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Quantifying the cost of quality in construction projects: an insight into the base of the iceberg

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Abstract
Construction projects are complex endeavors where achieving higher quality standards is challenging due to the intrinsic difficulties and dynamic quality management processes. Several quality management techniques exist to overcome quality concerns, such as the cost of quality (COQ). However, implementing COQ in building construction is challenging due to the absence of a comprehensive quality cost-capturing system. Several studies have tried to quantify different quality costs but are mainly focused on visible failure cost—the tip of the iceberg while the base of the iceberg has rarely been explored. This study develops and quantifies each component of the visible and hidden quality costs—the base of the iceberg. Accordingly, a modified prevention, appraisal, and failure model is developed and applied to the primary data of 25 building projects. The findings highlight the unfamiliarity and passive attitude of the involved construction firms towards quality, thus, incurring higher failure costs amounting to over 12% of the total project cost. Most of this cost remains hidden as traditional accounting systems cannot capture it. Such costs must be eliminated by implementing COQ systems as utilized in the current study. Further, a quality costing framework is established for building projects and applied to the local construction industry to reduce construction failures and improve the quality performance of building projects.

Keywords Cost of quality · Hidden failure cost · Construction projects · Buildings · Quality management

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1 Introduction

Construction is the art of delivering a unique product by integrating complex, extensive, and interdependent planning, management, design, and execution processes. Such integration ensures smoother project execution and overall management (Garg and Misra 2021b). Construction projects are different from their counterparts in other sectors such as manufacturing and service industries. Thus, it is challenging to complete construction projects within the scheduled time, cost, and required quality standards (Shafiei et al. 2020; Khadim et al. 2021). Construction project management is conventionally divided into four primary categories: cost, schedule, safety, and quality management, which support the iron triangle criteria of project management success. The first three lie at the edges of the triangle and are well understood, but the understanding of quality—at the core of this triangle, is weak in the construction industry (Khalek et al. 2016). Thus, multiple quality issues are reported in construction projects making quality management challenging and time-consuming.

Out of several reasons behind this situation, inherent subjectivity is the main problem in assessing quality. This subjectivity means different things to different individuals and is generally associated with customer needs and satisfaction (Defeo and Juran 2010). Therefore, several quality definitions exist in the literature, which vary from industry to industry, even from project to project. From the construction industry perspective, Khalek et al. (2016) stated that quality is fitness for use, whereas Daddow and Skitmore (2005) defined it as meeting or going beyond the needs of a customer. Due to subjectivity and lack of comprehensive success indicators, accomplishing adequate quality standards has long been problematic in the construction industry (Egwunatum et al. 2022; Rosenfeld 2009). Additionally, several valuable and depleting resources are wasted because of ineffective quality standards, negatively impacting project sustainability and the economy (Siddiqui et al. 2016; Shafiei et al. 2020). In the era of growing sustainability demands and focus on efficient resource utilization with minimum waste and reduced costs, this paints a negative image of the construction industry, especially in the industry 4.0 times (Khadim et al. 2022).

To solve the quality problems, several quality management systems (QMS) have increasingly been adapted from the manufacturing industry to the construction industry. Among them, total quality management (TQM), the international organization for standardization (ISO) ISO 9000–9001, cost of quality (COQ), and six sigma are the most common (Hoonakker et al. 2010; Siddiqui et al. 2016; Leong et al. 2014). This hints that implementing TQM and ISO 9000 in the construction industry has helped address communication problems and reduced material wastage and rework (Leong et al. 2014). Similarly, six sigma has long been adopted in construction as a management tool to improve the process, and it has served as an effective project performance improvement strategy (Ullah et al. 2017; Qayyum et al. 2021).

Despite these advantages of the adopted QMS, the lack of objective and quantitative decision criteria is still elusive for construction industry stakeholders. Responding to this, COQ has gained much attention recently (Dimitrantzou et al. 2020) as it translates quality into monetary terms by identifying the cost incurred in providing quality (Farooq et al. 2017). This objective system is easy to comprehend and communicate to the stakeholders. It helps attain a quality-cost balance to remain competitive in the market (Abdelsalam and Gad 2009; Shafiei et al. 2020). Juran (1951) defined COQ to represent "all those costs which would disappear if there were no shortcomings". COQ assesses the organization's quality performance, emphasizes the area which requires improvement, and helps continuous improvement and enforcement of TQM (Glogovac and Filipovic 2016). The primary purpose of COQ implementation is to emphasize the advantages of enhancing quality and relating it to customer satisfaction and cost reduction (Beshah et al. 2017). It has a vital role in boosting productivity, reducing unwanted expenditures, and amplifying profitability (Yang 2018). The evidence shows that companies that adopt COQ methods successfully reduce Total Project Cost (TPC), construction failures, material waste, and unnecessary use of resources. This results in enhanced quality standards and the ability of failure analysis, which enables construction companies to apply possible remedies to prevent future reoccurrence (Glogovac and Filipovic 2016; Taggart et al. 2014).

The idea of COQ is old and well-known in the manufacturing and service industries (Dimitrantzou et al. 2020) but not so much in the construction industry. COQ dictates the total project cost. However, separating the quality costs from other costs is challenging and time-consuming (Garg and Misra 2022). Lack of management interest, the nonexistence of detailed costing and accounting systems, and lack of knowledge are the main barriers to implementing quality cost systems in construction (Al-Tmeemy et al. 2012). Few studies about COQ in the construction industry can be found in the extant literature (Mahmood and Kureshi 2015; Shafiei et al. 2020). Rosenfeld (2009) reported that a smart investment in COQ could save a significant part of the costs due to poor quality. Heravi and Jafari's (2014) research on the implementation of COQ in mass-housing projects concluded that the successful application of COQ could help save 10% of TPC. Further, Mahmood et al. (2014) highlighted that an increase in COQ negatively impacts labor productivity and profitability in construction. Hence, COQ is highly relevant in this context, and the construction industry needs a well-defined quality cost system that can deliver the project at the least possible cost and can satisfy customers (Sellés et al. 2008). However, today's accounting systems cannot track quality costs in construction, and the original COQ remains concealed (Mahmood and Kureshi 2015).

To overcome this problem, different models have been adopted and implemented in the construction industry. Among these, Prevention, Appraisal, and Failure (PAF) is the most used technique to quantify the COQ (Farooq et al. 2017; Janatyan and Shahin 2021). It classifies the costs into prevention, appraisal, and internal and external failure costs (Balouchi et al. 2019b). It was accepted as the basic framework for classifying quality costs by British Standard Institute (BSI) in 1992 (Farooq et al. 2017; Kazaz et al. 2005). It was initially used in the manufacturing and service sectors and was later adopted in the construction industry (Malik et al. 2016; Garg and Misra 2022).

Although PAF is widely used, it has a few limitations. Firstly, assigning cost items to defined PAF categories (prevention, appraisal, failure) is difficult. Secondly, the original PAF model does not incorporate the indirect or Hidden Failure (HF), which can be a significant part of TPC. Most of the previous studies on COQ in construction projects have focused on the Visible Failure (VF) costs, including rework and material wastage (Abdelsalam and Gad 2009; Garg and Misra 2021a). Only a few authors attempted to calculate all the components of the PAF model (Rosenfeld 2009; Jafari and Love 2013). Also, many studies pointed out the HF costs but did not comprehensively quantify them on actual projects. The absence of a comprehensive system for defining and collecting quality costs was the primary concern of these studies (Jafari and Rodchua 2014). This presents a research gap that, in order to apprehend the effectiveness of the COQ system, there is a need for comprehensive and complete quantification of every component of PAF including the physical as well as the HF costs using a well-developed COQ framework for construction.

To bridge this gap, the current study sets the following main objectives.

1. To identify the most occurring prevention, appraisal, visible and hidden failure costs in construction projects
2. To develop a quality-cost framework for quantifying COQ (including HF) in construction projects
3. To quantify the COQ using the improved model for building projects

The current study first defines visible (PAF) components and hidden quality costs (tangible and intangible). It develops a data collection instrument based on a comprehensive literature review and questionnaire survey. Then to quantify COQ, 25 building projects are used for data collection. The data collection was comprehensive, and it took around four months to collect the data. Every quality-related activity (training, testing, audits, etc.) and failure events (rework, variations, warranty works, demolition, etc.) as defined by the developed instrument were identified. A comprehensive cost analysis using the detailed bill of quantities (BOQ) and project reports was performed for every single cost item in all case study projects. In the end, analyzed COQ data were compared, and spending was equated against the economic benefits to give the project stakeholders a better understanding of the effectiveness and significance of quality cost systems. Accordingly, the novelty and originality of the study lie in the development of a specific COQ framework through the in-depth categorization of cost items and in its comprehensive quantification of the quality cost that not only includes the physical (VF) but also the tangible and intangible HF costs using the accurate building data acquired directly from the project personnel. Though the quantification is focused on building projects, the scope of the study is not limited to buildings. The findings of this study can be used by construction designers, practitioners, and consultants to quantify the COQ on buildings and other construction projects. The successful application can help eliminate excessive wastage, rework, and customer dissatisfaction, contributing to sustainability by enabling a cleaner and circular construction. The study also contributes to the construction quality literature, which is relatively a less explored area, especially in developing countries like Pakistan.

The rest of the paper is organized as follows. The PAF model and related terms used in this study are defined in Sect. 2. Section 3 explains the research methodology to identify, analyze, and characterize the COQ items related to the PAF categories. These categories are used to develop the instrument and the data collection process associated with COQ quantification. In Sect. 4, the analysis of findings, results, and comprehensive discussions are presented. Finally, Sect. 5 presents the conclusion and recommendations of the current study.

2 Prevention, appraisal, and failure (PAF) Model

2.1 Visible COQ: the tip of the iceberg

PAF model classifies the COQ into the Cost of Conformance (COC) and the Cost of Poor Quality (COPQ). COC is positive while COPQ is the negative cost, as shown in Fig. 1. The COC consists of prevention and appraisal costs. Prevention cost is associated with the actions taken to ensure that a process provides quality products and services (Garg and Misra 2022; Schiffauerova and Thomson 2006). The appraisal cost is incurred in assessing the accomplishment of quality standards (Tawfek et al. 2012). Among these costs, prevention is most important as it can reduce every other quality cost. The famous "1–10–100

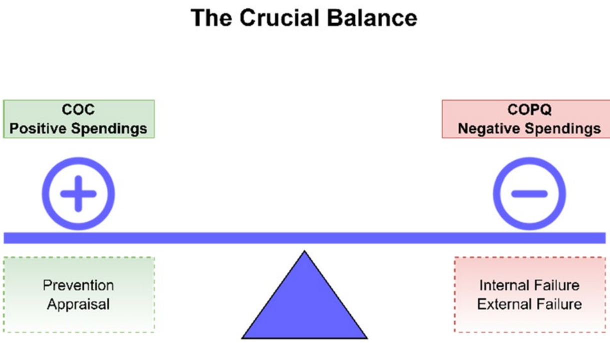

Fig. 1 The crucial balance between COC and COPQ

Rule" is widely used to explain the COQ (Teli et al. 2012). The rule states that prevention is less costly than correction, which is less costly than failure. Therefore, it makes more sense to invest $1 in prevention than to spend $10 on correction or incur a $100 failure cost. The rule is the same as the traditional medical axiom, "An ounce of prevention is worth a pound of cure." Accordingly, it is reported that by spending 1% extra on prevention efforts, the failure costs of construction can be reduced from 10 to 20% (Kazaz et al. 2005). However, it should also be noted that extravagant spending on COC may not always reduce the failures and associated costs (Tawfek et al. 2012).

COPQ is the cost of the product not meeting the requirement, also known as failure cost (Kazaz and Birgonul 2005). COPQ can be split into VF and HF. While VF is further divided into internal and external failures. The former occurs before dispatching, whereas later cost arises after dispatching the product to the client (Farooq et al. 2017). Both these failures must be carefully managed to minimize the overall COQ (Balouchi et al. 2019a). COPQ can have a detrimental impact on project constraints and dent the company's reputation and customer satisfaction (Sansalvador and Brotons 2017). It can also have a significant hidden cost component (HF) that is not straightforward to identify.

COC and COPQ do not share a linear relationship. After a certain point, the slope of the COPQ curve flattens and any further increase in COC may not help reduce the COPQ. Further, the efficiency of interventions made to avoid nonconformance depends on various factors. Hence some prevention or appraisal activities may not eliminate the failures (Giakatis et al. 2001). Therefore, balancing the COC and COPQ (negative and positive side) is crucial and should be carefully considered in project costings. It should be noted that the term "COQ" has varyingly been used in the extant literature. For instance, sometimes it is also referred to as the cost of conformance, the positive side (Garg and Misra 2022). So, to eliminate this clutter, the term COQ is used for the whole system in the current study, whereas COC is used for the cost of conformance.

American Society for Quality (ASQ) provides general guidelines about PAF classification (Campanella 1999). However, the cost items do not take the industry type into account. Hence, there is a need to categorize the main COQ cost items as per the construction projects (Balouchi et al. 2019a). Based on the previous research regarding COQ in building construction, different prevention, appraisal, and failure costs have been identified. As a result, 26 peer-reviewed research publications from different construction and project management journals published between 1999 and 2022 have been found relevant. This particular period is selected to focus on recent trends. Papers published in English, with full text available, and discussing quality costs in building construction are selected. The most common quality costs are shortlisted based on the frequency of appearance (F), as shown in Table 1. Identified cost items under different categories would occur in most building construction projects, but the specific activities that will fall vary for every project, i.e., the type of testing will be different for different types of buildings. As shown in Table 1, P_i and A_i represent Prevention and Appraisal costs, while IF_i and EF_i represent Internal and External Failure costs, respectively. The sum of every cost category is denoted with the summation sign (Σ).

2.2 Hidden failure: the base of the iceberg

COC is a tangible expense on quality conformance, whereas traditional failure costs (VF) are either visible or easily quantifiable nonconformance costs. However, they are only a part of the picture, or rather the 'tip of the iceberg,' since the VF costs are always followed by considerable hidden costs (Feigenbaum 1991; Rosenfeld 2009). These costs form a significant part of the quality costs and remain hidden like the immersed 'base of the iceberg' (Sansalvador and Brotons 2017). It is challenging to objectify and quantify HF accurately (Love and Irani 2003). Furthermore, HF have a ripple effect such that errors caused in one department can lead to work in another. Examples of HF include the cost of accelerating the project in case of delays due to failure, the cost of loss of sales if a poor quality product is delivered to customers, the cost of customer dissatisfaction, cost of productivity loss, and interruption in project flow due to failure events. It is important to note that there is a fine line between visible and HF, and the difference is not always clear. Spanish Association of Accountancy and Business Administration (AECA) defines HF as the costs which are not generally taken into account or are not recorded in the financial records (Sellés et al. 2008). Further, it is also recommended for each company to decide according to data availability and the nature of the cost.

Figure 2 is a modified visual of the HF iceberg, prepared specially for the construction industry. It has been adopted from Krishnan's (2006) original model. The shown cost items are shortlisted by a systematic procedure, explained subsequently. As shown in Fig. 2, failure events like reworks, design errors, and wastages can be captured and quantified using primary project data and site reports. Therefore, they are labeled as 'visible.' However, for instance, a faulty design that causes rework can trigger further events like disruption in the supply chain, construction delays, and quality degradation. These costs are not accounted for and captured as 'quality costs' since these are not 'directly' linked to a failure event. However, these would fade away if the particular event did not happen (Juran and Godfrey 1999). Therefore, they are labeled as 'hidden' (Sellés et al. 2008). Further, a single failure event can have multiple hidden costs associated with it.

Despite being difficult to quantify, HF is pertinent as it can hurt a construction company severely. Further, HF decreases profitability and productivity and is higher than all visible quality costs (Cheah et al. 2011; Mahmood and Ishaque 2013). Failure costs incorporating the HF can go beyond the estimated project budgets (Mahmood 2010). Mashwama et al. (2017) stated that HF could eat up to 40% of the revenues of a construction company. Likewise, Mahmood and Kureshi (2015) found that traditional quality costs are three times less than HF. Various researchers have attempted to quantify the HF in different industries. Cheah et al. (2011) implemented the COQ model on a wooden manufacturing company and found that the visible quality cost was 5.64%, while the HF was 8.78% of the total sales volume. Krishnan (2006) developed an HF model whose application to a packaging

Table 1 Identified quality costs in construction

COC							
$\sum P$	Prevention cost	Selected references	F	$\sum A$	Appraisal cost	Selected references	F
P_1	Training and education	Psomas et al. (2018b) and Mansor (2020)	17	A_1	Material laboratory inspection and testing	Shafiei et al. (2020), Mahmood and Ishaque (2013)	16
P_2	Accreditation of suppliers	Shafiei et al. (2020), Mansor (2020)	14	A_2	After build final testing	Özkan and Karaibrahimoğlu (2013), Malik et al. (2016)	14
P_3	Preparing quality plans	Heravi and Jafari (2014), Rosenfeld (2009)	13	A_3	Operating and maintaining quality equipment	Kazaz et al. (2005), Garg and Misra (2022)	14
P_4	Internal quality audits	Al-Tmeemy et al. (2012), Abdel-salam and Gad (2009)	10	A_4	Onsite inspection and testing	Hall and Tomkins (2001)	12
P_5	Quality manager	Yang (2018), Jafari and Love (2013)	10	A_5	External quality audits	Balouchi et al. (2019a), Giakatis et al. (2001)	10
P_6	Time invested in design review	Kazaz et al. (2005), Garg and Misra (2022)	9	A_6	Document reviews	Yang (2008), Mansor (2020)	5
P_7	Quality assurance staff members	Mansor (2020), Mashwama et al. (2017)	8	A_7	Evaluation of stock	Juran and Godfrey (1999)	3
P_8	New product/inventory review	Krishnan (2006), Juran and Godfrey (1999)	4				
P_9	Purchasing control planning	Yang (2008), Garg and Misra (2022)	4				
P_{10}	Root cause analysis	Juran and Godfrey (1999), Heravi and Jafari (2014)	3				
VF							
$\sum IF$	Internal failure cost	Selected references	F	$\sum EF$	External failure cost	Selected references	F
IF_1	Reworks	Balouchi et al. (2019a), Garg and Misra (2022)	26	EF_1	Warranty works	Heravi and Jafari (2014), Abdel-salam and Gad (2009)	18
IF_2	Scrap and demolition	Shafiei et al. (2020), Simpeh et al. (2012)	24	EF_2	Customer complaints	Tawfek et al. (2012), Psomas et al. (2018a)	18
IF_3	Repairs and corrective actions	Psomas et al., (2018a), Cheah et al. (2011)	14	EF_3	Legal costs and compensations	Mansor (2020), Barber et al. (2000)	11

Table 1 (continued)

VF							
$\sum IF$	Internal failure cost	Selected references	F	$\sum EF$	External failure cost	Selected references	F
IF_4	Variations due to failure	Balouchi et al. (2019a), Mahmood and Kureshi (2015)	14	EF_4	Penalties due to nonconformance	Shafiei et al. (2020), Giakatis et al. (2001)	8
IF_5	Material wastage	(Malik et al. 2016; Krishnan 2006)	13	EF_5	Revenue losses	Juran and Godfrey (1999)	6
IF_6	Failure analysis	Chatzipetrou et al. (2017), Mansor (2020)	9				

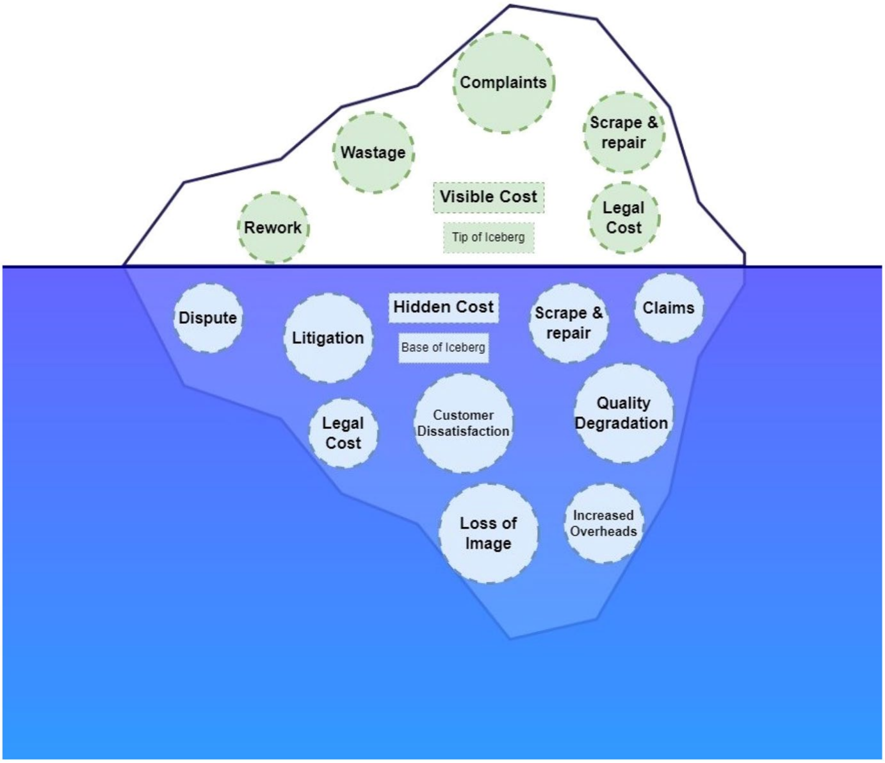

Fig. 2 COPQ iceberg for construction projects

company revealed that HF was a significant portion of total COQ. Giakatis et al. (2001) calculated the quality cost of a printing company and found that the HF are three times greater than the traditional COQ.

In construction, Mahmood and Ishaque (2013) applied the HF technique to a public-sector construction project and reduced the COPQ from 40.43 to 16.65%. Sellés et al. (2008) developed an HF model for the loss of the image of construction companies using fuzzy logic. Similarly, Mahmood and Kureshi (2014) designed a COPQ system and tested it on a single public sector project in Pakistan. The current study is also focused on Pakistan. It improves upon the existing body of knowledge by engaging a larger sample (25 buildings) and defining a more up-to-date and comprehensive framework to quantify the cost. However, there are only a few efforts to point out the HF in the construction industry. Furthermore, very few studies have quantified the HF and the VF on actual construction projects through primary data. This study attempts to compare the investments in quality by quantifying 'true failure costs' that include the both VF and HF in construction projects with maximum possible accuracy.

2.3 COQ quantification in construction

The unique nature of the construction industry, lack of management interest, incompetency of existing accounting systems, and lack of knowledge are the main barriers to managing

COQ in construction (Al-Tmeemy et al. 2012; Mahmood and Kureshi 2015). Despite these hindrances, a few case studies have attempted to determine the rework and quality failure costs in construction projects, as shown in Table 2. To assess the recent trends in the construction industry, the study period was restricted to 2000–2022. Most of the studies shown in Table 2 used the PAF model to estimate the COQ on construction projects. However, a dispersion can be seen in the values obtained, which can be reasoned by different factors. Firstly, due to the non-availability of a standardized approach for measuring COQ in construction, every study developed its own version of PAF and associated cost items. Secondly, the data collection technique varied significantly for every study. Some studies used qualitative data, while others used purely quantitative measures. For instance, Love et al. (2010) estimated the COQ based on a post-project questionnaire survey, while Hall and Tomkins (2001) used the quantitative data collected through continuous observations. The post-project questionnaire survey and interview technique have been criticized due to their dependence on the interviewees' memory (Hall and Tomkins 2001). Thirdly, every study used varying samples for data collection. For example, Garg and Misra (2022) collected data from 122 projects, while Mahmood et al. (2014) and Mohamed and Abdelhaleem (2019) based their study on a single project.

Further, the COQ value is highly dependent on the locality of the project, total allocated budget, construction technique, and type of project. Therefore, COQ values are higher in some countries and lower in others. However, referring to the crucial balance, the results shown in Table 2 at some places indicate that investment in COC seems productive. For instance, in the study conducted by Rosenfeld (2009), two companies that invested the lowest (0.99%) in COC got the highest COPQ (3.86% and 3.95%) among the eight studied projects. However, this may not always be true, and a range of other factors play their part in COPQ.

As previously mentioned, P and A represent Prevention and Appraisal costs, while IF and EF represent Internal and External Failure costs, respectively.

3 Research material and methods

The main objective of this study is to comprehensively quantify visible and hidden COQ in building projects using PAF and quantitative project data. For achieving this purpose, the study first identified and classified the cost items for the PAF model. As stated previously, various authors have already discussed the so-called visible part of COQ. Therefore, the classification of prevention, appraisal, and VF was done through a literature review, which has already been discussed in Sect. 2.1. A combination of a questionnaire survey and a literature analysis was used to identify the HF. The identified visible and hidden PAF cost items supported the development of a data collection instrument used to collect the demographic and cost data of 25 building projects in Pakistan. Data was analyzed in spreadsheets, and results were presented accordingly. A detailed discussion followed the results, and finally, conclusions were made, and the limitations of the study were discussed. Figure 3 illustrates the overview of the research methodology. The development of data collection instruments, data collection, and analysis are subsequently explained.

Table 2 Application of COQ in construction

Reference	Project	Location	Methodology	P	A	COC	IF	EF	VF
Garg and Misra (2022)	Various projects	India	Interviews	0.19–8%	0.05–5%	0.3–10%			0.01–5%
Mohamed and Abdelhaleem (2019)	Bridge	Egypt	Onsite observations			1.10%			0.44%
Mahmood and Kureshi (2014)	Road	Pakistan	Observation & interviews						15.07–36.44%
Marzuki and Wisridani (2014)	Multi-story building	Indonesia	Questionnaire survey & interviews	0.30%	0.88%	1.18%	1.03%		1.03%
				0.86%	1.79%	2.65%	1.03%		1.03%
				0.95%	2.32%	3.27%	0.55%		0.55%
Mahmood et al. (2014)	Road bridge	Pakistan	Observations using data collection form						40.43–16.65%
Jafari and Love (2013)	Monorail	Iran	Documents and interviews			2.78%	0.05%		0.05%
Love et al. (2010)	Infrastructure	Australia	Questionnaire survey				5.07%	5.22%	10.29%
Abdelsalam and Gad (2009)	Residential building	United Arab Emirates	Documents and structured interviews			0.60%	0.70%		0.70%
Rosenfeld (2009)	Residential building	Israel	Data collection form	0.67%	0.78%	1.45%	0.5%	1.59%	2.09%
				0.27%	0.72%	0.99%	1.34%	2.52%	3.86%
				0.35%	0.64%	0.99%	0.89%	3.06%	3.95%
				0.76%	1.4%	2.16%	1.08%	0.76%	1.84%
				0.51%	2.16%	2.67%	0.87%	1.06%	1.93%
				1.27%	0.47%	1.74%	0.56%	1.72%	2.28%
				0.75%	1.27%	2.02%	1.07%	0.87%	1.94%
				0.89%	0.89%	1.78%	1.05%	1.05%	2.1%
Kazaz et al. (2005)	High rise building	Turkey	Documents and questionnaire survey			17.70%			10.27%
Hall and Tomkins (2001)	Office building	United Kingdom	Onsite observations			12.68%			5.84%

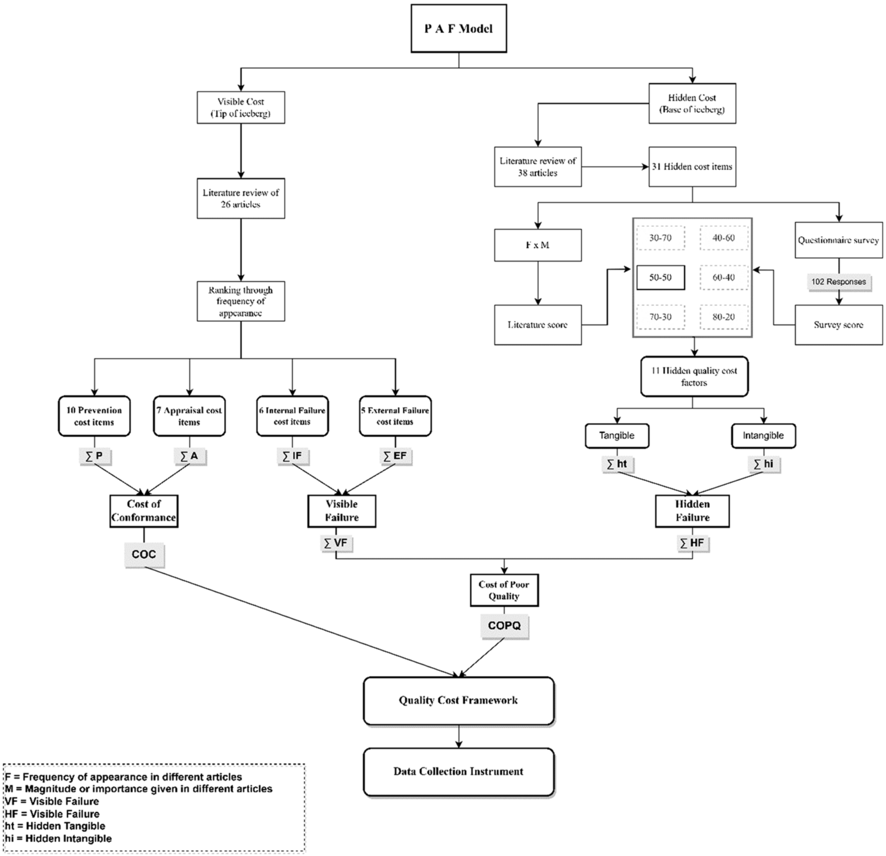

Fig. 3 Overview of research methodology

3.1 Identification of HF cost items

3.1.1 Literature analysis

As stated previously, there is a lack of literature on HF in construction. Therefore, the identification of HF items has been made more rigorously in this study. To begin with, studies conducted on HF in other industries and research on indirect impacts of common construction quality failures like rework, variations, delays, change orders, and cost overruns were consulted. A total of 31 cost items were inventoried with the help of 38 peer-reviewed research papers. To rank the factors, a literature analysis was performed. Every identified cost item was given a frequency of appearance score (F) and importance score (M), on a scale of 1 to 5, based on the importance given by authors in a particular study. The normalized product of 'F x M' resulted in a 'Literature Score' that was used for further analysis.

3.1.2 Initial questionnaire survey

Most of the items in this study were identified from a diverse range of studies that may or may not directly target HF in construction and may create a bias toward certain cost items. An initial questionnaire survey was developed to address this concern and solicit the significance of identified cost items from a construction perspective. The survey, developed in Google® Forms, consisted of two sections. The first section collected respondent information such as their qualification, position, job description, professional experience, and country of origin. The second section inquired about the importance of HF cost factors. The respondents were required to rate the HF factors on a Likert scale of 1–5 (1 = very low, 2 = low, 3 = medium, 4 = high, and 5 = very high) based on their experience. The survey was distributed to over 400 practitioners and researchers worldwide through email and social networking websites (Facebook, LinkedIn, Twitter, etc.). As a result, 104 responses were received, and 102 were found valid. The remaining two were incomplete and thus rejected. Based on the survey responses, a "Survey Score" by using the normalized Likert scale values was calculated.

3.2 Data collection instrument

All the visible PAF items from Table 1 were incorporated to develop the data collection instrument. First, six different weighting combinations of survey and literature scores were computed for shortlisting HF items. Then, an analysis of variance (ANOVA) was performed to check if there was any significant statistical difference between various combinations of these scores. The *p*-value (1.0) was insignificant, indicating no significant difference between different combinations. The middle 50–50 weighting combination was used to avoid any bias. The whole exercise resulted in 11 shortlisted HF cost items. Based on 39 (28 visible + 11 hidden) cost items, a project data collection instrument in the form of a detailed form, having three sections, was prepared. The first section collected the general project data such as description, location, budgeted cost, etc. The second section collected data about the quantifiable portion of COQ. This section was subdivided into different segments for ease of data entry as data may come from different related departments. In the final section, the data on intangible costs were collected and documented.

The respondents for this data collection included project personnel such as site engineers, quantity surveyors, and project managers. Where it was possible, accounts and procurement departments were also consulted. The respondents, who were directly involved in recording and providing data, were taken into confidence by assuring the anonymity of their personal and project information. The material, labor, and equipment costs incurred on correcting the nonconformance were calculated using the quantities from detailed estimates, while the intangible cost was worked out based on the judgment of respondents. This methodology is quite different from Love and Li (2000) and Love and Edwards (2005), who collected the data using post-project interviews. However, Hall and Tomkins (2001) have objected to such methodologies due to their dependence upon the memory of participants. Accordingly, the method applied in the current study is relatively more accurate due to its reliance on direct field data.

Using the developed instrument, 40 midrise building construction sites across the country were visited. Project managers, site engineers, and quantity estimators working on the building projects were approached. As a result, 25 building projects provided the required data, whereas the remaining either did not provide the complete data or refused to participate due to the sensitivity of their projects. The geographical distribution of selected projects is such that they represent the practices of the local construction industry of Pakistan. Being the largest province, Punjab shares the largest portion with 15 projects, followed by Islamabad Capital Territory (8) and Khyber Pakhtunkhwa (2). To collect more reliable and recent data, different projects in the execution stage or just recently completed were selected. To simplify the analysis, COQ was assumed to vary linearly throughout the project lifecycle. Finally, the whole data was analyzed and presented in terms of TPC percentage, and analyses were conducted accordingly.

3.3 Improvement to the PAF framework

The cost items of prevention, appraisal, internal failure, and external failure were defined based on Table 1. Further, a new category of 'HF cost' was introduced in the original PAF model to accommodate hidden costs. It was further divided into tangible and intangible hidden quality cost categories. This split helps differentiate between the portions based on the convenience of measuring. The improved PAF model used in this study is shown in Fig. 3. Finally, various equations (see Eqs. 1–6) were formulated based on the defined framework to calculate the different quality costs.

The COQ can be mathematically presented as

$$COQ = COC + COPQ \tag{1}$$

where

$$COC = \sum P + \sum A \tag{2}$$

$$COPQ = \sum VF + \sum HF \tag{3}$$

VF is a visible failure cost, while HF is a hidden failure cost. *VF* can be further defined as

$$\sum VF = \sum IF + \sum EF \tag{4}$$

where IF is an internal failure and EF is an external failure cost. Similarly, HF can be presented as

$$\sum HF = \sum ht + \sum hi \tag{5}$$

ht is hidden tangible, and hi is hidden intangible. Further, to present the results as a percentage of TPC, Eq. 6 was used

$$Cost\%ofTPC = \frac{Cost\ in\ question\ (PKR)}{\%\ of\ Project\ Completion \times TPC} \times 100 \tag{6}$$

The cost breakdowns of *COC* in the form of $\sum P$ and $\sum A$ are well established in the literature. Their measurement mechanisms and assessment techniques are also well-documented (Rosenfeld 2009; Krishnan 2006). The same is the case with the two constituent parts of *VF*; $\sum IF$ and $\sum EF$ (Sun and Meng 2009; Cheah et al. 2011). However, the introduction of hidden tangible (*ht*) and intangible (*hi*) costs of failure is the novelty of this study.

4 Results and discussions

4.1 Shortlisting of hidden quality costs

After successfully conducting the initial questionnaire survey, responses were sorted out, and the survey score was normalized. Table 3 gives a general overview of the respondents' demography. It can be seen that data is collected from experts with pertinent education and experience in the relevant areas of construction project management. This helps enhance the confidence in findings generated from the collected data. Afterward, spreadsheets were prepared by giving different weightings to literature and survey scores, as discussed in Sect. 3.1.

The reliability of data was checked through Cronbach's alpha, which resulted in $\alpha = 0.94$. Values of Cronbach's alpha above 0.7 show reliable data. This suggests that the collected data is highly reliable for further analysis. Based on it, the shortlisting of factors using the cumulative score was performed as given in Table 4. For shortlisting, a cut-off has been made on the 50% cumulative score, since it highlights the key cost items in the first 2 quarters, having 50% or more influence on the overall results (Ullah and Thaheem 2018; Ullah et al. 2016). A deeper analysis of shortlisted hidden cost items revealed that some cost items are subjective and difficult to quantify objectively. It has been highlighted by previous studies that HF can consist of intangible parts (Cheah et al. 2011). From a quantification point of view, which is the primary aim of this research, hidden quality cost factors can be divided into 'tangible' and 'intangible' parts (Rosenfeld 2009). Cost items like loss of image and customer dissatisfaction are perception-based. Therefore, they can

Table 3 General respondent demography

Respondent Demography		Frequency	Percentage
Education	Bachelors	53	52
	Masters	40	39
	PhD	9	9
Field of specialization	Construction	36	35
	Engineering	38	37
	Architect	6	6
	Project Management	22	22
	Others	40	39
Area of work	Industry	56	55
	Academics	46	45
Experience	Less than 1 year	25	25
	1–5 Years	58	57
	5–10 Years	11	11
	More than 10 years	8	8
Country	Pakistan	44	43
	Qatar	6	6
	India	7	7
	Bahrain	6	6
	Others	39	39

Table 4 Selected hidden failure (HF) cost items

Rank	Factor	Nature	Literature score	Survey score	Total score	Cumulative score
1	Waste of time/delays	Tangible	0.0901	0.0427	0.0664	0.0664
2	Loss/dissatisfaction of customer	Intangible	0.0901	0.0342	0.0621	0.1285
3	Variations	Tangible	0.0826	0.0342	0.0584	0.1869
4	Project cost overrun	Tangible	0.0676	0.0342	0.0509	0.2378
5	Loss of image	Intangible	0.0676	0.0342	0.0509	0.2886
6	Loss of future business/sales	Intangible	0.0631	0.0342	0.0486	0.3373
7	Disputes	Tangible + Intangible	0.0526	0.0342	0.0434	0.3806
8	Loss of productivity	Tangible	0.0405	0.0342	0.0374	0.4180
9	Quality degradation	Intangible	0.0405	0.0342	0.0374	0.4554
10	Litigation and claims	Tangible + Intangible	0.0450	0.0256	0.0353	0.4907
11	Lost opportunity cost	Intangible	0.0315	0.0341	0.0329	0.5236

be characterized as intangible (Sellés et al. 2008), while factors like delays and cost overrun are measurable through primary data with reasonable accuracy (Garg and Misra 2022), hence characterized under the tangible category.

Further, it is also observed that some factors, such as disputes and litigation, have both tangible and intangible portions, i.e., cost spent on sorting disputes (tangible) and loss of reputation (intangible). A portion of these costs can be calculated using data from documents and site reports, but these also consist of some intangible losses. Therefore, such factors are considered under both categories. To accommodate this in the data collection instrument, the tangible portion is calculated in the same objective way as the other cost items. Further, a structured questionnaire containing four questions about any quality failure that could trigger these costs is developed for intangible cost items.

4.2 COC versus VF

After a critical analysis of data, it was found that most of the projects (13) received investments of less than 1% of TPC in COC, while only a few projects (6) received more than 3% investment, as shown in Fig. 4. The maximum invested COC was 5.89% of TPC. This shows the lack of interest of local industry in implementing and scrutinizing COQ. This was expected as most participants revealed that their organizations neither formally calculate the COQ nor follow any particular COQ system. This was mainly because higher management in these organizations trusts their technical capabilities due to their experience. Further, there is an inherent reluctance to change due to rigid archaic regimes and mindsets. Hence, no need to spend extra to find out another cost was felt, which is what was reported by Cheah et al. (2011). It was also mentioned by Al-Tmeemy et al. (2012) that this lack of awareness causes the firms to invest low in COQ because they do not anticipate an attractive benefit. Further, it can also be seen that despite investing low in COC, many projects (8) do not incur much (< 1%) VF costs. Only seven projects incurred a high cost (> 3%). Bearing this in mind, it is interesting to see how COC and VF vary in different projects. Hence a subsequent analysis is carried out.

The comparison of COC with VF, as shown in Fig. 5, highlights that in almost half of the projects (12), invested COC is greater than the VF. It means that in these projects, companies have invested an adequate amount in quality and, as a result, got a low failure cost. However, Fig. 5 also reveals that projects that invested extravagantly (> 4%) incurred a higher failure cost than the project that invested significantly low (< 2%). Interestingly,

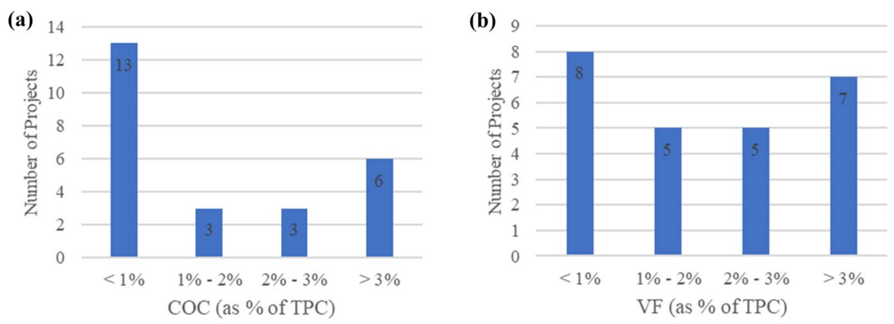

Fig. 4 % of TPC invested by various projects as **a** COC, **b** VF

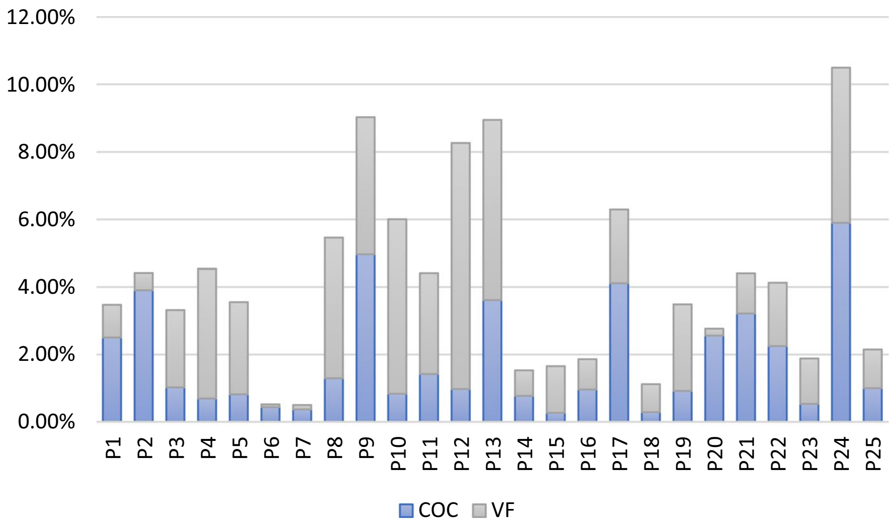

Fig. 5 A comparison of COC and VF in studied projects

some projects (7) that invested between 2 and 4% in COC got the lowest failure cost (1.68%). Further, it can be seen that projects P6 and P7 incurred the lowest visible COQ, which is 0.52% and 0.50%, respectively. The bars of these projects have more blue shades (representing COC) in them. This means that the major spending of these projects is on the positive side, i.e., COC, and lesser on failure costs. On the contrary, projects P2 and P21, despite spending a lot on COC, incurred a relatively higher overall COQ. These observations highlight the importance of the already discussed phenomenon of crucial balance.

The main aim of implementing COQ is to reduce the overall project cost by minimizing the failure cost and the COC (positive side). Therefore, while planning COC, the 'quality loss' factor should be considered (Chatzipetrou and Moschidis 2018). Quality loss is defined as the money spent because a conformance cost failed to deliver certainty and hence failures happen (Giakatis et al. 2001). Theoretically, COQ is minimized to the point where the COC equals the COPQ, as shown in Fig. 6 (Kazaz et al. 2005). The average VF (2.34%) for the given projects is greater than the average COC (1.83%) for all 25 projects. It lies on the left side of the quality conformance diagram, as shown in Fig. 6. This means that companies invest a larger part of COQ in correcting defects, which is highly unfavorable (Garg and Misra 2022). This VF always invites some extra fieldwork and hidden loss (Mahmood and Kureshi 2015).

To achieve the optimum value of COQ, innovative construction techniques and different interventions to avoid nonconformance should be chosen carefully. In this regard, Value Engineering (VE) can help optimize the cost and get the best value from the materials and products (Gunarathne et al. 2022). VE is a well-defined procedure to gain monetary value by delivering the same functions at the minimum costs with the required quality (Al-Fadhli 2020). VE aid in reducing financial risks by identifying unnecessary costs by improving or at least maintaining performance, reliability, and quality (Al-Ghamdi and Al-Gahtani 2022). The evidence shows that VE can help eradicate quality loss by evaluating the substitute design solutions at the early project stage. For instance, Arumsari and Tanachi (2018) found that VE could save up to 8% of TPC in high-rise buildings by delivering the same

Fig. 6 COQ versus quality level

quality if applied in the design phase. Therefore, the VE process can be carried out as a prevention activity to achieve cost effectiveness with required quality standards.

4.3 The impact of hidden cost: base of the iceberg

During the data collection process, it was discovered that most firms are only aware of the visible costs and do not bother to incorporate the hidden consequences of failures. Hence, they remain oblivious to the significance of the COQ system and its effects on project performance. This is in line with Sellés et al. (2008). Figure 7 highlights the seriousness of hidden costs or the 'base of the iceberg.' In most investigated projects, COPQ—incorporating the VF and HF—rose drastically and went beyond the invested COC. On average, the VF is 2.34%, while HF amounts to 8.59% of the TPC. This means that the majority part of the failure cost is never realized. As a result, failure cost, which seemed relatively a smaller percentage, is highly underestimated by stakeholders, contractors, and policymakers. Such underestimation can cause cost overrun, which is fairly common in construction projects (Ayat et al. 2021). The result represents a visible-to-hidden failure cost ratio of 1:3.67 (VF to HF), which nearly matches the assumption of Rosenfeld (2009), who used the factor of 4 for external and 2 for internal failure costs to adjust to HF costs.

Likewise, the HF is 2.06 times greater than the visible portion of COQ. This value falls between 3 (Giakatis et al. 2001) and 1.6 (Cheah et al. 2011). The COPQ rises from 2.34% to 10.94% of TPC by incorporating the HF, and the difference between COC and COPQ rises to 9.11%. This aggravates the situation as it further pushes the line toward the left of the optimum point on the quality conformance diagram shown in Fig. 6. With the incorporation of HF, the projects P9 (27.05%) and P23 (22.48%), shown in Fig. 7, surpass the projects P24 (10.50%) and P9 (9.01%), shown in Fig. 5, as the top 2 projects with the highest quality cost. In total, 8 out of 25 projects spent 15% or more cost on quality, which is a considerable amount when converted to monetary units. Practically, it can eat up the

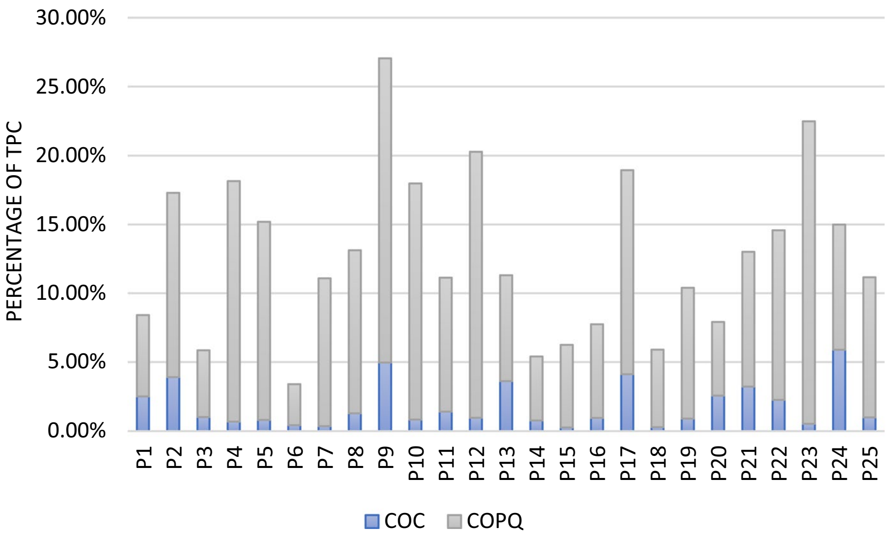

Fig. 7 Comparison of COC and COPQ

contractors' and subcontractors' profit margins and lead to reasonably low quality and poor workmanship.

Further, project P23 got the highest HF cost among all the projects. It is in a dispute with the local authority regarding interim payment and build quality. As a result, the project remained closed for four months, causing the contractor additional plan and equipment rental and labor costs. Also, the dispute with the client led to litigation which eventually painted a negative image of the contractor in the market. Further, project P6 (3.39%) has the lowest overall COQ, followed by P14 (5.41%).

The overall average COPQ amount turns out to be 10.94% indicating the poor performance of the local construction industry in terms of quality. COQ may seem to be a mere percentage of TPC, but in reality, it refers to the loss of image or the dissatisfaction of a loyal customer in a highly competitive market (Šatanová et al. 2015). Hence, it must be eliminated by enhancing quality management practices in local construction projects.

4.4 The total cost of quality

As shown in Fig. 8, the breakdown of COQ uncovers the expected outcome that the failure costs take up the largest share, with 67% as hidden (ht, hi) and 17% as visible (IF, EF) portion. Though EF cost is lesser, it will increase throughout the defect liability period as most of the studied projects were in the execution or closure phases. According to the definition, these costs occur when a defective product is delivered to the customer. On the other hand, COC only shares 14% of COQ, with significant spending (12%) on prevention activities. The low appraisal cost highlights the lack of quality checks and product tests in the studied projects. This implies that, despite adequate prevention measures, some errors may remain undetected and contribute to failure costs in the latter part of the project. Therefore, quality checks and audits should be performed regularly to identify nonconformance at an early stage.

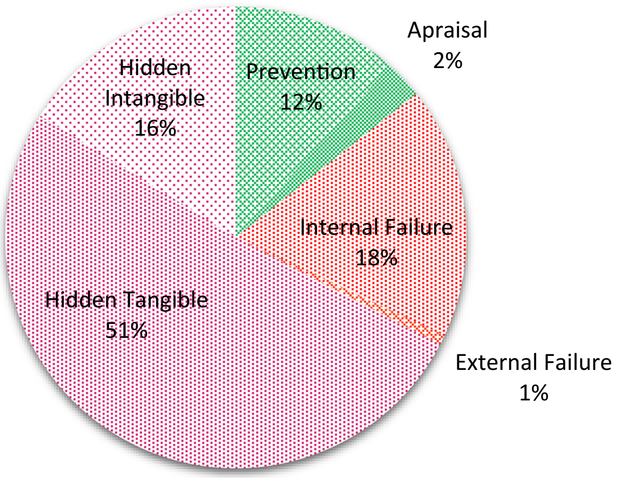

Fig. 8 Breakdown of COQ

Further, it is also observed that there was no dedicated QA/QC staff in some of the projects. Other project personnel, not possessing the required qualification or experience, were performing the additional duties of QA/QC. It highlights a huge area of improvement in the local construction industry.

The average COQ for all the projects is 12.76% of TPC. According to Abdelsalam and Gad (2009), this percentage is greater than the best COQ practices; around 1% of TPC. This could be because the local construction industry is more manual and labor-intensive, and there is no formal quality management in projects. However, when compared with the study of a building project in a highly developed country such as the UK (Hall and Tomkins 2001), the results are arguably closer. Although the COQ found by this study should be greater as the study is conducted in a developing country while incorporating the HF cost, the difference is in methodology. The above-mentioned study was conducted on a single building project, and site staff manually recorded nonconformance data from the start of the project to the end. On the contrary, the current study is conducted on a relatively larger sample with only a few interactions with the project key personnel. Therefore, some of the smaller events may be overlooked as they were never documented in the progress reports of studied projects. Thus, a true cost of failure may be slightly higher than the current findings.

As mentioned earlier, there is a large dispersion in COQ in previous studies, and it can range anywhere from 0.5% to over 18% of the TPC in residential and industrial building projects, as shown in Table 1. A similar disparity is found in the studied projects. Although the projects are quite similar in terms of the type of construction, localities, laws, and conditions, they still got a high standard deviation (5.84%). It signals that COQ depends on the project characteristics and some external factors, like firm culture and size, experience, etc. Therefore, the COQ technique should be implemented in light of other developed standards like TQM guidelines for effective quality management.

COC and COPQ also vary with project size, building height, and percentage completion, as shown in Fig. 9. In larger projects, these values are smaller in terms of the percentage of TPC but more significant in terms of money. For example, building projects having

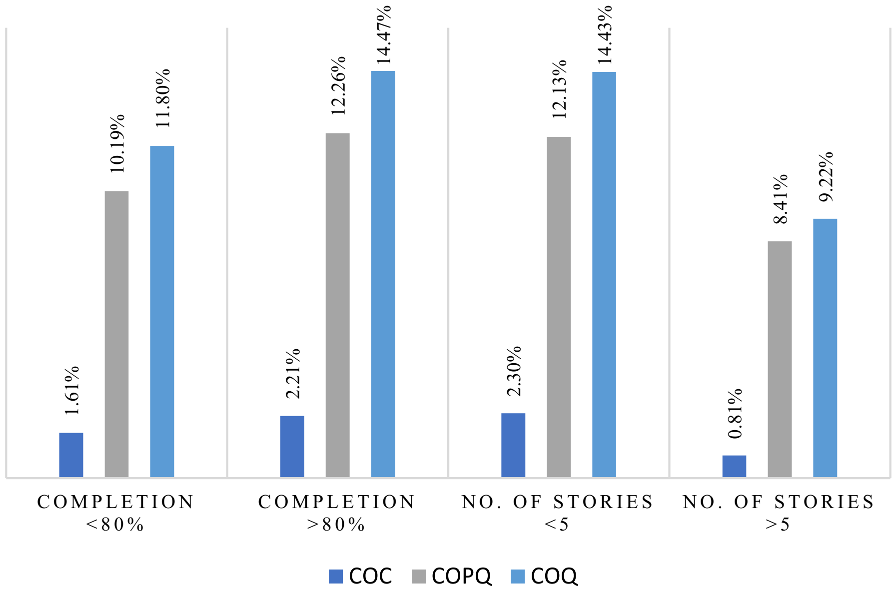

Fig. 9 Comparison of quality costs in various scenarios

more than five stories have a low COQ percentage (9.22%) compared to the opposite with 14.43%. Likewise, COC and COPQ are lesser in projects in the initial or medium stage and higher in projects that are either completed or in the finishing stage. This is because more valuable resources are utilized in the finishing and closure stages. As shown in Fig. 9, projects having completion of 80% or more have slightly higher COC (2.21%) and COPQ (12.26%) compared to 1.61% and 10.19% of the projects with less than 80% completion. This points out that the finishing and closure phases are crucial from a quality perspective and need more careful attention from all the project stakeholders.

4.5 The optimum value of COQ

In the classic view of PAF, the optimum value of COQ, as shown in Fig. 6, is such a lowest value of COQ above which benefits are marginal (Kazaz et al. 2005; Heravi and Jafari 2014). Finding the optimum level is not a simple task. Therefore, many methods exist in the literature and there is a remarkable difference between their results. Kazaz et al. (2005), Heravi and Jafari (2014), and Krishnan (2006) argued that finding the optimal value is not harmonized with the continuous quality improvement principle of TQM. Collected COQ data also unveiled that the optimum value would not be the same for different projects (even of similar nature). For example, after every failure event, the cause can be found by root cause analysis, which is a prevention cost. This will not only rectify the defect but will also prevent the future reoccurrence and will lead to improvement in optimum value in future projects.

We found a similar phenomenon; quality is not solely dependent on invested COQ. Not every prevention and appraisal activity needs to add value to the project. Thus, there will be some quality activities that will not be successful in achieving project objectives. Such activities are termed quality or opportunity loss (Giakatis et al. 2001; Cheah et al. 2011). Furthermore, COQ is also dependent on factors like labor skills, construction methods, and technical capabilities. For example, for firms with well-experienced labor and staff, investing in training for an already familiar work environment seems wasteful and will be termed a quality loss. The collected data demonstrate a similar trend; the invested COQ in project P3 is 3.9%, and the failure cost was 13.4%. On the contrary, in project P13, an investment of 3.62% caused only 7.7% failure, as shown in Fig. 7. Therefore, other relevant factors should also be considered while assessing the optimum value of COQ. Furthermore, such optimization is iterative and will keep evolving with the quality maturation of the organization.

5 Conclusions and recommendations

Being a developing country, construction is a valuable income-generating sector of the country but the local construction projects are infested with cost and time overruns, and poor quality. To eradicate these problems, regular and careful supervision of project quality performance is required. Adoption of COQ as a quality management tool can help identify the quality nonconformance at early project stages, thus improving the cost and quality performance of the projects. Accordingly, the current study applies the PAF model by identifying and quantifying the COQ to improve quality management practices.

The novelty of the study lies in the comprehensive categorization of PAF cost items (tip of the iceberg) and the hidden quality cost (base of the iceberg). An in-depth quantification of COQ using secondary data as previous studies on the construction industry was focused on the VF cost. For this purpose, a model was developed by adding a category of hidden costs to the conventional PAF. COQ data of 25 building projects were collected. The results support the assumption that hidden costs are greater than visible COQ. Accordingly, the HF cost was 2.06 times greater than the traditional visible quality costs. The findings highlight the poor performance of the local construction industry in terms of quality, incurring 12.76% of TPC as COQ. It was also discussed how badly COPQ can hurt an organization and how COQ data can be used to improve quality performance.

This study will help improve quality awareness since stakeholders would be aware of the impact of failures. It also proposed a modified quality framework for implementing COQ in building projects, as traditional accounting systems are inadequate to capture the quality cost. Contractors, engineers, surveyors, QA/QC experts, and site supervisors can use the modified PAF framework and data collection instrument to track the quality costs. Successful implementation can lead firms to achieve higher quality standards at a lower cost than their competitors. This will also help achieve more sustainable construction operations as it will reduce resource wastage by avoiding rework and change orders. This will help with the circularity and waste minimization goals of the modern era. Finally, we hope that this study and its framework will stimulate further research on quality in construction.

Although the current study has satisfactorily achieved the main objectives, some areas of improvement should be addressed by future research. First, the data was collected with a data collection instrument under limited interactions with the project personnel. Although this technique is more accurate than a questionnaire survey, a more accurate assessment can be done by regular observation of field data and by making quality cost an integral part of daily site reports. This can be aided through technological innovations to record site data automatically. Secondly, there was a severe lack of familiarity with the COQ concept in most organizations dealing with the studied projects. So, regular training should be provided to spread awareness. Likewise, the intangible part of the hidden cost was calculated by a semi-quantitative questionnaire method due to the subjectivity involved. Future research may develop a practical quantification proposal for different intangible factors. It is recommended that the design and bidding procedure should also be evaluated from the quality point of view, as the quality is not the concern of only the execution phase; planning and design have a significant impact on the quality achieved during the execution phase. VE is highly relevant to quality-cost tradeoff and found effective in construction projects but the extant literature on COQ did not mention it as a core quality cost item. Therefore, it is recommended to include the 'Cost of conducting VE' in the COC part of COQ framework.

Author Contributions All authors contributed equally to the study's conception and design. Material preparation, data collection, and analysis were performed by Nouman Khadim and Muhammad Jamaluddin Thaheem. The first draft of the manuscript was written by Nouman Khadim, Muhammad Jamaluddin Thaheem, Fahim Ullah, and Muhammad Nateque Mahmood and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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