IDENTIFICATION OF THE MANAGEABLE CONSTRUCTION REWORK INDICATORS AND RELATED SUCCESSFUL STRATEGIES

by

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Abstract

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In construction projects whether small or large scale, in the design and construction phases, contractors and owners face numerous reworks which finally leads to schedule delays and cost overruns. Although studying the causes of the rework has been of interest of many scholars and researchers, they have mainly focused on identifying the entity-based rework indicators. It is pivotal to identify the key project, organizational, and human factors that lead to the rework. Therefore, this study investigated, identified, and prioritized the human, organization, and project-based manageable indicators of rework. In addition, successful strategies which lead to overcoming rework challenges were evaluated. More than 112 previous research were reviewed to identify the leading rework indicators and rank them, based on their frequency of occurrence in the literature. Then, a survey was developed and distributed among experienced practitioners to identify the significant rework leading indicators and successful overcoming strategies. 44 case studies and response from 44 different industrial, infrastructure, and building projects were collected and analyzed. PM’s experience in the construction (6.06%) and design (5.68%) phase, and number of PM staff (5.87%) was evaluated as most weighted indicators. It was concluded that design related issues, a vague scope definition, and owner/client involvement issues are the project-based indicators; ineffective coordination and poor communication are the organizational-based rework indicators; and lack of experience and expertise, level of skill, and experience are the most critical human-based rework indicators. Concluded results were implemented in two construction projects. Reviewing this study will help practitioners identify the causes of rework early in the project to implement suggested best practices to reduce the number of rework cases and mitigate the consequences of rework undesired outcomes.

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Chapter 1 Introduction

Rework are bound to happen in all sort of construction projects. They have great significance or value in a project's success or failure, as they impact the cost of a project, generate scheduling delays, and fall in productivity. Rework and their reactions or effects vary significantly on the different project because of the uniqueness of each budget; calculated schedule; and availability of resources for planning, such as time, funds, and crew.

Rework is usually implemented in order to change the design during the design and construction phases but can be issued for various reasons by the owner or stakeholders. They have a huge potential for making genuine difficulties for proprietors, designers, and contractual worker partners, and may likewise cause clashes among them. Henceforth, it is basic to distinguish the reasons for change orders and measure their effects on the execution of construction projects (Wu et. al 2004, Sunday 2010, Desai 2015; Safapour et al. 2018; Safapour et al. 2019; Safapour and Kermanshachi 2019).

Rework negatively affects construction performance and efficiency (Kermanshachi and Rouhanizadeh 2019). According to Baxendale and Schofield (1986), rework can be defined as any change that veers from the agreed upon and signed contract. Ssegawa et al. (2002) expressed that changes of plans or in the construction procedure itself must be normal in light of the multifaceted nature of construction projects and change orders in both the design and construction phases are unavoidable. Along these lines, the construction industry is liable to poor cost management and schedule performance due to design alterations (Ssegawa et al. 2002; Habibi et al. 2018a, 2018b, 2019).

In this investigation, through a comprehensive literature review, 124 causes of rework were identified according to the studies of Hsieh et al. (2004), Keane et al. (2010), Love et al. (2012), Forcada et al. (2014), Karthick et al. (2015), Ye et al. (2015), and Safapour and Kermanshachi (2019). According to the comprehensive research of CII (2012), of the identified manageable causes for rework, 35 were manageable by implementing BPs during the execution of a construction project. Most of the remaining causes for the rework were attributed to uncontrollable situations (e.g., weather conditions) and the need for more resources, including allocations related to additional management strategies (e.g., owner's change of schedule because of financial problems).

According to explore directed by CII (2012), the usage of BPs aids the administration of attributes related to organizations, projects, and team members. Alluding to the works of Love et al. (2012) and Forcada et al. (2014), the recorded manageable causes of rework were grouped into three primary classes: organization, project, and people.

The general objective for this examination is to decide the IMRCs and explore how the usage of suitable BPs decreases the expense of rework, with regards to total budget baseline, related with the difficulties from IMRCs in construction projects; in this manner, this investigation was intended to respond to the accompanying exploration questions:

1. What are the early IMRCs?

2. What are the suitable BPs to decrease the cost of rework related with IMRCs?

The accompanying targets were defined to respond to the exploration questions: (1) distinguish potential IMRCs through a review of the existing literature; (2) group the recognized IMRCs based on past examinations; (3) decide IMRCs with a huge effect on rework through statistical methods; (4) research the advantages of actualizing each BP for tending to the issues of IMRCs; and (5) figure how much each BP adds to the decrease in the expense of rework in connection to the total contract budget baseline.

In outline, the capacity to anticipate design changes from the get-go in construction extends altogether benefits industry specialists, explicitly partners (i.e., proprietors, architects, and contractors) and project managers (PMs). Moreover, executing the fitting BPs at the right time aids the administration of undesired results and empowers the decrease in the expense of the rework as it identifies with the expense for the whole project. For example, the scope of a common vast scale project is intricate, and exact elucidation of the scope of the project is embraced at the construction stage. In this way, owners can allocate adequate assets in the preplanning stage to actualize the fitting strategy. Executing an appropriate strategy results in the early elucidation of the project scope and lessens the requirement for rework of a project. For instance, when designers need adequate abilities or skills in new technology, the execution of a suitable methodology might be helpful for the aversion of design blunders.

The paper is sorted out is portrayed. Initial, a Literature review is introduced and the examination approach for this investigation is then depicted with definite case studies and information gathered from 44 construction projects. At that point, the procedures utilized and the outcomes from the descriptive data analysis are exhibited. The method for the way huge IMRCs were resolved is tended to. Next, the research discoveries are examined to delineate the manner in which the execution of BPs deals with the expense of rework related to IMRCs. Last, the confirmation of the results of this examination is depicted.

1.1 Problem Statement

Throughout the recent twenty years, numerous researchers have attempted to identify the critical causes of rework. Despite the investigation of a few rework indicators, still, there is no definitive list of project, organization, or human based rework indicators in the literature.

Moreover, although extensive research has been conducted to identify the manageable causes of rework indicators, few studies have focused on project-based, organization-based or people-based rework indicators. Herein, finding the key causes of rework and change orders in a construction project has been the center of attention in the literature and as a result, the significance of using best practices to reduce rework costs have been neglected by the industry.

According to literature, the issue of design errors or changes was mostly examined indicator of rework or change orders in building, infrastructure, and heavy industrial projects.

1.2 Scope of work

This research is based on finding indicators of manageable rework causes using literature review and categorizing them based on project, organization and human based manageable rework indicators. Significance of each indicator is calculated using statistical analysis and significant successful best practices are implied on significant IMRCs.

1.3 Goals and Objectives

The primary goal of this research is to find indicators of rework and change orders and to use best practices in order to mitigate factors leading to rework. Thus, the objective of this study is to conduct a comprehensive review of related papers written on rework, to provide a list of human, project, and organization rework indicators. For this purpose, this study first critically examined the research efforts pertaining to rework indicators that belong to the project, organization, and human categories. Then, the effectiveness assessment methods that were used in the reviewed journal articles to collect the rework indicators were studied. Next, the most frequently mentioned human, organization, and project-based rework indicators were investigated and listed. In summary, the ability to predict potential causes of rework early in the design and construction phases offers significant benefits to industry practitioners and project managers.

1.4 Research Hypothesis

To identify the early rework or change order indicators that truly affect the project cost, the cost of the issued rework was normalized on the bases of project size. Details about statistical tests, methods and the weight of best practices were discussed in the data analysis section. The main research hypothesis was proposed to statistically determine significant indicators of rework. The hypothesis is as follows:

Null Hypothesis (H0) – The identified indicators of manageable rework causes are not significant in the construction phases of a project.

Alternative Hypothesis (H1) – The identified indicators of manageable rework causes are significant in the construction phases of a project.

The second research hypothesis of this research is to examine if identified best practices truly reduce the cost of rework associated with indicators of manageable reworks. Like the first hypothesis, if any of the best practices were not statistically significant for reducing the cost of rework associated with rework indicators, it was excluded from the list. The following research hypothesis was proposed:

Null Hypothesis (H0) – The identified best practices are not significant in reducing the cost of rework associated with their indicators.

Alternative Hypothesis (H1) – The identified best practices are significant in reducing the cost of rework associated with their indicators.

1.5 Expected Outcome

List of significant indicators of manageable rework causes is obtained and prioritized based on project, people and organization. Successful strategies are suggested for different IMRCs and their significance and effectiveness will be evaluated.

1.6 Contribution

The findings of this study not only can help construction practitioners to identify the most significant rework or change order indicators and the appropriate best practices available to reduce cost, but also will enable them to make proper decisions in difficulties faced due to rework or change orders in a construction project. Furthermore, these findings help construction experts to allocate their resources and consideration into relevant activities and other affecting factors saving a large amount of time and money. The findings of this study also provide guidance for academic scholars to conduct further research and give insight on rework and change order indicators in other construction projects including airports, ports and entertainment projects and find best practices for these mitigating factors.

1.7 Thesis Layout

In summary, chapter one of this thesis gives a general introduction about the importance of the research topic and the problem statement, objectives, research hypothesis and contributions of this research for future work. Chapter two provides an extensive literature review about the past efforts for identification of rework and change order indicators and their best practices in a different sector of industries. Chapter 3 explains the research methodology. A vast range of data and information were collected through literature reviews and case studies of different projects and classified based on different factors like based on industry type in chapter 4. In chapter 5, different data analyses are utilized to determine the significance of different indicators and best practices to reduce cost. Finally, in chapter 7 conclusion is drawn and recommendations are given for future studies. It should be noted that the complete list of the rework and change order indicators and abbreviations used in this study are presented in the appendix B section of the research.

Chapter 2 Literature Review

Cost and schedule overrun are the most common issues that emerge in construction projects (Kermanshachi, 2016). Rework in construction comes out to be the most common factor for such overruns. Josephson et al. (2002) states rework as work that must be done again as a result of not achieving the desired result during the execution of the construction project. Whereas Atkinson and Rogge (2001) simply states rework as work that has been done more than once. The effects of rework have been observed on different aspects of construction, like an average of about 30% loss in efficiency on labor productivity due to disruptions caused by rework in a construction project has been observed (Thomas and Napolitan, 1995).

Several studies and researches have been done to study the effect of rework on different aspects of construction like labor productivity (Thomas and Napolitan, 1995), cost and schedule overrun (Hwang et al., 2009) due to many reasons or causes like design changes or vendor change (Hwang et al., 2009), material supply (Hwang and Ho 2012; London and Singh 2013, Kermanshachi et al. 2017), client-directed changes, project communication, and site-management and subcontractors (Love et al. 2009). Quality management has also been observed as the main cause for rework as the desired level of quality was not achieved during the initial first-time execution of the project leading to rework (Love et al. 2009). Thus, identifying the root causes of rework has been of utmost importance for researchers to optimize construction performance.

Palaneeswaran (2006) stated that rework directly impacts projects cost, additional time to redo the work, additional material for rework and wastage handling, and additional labor and extension in supervision manpower which can be minimized or omitted by quality management, value engineering, and value management. Therefore, identifying the possible indicators of rework causes and best practices used to minimize their effects have been of utmost importance (Fayek and Dissanayake, 2003; Safapour, 2018).

For effective management of rework, it is necessary to investigate its root cause (Hwang et al. 2009). Throughout the world, many different studies have been conducted to investigate the root causes of rework and their unfavorable effects on construction projects (Hwang et al. 2009; Love et al. 2010, 2016b; Ye et al. 2015; Forcada et al. 2017a). As stated in previous studies, rework causes can be classified as constructability (Feng 2009), the project management team (PMT) (Arashpour et al. 2012). Also, as per Tuholski (2008), it can be classified as project scope, material supply (Hwang and Ho 2012; London and Singh 2013), and skill (Arashpour and Arashpour 2011). Love et al. (2012) and Forcada et al. (2014) come to an end that potential dormant issues are inherent in project systems, such as organizational issues (e.g., lack of communication, lack of quality management), project issues (e.g., definition of scope, poor design integration), and individual issues (e.g., work experience of staff, skill level); these authors also found that these issues could set the stage for designers to make mistakes. Love et al. (2012) classified and established orthodoxy as people, organization, and project systems. This terminology featured the procedure that empowers the mapping of conditions that influence mistake counteractive action. This mapping helps avoidance of design mistakes.

2.1 Rework in Construction Projects

The strategies for rework evaluation and their management are generally tedious and lead to cost overwhelms when they are neither efficient nor directed at the proper time (Kermanshachi et al. 2018 and 2019). As the multifaceted nature in present-day construction projects has expanded, stricter improve appraisal or reworks and the management practices are required to limit schedule delays and cost overwhelms (Love et al. 2015, 2016a, b, Kermanshachi 2016). Zaneldin (2000) clarified that through the beginning time of a design stage, change orders (rework) may be issued with least cost overwhelms. The absence of commonality with approaches to oversee change orders (rework) suitably frequently prompts genuine schedule delays and cost overwhelms (Alnuaimi et al. 2010). Subsequently, change orders (adjust) are simpler to oversee amid the early stages, in light of the fact that, to say it basically, they make shirking of alterations conceivable (Arain and Pheng 2007; Love et al. 2015; Du et al. 2016). Palaneeswaran et al. (2014) recommended that an efficient plan review for construction projects would be best for decreasing the quantity of reworks. Zhang et al. (2012) produced a model to decrease rework by concentrating on dealing with a consistent improvement circle through four principal stages: (1) following reworks and categorizing cause, (2) assessing rework including the reason for it, (3) getting ready for remedial activity, and (4) coordinating changes into the complete administration framework. The frequent occurrence of rework has been known as a major challenge in complex projects which if not addressed properly, might lead to significant cost overrun and schedule delays. Several researchers attempted to identify and quantify the complexity dimensions which lead to cost increases and time extensions (Dao et al. 2016a, 2016b, and 2017, Kermanshachi and Safapour 2019). In this regard, some researchers proposed strategies/management tools to increase the efficiency of construction work zones and prevent potential reworks in the execution of the complex projects (Kermanshachi et al. 2016a, 2016b, 2018).

2.2 Rework Impact on Project Performance

In order to know study, the impact of rework on project performance different studies have been done in the past by many researchers. In a study done on seven different Sweden construction projects, the researcher contacted with project managers, clients, and owner and found out that about 4.4% of the total project cost was spent on rework and about an additional 7.1% of total work time was needed to cover that (Josephson, Larsson, & Li, 2002). In another study, surveys from 32 companies in Singapore were collected and face to face interviews with 6 industry experts was conducted to get an in-depth understanding of survey results. It was found out that rework has been the primary factor leading to schedule performance which is having a high occurrence in the construction industry. About 58% of projects experienced rework which led to 25% of increase in time on an average which was mainly focused more on new construction, commercial and large-scale projects (Hwang & Yang, 2014). Thomas & Napolitan (1995) and Kermanshachi et al. (2018) studied the impact of rework on labor productivity. It was observed that about a 30% loss in labor efficiency is observed when rework occurs.

2.3 Change Orders in Construction

A few examinations have been directed to research the main drivers of change orders and their negative outcomes on construction projects. Numerous researchers (Moselhi et al., 2005; and Keane et al., 2010) classify the main drivers of change orders by the source: those that are suggested by the owner, consultant related, and contractor related. Owners normally adjust the extent of activities, and consultants and contractors, for the most part, utilize rework to address or alter the design changes of the construction project. Few researchers have expressed that owner induced enhancements or changes in designs and scope are the fundamental wellsprings of change orders, and design related errors and alterations are the auxiliary sources (Al-Dubaisi et al., 2000, and Al-Hams, 2010).

Change arranges because of design mistakes and alterations are normal and practically inescapable in a wide range of construction projects (Li and Taylor 2014). They influence the expense of an undertaking, make schedule delays, and a decline in the efficiency or productivity of manpower (Love 2002; Arashpour et al. 2014; Li and Taylor 2014). Accordingly, rework assumes a vital job in the achievement or disappointment of a project. Due to the uniqueness of the financial plan and schedule estimation of every construction project, also the accessibility of assets for planning, for example, time, cash, and workforce change orders and reworks differ fundamentally from projects to projects. Taylor and Ford (2006) characterized reworks as work found to require change (either through mistakes, oversights, or guideline changes). As indicated by the investigation of Love and Forcada and their associates, the absolute expense of rework in civil infrastructure projects was 10.29% (Love et al. 2010) and 16.5% (Forcada et al. 2017b) of the agreement or contract cost. Henceforth, recognizable proof of the underlying drivers of rework and the administration of them to decrease the horrible effect of them on the execution of construction project is critical (Love and Smith 2003; Zhang et al. 2012; Palaneeswaran et al. 2014; Dehghan and Ruwnapura 2014).

2.4 Rework due to Design error or changes

Design changes or errors in designs have been classified as one of the most important factors affecting rework or change orders in construction projects. Change orders due to design-related changes have been one of the most important causes of rework (Chandrusha & Basha, 2017). Hence studying their effect has been important for many researchers. In a research done on a case study of different highway and masonry project, it was observed that due to design changes and design errors in the construction drawings there was rework accounted leading to elevated project cost and delay in the schedule (Forcada et al. 2014). Lack of coordination among the design teams leads to major design deficiencies and aggravate the causes of rework (Chandrusha & Basha, 2017; Lopez, Robert, et al, 2010). Supporting this many researchers stated that lack of communication leads to rework (Alnuaimi et al., 2009; Ruqaishi & Bashir, 2013; Ye et al., 2015; Chandrusha & Basha, 2017; Kamalirad et al. 2017; Safapour et al. 2019). In order to overcome design-related errors, it is recommended to have a clear picture of design and requirements during the design phase, this will lead to less rework and changes leading them (Sommerville 2007). It is also suggestible to apply design freeze as soon as possible in order to stop rework due to design changes (Sommerville 2007).

In a research done by Wilson & Odesola (2017) studying various oil and gas projects when asked by different team members about causes of design related rework following top five causes were highlighted (i) errors and omissions in design documents, (ii) ineffective communication between project team members, (iii) design changes, (iv) lack of site verification by project team, and (v) lack of as-built documentation. Thus, the study recommended implementing design management surveillance and constructability reviews during the design phase to the professionals and experts in the oil and gas industry to effectively reduce design related causes and enhance performance in oil and gas sector.

Lack in the use of technology has been termed as one of the reasons for rework causes in a construction project (Love & Smith, 2003; Zaiter, 2014; Love et al., 2016). Effectively using Building Information Modeling for reducing design-related errors in construction is a good alternative (Love et al., 2011). Although implementing it has been a matter of difficulty due to its lack of usability and manageability. Using BIM helps in the conceptual understanding of the designs and the interconnected processes involved in construction which enables individuals on site ease of execution (Love et al., 2011). It is beneficial to have BIM or other technological advancements as an alternative way of reducing design-based errors. Hwang, Zhao & Yang (2018) identified these top three strategies to use BIM for reducing rework (i) Using BIM throughout design and construction phase, (ii) performing design reviews, verifications, and audits to reduce system errors, and (iii) rework tracking system to prevent future occurrences of rework.

2.5 Other factors causing rework

One of the most common concerns in the construction industry is change order or rework. Among others, the involvement of clients in projects has been one of the major factors in rework that has the interest of many researchers (Lopez et al., 2010; Taylor et al., 2012; Staiti et al., 2016). In a study done by Hwang, Zhao, and Goh (2014), data from about 381 projects by 51 companies in Singapore based building projects were analyzed and results were 80.4 % of companies with their 59.3% projects experiencing client related rework leading to an increase of 7.1% project cost and an average of 3.3 weeks project delay. Among the various factors in client-related rework replacement of material by the client and change of plans or scope by the client was termed as the most contributing factor impacting projects schedule, cost, and quality performance (Kermanshachi et al. 2017, 2019a and 2019, Safapour et al. 2018).

Love, Irani & Edwards (2004) stated following other factors affecting rework like (i) staff turnover and reallocation to other projects, (ii) failure to protect completed work, (iii) errors occurred during setting out, (iv) inadequate supervision by subcontractors, (v) damage caused due to carelessness of subcontractors, (vi) low skill level of workmen involved and (vii) poor use of materials by subcontractors. Wrong initial budget because of poor documentation and technical specifications without proper on-site inspections and validations lead to budget and scope modification finally leading to change orders and rework (Forcada et al., 2016). Also, other factors like rework occurrence due to bad weather conditions, poor economic solvency of subcontractors leading to halt in work and rework later, lack of workers experience, and lesser expertise or skills lead to rework (Forcada et al., 2016). Nepal, Park & Son (2006) studied the effects of schedule pressure on construction performance and found out that working out of order or sequence, generating work defects due to rushing, and losing the motivation to work are few negative effects arose due to scheduling pressure leading to rework in the end.

In a research done by Josephson, Larsson, & Li, (2002) six factors affected rework cost which was: (i) client, (ii) production management, (iii) machines, (iv) materials, (v) workmanship and (vi) design. Whereas the client changes and extra orders from the client were the primary factors in the client segment. Production management included factors like mistakes in planning, faulty work preparation, and faults in material administration. Machines breakdown and manufacturing defects in machines were termed as most occurring factors for rework due to machine errors. Late deliveries and faulty manufacturing of materials were the top reason followed by material too hard to use. Erroneous workmanship, faulty material, and machine handling lead to rework due to workman factor. Lack of coordination, unsuitable designs or incomplete designs were few other reasons mentioned for rework.

2.6 Best Practices

A few techniques have been acquainted by the CII with professionals and researchers to improve construction execution and decrease the quantity of change orders. In such manner, numerous huge examinations have been led to research the effect of actualizing single or various BPs planned to improve the administration of construction projects (CII 2012; Akpan et al. 2014; Du et al. 2016; Safapour et al. 2017). In spite of the fact that usage of all BPs could be valuable for upgrading construction performance, it isn't attainable (Safapour et al. 2017). A hole of data relates to the determination of suitable procedures as per the IMRCs in construction projects. In this manner, an intensive examination and investigation of how to utilize construction BPs in construction projects are required.

Best practices (BPs) can improve the execution of construction projects and aid successfully overseeing expansive scale projects, as clarified by the Construction Industry Institute (CII): A BP is a procedure or strategy that prompts upgraded project performance when executed viably. CII (2012) characterized and presented the accompanying 14 BPs: front-end planning, alignment, constructability, materials management, planning for start-up, team building, partnering, quality management, lessons learned, benchmarking and metrics, change management, dispute prevention, and resolution, project risk assessment, and zero accidents and techniques. Since it is a procedure usually actualized when a project is nearly finished (CII 2012), making arrangements for a start-up does not altogether add to the administration or decrease of the remaining task at hand required for rework; along these lines, the making arrangements or planning for a start-up BP was excluded in this investigation. Moreover, in light of the fact that the motivation behind actualizing it is to gauge the utilization of CII BPs as indicated by the measured project performance (CII 2012), the benchmarking and metrics methodology does not help with the administration and decrease of the remaining task at hand for rework as indicated by the indicators of manageable rework causes (IMRCs) in a project and was, in this way, likewise avoided from this examination. Change management was moreover prohibited on the grounds that the usage of it straightforwardly influences all parts of change orders and reworks. In a rundown, all BPs that could conceivably diminish the expense of rework, in connection to the project cost, were researched to decide the effect of each on the decrease of the expense of manageable design changes for construction projects.

Subsequently, the focal point of this examination was to decide IMRCs and to characterize the advantages of receiving BPs for diminishing the expense of rework, as it identifies with the all-out project cost, which is the aftereffect of difficulties related with IMRCs. For this reason, suitable construction related BPs, as talked about in this, for mitigating IMRCs were chosen. The meaning of these BPs is introduced in Table 2-1.

Table 2-1. List of construction BPs with definition and sources.

BP	Explanation	Previous studies
Partnering	Companies may team up to accomplish specific business objectives by maximizing the effectiveness of each participant's resources	Du et al. (2016); Wang et al. (2016)
Alignment	The condition for which appropriate project members are working within acceptable resistance to create and meet a consistently defined and understood set of project priorities	Griffith (2001)
Front-end planning	The process through which owners create sufficient strategic information to address risk and commit resources for the sake of maximizing project success	George et al. (2008); Hwang and Ho (2012)
Constructability	The most advantageous use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives	Kifokeris and Xenidis (2017); Mattos Nascimento et al. (2017)
Team building	A project-focused procedure that builds and develops common goals, interdependence, trust, and commitment, and accountability between team members	Spatz (2000); Mohammadi et al. (2016)
Risk assessment	The process used to identify, assess, and manage risk; the project team evaluates risk exposure for potential project impact to provide a focus for relief methodologies	Jannadi (2003); Zavadskas et al. (2010)
Material management	An integrated process for planning and controlling every single important effort to ensure that the quality and quantity of materials and equipment are appropriately specified in a timely manner is obtained at a reasonable expense and are available when needed	Thomas et al. (2005); Donyavi and Flanagan (2009)
Dispute prevention	Utilization of a dispute review board as an option to litigation; the dispute review board technique provides a procedure for addressing disputes in the early stages before the dispute influences the progress of the work, creates adversarial positions, or leads to litigation	Barry and Leite (2015)
Quality management	Consolidation of all activities conducted to improve the efficiency, contract compliance, and cost-adequacy of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects	Chandra (1993); Sullivan (2011)
Lesson learned	Knowledge gained from experience, successful or otherwise, for the motive of improving performance in future	Carrillo et al. (2013); Shokri and Chileshe (2014)

Note: QA = quality assurance; and QC = quality control.

2.7 Summary

This chapter features a comprehensive literature review about construction rework and the factors deviating projects from the proposed time and cost. More than One hundred previous researches were studied from 2000 to 2018 and the findings of each study, along with their utilized methodologies were completely discussed. Also, BP that can be utilized for further enhancement of the construction process, minimize cost overruns and decrease schedule delays were discussed and explained.

Chapter 3 Research Methodology

To accomplish the thought process of this investigation, a seven-step advance research approach was prepared and executed as displayed in Fig. 3.1. This examination was begun by looking into existing literature to explore potential IMRCs that could be taken care of through the utilization of construction BPs. The early indicators which were discovered were then classified as per past examinations. In the third step, information from 44 case studies of construction projects was acquired. So as to audit, the project more data was required which was gotten through questionnaires. The questionnaire was set up to acquire other data like the cost of rework, level of usage of BP procedures and so forth from the required projects. Next stage was performing descriptive data analysis. In Step 5, quantitative analysis was directed to decide the IMRCs with a significant sway on rework. Diverse statistical tests were utilized relying upon shifting information gathered from the survey. Table 3.1 presents a summation of the fundamental formal statistical analysis that was used for the quantitative examination for this investigation. At that point, BP that lessen the effect of these IMRC were discovered and their weight for the best application was assessed utilizing Cohen's d technique.

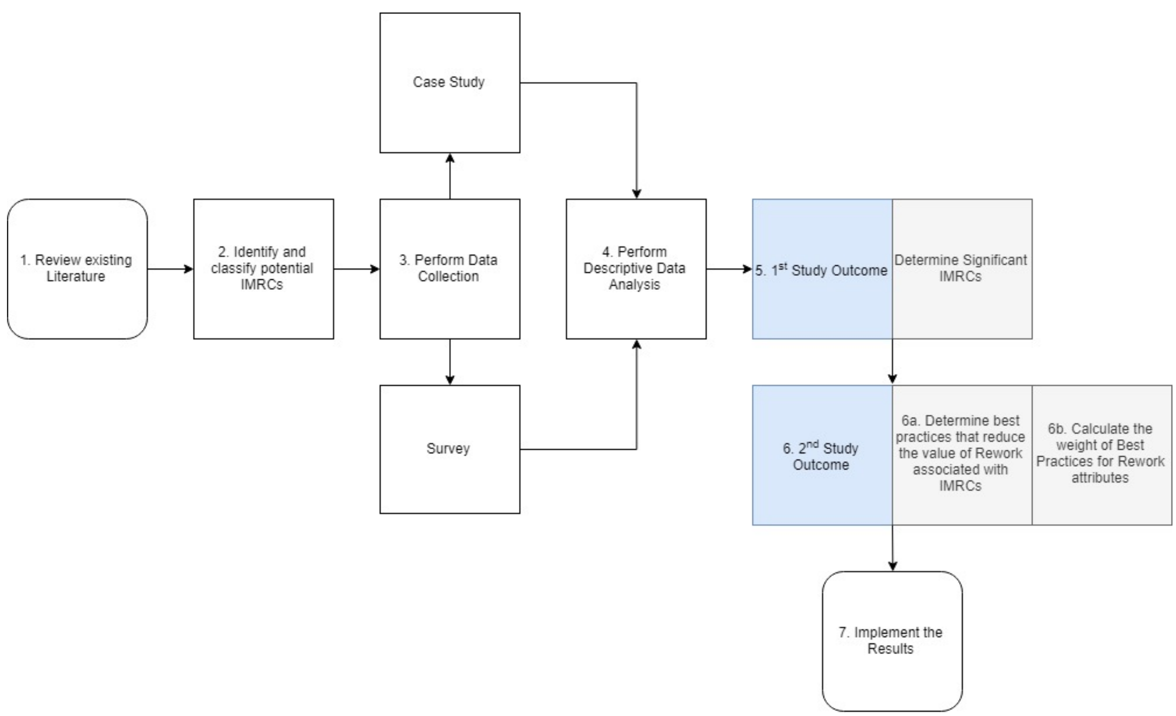

Figure 3-1. Research methodology approach.

IMRC*= indicators of manageable rework causes.

Table 3-1. Statistical analysis method

Statistical test	**Assumptions**
The two-sample *t*-test (adjusted R^2): This test was used where a count or numerical value is the response	A normal distribution is followed by two groups. Each project is different from the other project and not dependent on them.
Kruskal-Wallis: This test was used for Likert scale items (ordinal 7-point scale) that cannot be assumed for a normal distribution of data.	Two groups follow a distribution that is identically scaled. Not every project dependent on other projects. There was the same distribution of the two groups.

Cohen's *d* parameter (Cohen 1988) was used to examine the extent of significance for each indicator of manageable rework. Cohen's *d* yields information about the difference between the means of two sample groups that are divided by standard deviations.

For a two-sample t-test, the raw data for the two sample groups were used to formulate the following equation:

$$\text{Cohen's } d = \frac{M_2 - M_1}{\text{SD}_{\text{pooled}}} \qquad (1)$$

Where M_1 and M_2 = mean difference between two sample groups (dollar cost of rework associated with significant indicators of manageable rework by a two-sample *t*-test); and $\text{SD}_{\text{pooled}}$ = pooled standard deviation, which is calculated by

$$\text{SD}_{\text{pooled}} = \sqrt{\frac{(n_1 - 1)\text{SD}_1^2 + (n_2 - 1)\text{SD}_2^2}{n_1 + n_2 - 2}} \qquad (2)$$

Where SD_1 and SD_2 = the first and second groups standard deviation, respectively. Furthermore, respectively, n_1 and n_2 = size of the first and second sample.

Step 6 of this study was split into two sub-steps: Steps 6a and 6b. In Step 6a, identified the significant BPs to reduce the cost of design changes and/or modifications. In Step 6b, recorded the total weight of each BP associated with IMRCs attributes. In the final step, two case study projects were evaluated by implementing BPs to measure a cost reduction of rework as it relates to the total cost of the project.

Step 2: Identify and Classify Potential Manageable Rework Indicators

With the help of literature review about 51 manageable causes of rework have been identified from previous studies; 35 of these causes, have been found to be manageable by implementing BPs according to the CII study (2012). The IMRCs were then classified into three main categories (organization, project, and people). These nomenclatures were selected based on the nature of the BPs used to manage the issues related to the organization, project, and team members, which were thoroughly described in the CII (2012) research and were informed by the Love et al. (2012) and Forcada et al. (2014) studies.

Next, inspired by previous studies (Hsieh et al. 2004; Love et al. 2008; Sun and Meng 2009; Love et al. 2012; Ye et al. 2015), the three categories of IMRC were classified into 13 attributes, as shown in Fig.3.2. These classifications and attributes have resulted in significant progress in IMRCs understanding. This classification may, therefore, help to prevent design errors.

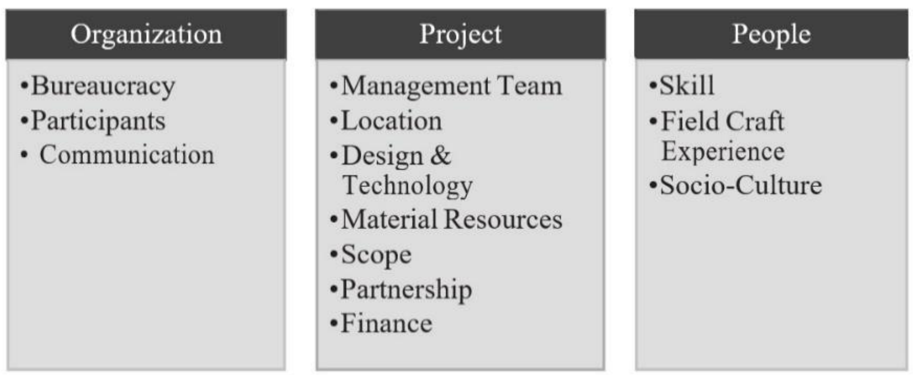

Figure 3-2. Classification of IMRCs

As depicted in Fig.3.2, the IMRCs were classified into attributes of bureaucracy, participant, and communication is the organization category. In addition, project category IMRCs have been classified into attributes of the management team, location, design and technology, material resources, scope, partnership, and finance. Skill, field craft experience, and socio-culture attributes classified the indicators in the category of people. The purpose of selecting an appropriate terminology for the attributes, as stated in the "Literature review", was to make the IMRCs more understandable in order to facilitate a greater reduction in the cost of rework as it relates to the total project cost. For example, the term design and technology was chosen since design and technology management is a critical factor influencing rework in construction projects (Hwang et al. 2009). The other attribute is socioculture, comparing to cross-cultural differences and related conflicts between team members or colleagues. For instance, IRMC-32, the percentage of craft labor sourced locally, was related to the socioculture attribute because construction project team members or colleagues may confront difficulties on account of various cultural perspectives.

Step 3: Collect Data

Once potential IMRCs are identified and classified, data from 44 construction case study projects were gathered. Then a structured questionnaire was developed by the research team in order to collect comprehensive data associated with the same projects.

Three groups were created in order to categorize survey items: (1) general project description, (2) potential indicators of manageable rework, and (3) level of BP implementation. Fig.3.3 gives two instances of the items incorporated into the study to show that responses were procured in two forms: as ceaseless numerical with general data and project characteristics. The second area comprised of 35 items that were identified with the potential manageable causes of rework. In the third segment, 10 items tended to the implementation level of the most relevant rework BPs.

To maintain a strategic distance from respondent disarray and gather predictable information, the definition of a BP was incorporated toward the start of the survey. A pilot test was directed to four experienced professionals from the industry to inspect the clearness of everything. After it was approved, the questionnaire was finalized and conveyed among experienced industry experts. The survey procedure was totally set up and overseen through an online framework. In the wake of sending two follow-up messages, information from 44 finished reviews, used to secure data identified with the case studies, were gathered.

Question 23. Were there joint-venture partners in this project? If yes, how many?

Question 39. Please indicate the impact of external agencies on the project execution plan.

No Impact on Meeting the Execution Plan			Moderate		Substantial Impact on Meeting the Execution Plan	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

Figure 3-3. Two example items from the survey.

The survey respondents demographic information is presented in Table 3-2, showing that 69% of respondents identified their role as a PM. The motivation behind choosing the highest level respondents was to collect dependable and valid data about the construction projects.

Table 3-2. Respondent’s demographic information.

Category	Number of respondents	Weightage in Percentage (%)
Year of experience		
0-10	4	9
11-20	12	27
21-30	14	32
31-40	12	27
41 or more	2	5
Current role in the company		
Program director	10	22
Project manager	30	69
Engineer	4	9

3.1 Summary

This chapter briefly describes a methodology that the author adopted throughout the study. First reviewing the existing literature and identifying and classifying potential IMRCs through it. The data collection was performed with the help of two methods (i) Case study of real field cases in the industry and (ii) Survey from experts involved in the field looking after project on a different managerial level. Descriptive data analysis was performed on collected data to determine significant IMRCs and to determine the best practices that would help in reducing the rework associated with IMRCs. In order to know the effectiveness of each best practices for rework their weight was calculated in order to help with deciding which Best Practice to be used is much more effective than others. After performing all the required process then the light is thrown on the process of implement the results from the study in order to help others in the future to deal with issues referring to rework in the construction industry.

Journal Name: Project, organization and human rework indicators found in construction have been published mainly in ten different journals around the world, as presented in Table 4-1. This table specifies the distribution of the journal articles by the name of the journal. As indicated in Table 4-1, the largest number (15) and percentage (23%) of the reviewed articles were published by the Journal of Construction Engineering and Management. The Journal of Management in Engineering published the second highest number of articles related to rework indicators (7), which amounted to 11% of all of the articles published on the subject. A fair amount of articles (4 each) have been published by both IEEE Transactions on Engineering Management and International Journal of Sustainable Construction Engineering and Technology contributing about 6% each of total weightage. There were few Journals with a frequency of about 1 article which have been considered in Other Journal in Table 4-1 contributing a total of 31% weightage.

Table 4-1. Frequency and Percentage of Reviewed Articles for Rework Indicators

Journal Title	Frequency	Percentage
Journal of Construction Engineering and Management	15	23
Journal of Management in Engineering	7	11
IEEE Transactions on Engineering Management	4	6
International Journal of Project Management	4	6
International Journal of Sustainable Construction Engineering and Technology	4	6
Construction Management and Economics	3	5
Journal of Engineering Design and Technology	2	3
Journal of Infrastructure Systems	2	3
Civil Engineering and Environmental Systems	2	3
Journal of Performance of Constructed Facilities	2	3
Other Journals*	20	31

*Other Journals are those which published one article like International Journal of Engineering Research and Technology.

Industry Type: Table 4-2 indicates the distribution of research done based on the different sector of the industry. As it can be clearly observed that most of the researches have been done on Building Construction

Projects with a majority of about 18% in total. Second, the most highly studied sector in the industry is Infrastructure projects containing about 12% weight of the total, followed by Road Construction with 11%. Commercial offices, retail projects, Educational School and Universities were popular among researchers and composed a total of 8% each. Whereas moderate study in the range of 3-7% has been done in the field of Industrial projects, Residential Projects, and projects related to Tunnel and Bridge construction. Very few researchers in total about 22% showed interest in the combined sector of hospitals, airports, entertainment industry, etc.

Table 4-2. Frequency and Percentage of Reviewed Articles for Rework Indicators

Sector of Industry	Frequency of Occurrences	Percentage
Building Construction projects	22	18
Infrastructure project like water lines, pumping stations, treatment plants, etc.	14	12
Road Construction	13	11
Commercial offices, retail and recreational Projects	10	8
Educational School & University	10	8
Industrial projects	9	7
Residential Projects	7	6
Tunnels & Bridges	5	4
Oil & Gas and Port projects	4	3
Other projects including Hospitals, airports, entertainment, etc.	27	22

Year of Study: As indicated in Figure 4-1, the journal articles published after 2000 were grouped and analyzed. This figure also shows that after 2011, there was a sudden increase in the number of journal articles written about construction rework indicators belonging to project, organization, and human categories. With 33 journal articles published between 2012 and 2017, this time period was recorded as the highest frequency of rework-indicators-related studies among all two-year targeted intervals. The last group consisted of articles published in 2018, as the year 2019 has just begun.

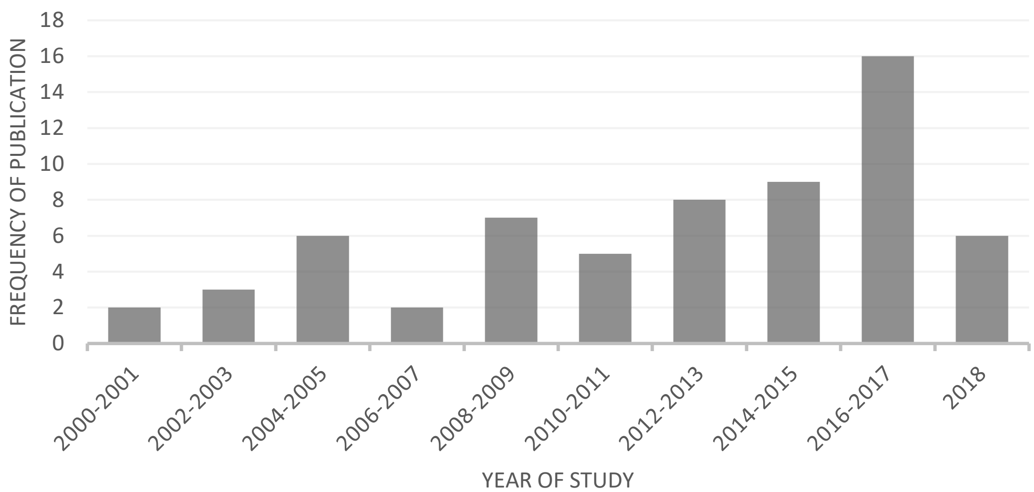

Figure 4-1 Distribution of Journal Articles According to Year of Study

Country of Origin: Figure 4-2 illustrates the distribution of papers, based on percentage, according to their country of origin. Researchers from all over the world have identified and studied the rework indicators belonging to the three stated main categories. As shown in Figure 3, rework issues have been a challenging phenomenon in developing countries on the continents of Asia and Africa. This map shows that Asia (22%) and the Middle East (17%) were recorded as publishing more papers than any other continent.

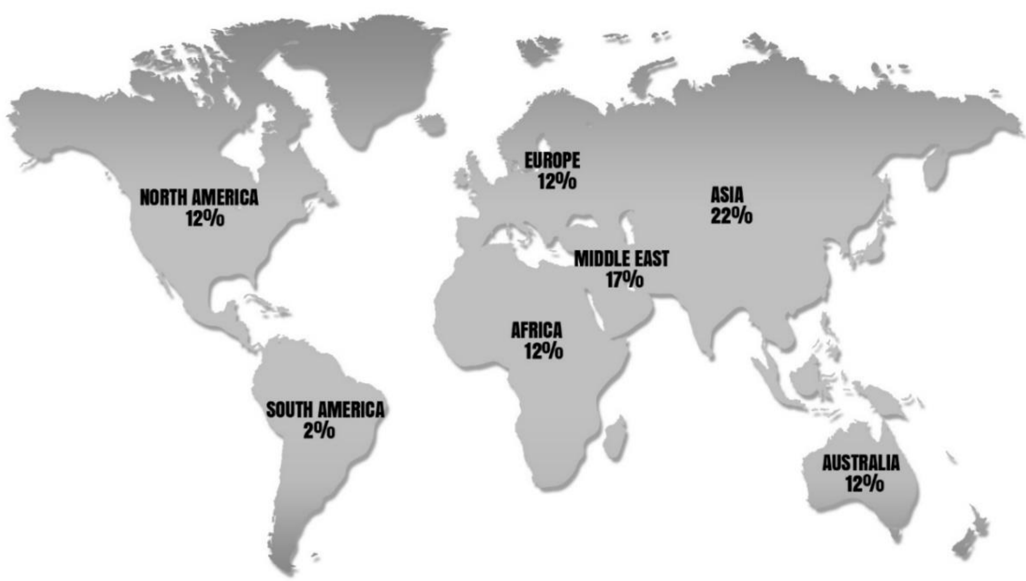

Figure 4-2. Distribution of Papers According to Their Country of Origin

Identification of Performance Causes: Figure 4-3 illustrates identification of Performance causes based on the method used for Data Collection. A most common technique used for Data collection was using Survey or Questionnaires. About 46% of studies indicated the use of Survey or Questionnaires as a method for data collection. Alternatively, about 34% of researchers relied on Case Study methodology to complete their study. Whereas, the use of Literature reviews was also observed in 11% of studies followed by 9% of researchers using Interviews and documentary sources or Data from Site as an alternative to complete their study.

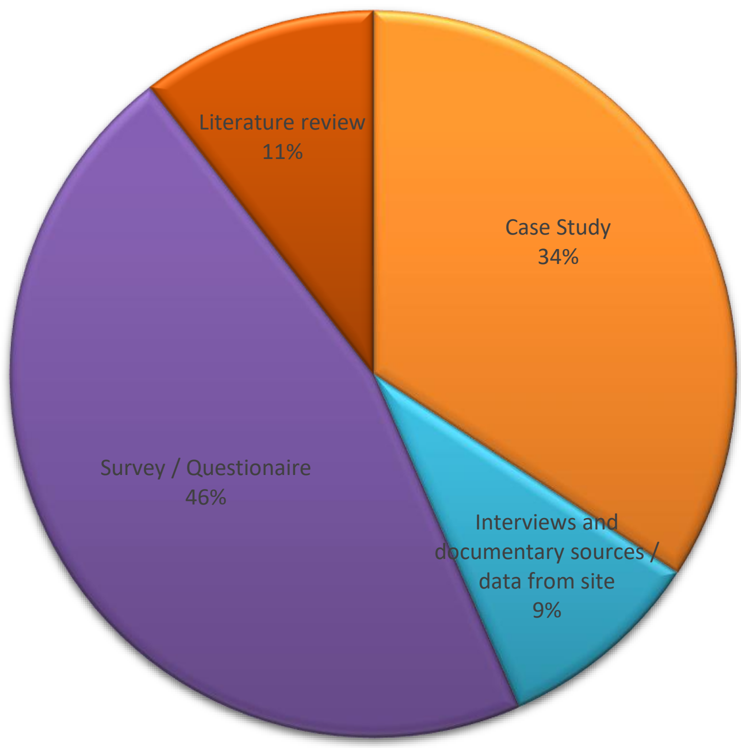

Figure 4-3. Identification of Performance Causes

Data Analysis Techniques: Table 4-3 illustrates the division of papers based on the use of different kind of Data Analysis techniques. It is observed that the most common technique used in researches or study was Descriptive Statistics comprising about 16% weightage. Whereas, System Dynamics and Relative Importance Index (RII) have been utilized equally by about 11% in different studies. About 10% of studies were analyzed using Kruskal-Wallis H Test. Many researchers used moderately several methods of analysis like T-test, Important Index, Factor Analysis, Frequency Index (F.I) and Severity Index (S.I) and more. Whereas about 23% of other methods like Mann Whitney test or Grey Relation Analysis which had been used only once for analysis in studies by different researchers.

Table 4-3. Distribution of Papers According to the Technique of Data Analysis

Method	Frequency	Percentage
Descriptive statistics. One-way analysis of variance (ANOVA)	12	16
System Dynamics	8	11
Relative Importance Index (RII)	8	11
Kruskal-Wallis H Test	7	10
Regression (single and multiple)	4	5
T-test	4	5
Importance index	3	4
Factor Analysis	3	4
Pearson’s Chi-squared test	3	4
Severity Index (S.I)	2	3
Frequency Index (F.I)	2	3
Other (With frequency 1 like Mann Whitney test, Grey relation analysis, etc.)	17	23

Identification and Categorization of Factors:

Factor Project-Based Rework Indicators: The project-based rework indicators were distinguished and analyzed. Table 4-4 delineates the recurrence and ranking of the highest frequent project-based rework indicators and shows that the eight critical and most frequent project-based rework indicators were recognized through existing literature. These identified indicators were inappropriate/poor design, unclear scope definition, owner induced enhancements, wrong material selection or material issues, supervision-related issues, financial issues, external environmental, site conditions specifications, differing or no site information about the site, unclear work specifications, quality issues, governmental policy changes and lack of clarity.

Table 4-4 shows that “inappropriate/poor design” indicator consisting of several design issues was recorded as the most highly observed rework indicator belonging to the project category. Poor design is defined as a deviation from an intended course of action and path of actions planned in order to achieve a favorable target by Reason and Hobbs (2003). An explanation stated according to Love et al. (2009) states that poor construction design commonly arises and causes considerable schedule delays.

Table 4-4 clearly shows that the indicator “unclear scope definition” occurred with the second highest frequency (28) among those belonging to the project category. As described by Fageha and Aibinu

(2013), the project scope definition is "*the process whereby a project is defined and prepared for execution*." Gunhan and Arditi (2007) believed that the design contingency is absorbed into the baseline budget for a specific cost factor if the scope of a project is thoroughly defined. A clear definition of the scope leads to early clarification of the scope and objectives of the project and reduces the late design changes/modifications due to changes in the scope of the project (Safapour and Kermanshachi 2019). Usually, an unclear definition of the scope causes some design changes/modifications at the beginning of construction, and construction can begin with undefined discrepancies over the workspace.

As presented in Table 4-4, the project-based rework indicator "owner induced enhancements" received the third highest indicator. Ye et al. (2015) discussed causes of rework due to changes suggested by the owner in order to achieve more quality and design changes as per their need. Material issues were the other critical project-based rework indicator, as shown in Table 4-4. Wu et al. (2004) stated that changes in the material(s) used and/or method(s) used to occur when certain material items required by the design are either inadequate or out of stock. Similarly, Sun and Meng (2009) stated that the unavailability of material during the project execution leads to a replacement and could cause the issuance of change orders. Wu et al. (2004) explained possible cause of change orders can be due to varying soil strength and foundation location from expectations. Underground pipes are often not located where they were reported to be creating problems causing rework.

Table 4-4. Frequency and Ranking of Project-Based Rework Indicators

Indicator	Frequency	Ranking
Inappropriate design/ design issues/ poor design integration	42	1
Scope definition / scope changes	28	2
Owner induced enhancement/client involvement or changes	25	3
wrong material selection/ material resource	17	4
Lack of supervision/project governance / poor monitoring and control	15	5
Finance	15	5
Weather Conditions / external environment	13	6
Location / site conditions	11	7
differing/no information about the site	10	8
Unclear work specification	10	8
Type of Contract / contract management	9	9
lack of adherence of quality control	8	10
Design omissions	8	10
Inadequate interface management between contractors and consultants	7	11

Change in government policies	7	11
Poor decision-making process	7	11
Contract documentation	6	12
Lack of Clarity	5	13

Organization-Based Rework Indicators: The other important rework indicators identified and analyzed through an existing review of literature belong to the organization category. Table 4-5 presents the most frequent and important organization-based rework indicators. Seventeen most important and frequently occurring indicators are: lack of communication, inadequate coordination, lack of resource management, ineffective implementation of QA, poor use of technology, poor management, construction error, changes made by contractor, change in method of construction to enhance constructability, lack of design audit, lack of staff supervision, non-functional equipment and tools, lack of documentation control, poor scheduling of construction resources, damage caused by subcontractors, staff turnover or relocation and defect in material or prefabrication.

As displayed in Table 4-5, ineffective communication was recorded (21) as the most frequent rework indicators having a place in the organization category. Malisiovas (2014) portrayed the meaning of communication as "*friendship or collaborations in projects, mutual organizational work, and others*." Likewise, Chinowsky et al. (2010) describe communication as "*a direct relation within the success of a project and the appropriate amount of communication and knowledge-sharing while completing a set of tasks*." Senescu et al. 2013 characterize communication as the collaboration that develops as the members of the project interact. Many studies have been conducted (Cheng et al. 2001, Affare 2012, Forcada et al. 2017, Lee and Kim 2018; Kamalirad and Kermanshachi 2018, Safapour et al. 2019) to reveal that communication is one of the most important success factors due to the number of parties involved and the number of issues that need to be addressed. Ineffective communication prevents the timely sharing of information and knowledge between parties, often leading to errors in the construction phase resulting in rework.

Table 4-5 shows that inappropriate coordination got the second highest recurrence (20) among the organization-based rework indicators. Numerous researchers (Si et al. 2008, Noor 2010, Kermanshachi 2010, Lotfi and Ghaderi 2013, Alaloul et al. 2016) were confident that poor coordination between partners could prompt rework that is essential for project implementation and delivery. Hwang and Yang (2014) clarified that inadequate coordination prompts deviations from the essential necessities; consequently, rework occur to minimize schedule delays. For example, unseemly coordination between design staff in the design phase may prompt inconsistencies, likely to result in mistakes made in the construction phase. Effective coordination between consultant stakeholders or partners during the construction phase limits the number and cost of rework.

Poor management has been identified as one of the literature's critical organization-based rework indicators. Xie et al. (2010) explained that they can effectively manage projects by an experienced project management team. Because while the project management team is commonly responsible for applying knowledge, skills, tools, and techniques to offer the objectives of the project, minimal experience and poor management results in improper staff management and ultimately rework.

Table 4-5. Frequency and Ranking of Organization-Based Rework Indicators

Indicator	Frequency	Ranking
Lack of communication	21	1
Inadequate coordination	20	2
Lack of planning and resources	19	3
Ineffective implementation of QA	14	4
Poor use of Technology	13	5
Poor Management	12	6
Construction Error	12	6
Changes made by the contractor	10	7
Changing the construction method to enhance constructability	7	8
Lack of design audit	6	9
Lack of staff supervision	6	9
Equipment and tools not sufficiently functional	6	9
Deficiencies in documentation control	5	10
Poor scheduling of construction resources	5	10
Damage caused by a subcontractor	5	10
Staff turnover or relocation to another place	5	10
Defect in material or prefabrication	4	11

Human-Based Rework Indicators: The other crucial rework indicators identified and analyzed by the literature belonged to the human-based category. Table 4-6 presents the most common and important human-based rework indicators. Eleven most critical and frequent indicators were: lack of experience and expertise, level of skill, misinterpretation due to lack of knowledge, conflict among team members/workers, lack of safety commitment, lack of motivation and reward, inadequate training, stress, slips, socio-culture/cultural issues and excessive overtime. In this regard, Kermanshachi et al. (2018) concluded that organizing advanced training sessions and workshops for employees will improve the knowledge of cost estimators and reduce the reworks later in the execution of the complex projects.

Table 4-6 demonstrates that if the staff has inadequate experience, the likelihood of rework increments. For example, if the designers have lacking knowledge, skill, and experience about the design of the construction project, the quantity of mistakes will increment, and there is a noteworthy likelihood that the expense of rework due to design changes and modifications will likewise increment. Likewise, Forcada et al. (2014 and 2017) clarified that design and construction errors will be made when the workforce experience the ill effects of an absence of knowledge, skill, and expertise.

As appeared in Table 4-6, the other imperative human-based rework indicator in literature is safety commitment. According to Wanberg et al. (2013), the quantity of rework is legitimately associated with recordable wounds. So also, Love et al. (2018) clarified that when staff does not have a solid pledge to safety, they frequently participate in unsafe conduct by not doing what was planned. Injuries that are because of an absence of safety commitment or wellbeing responsibilities apply weight on other staff to comply with the schedule deadlines, and working under strain often results in rework.

Table 4-6. Frequency and Ranking of Human-Based Rework Indicators.

Indicator	Frequency	Ranking
Lack of experience and expertise	22	1
Skill level	19	2
Misinterpretation due to lack of knowledge	13	3
Conflict among team members/workers	7	4
Lack of motivation and reward	6	5
Lack of safety commitment	6	5
Inadequate training	5	6
Stress	3	7
Slips	3	7
Socio-Culture / Cultural issue	3	7
Excessive Overtime	3	7

4.1. Summary

Chapter 4 descriptively analyzed the information found from an extensive literature review and presented them in different manners. In other words, this chapter compares different project types, countries of origin, data analysis techniques and research methodologies that previous studies utilized in the construction industry. A pattern on the trend of study based on years has been depicted in the study. The author has also classified researches done in previous literature based on the sector of industry like building or infrastructure projects.

Furthermore, a list of rework indicators in each project, organization and human-based classificatory were identified, categorized and presented. Then all factors were ranked based on the frequency of occurrence in the literature. With the help of this study, researchers can get an idea about how to approach and analytical options available for further reference and trend in research.

Step 4: Analyze Descriptive Data

Data are recorded in Table 5-1 for the 44 case study projects. Of the 44 projects, 31 (71%) were viewed as heavy industrial projects, and the rest of 13 (29%) were light industrial, infrastructure, and building projects. Table 5-1 demonstrates that 33 projects (75%) were located in the United States of America (USA), while the others (25%) were in Canada, China, Peru, Senegal, Indonesia, Saudi Arabia, Brazil, and The Netherlands. In the analyzed case studies the maximum project size was $5 billion for a heavy industrial project situated in Saudi Arabia with a baseline schedule of 42-months.

Table 5-1. Information about the case study projects.

Project	Project Type	Project Location	Baseline Budget ($)	Actual cost ($)	Baseline schedule (months)	Actual Schedule (months)
1	Heavy Industrial	USA	21,450,000	18,980,000	30	36
2	Heavy Industrial	USA	45,000,000	42,957,344	30	36
3	Infrastructure	USA	4,882,621	5,276,921.35	24	34
4	Heavy Industrial	USA	5,900,000	6,200,000	8	8
5	Buildings	USA	19,999,000	19,999,000	12	12
6	Heavy Industrial	USA	43,500,000	43,500,000	16	20
7	Heavy Industrial	USA	575,000,000	650,000,000	39	52
8	Heavy Industrial	USA	11,053,269	9,015,969	24	30
9	Heavy Industrial	USA	17,400,000	17,800,000	24	24
10	Heavy Industrial	USA	13,500,000	13,888,000	15	17
11	Buildings	USA	17,003,722	14,039,249	27	34
12	Infrastructure	USA	81,800,000	79,500,000	47	70
13	Light Industrial	USA	77,000,000	83,249,000	16	21
14	Heavy Industrial	USA	166,333,047	192,884,724	24	36
15	Light Industrial	USA	77,000,000	90,000,000	22	23
16	Heavy Industrial	USA	273,550,000	295,037,296	22	24
17	Heavy Industrial	USA	217,250,000	214,600,000	30	36
18	Heavy Industrial	USA	111,818,500	105,041,153	24	22
19	Heavy Industrial	USA	11,000,000	13,600,000	30	36
20	Heavy Industrial	USA	448,864,480	666,347,825	26	35
21	Heavy Industrial	USA	376,433,800	319,660,518	26	35
22	Buildings	USA	273,550,000	295,037,296	22	24
23	Heavy Industrial	USA	7,000,000	5,910,365	30	31
24	Buildings	USA	425,000	418,293	24	26
25	Infrastructure	USA	1,600,000	1,259,000	24	26
26	Heavy Industrial	USA	18,300,000	15,260,000	19.4	19.1
27	Heavy Industrial	USA	9,250,000	7,706,000	16.5	18
28	Heavy Industrial	USA	125,000,000	138,000,000	24	30
29	Light industrial	USA	11,000,000	10,700,000	17.5	16.6
30	Heavy Industrial	USA	25,700,000	42,700,000	22	24
31	Buildings	USA	639,326	698,056	10	12
32	Heavy Industrial	USA	39,754,613	29,364,523	54	55

33	Heavy industrial	USA	560,000	560,000	10	11
34	Buildings	Senegal	203,638,000	190,083,306	36	31
35	Buildings	Indonesia	273,550,000	295,037,296	22	24
36	Heavy industrial	Saudi Arabia	5,000,000,000	5,600,000,000	42	44
37	Heavy industrial	Brazil	450,000,000	490,000,000	42	45
38	Heavy industrial	Netherlands	30,000,000	30,500,000	21	23
39	Heavy industrial	Canada	550,000,000	575,000,000	22	25
40	Heavy industrial	Peru	166,333,047	192,884,724	26	35
41	Heavy industrial	Indonesia	1,443,000,000	1,563,340,000	33	36
42	Heavy industrial	Alaska	639,326	698,056	10	12
43	Heavy industrial	Canada	273,550,000	295,037,296	22	24
44	Heavy industrial	China	4,290,000	4,648,000	8	9

Table 5-2 provides descriptive data from baseline and actual budgets and schedules analyze as well as rework costs for the 44 construction projects.

Table 5-2. Descriptive data analysis of the data collected in the construction phase.

Category	**Construction phase**	**Minimum**	**Mean**	**Maximum**	**Standard deviation**	**Variance**
Cost ($)	Baseline budget	337,721	87,279,265	740,100,000	134,588,433	18,000 Trillion
	Actual cost	327,000	151,578,590	2,500,000,000	393,970,564	150,000 Trillion
Schedule (months)	Baseline schedule	4	16	40	9.6	93.7
	Actual schedule	3	17.5	46	10.5	110.1
Rework ($)	Rework	21,000	2,068,557	9,350,000	2,081,929	4.3 Trillion

Table 5-3. Significant IMRCs and corresponding p-values.

Category	Attribute	IMRC number: description	Causes of rework from previous studies	p-value
Organization	Bureaucracy	IMRC-1: Difficulty obtaining design approval	Long waiting time for approval (Chan and Kumaraswamy 1997)	0.015[b]
		IMRC-2: Number of financial approval authority thresholds	Long-lead procurement (Fisk 1997)	0.001[b]
		IMRC-3: Number of external entities required to approve the design	The occurrence of conflicts and disputes (Wu et al. 2005)	0.034[b]
	Participants	IMRC-4: Number of active internal stakeholders in the decision-making process	Impediment of prompt decision making (Sanvido et al. 1992)	0.043[b]
		IMRC-5: Alignment quality of internal stakeholders	Poor coordination (Arain and Pheng 2005)	0.020[b]
		IMRC-6: Number of owner organizations	Impediment of prompt decision-making (Sanvido et al. 1992)	0.003[b]
		IMRC-7: Number of designer organizations	Poor coordination (Arain and Pheng 2005)	0.055[a]
		IMRC-8: Number of contractor organizations	Poor site management (Sunday 2010)	0.016[b]
	Communication	IMRC-9: Communication effectiveness within owners	Owner fails to make decision right time (Jadhav and Bhirud 2015)	0.006[b]
		IMRC-10: Communication effectiveness within designers	Failure by a consultant to supervise effectively (Jadhav and Bhirud 2015)	0.001[b]
		IMRC-11: Communication effectiveness among contractors	Poor project management by the contractor (Ye et al. 2015)	0.001[b]
Project	Management Team	IMRC-12: Percentage of actual project management staff	Poor Site management and supervision (Ye et al. 2015)	0.023[b]
		IMRC-13: Number of executive oversight entities above the PM	Low speed of decision making (Chan and Kumaraswamy 1997)	0.035[b]
		IMRC-14: PMT experience in the design phase	Lack of experience (Arain and Pheng 2005)	0.001[b]
		IMRC-15: PMT experience in the construction phase	Lack of experience (Arain and Pheng 2005)	0.001[b]
	Location	IMRC-16: Number of execution	Inappropriate linking of all design team (Chan	0.051[a]

		locations on this project during the detailed design phase	and Kumaraswamy 1997)	
		IMRC-17: Number of countries involved in the design phase	Sociocultural factors (O'Brien 1998)	0.057[a]
		IMRC-18: Number of countries involved in the construction phase	Sociocultural factors (O'Brien 1998)	0.081[a]
	Design and technology	IMRC-19: Difficulty in system design	Mistake and defect in design (Hsieh et al. 2004)	0.038[b]
		IMRC-20: Percentage of design at the start of construction	Incomplete design information (Jadhav and Bhirud 2015)	0.031[b]
		IMRC-21: RFI leads to design changes	Changes in design (Arain and Pheng 2005)	0.018[b]
		IMRC-22: Number of new systems tied into existing systems	Lack of experience (Arain and Pheng 2005)	0.035[b]
	Material resources	IMRC-23: Delay in the delivery of permanent facility equipment	Unavailability of equipment (O'Brien 1998)	0.003[b]
		IMRC-24: Permanent equipment quality issues	Low productivity of equipment (Assaf and Al-Hejji 2006)	0.047[b]
		IMRC-25: Quality of bulk materials	Replacement of material (Karthick et al. 2015)	0.043[b]
	Scope	IMRC-26: Clarity of the owner's project goals and objectives	The owner may make changes to achieve certain milestones within a given time frame (Wu et al. 2005)	0.039[b]
	Partnership	IMRC-27: Total number of joint-venture partners in a project	Low speed of decision making (Chan and Kumaraswamy 1997)	0.042[b]
	Finance	IMRC-28: Number of funding phases	Delay in payment (Karthick et al. 2015)	0.044[b]
People	Skill	IMRC-29: Degree of familiarity with technologies in design	A defect in design (Hsieh et al. 2004)	0.082[a]
		IMRC-30: Familiarity with technologies in the construction phase	Changes in construction method (Wu et al. 2005)	0.063[a]
	Fieldcraft experience	IMRC-31: Field craft labor quality issue	Skill shortage (Arain and Pheng 2005)	0.069[a]
	Socioculture	IMRC-32: Percentage of craft labor sourced locally	Sociocultural factors (O'Brien 1998)	0.011[b]

Note: RFI = request for information

[a]Significant differences with 90% confidence. [b]Significant differences with 95% confidence.

To avoid any bias generated by incorporating large projects into the results, the expense of the issued rework was normalized based on the size of the project. The cost of the rework was divided by the baseline budget for the construction phase to calculate the standardized rework cost for any project. For the remainder of the analyses carried out for this study, these costs were recorded and used.

Determine Significant IMRCs

Table 5-3 presents the p-value corresponding to the significant IMRCs. Because the survey collected two data types (continuous and 7-point Likert-scale scores), the two-sample *t*-test and the Kruskal-Wallis test were conducted. As noted, a review of the existing literature originally found 51 manageable causes of rework. By implementing BPs 35 of these causes were found to be manageable. Finally, as indicated in Table 5-3, 32 significant IMRCs were identified. In Table 5-3 the first column represents the category of the indicator (organization, project, and people). Whereas the second and third column has data related to attributes and a significant list of IMRCs, respectively. According to the previous studies in which they were described the fourth column shows the causes of rework; that is, Column 4 provides the origin of each IMRC in the existing literature. IMRCs abbreviations and associated numbers have been used (e.g., IMRC-2). The results of statistical data analysis are presented in Column 5. As Table 5-3 suggests, this study initially conducted the statistical analysis at the significance level of 0.05 and then raised it to 0.1 to include more IMRCs.

The organizational category and communication attribute IMRC-10, which indicated a failure to reach an agreement, indicated time-consuming disputes between designers. Consequently, designers decision-making processes required additional time and the likelihood of design changes increased.

IMRC-19, of the project category and the design and technology attribute, stated that an elevated number of mistakes are more likely to occur when designing a system is complex due to lack of knowledge and/or experience of the designers. Eventually, during much of the construction phase, such errors cause design changes and modifications. Poor material quality (category and material resource attribute IMRC-25 of the project) leads to material replacement and results in design modifications. As can be seen in Table 5-33, if designers lack skills in the design phase of the project in working with the new technologies (i.e., IMRC-29 belonging to the category of people and skill attribute), then the likelihood of design errors in a complex project increased.

Determine BPs that reduce the cost of Rework Associated with IMRCs

In this section, the selection of suitable BPs that bring down the expense of rework has been depicted in the context of the entire cost of the project, corresponding to IMRC related issues, and the results of the p-values are delivered. Because the implementation level of BPs was addressed in the survey with 7-point Likert scale items in the survey, the Kruskal-Wallis test was used to investigate whether there was a significant difference between the median levels of IMRC related BPs implementation.

As shown in Table 5-4, front-end planning implementation was found to be effective in managing an organization's bureaucracy – related obstacles. Bureaucracy is a systematic structure that requires time to effectively manage an organization's business. Consequently, rework associated with bureaucracy could be diminished by implementing front-end planning that assigns appropriate functions.

Table 5-4. Results of the Kruskal-Wallis test of BPs to reduce the cost of rework associated with IMRCs

Category	Attribute	IMRC-number	Constructability	Team building	Alignment	Partnering	Front-end planning	Risk assessment	Material management	Quality management	Dispute prevention	Lesson learned
Organization	Bureaucracy	IMRC-1	0.198	0.258	0.051[a]	0.111	0.369	0.875	0.663	0.660	0.741	0.396
		IMRC-2	0.825	0.321	0.285	0.174	0.074a	0.241	0.440	0.446	0.528	0.547
		IMRC-3	0.475	0.147	0.025[b]	0.285	0.352	0.178	0.685	0.358	0.355	0.187
	Participants	IMRC-4	0.285	0.415	0.698	0.012[b]	0.526	0.369	0.357	0.359	0.745	0.658
		IMRC-5	0.175	0.284	0.035[b]	0.321	0.354	0.147	0.158	0.169	0.645	0.586
		IMRC-6	0.497	0.617	0.188	0.222	0.014[b]	0.444	0.266	0.442	0.028[b]	0.333
		IMRC-7	0.112	0.085	0.321	0.312	0.483	0.397	0.199	0.174	0.633	0.063[a]
		IMRC-8	0.458	0.058	0.0741[a]	0.297	0.743	0.645	0.196	0.456	0.045	0.697
	Communication	IMRC-9	0.423	0.064[a]	0.147	0.374	0.345	0.456	0.625	0.412	0.312	0.387
		IMRC-10	0.108	0.081[a]	0.120	0.321	0.147	0.145	0.652	0.354	0.295	0.274
		IMRC-11	0.477	0.052[a]	0.346	0.354	0.466	0.117	0.284	0.365	0.475	0.145
Project	Management team	IMRC-12	0.365	0.394	0.168	0.116	0.016[b]	0.746	0.373	0.191	0.711	0.623
		IMRC-13	0.185	0.852	0.096[a]	0.174	0.196	0.285	0.221	0.356	0.341	0.285
		IMRC-14	0.001[b]	0.174	0.146	0.375	0.159	0.525	0.424	0.075[a]	0.324	0.303
		IMRC-15	0.252	0.256	0.344	0.303	0.055[a]	0.354	0.074[a]	0.064[a]	0.654	0.666
	Location	IMRC-16	0.395	0.354	0.687	0.489	0.156	0.131	0.208	0.058[a]	0.158	0.302
		IMRC-17	0.425	0.052[a]	0.145	0.203	0.361	0.220	0.334	0.035[b]	0.330	0.357
		IMRC-18	0.202	0.235	0.362	0.132	0.144	0.085[a]	0.068[a]	0.346	0.365	0.145

	Design and technology	IMRC-19	0.047[b]	0.684	0.456	0.114	0.178	0.568	0.248	0.863	0.148	0.351
		IMRC-20	0.025[b]	0.196	0.387	0.135	0.112	0.189	0.684	0.374	0.198	0.257
		IMRC-21	0.285	0.555	0.456	0.394	0.415	0.285	0.341	0.396	0.645	0.036[b]
		IMRC-22	0.412	0.396	0.550	0.465	0.394	0.745	0.195	0.375	0.684	0.045[b]
	Material resources	IMRC-23	0.202	0.145	0.265	0.665	0.209	0.406	0.063[a]	0.175	0.556	0.145
		IMRC-24	0.202	0.112	0.352	0.363	0.564	0.550	0.008[b]	0.065[a]	0.333	0.145
		IMRC-25	0.285	0.312	0.256	0.110	0.393	0.282	0.035[b]	0.044[b]	0.355	0.268
	Scope	IMRC-26	0.202	0.112	0.625	0.285	0.059[a]	0.145	0.465	0.368	0.756	0.642
	Partnership	IMRC-27	0.333	0.125	0.170	0.015[b]	0.041[b]	0.695	0.375	0.674	0.312	0.202
	Finance	IMRC-28	0.475	0.485	0.685	0.185	0.018[b]	0.396	0.358	0.425	0.484	0.356
People	Skill	IMRC-29	0.117	0.157	0.145	0.325	0.486	0.545	0.357	0.303	0.119	0.022[b]
		IMRC-30	0.414	0.158	0.325	0.374	0.315	0.084[a]	0.458	0.417	0.636	0.063[a]
	Field craft experience	IMRC-31	0.185	0.195	0.174	0.525	0.505	0.110	0.151	0.015[b]	0.147	0.417
	Socioculture	IMRC-32	0.452	0.302	0.415	0.405	0.220	0.111	0.325	0.369	0.101	0.002[b]

[a]Significant differences with 90% confidence. [b]Significant differences with 95% confidence

Adopting the strategy for team building results in realistic expectations and enhanced engagement among team members. This strategy also promotes trust and accountability between the team members. Using team building along the lines decreases the share of rework expenses or cost caused by the communication challenges between owner stakeholders, designers, and contractors.

Utilization of a constructability strategy aids improvement in the development of plans and specifications. For example, technical software, such as the Building Information Modeling Technique for Coordination, is utilized to audit the architectural and engineering disciplines for proper coordination, by implementing constructability BPs. In this study, the respondents indicated that if the PMT has sufficient work experience and/or complex project design, it would be beneficial to adopt constructability BPs to bring down the expense of rework in the context of the overall expense of the project.

Trying to implement quality management results in regular audits and historical data analysis to identify errors in design. This strategy has been utilized in order to successfully complete analyzes of root causes and to notify corrective measures at the appropriate time. As a matter of fact, when the design phase involves several locations and/or countries, the implementation of quality management is advantageous to reduce the number of design errors.

It is vital that all 44 case studies had actualized the safety strategy into projects to such an extent that assurance of whether implementing this strategy significantly diminished the difficulties associated with manageable causes of rework was impossible. In this manner, since the examination of this technique would not help with deciding if the adoption of safety diminished the expense of rework related to IMRCs, safety was kept out from the prepared rundown of BPs.

As illustrated in Table 5-4, front-end planning was successful in handling an organization's bureaucracy related obstacles. Bureaucracy is a systematic, time-consuming structure utilized for managing an organization's business. Hence, rework associated with bureaucracy could be diminished by implementing front-end planning, which allocates appropriate functions.

Development of plans and specifications can be eased by utilizing constructability strategy. For example, utilization of technical software such as Building Information Modeling Technique for coordination could be used as a mode for auditing architectural and engineering disciplines for proper coordination through the implementation of this BPs. Thus, if the PMT has unsatisfactory limited work experience and/or complex project design, it would be beneficial to embrace constructability in lowering rework expenses.

Quality management, which incorporates regular audits and examinations of historical data to recognize design errors, is utilized to perform root cause investigations and to illuminate corrective actions at the correct time. Thus, when a few areas, as well as nations, are engaged in the design phase, the selection of quality management would be beneficial for diminishing the quantity of design errors or mistakes.

Calculate the weight of BPs for rework attributes

The effect size results corresponding to IMRCs, as shown in Table 5-5, were calculated by using Cohen's d method. The effect sizes values were then standardized, also addressed in Table 5-5. These standardized values were determined based on the effect size result affiliated with each IMRC, divided by the summation of all effect size results. The IMRCs highest possible standardized weight (6.06%) was consistent with the PM's experience in the construction phase (IMRC-15). As shown in Table 5-5, the standardized weight of the number of PMTs incurved in the project (IMRC-12) and the PM experience in the design phase (IMRC-14) were recorded as 5.87% and 5.68% respectively. Two important tasks are commonly undertaken by the PMT: directing a project to achieve goals and improving relationships within the organization to achieve greater efficiency. The highest standardized weights recorded therefore corresponded to the PMT.

The weights of the BPs for managing rework attributes have been estimated and provided in Table 5-6, which demonstrates that the greatest support practitioners have been given for front-end planning and dispute prevention as it relates to the total cost of the project, corresponding to the participant attribute (i.e., owner, designer, and contractor stakeholders). Both weights were recorded as 0.0416 for front-end planning and dispute prevention. A useful example to clarify how these weights were recorded, front-end and prevention of disputes, as shown in Table 5-4, correlates to the attribute of the participant. Which can be seen, as a participant for both BPs, IMRC-6 (number of owner organizations) was significant. The weight of IMRC-6 was calculated as 0.0416 according to Table 5-5. Consequently, as shown in Table 5-6, weights were recorded as 0.0416 for both front-end planning and prevention of disagreements associated with the participant attribute. Team building encourages trust and accountability between many project participants and develops shared goals among stakeholders, eliminating potential time-consuming conflicts and disagreements. Additionally, the adoption of dispute prevention is essential for the early recognition of the conflict indicators between many participants and the establishment of a strong commitment to evade them.

Table 5-5. The weight of early IMRCs

IMRCs	Weight	Impact
IMRC-15: PM experience in construction	0.0606	High
IMRC-12: Number of PM staff	0.0587	
IMRC-14: PM experience in design	0.0568	
IMRC-13: Number of entities above PM	0.0549	
IMRC-2: Number of financial approval authority thresholds	0.0530	
IMRC-3: Number of entities for design approval	0.0511	
IMRC-9: Communication within owners	0.0492	
IMRC-10: Communication within designers	0.0473	
IMRC-23: Delay in the delivery of facility	0.0454	
IMRC-11: Communication within contractors	0.0435	
IMRC-6: Number of owner organizations	0.0416	
IMRC-29: Familiarity with design technology	0.0397	Medium
IMRC-7: Number of designer organizations	0.0378	
IMRC-8: Number of contractor organizations	0.0359	
IMRC-5: Alignment of internal entities	0.0340	
IMRC-16: Number of locations in the design	0.0321	
IMRC-1: Difficulty in design approval	0.0303	
IMRC-32: Percentage of local craft staff	0.0284	
IMRC-22: Number of new systems	0.0265	
IMRC-20: Design completion before construction phase	0.0246	
IMRC-21: RFI leads to design changes	0.0227	
IMRC-18: Number of countries in construction	0.0208	Low
IMRC-31: Field craft labor quality issues	0.0189	
IMRC-19: Difficulty in system design	0.0170	
IMRC-24: Equipment quality issues	0.0151	
IMRC-4: Number of active internal entities	0.0132	
IMRC-25: Quality of bulk materials	0.0113	
IMRC-28: Number of funding phases	0.0094	

IMRC-30: Familiarity with construction technology	0.0075	Low
IMRC-26: Clarity of owner goals	0.0056	
IMRC-27: Number of joint-venture partners	0.0037	
IMRC-17: Number of countries in the design phase	0.0018	

Note: RFI = request for information.

The team building this strategy encourages trust and accountability between project participants and produces common goals among stakeholders, thus reducing potential time-consuming internal disputes and clashes. Moreover, it is important to embrace dispute prevention in order to identify the conflict indicators between participants early on and to build a strong commitment to eliminating them.

Table 5-6 shows that constructability supplied the substantial support for lowering design errors linked to management team attributes and design and technology: Constructability weights relating to the management team and design and technology attributes respectively were estimated as 0.0568 and 0.0416. For an illustration of how design and technology weight (0.0416) was calculated, Table 5-4 shows that constructability was considerably related to design and technology attributes IMRC-19 (system design difficulty) and IMRC-20 (pre-build design completion). Furthermore, Table 5-5 lists IMRC-19 and IMRC-20 computed weights as 0.0170 and 0.0246, respectively. Consequently, the design and technology attribute weight of constructability was recorded as 0.0416 (the sum of 0.0170 and 0.0246). This strategy advantages from design quality control and clash checking and reduces design errors due to the lack of experience of the design management team operating with new technologies during the design phase.

As indicated in Table 5-6, the implementation of front-end planning led to early clarification of the project goal to make sure well-defined and documented scope and technical specifications. It tends to result in limiting the scope attribute's late design changes. This BP tells the creation of a financial strategy that improves the reliability of project costs and schedule targets. This front-end planning strategy therefore strongly supports the attribute of finance.

The data in Table 5-6 also indicate that the use of risk assessment was strongly recommended when team members lacked the required skills. This strategy provides a framework for constructing the compliance program with training, monitoring, and auditing, thus decreasing the number of design changes issued for a construction project. Furthermore, survey respondents characterized that the implementation of risk assessment could be beneficial for having established structured and disciplined regular audits if different locations and/or countries are involved in the design and/or construction phase.

As shown in Table 5-6, front-end planning and alignment strategies were strongly recommended as supporting partnership challenges. These strategies are embraced in order to generate a standard template for stakeholders to communicate about the objectives and scope of the project and thus accomplish project excellence. In addition, these strategies give rise to the analysis needed to align stakeholder requirements and expectations.

Because communication between and within multicultural teams has a significant impact on project performance, adopting the lesson learned strategy continues to increase cost and schedule performance when craft workers belong to different cultures (i.e., an attribute of socioculture). The lesson learned strategy benefits from utilizing knowledge about differences in culture to efficiently monitor a project's execution.

Table 5-6. The weight of each BP for manageable rework attributes.

Category	Attribute	Constructability	Team Building	Alignment	Partnering	Front-end planning	Risk assessment	Material management	Quality management	Dispute prevention	Lesson Learned
Organization	Bureaucracy			0.0814		0.0530					
	Participant			0.0699	0.0132	0.0416				0.0416	0.0378
	Communication		0.14								
Project	Management Team	0.0568		0.0549		0.1193		0.0606	0.1174		
	Location		0.0018				000208	0.0208	0.0339		
	Design and technology	0.0416									0.0492
	Material resources							0.0718	0.0264		
	Scope					0.0056					
	Partnership				0.0037	0.0037					
	Finance					0.0094					
People	Skill						0.0075				0.0472
	Field craft experience								0.0189		
	Socioculture										0.0284

Implementation of Results

To authenticate the results of this study, two heavy - industrial case study projects were chosen. The baseline budget for the construction phase of each of the two projects, as provided in Table 5 - 7, was approximately $ 5 million. The case studies with a short construction phase were deliberately selected to get the results immediately. Data in Table 5 - 7 show that for the first and second projects, the baseline schedule for the construction phase was 8 and 7 months, respectively.

Table 5-7. General information corresponding to two case study projects used for the implementation of results.

Project	Type of project	Baseline budget construction phase ($)	Baseline schedule construction phase (months)	Rework ($)
1	Heavy industrial	5,022,000	8	1,239,831
2	Heavy industrial	5,000,000	7	1,667,500

In the first project, five BPs (constructability, material management, quality management, lesson learned, and risk assessment) were implemented, and the rework expense was about $ 1.2 million. Only the material management, lesson learned, and strategies for risk assessment were implemented for the second project. The expense of the second project's derived rework was about $ 1.7 million. The results indicate that the implementation of constructability and quality management strategies contributed to a cost savings of approximately $ 600,000 for two industrial projects with similar construction - phase baseline budgets and schedules in the rework in the context of the overall project.

The rework indicators affiliated with the attribute of the management team (i.e., IMRC-14, little PM experience in the design phase) and the design and technology attribute (i.e., IMRC-19, complex system design) have been used in the first and second projects in Table 5-8. The rework indicators affiliated with the attribute of the management team (i.e., IMRC-14, little PM experience in the design phase) and also the design and technology attribute (i.e., IMRC-19, complex system design) have been utilized in the first and second projects in Table 5-8. In addition, the data in Table 5 - 7 recommend that the rework indicators correlated with the management team (i.e., IMRC-16, several execution sites in the design phase, and IMRC-17, two countries involved in the design phase) were also discovered in the first and second projects. Thus, as shown in Table 5 - 6, the application of a quality management strategy helped to reduce the expense of rework in the context of the total cost of the project, which was triggered by the management team and location problems for the first project. As a result, the implementation of constructability and quality management strategies resulted in the rework cost of the first project being relatively low in the context of the total dollar value.

Table 5-8. Breakdown of information for two case study projects used for the implementation of results.

Project	**Existing IMRCs in the project**	**Implementation of BPs**
1	IMRC-3: High number of external entities required to approve the design	Constructability: Yes
	IMRC-4: High number of active internal stakeholders in the decision-making process	Team building: No
	IMRC-12: Low percentage of PM staff	Alignment: No
	IMRC-13: High number of executive oversight entities	Partnering: No
	IMRC-16: Several f execution locations in the design phase	Front-end planning: No
	IMRC-17: Two countries involved in the design phase	Material management: Yes
	IMRC-19: Complex system design	Quality management: Yes
	IMRC-21: RFIs drive serious project changes	Lesson learned: Yes
	IMRC-22: Several new systems tied into existing systems	Risk assessment: Yes
	IMRC-23: Several weeks delay in delivery of permanent facility equipment	Dispute prevention: No
	IMRC-28: Two funding phases	
2	IMRC-8: Several contractor organizations	Constructability: No
	IMRC-14: Little PM experience in the design phase	Team building: No
	IMRC-15: Little PM experience in construction phase	Alignment: No
	IMRC-16: Several execution locations in the design phase	Partnering: No
	IMRC-17: Two countries involved in the design phase	Front-end planning: No
	IMRC-18: Six countries involved in the construction phase	Material management: Yes
	IMRC-22: Several new systems tied into existing systems	Quality management: No
	IMRC-23: Several weeks of delay in the delivery of permanent facility equipment	Lesson learned: Yes
	IMRC-26: Little clarity of owner's project goal	Risk assessment: Yes
	IMRC-28: Three funding phases	Dispute prevention: No
	IMRC-32: Between 60% and 80% of craft labors not sourced locally	

5.1 Summary

All the results of respondents were collected and analyzed in this chapter. About 44 case study data was collected and analyzed. Then significant identical manageable rework causes were identified from the literature and after that best practices to manage those rework causes were identified. In order to know the effectiveness of suggested best practices, their weight was calculated. Two heavy - industrial case study projects were evaluated in order to verify the results of this study and the results were that the adoption of constructability and quality management strategies resulted in relatively low rework costs.

Chapter 6 Conclusion and Future Research Recommendations

This study identified early rework indicators and classified them through existing literature according to the organization, project, and people. The results revealed most important and frequently occurring organization-based indicators were lack of communication, inadequate coordination, lack of resource management, ineffective implementation of QA, poor use of technology, poor management, construction error, changes made by contractor, change in method of construction to enhance constructability, lack of design audit, lack of staff supervision, non-functional equipment and tools, lack of documentation control, poor scheduling of construction resources, damage caused by subcontractors, staff turnover or relocation and defect in material or prefabrication. This study also demonstrates that the seven most frequent rework indicators belonging to the project-based category are: inappropriate/poor design, unclear scope definition, owner induced enhancements, wrong material selection or material issues, supervision-related issues, financial issues, external environmental, site conditions specifications, differing or no site information about the site, unclear work specifications, quality issues, governmental policy changes and lack of clarity. Finally, it was concluded that, based on the literature, lack of experience and expertise, level of skill, misinterpretation due to lack of knowledge, conflict among team members/workers, lack of safety commitment, lack of motivation and reward, inadequate training, stress, slips, socio-culture/cultural issues and excessive overtime are the most crucial human-based rework indicators.

This research was focused on two objectives: to evaluate the early IMRCs and to designate the BP strategies that bring down the cost of rework related to manageable rework attributes in the context of the total cost of the project. In this regard, for three main categories and 13 attributes, 32 significant indicators were recognized. In addition, in the context of the total final cost associated with rework attributes, 10 appropriate BPs were selected as beneficial for decreasing the dollar value of rework.

Since the PMT is normally in charge of the planning, execution, and shutting of any construction project, the experience of the PMT in the design and construction phases (i.e., IMRC-15 and IMRC-14) and the quantity of project management staff who take a shot at the project (i.e., IMRC-12) were resolved to be the three vital indicators with the best loads in the construction projects examined. The observations also led to the conclusion that alignment implementation and front - end planning strategies aid in the effective management of obstacles in a construction project due to bureaucracy. The implementation of these strategies builds an organized framework for developing business - like communication inside an organizational system that reduces the amount of changes in design during a construction project. Furthermore, this study suggested that quality management is advantageous when several nations participate in the design and/or construction phase because regular audits and data collection analyzes are performed to avoid potential design errors. The results of this study are expected to assist project managers and practitioners in interpreting the factors that causes rework so that minimal design modifications and rework are required to carry out their projects and also expected that stakeholders and corresponding PMs will be assisted in the timely implementation of appropriate BPs in order to achieve minimum design changes throughout construction projects.

6.1. Limitations

During this study, limitations faced by the author were firstly the size of respondents, about 44 which is few in number compared to many studies but sufficient enough to get results and get to a conclusion. Furthermore, incomplete feedback or response to the questions asked in the survey from the respondents led to missing data in the generation of results.

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Appendix A

List of indicators causing rework and change order in construction

Table 8-1. List of indicators causing rework and change order in construction.

No.	Indicators leading to rework or change order in construction
1	Change is scope of work.
2	Scope definition not defined properly.
3	Wrong initial Budget
4	Inappropriate design
5	Issues in Design
6	Poor design Integration
7	Lack of clarity
8	Type of contract
9	Contract Management
10	Vandalism
11	Weather Conditions
12	External environment
13	Interference with existing services
14	Adversarial attitudes
15	Traditional procurement
16	Lack of supervision
17	Project governance issues
18	Poor monitoring and control
19	Competitive Tendering
20	Differing information about the site
21	No information about the site
22	Wrong material selection
23	Erroneous material resource
24	The pressure to start execution
25	The pressure to finalize works
26	Partnership
27	Commencement of construction before completion of the design
28	Inadequate interface management between contractors and consultants
29	Discrepancies between the administration and the management team.
30	Lack of adherence of quality control
31	Lack of Construction knowledge
32	Location of the site.
33	The actual condition of the site.
34	Management team issues
35	Enhancement suggested by the owner.
36	Lack of client involvement
37	Changes done by clients
38	Contract item overrun.
39	Number of funding phases
40	Lack of funding
41	Procurement method
42	Contract documentation
43	Type of Project
44	Change in governmental policies
45	Poor decision-making process
46	Omissions in construction
47	Omissions in design
48	Change in design due to field condition
49	Unclear work specification
50	Competitive or low design fee
51	Change in the social environment

52	Material is hard to work with
53	Design is unsuitable
54	Design is hard to construct
55	Design changes due to economic changes
56	Lack of experience and knowledge in the design process
57	Rework due to natural hazard
58	Insufficient time and money spent on briefing process
59	Stress
60	Slips
61	Lack of experience and expertise of manpower or workman
62	Omissions of checks
63	Wrong distribution of information
64	Misinterpretation due to lack of knowledge
65	Skill level
66	Accountability
67	Well being
68	Personality type
69	Cognitive dissonance
70	Socio-culture or cultural issues
71	Field craft experience
72	Morale level
73	Conflict among team members or workers
74	Absenteeism
75	Lack of motivation and reward
76	Excessive overtime
77	Inadequate training opportunities for workers
78	Inadequate workers safety and welfare
79	Lack of safety commitment
80	Loss of biorhythm
81	Competitive issues
82	Faulty material handling
83	Carelessness
84	Bureaucracy
85	Lack of professionalism
86	Poor leadership
87	Poor use of technology
88	Lack of communication
89	Lack of design audits
90	Lack of knowledge management structure
91	Inadequate skills and knowledge of personnel in the organization level.
92	Lack of planning and resources
93	Inadequate coordination
94	Lack of staff supervision
95	Ineffective implementation of Quality Analysis/ assurance
96	Design changes made by the contractor
97	Unexpected events occurrence
98	Inadequate execution
99	Slow client resolution
100	Inadequate economic solvency
101	Inadequate budget management
102	Poor management of the project
103	Health and safety consideration of staff
104	Deficiencies in documentation control

105	Poor development and application of realistic work procedures
106	Poor scheduling of construction resources
107	Defect in prefabrication
108	Defect in material supplied
109	Equipment and tools not sufficiently functional
110	Change in method of construction in order to enhance constructability
111	Error in Construction while execution
112	Error in fabrication
113	The error made in the method of transportation
114	Selection of the wrong supplier of material
115	Selection of wrong contractor unsuitable for a job task
116	Ineffective coordination among different design team members
117	Ineffective utilization of computer-aided automation
118	Misreading of drawing and building out of alignment
119	Damage caused by a subcontractor
120	Machine breakdown or defects
121	Relocation of staff to other place
122	Staff turnover
123	Unrealistic client’s initial requirements
124	Insufficient training of engineers and designers.

Appendix B

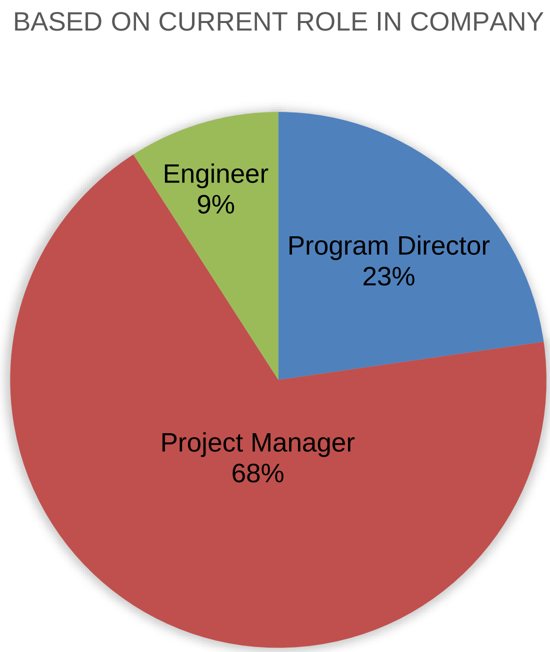
List of Acronyms

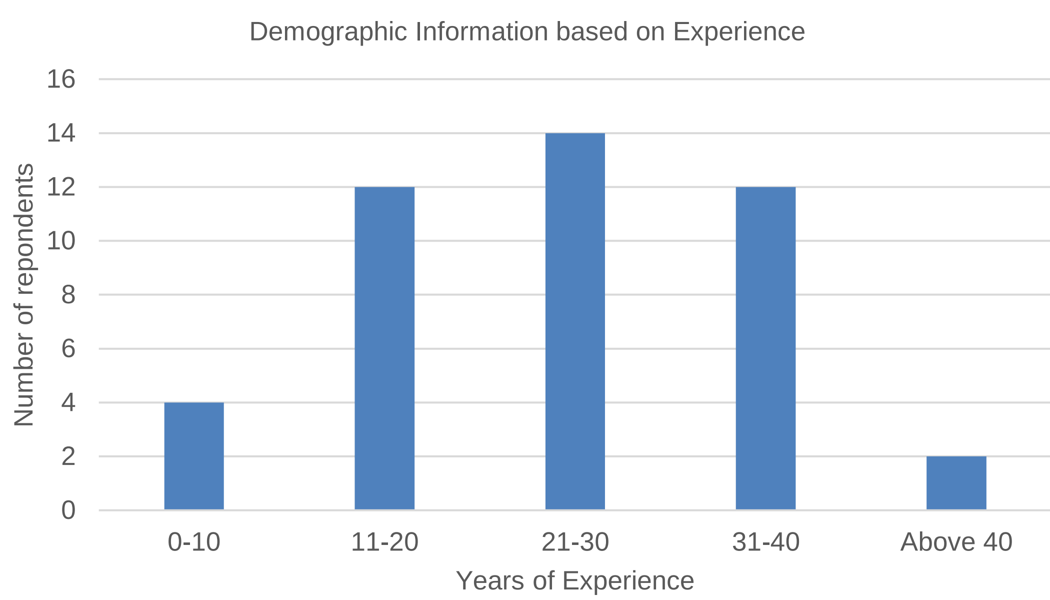
BIM	Building Information Modelling
BPs	Best Practices
CII	Construction Industry Institute
F.I.	Frequency Index
IMRC	Indicators of Manageable Rework Causes
PMs	Project Managers
PMT	Project Management Team
QA	Quality Assurance
QC	Quality Control
RFI	Request for Information
RII	Relative Importance Index

Appendix C

Demographic information of the survey respondents

The chart below shows the demographic information of 44 respondents of a survey based on their current role in the company and the number of years of experience they have.





Biographical Information

Piyush Taneja holds his bachelor's degree in Civil Engineering from the Jaypee University of Engineering and Technology, India in 2014. He also earned his master's degree in Civil Engineering focusing on Construction Engineering and Management at the University of Texas at Arlington in May 2019. His research was about investigation and analysis of rework leading indicators and their successful best practices. He has conducted research in this area for two years under the supervision of his advisor, Dr. Kermanshachi, and he has published two conference paper, one journal paper under review and one in-progress during this period. His paper was published in the American Society of Engineering Education Conference and Exposition, Salt Lake City 2018 and Proceedings of 7th CSCE International Construction Specialty Conference (ICSC), Laval, Canada, June 12- 15, 2019.

Piyush worked for University of Texas at Arlington as a research assistant (RA) for three semesters. During his education at the University of Texas at Arlington, Piyush attended North American Society of Trenchless Technology (NASTT) in Palm Springs (2018) and worked as a volunteer student. Piyush is also member of American Society of Civil Engineer (ASCE) and Design Build Institute of America (DBIA).