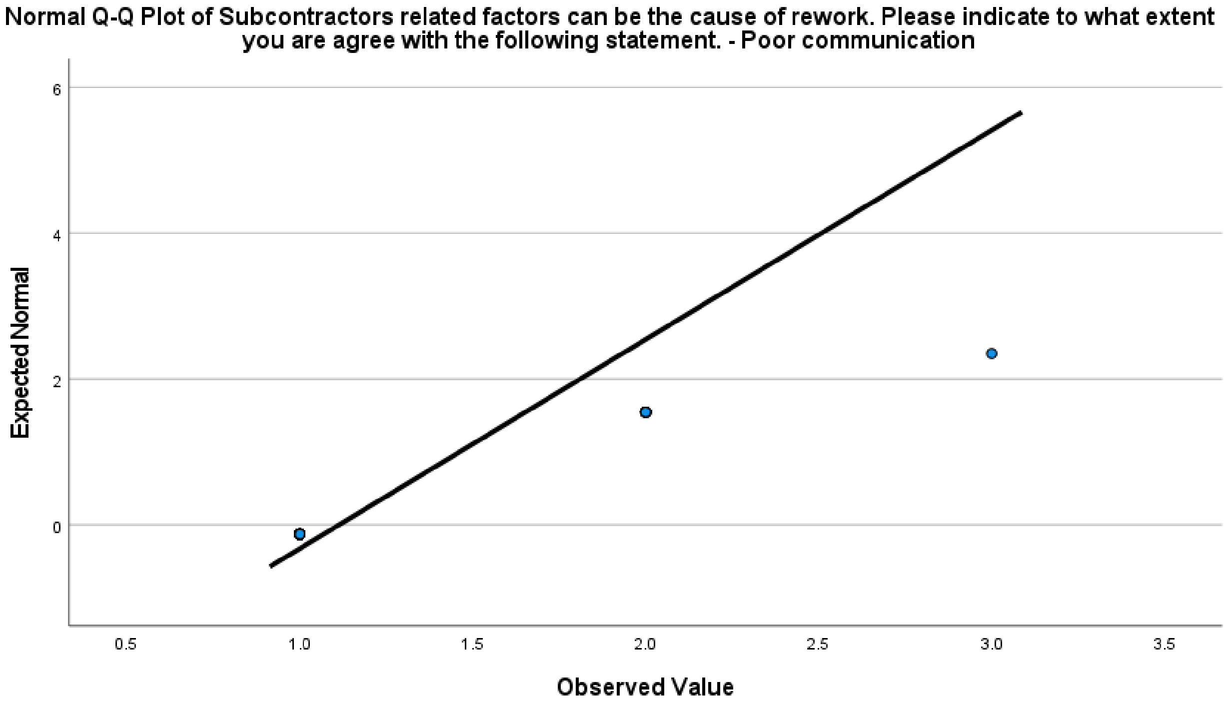

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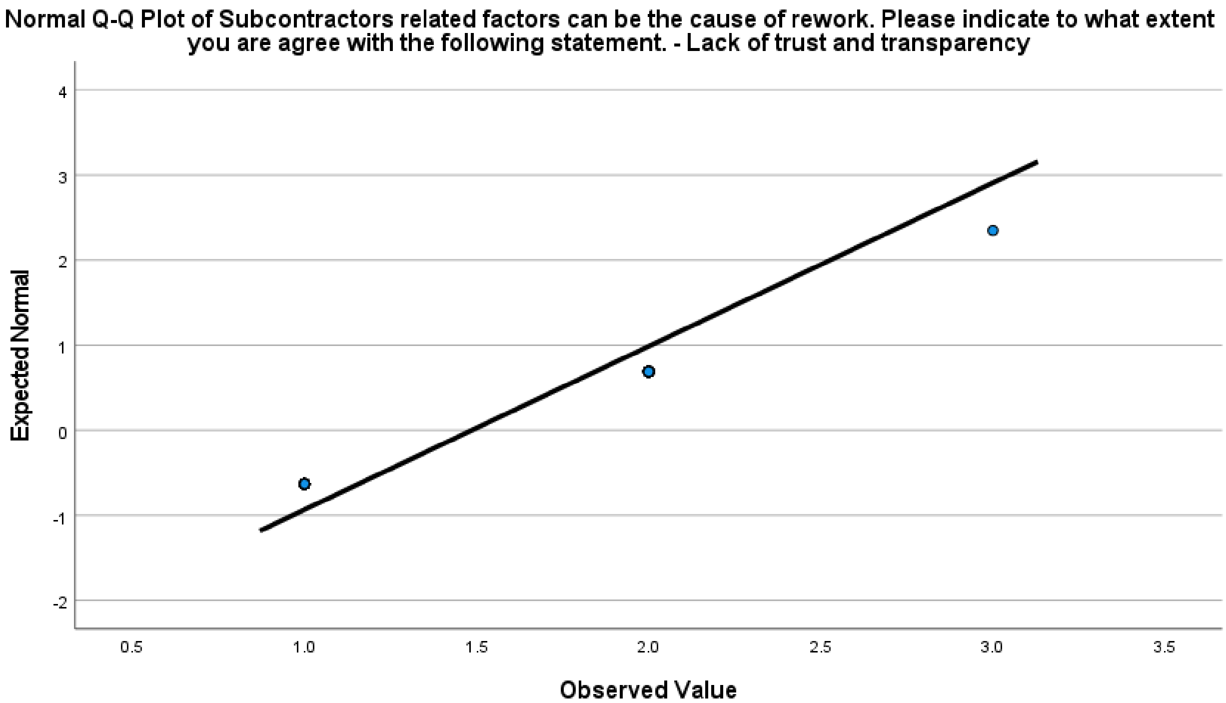

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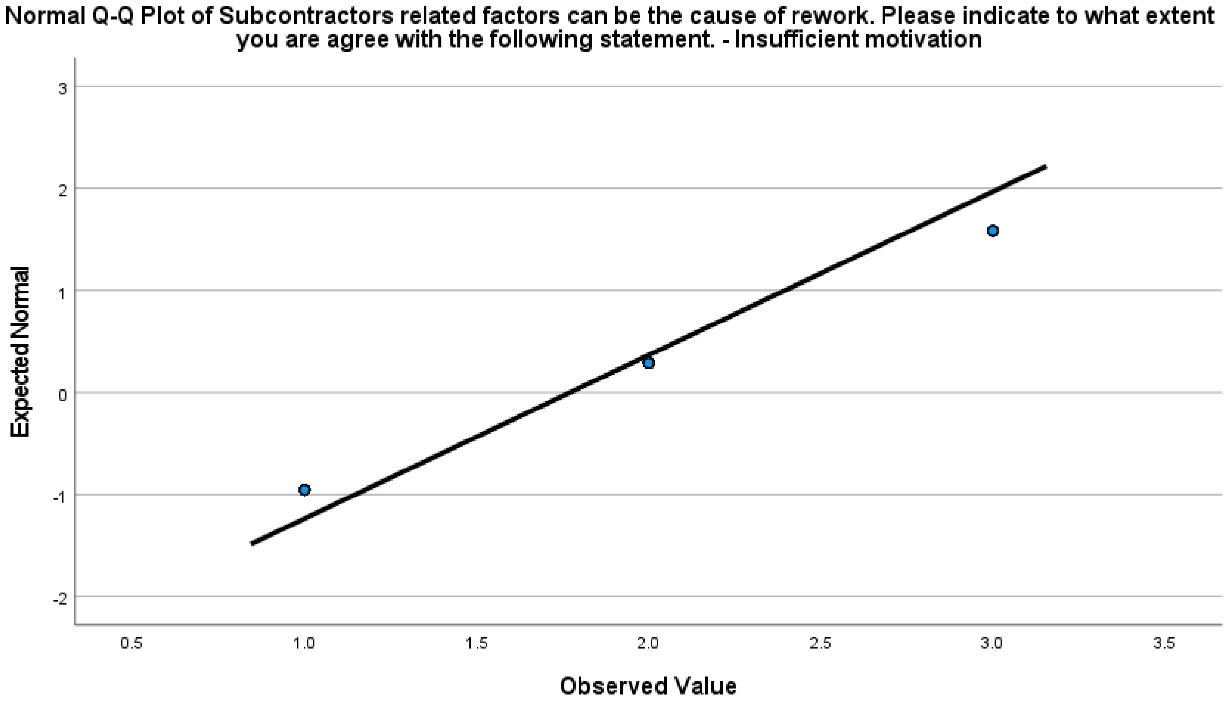

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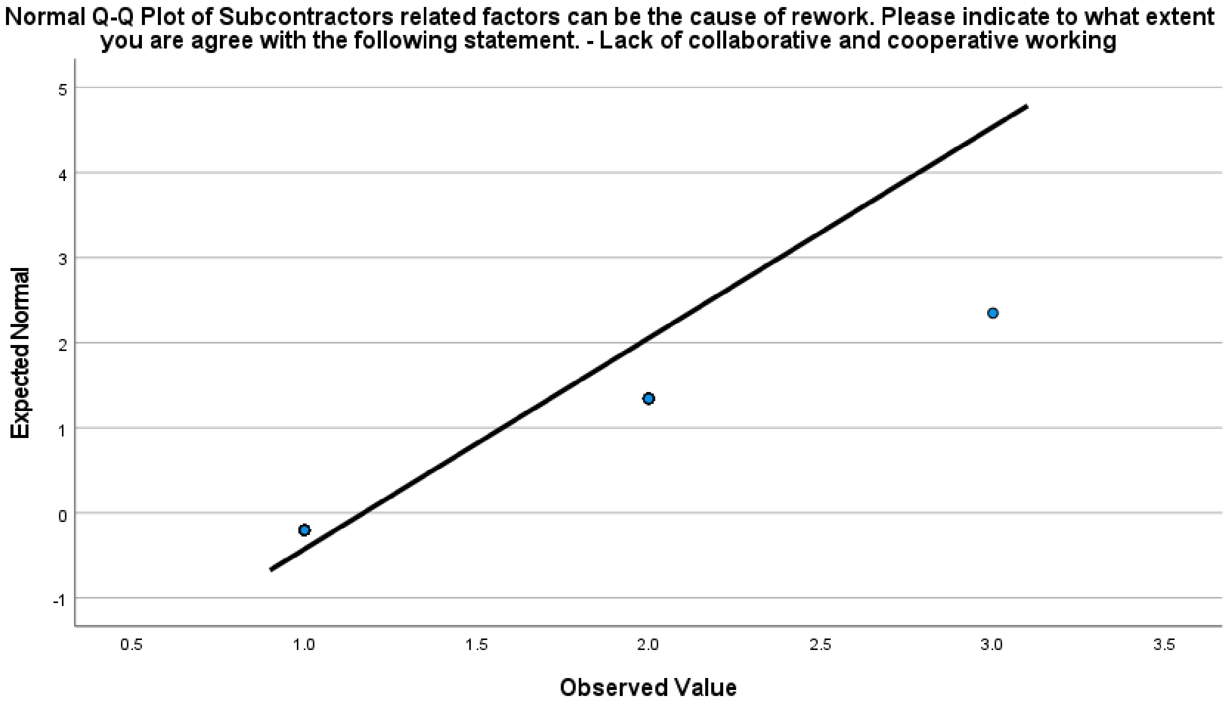

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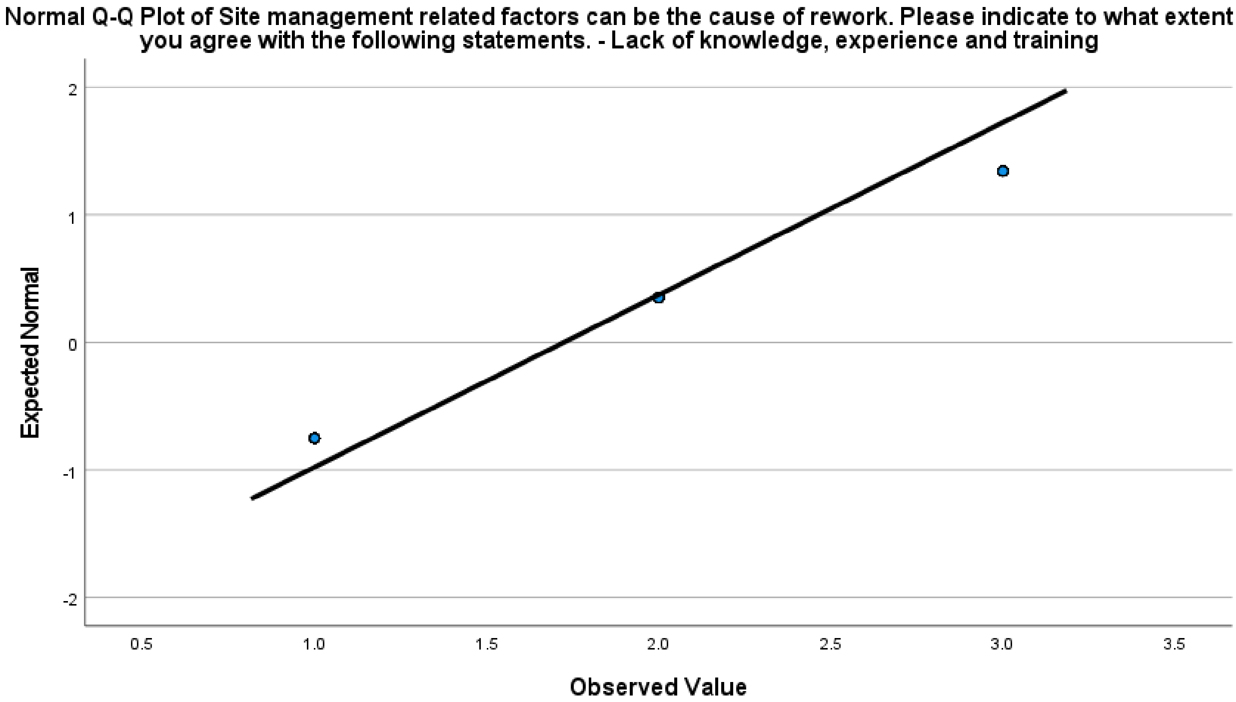

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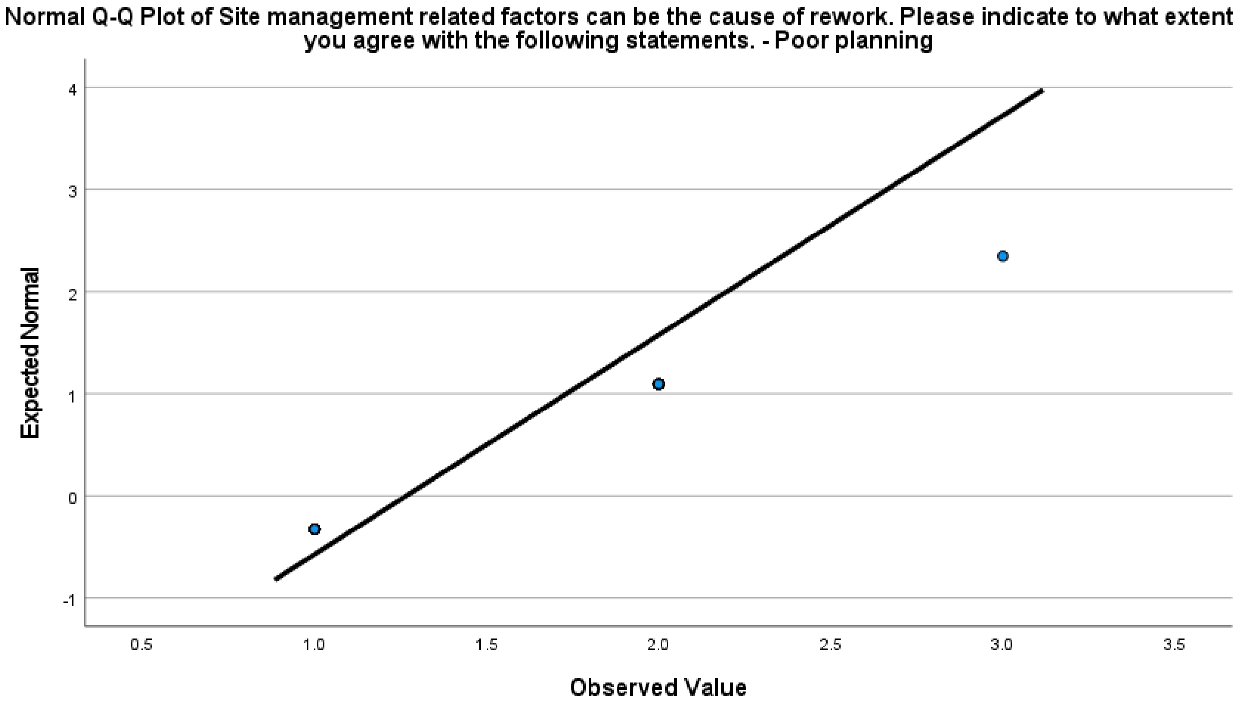

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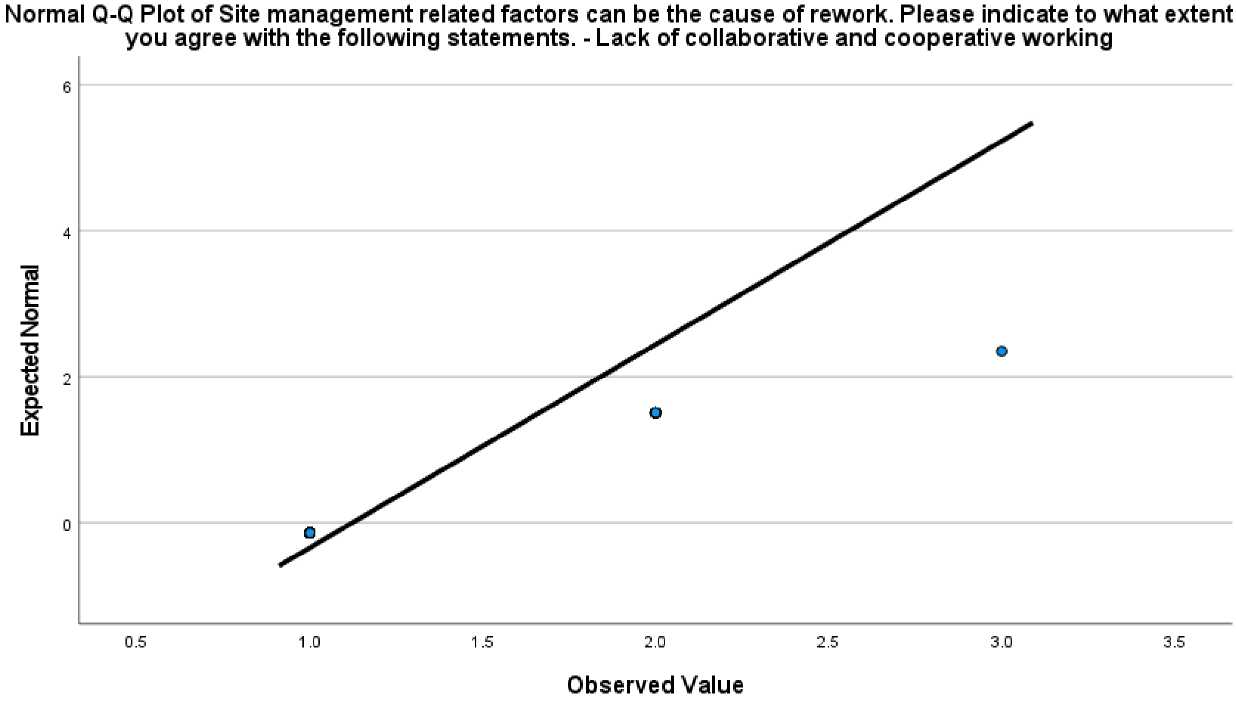

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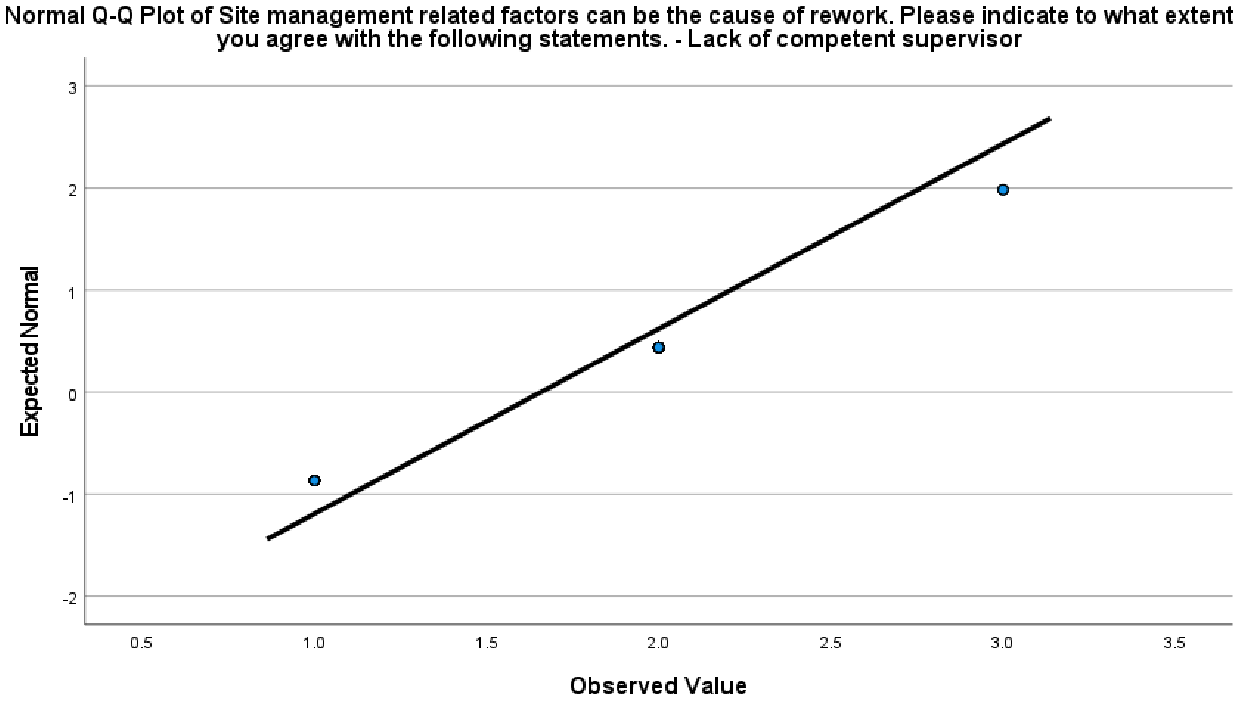

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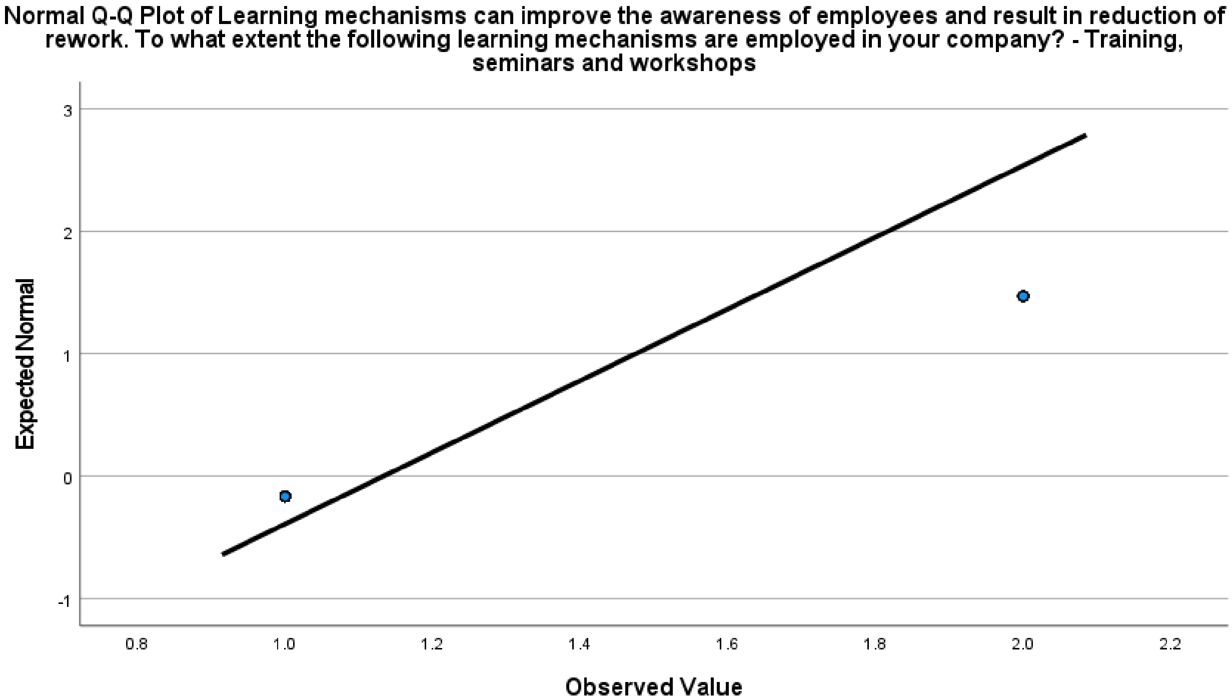

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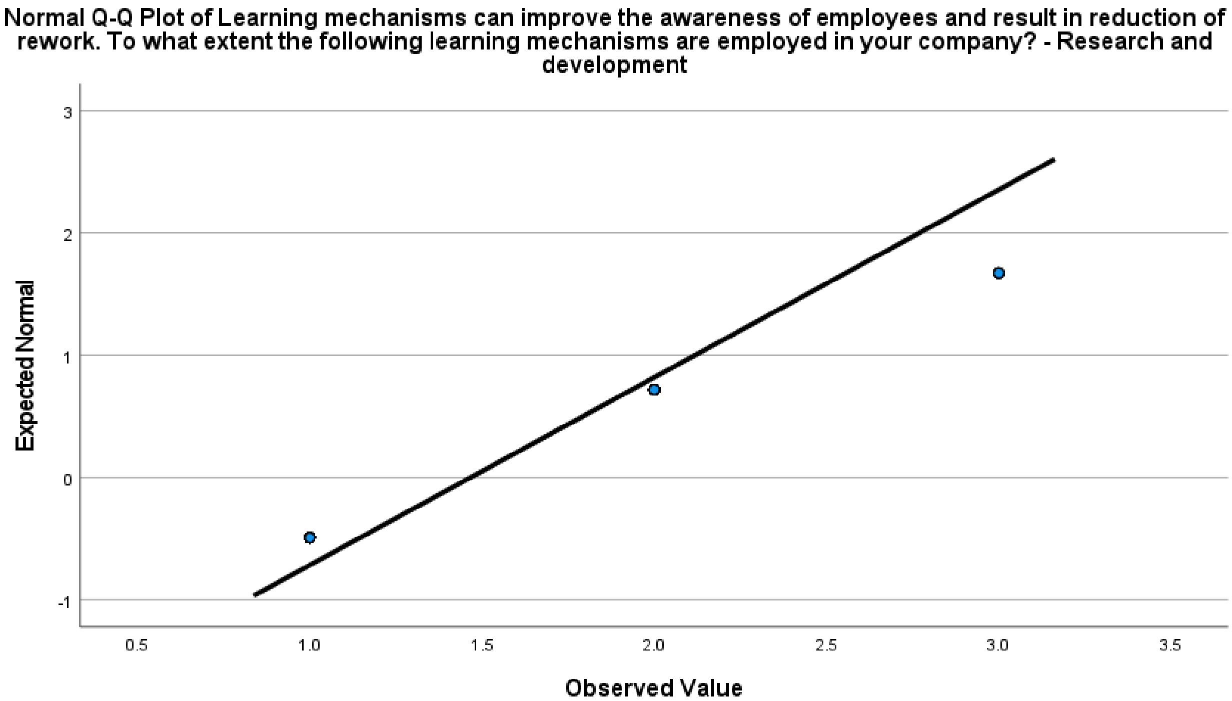

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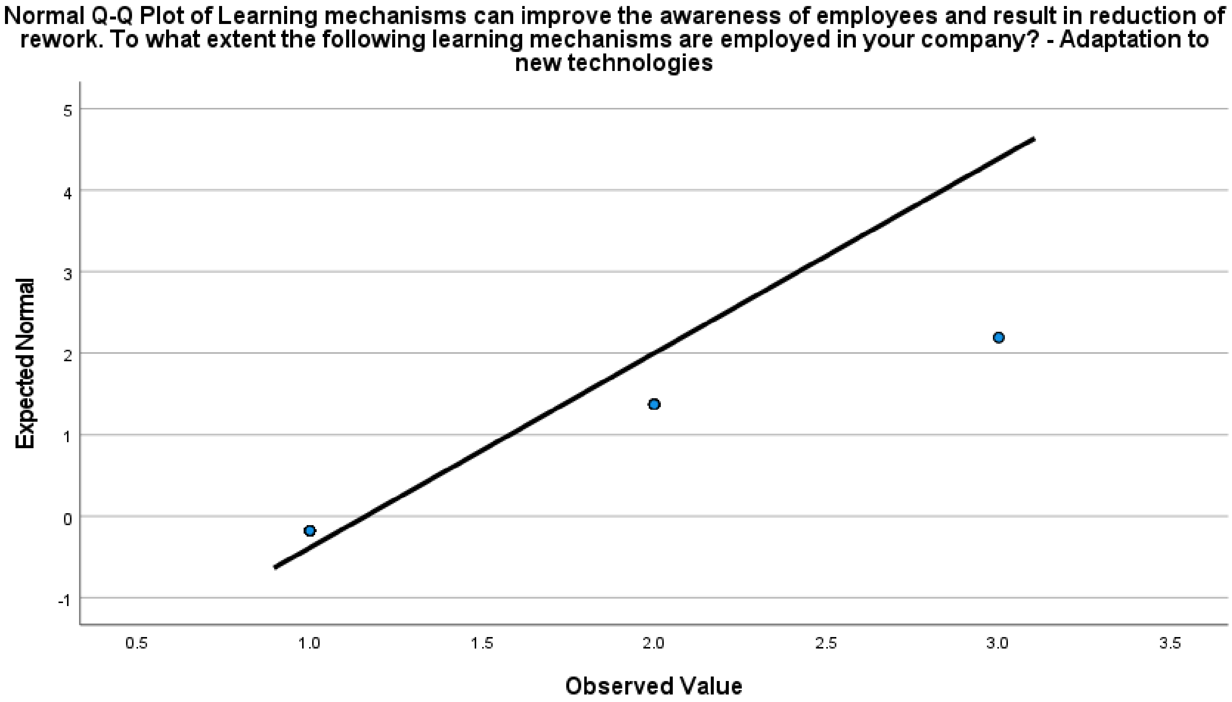

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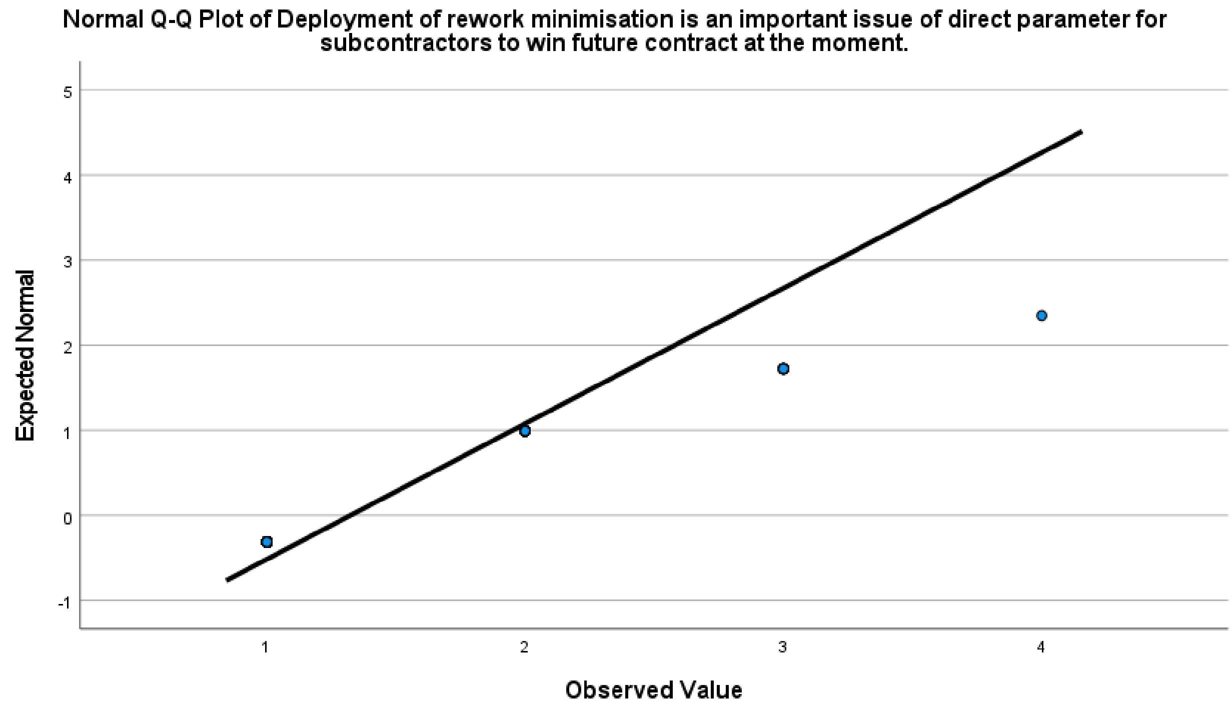

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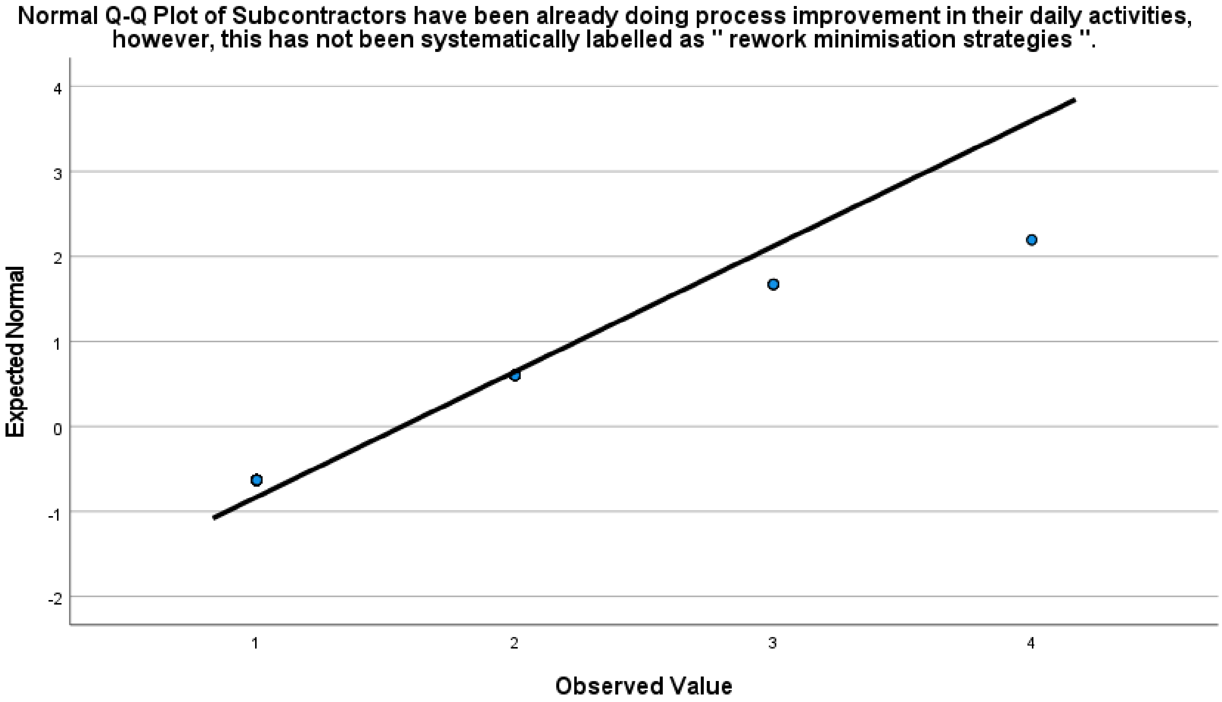

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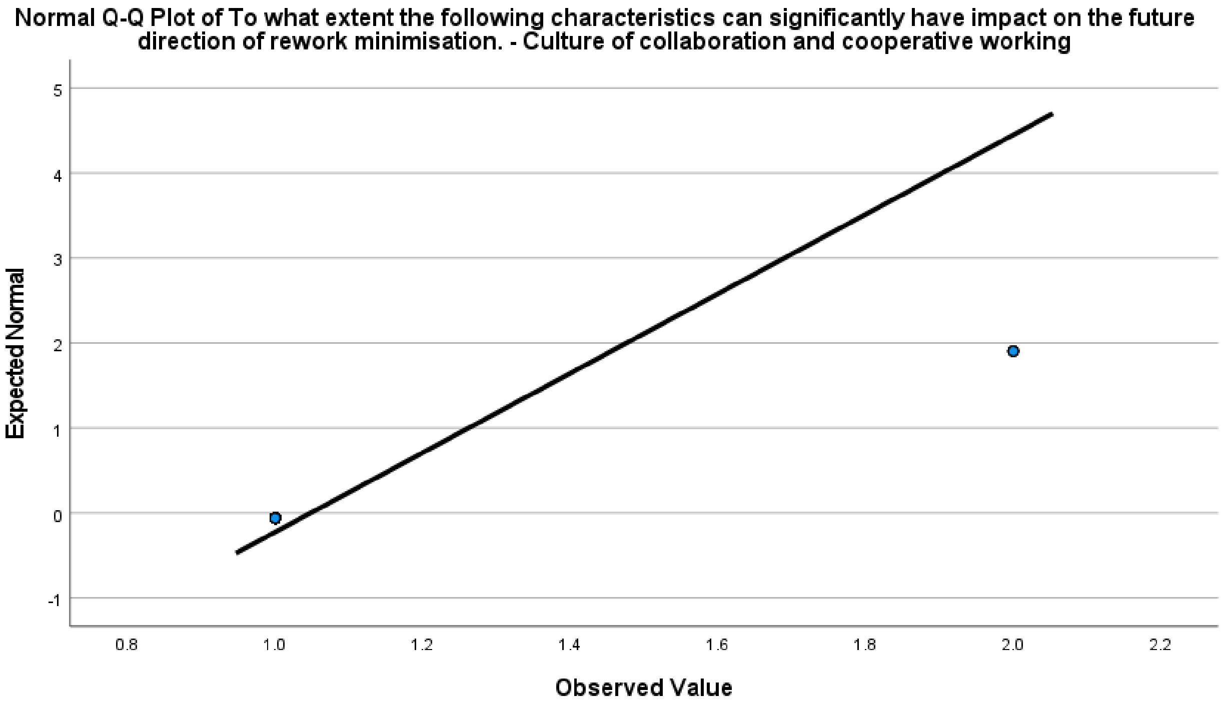
Q19-1



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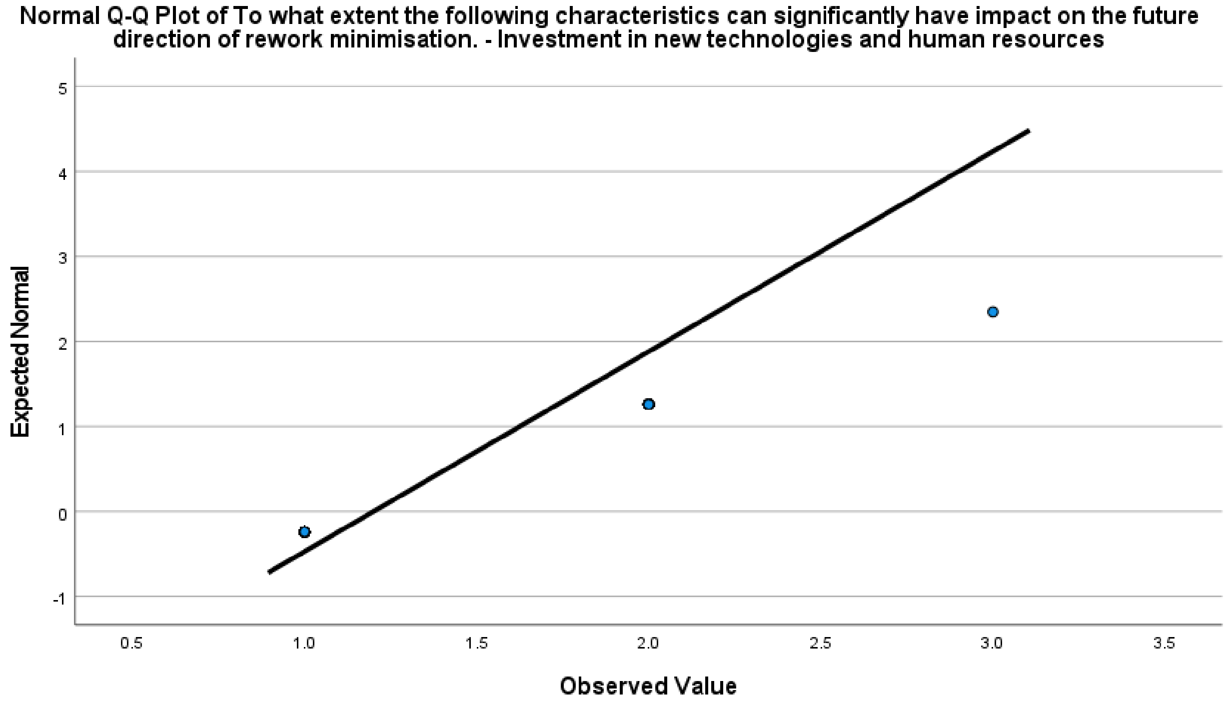

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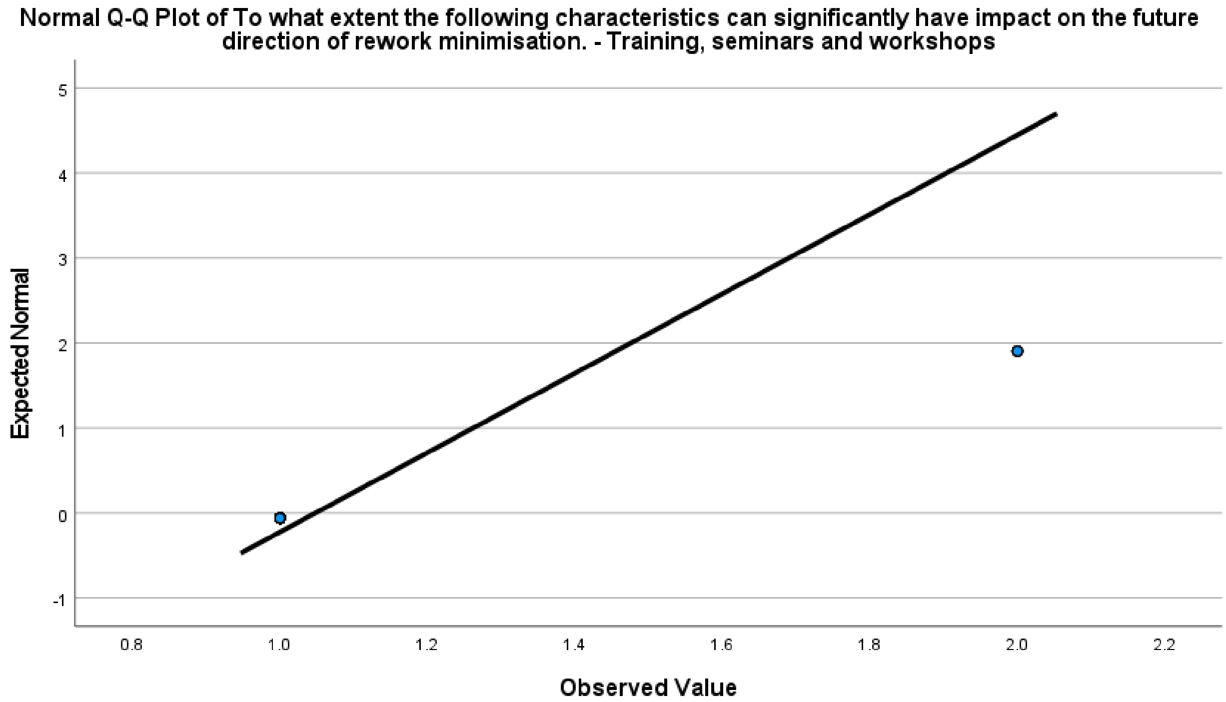

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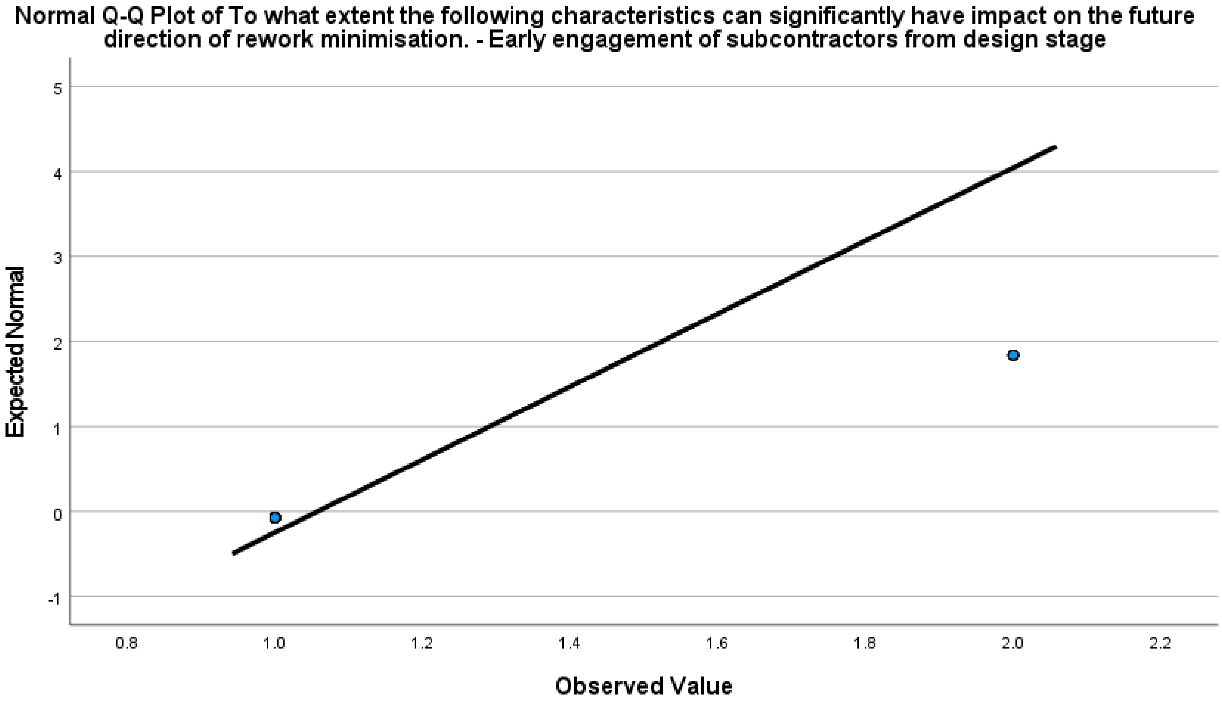

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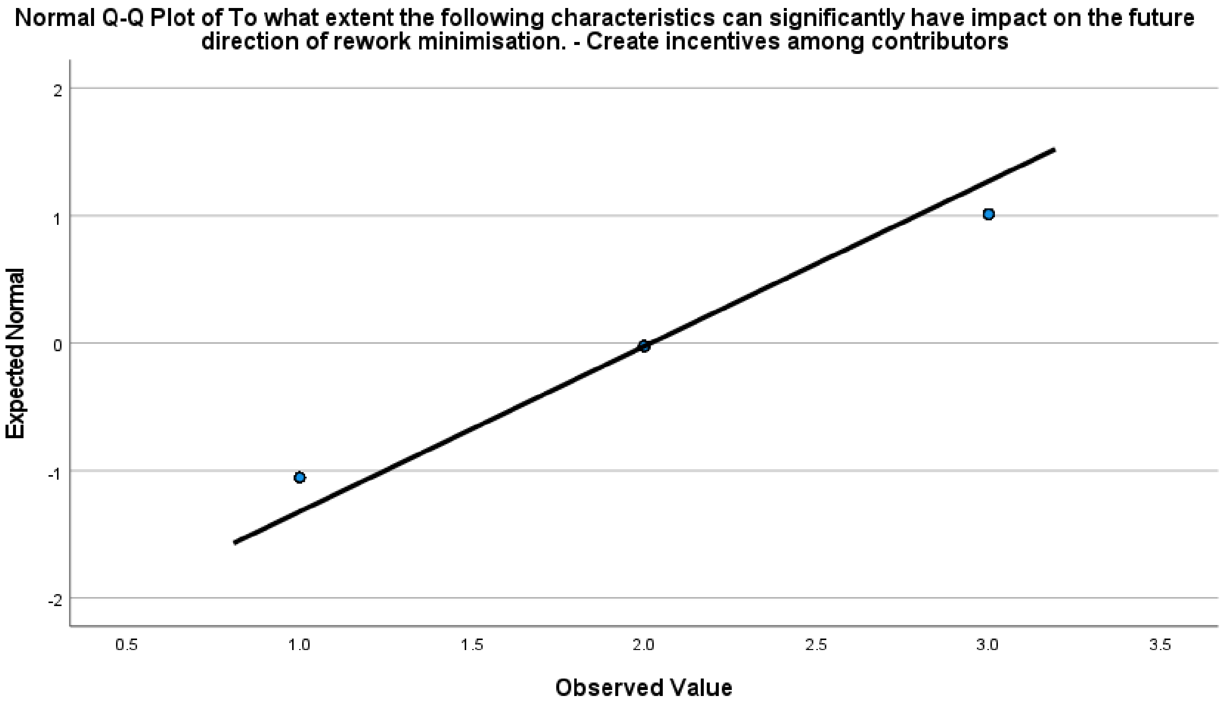

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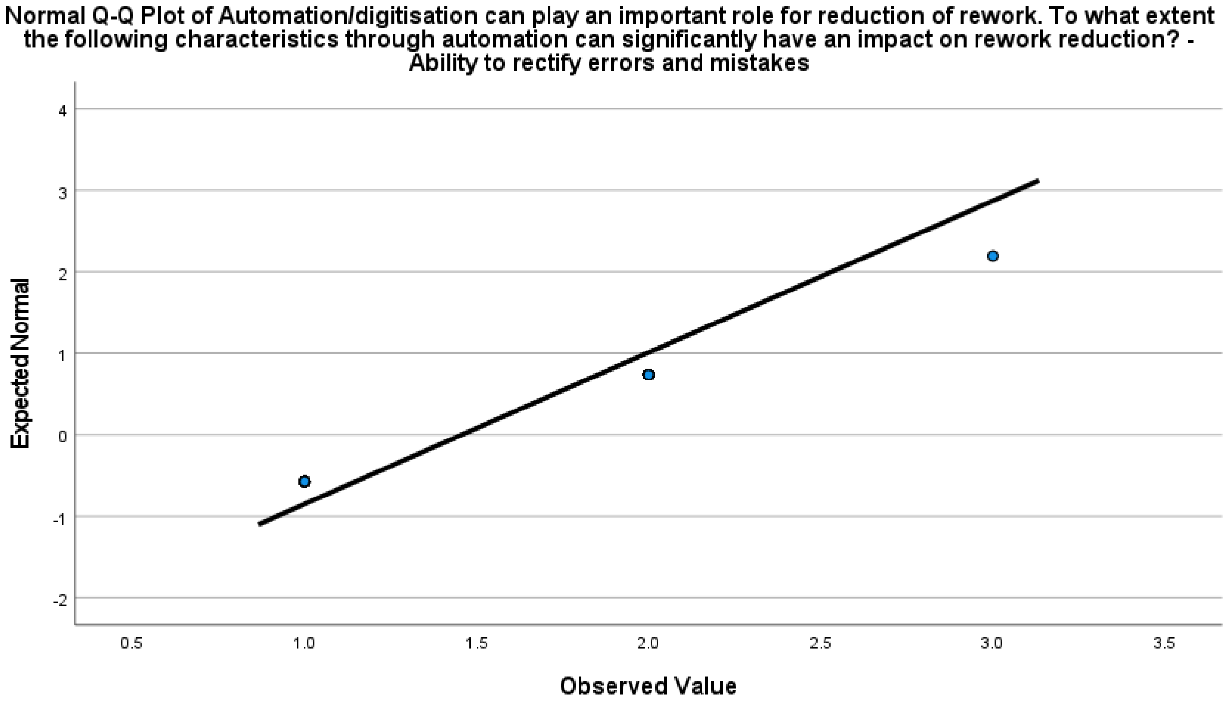

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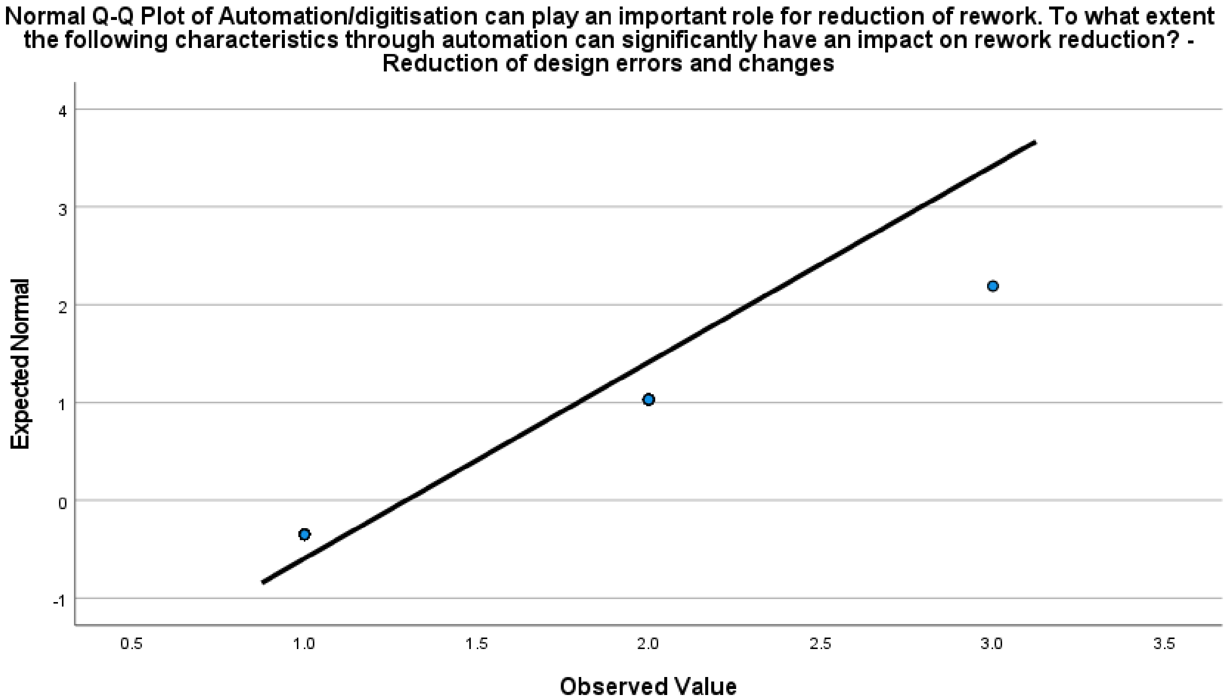

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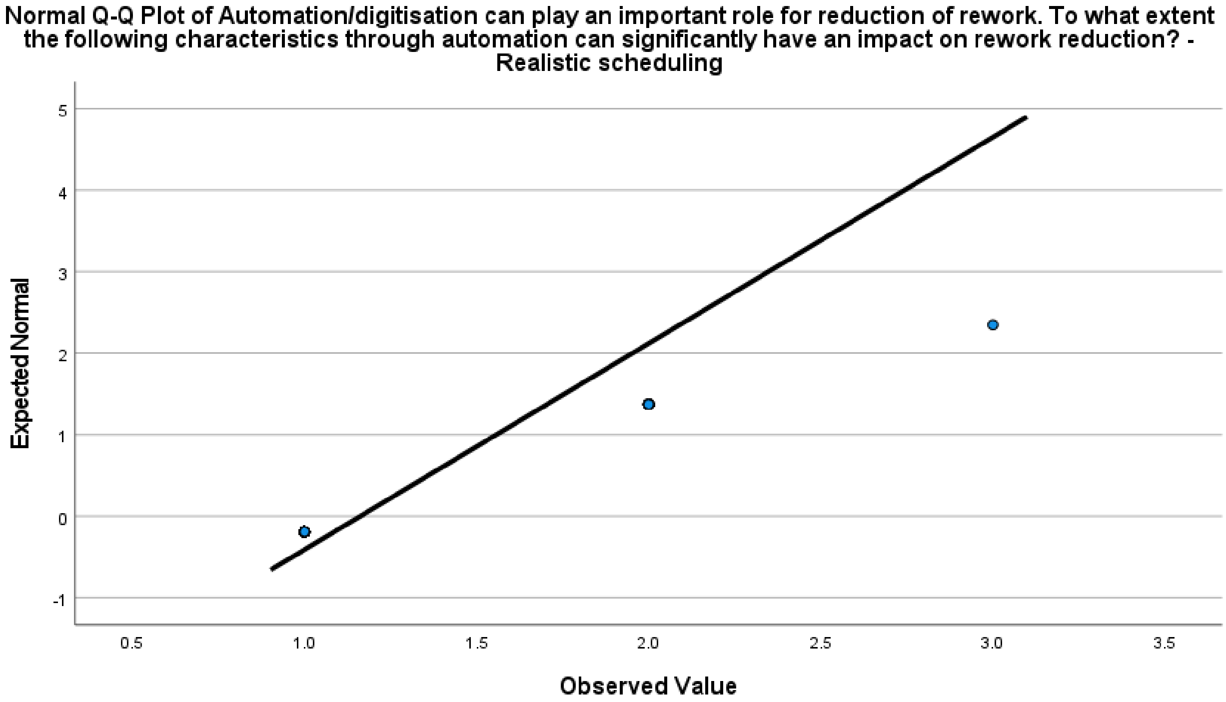

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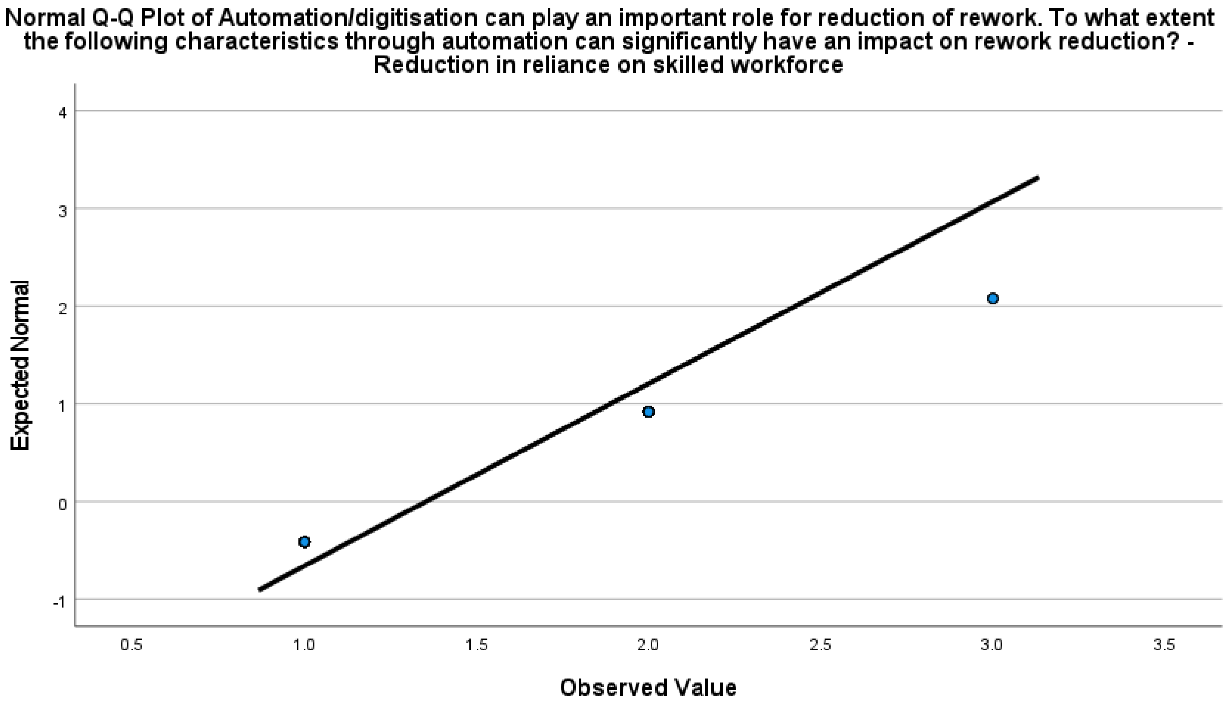

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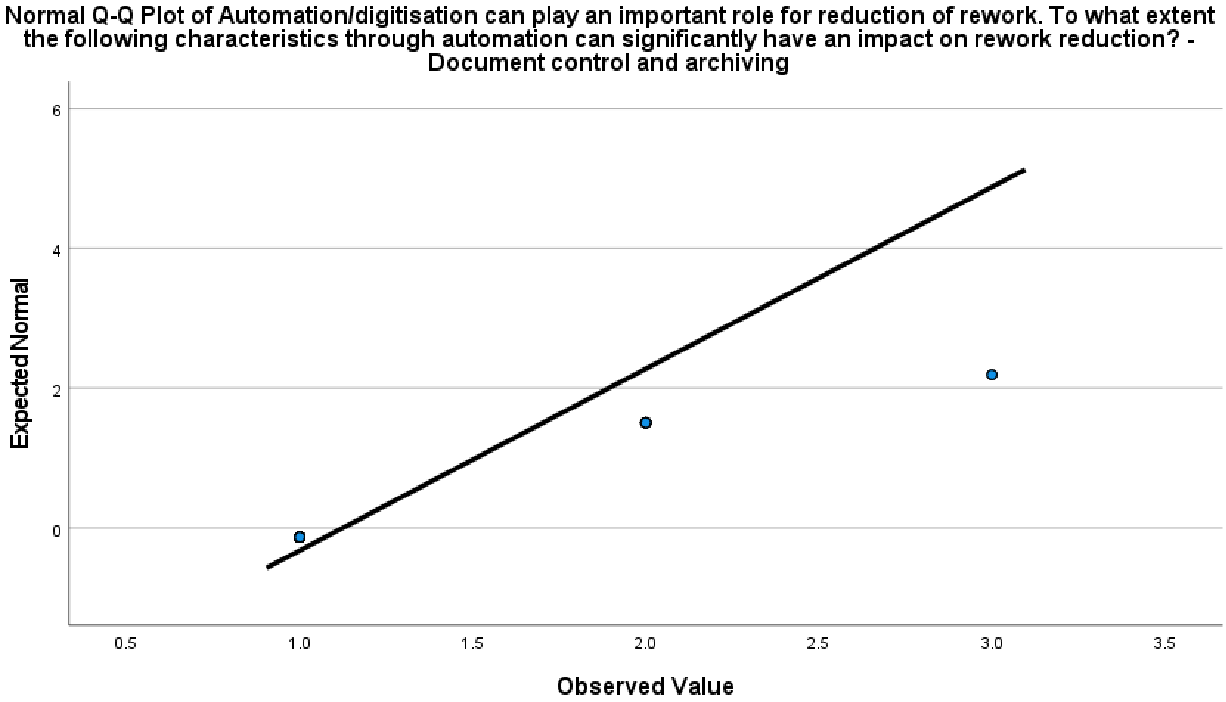
Q20-5



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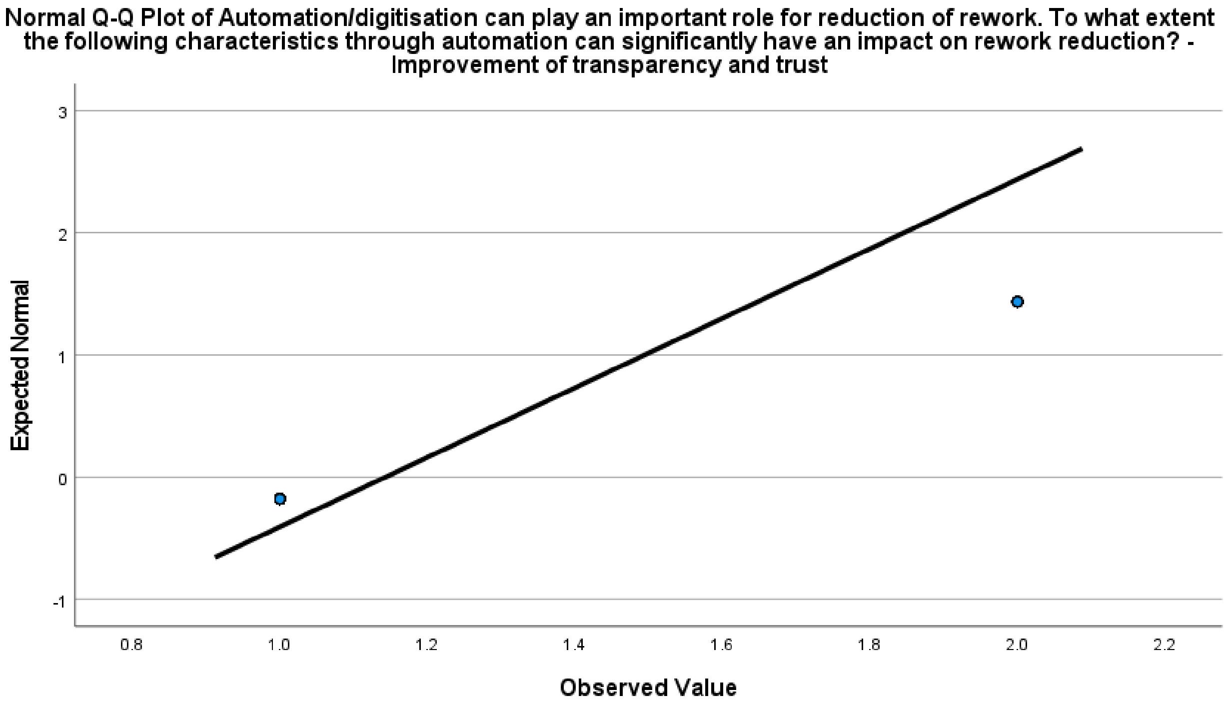

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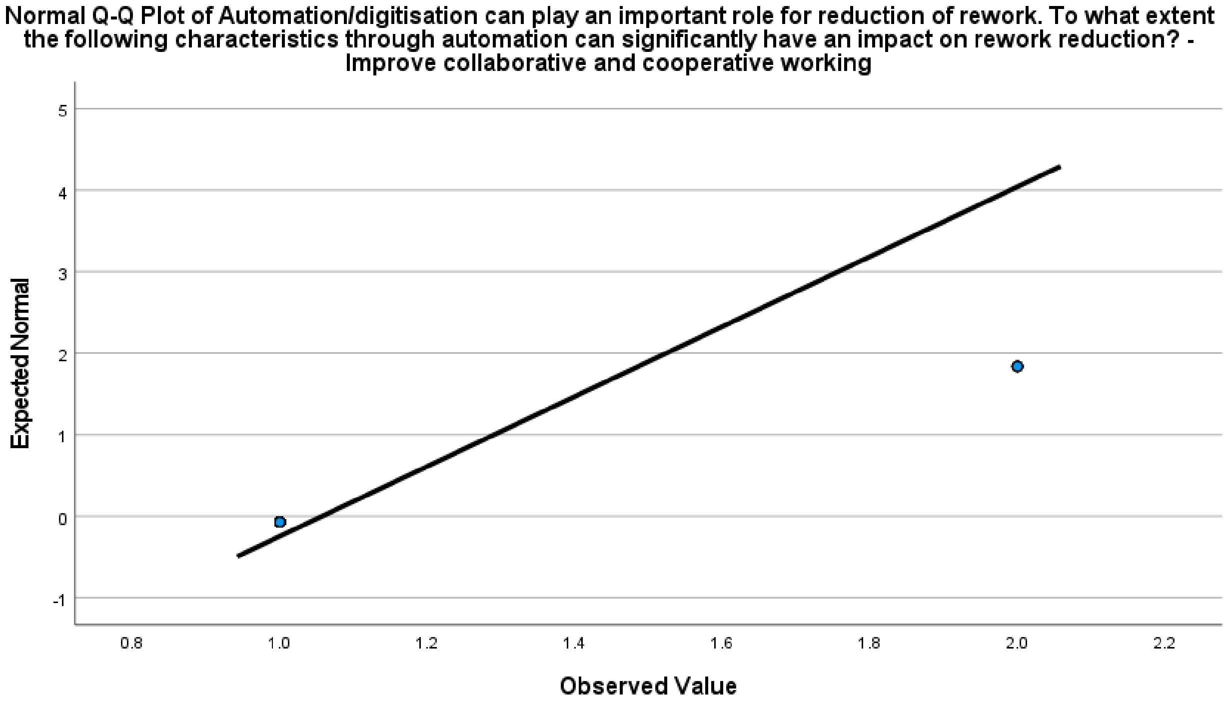

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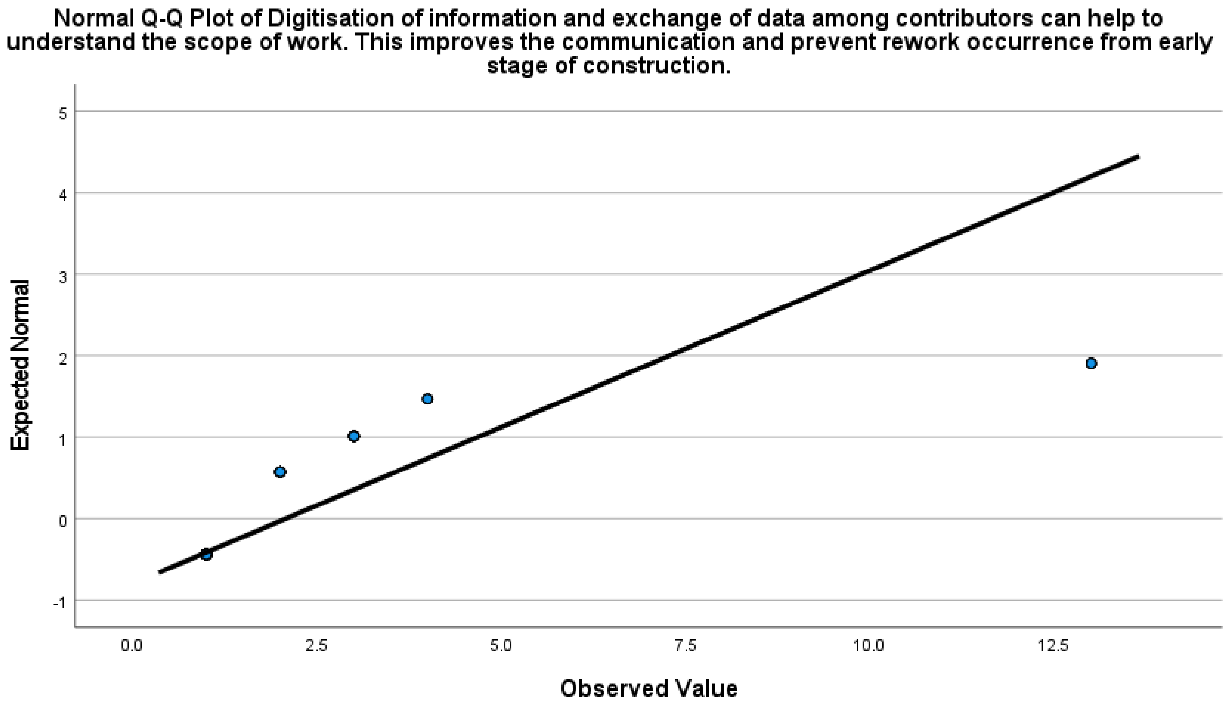

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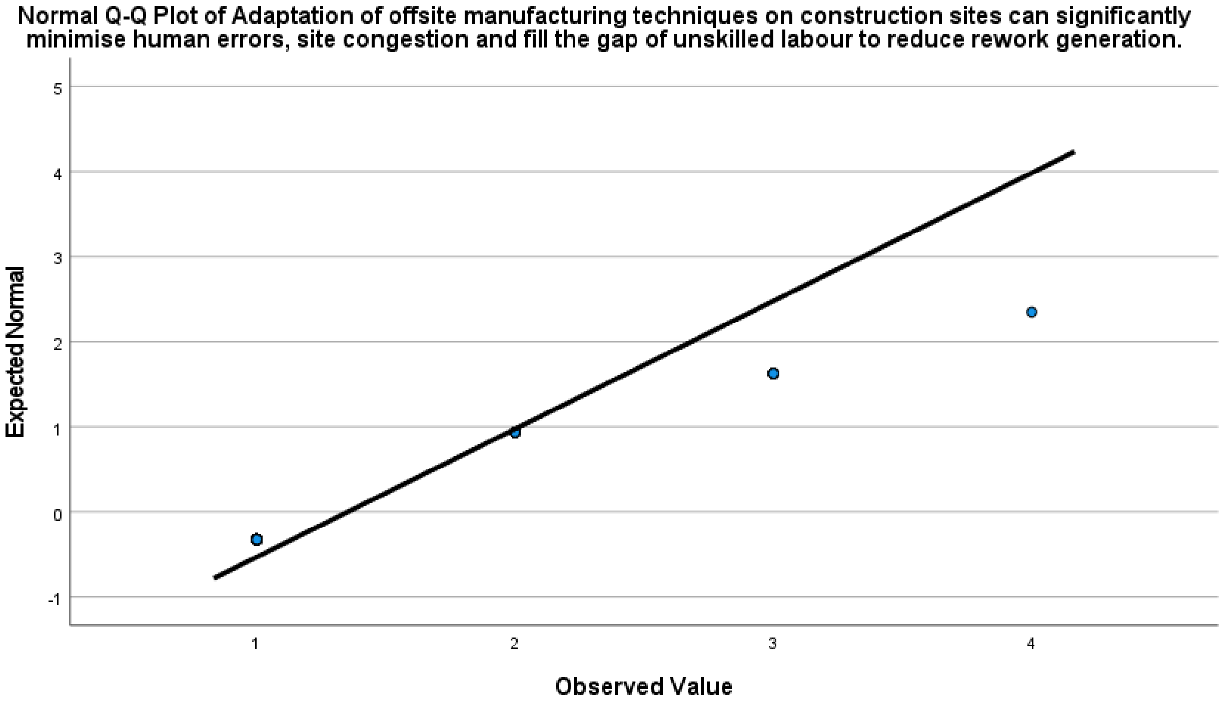

Appendix 4
Framework Validation Focus Group Interview Questions

Proposed Framework for Rework minimisation on housing supply chain

Aim

The aim of conducting focus group among contributors in housing construction development projects is to redefine and assess the appropriateness of the presented rework minimisation framework development for examples; such as; clarity of steps, information flow and improvement measures.

All participants' responses remain anonymous and confidential - any information indicates respondents' identity will be removed.

Schedule

We will discuss the following subjects during the focus group interview:

1. Generic Framework Validation

2. Detailed components of Framework Validation

3. Implementation Strategy

4. Further Thoughts

Yours Faithfully
Mehdi Shahparvari
PhD Researcher
The Built Environment and Architecture
London South Bank University

Section A Generic Framework Validation

1. Based on the framework, please comment on the following:

- Clarity of the framework's structure

- Information flow and appropriateness of the framework
- Practicality and usefulness of the framework

Section B Detailed Components of Framework Validation

1. Do the main elements identified in the proposed framework adequately cover the reduction of rework practice
2. Can the framework provide a clear roadmap for other contributors onsite to practice rework minimisation practice for future direction
3. Does the proposed framework provide a structured, well-informed, and holistic approach for implementation of rework minimisation practice?
4. What can your company do to further entrench the rework minimisation practice identified in the framework?

Section C Implementation Strategy

1. How can the framework to be implemented in housing supply chain?

For instance:

- Strategy for implementation
- Appropriate/ relevant methods, tools and standards
- To what extent it should be integrated among subcontractors onsite
- Which party should take the responsibilities and accountabilities?
- What are the barriers and challenges to hinder the implementation?
- What are incentives to drive rework minimisation forward for future direction

Section D Further Thoughts

1. Please feel free to add further suggestions that are pertaining to the proposed framework to further enhance rework minimisation practice implementation in housing supply chain

Thank you for your participation in this study