A Prototype Project Management Quality Cost Information System

Peter E.D. Love [1]
Zahir Irani [2]

[1] We-B Centre,
School of Management Information Systems
Edith Cowan University
e-mail:p.love@ecu.edu.au

[2] Department of Information Systems and Computing
Information Systems Evaluation and Integration Network Group (ISEing)
Brunel University

Abstract

A prototype Project Management Quality Cost information System, PROMQACS, was developed to determine quality costs in construction projects. The structure and information requirements that are needed to provide a classification system of quality costs are identified and discussed. The developed system was tested and implemented, in collaboration with a leading Australian construction contractor, so that the information and management issues needed to develop PROMQACS into a software program could be determined. The system was initially used to identify the cost and causes of rework that occurred within selected projects being procured by the contracting organization. PROMQACS can enable project participants to identify shortcomings in their project-related activities so that they can take the appropriate action to improve their management practices in future projects.

Keywords

Quality costs, rework, project management, information system, prototype

INTRODUCTION

In construction projects activities are typically divided into functional areas, which are performed by different disciplines (eg, architects, engineers, and contractors) and that therefore operate independently. Invariably each discipline makes decisions without considering its impact on others (Love *et al*., 1999; Love, 2002a). Moreover, these functional disciplines often develop their own objectives, goals, and value systems. As a result, each discipline has become dedicated to the optimization of its own function with little regard to, or understanding of, its effects on the performance of the project with which they are involved. The interfaces that exist between functional disciplines have become a potential barrier for effective and efficient communication and coordination in projects (Lahdenperä, 1995). When a breakdown in communication is identified, the source of the problem can be typically traced back along the supply chain and it often becomes evident that there were 'informational flow mishaps' in the process. This is linked to information sharing and channeling.

Information that is inaccurate or delayed is seldom filtered and delegated to specified parameters. Consequently, quality failures often occur as a result of ineffective decision-making (Love *et al*., 1999). This is often exacerbated by the absence of an integrated and systematic information system (IS) to support quality management (QM) activities in construction projects. The absence of such a system has caused many organizations to develop local insular ways to maintain control over their own domains of responsibility. Thus, information gathering, reporting, and management in a project become uncoordinated and multiple re-drawing and re-keying of information must be undertaken. Ultimately, this leads to time waste, unnecessary costs, increased errors, and misunderstanding, and thus rework, which has been found to be the primary factor of time and cost overruns in construction projects (Love, 2002b). Furthermore, the ineffective use of information technology (IT) in managing and communicating information exacerbates the amount of rework that occurs in a project (Love, 2002a,b). There is therefore a need for an IS that can be used to manage quality so that the performance of organizations can be monitored and quality costs determined. This will enable organizations to determine their quality failure costs (in particular rework) and therefore implement strategies for preventing it. The design and development of quality costing systems for construction projects has been limited, to date, because of the complexity associated with having to manage information from a number of organizations with different approaches to managing quality.

QUALITY COSTS

To acquire knowledge and learn about quality costs, a project quality IS should form an integral part of an organization's approach to managing its construction projects (Barber *et al*., 2000). To do so, it is necessary to collect, measure, and analyse quality. However, this is complex and problematic, because of the sheer number of activities and organizations involved with procurement. Organizations vary in size and technological capabilities, and this makes it difficult to manage project-related information, particularly data about quality costs. In fact, many construction organizations have no system in place or even collect quality cost data.

A project management IS with quality costing module added could provide the project team members and clients with information about quality failures and the activities that need to be designed to prevent their future occurrence. This can then be used to suggest quality improvement initiatives directed at achieving significant cost savings and quality breakthroughs. Quality related costs have been found to range from 5% to 25% of an organization's annual turnover or operating costs (Dobbins, 1975). Of this, 90% is expended on appraisal and failure costs (Hagan, 1985). According to Dale and Plunkett (1990) quality costs can be reduced by a third when a cost-effective QM system is implemented.

Calculating Quality Costs

There are numerous methods for calculating quality costs. For example, costs can be classified as either: cost of conformance or non-conformance. Conformance costs include: training, indoctrination, verification, validation, testing, inspection, maintenance, and audits. Non-conforming costs include: rework, material waste, and warranty repairs. However, the most widely accepted method of determining quality costs in construction is the traditional prevention-appraisal-failure (PAF) model, which classifies costs as follows:

- *Prevention* - all amounts spent or invested to prevent or reduce errors or defects, that is, to finance activities aimed at eliminating the causes of defects;
- *Appraisal* - the detection of errors or defects by measuring conformity to the required level of quality: issued architectural and structural drawings, work in progress, incoming and completed material inspection (eg, reinforcement, door hardware etc);
- *Internal failures* – due to scrapping or reworking defective product or compensation for delays in delivery; and
- *External failures* – after the delivery of a product to the customer: costs of repairs, returns, dealing with complaints, and compensation.

These relate only to preventing and correcting errors of a poor product/service quality. In fact, they only represent the direct, tangible, and visible portion of the costs. Some quality costs can be estimated with a high degree of precision, while others can be only estimated. As Banks (1992) points out, costs will rise as more time is spent on prevention. As processes improve, appraisal costs should then reduce, as inspection is no longer necessary. Thus, the greatest savings could be derived from reducing internal failure areas. Campanella and Corcoran (1983) suggest that increases in expenditures will not show immediate reductions in failure costs, primarily because of the time lag between cause and effect. Appraisal and prevention costs are unavoidable costs that must be borne by design and construction organizations if their products/services are to be delivered 'right' the first time. Failure costs, on the other hand, are almost avoidable in construction, as most originate from ineffective management practices.

Notably, quality costs can account for 8% to 15% of total construction costs (Lam, 1994). The Construction Industry Development Board (CIBD) in Singapore, for example, stated that an average contractor was estimated to spend be 5% to 10% of the project costs doing things wrong and rectifying them (CIBD, 1989). They concluded that an effective QM IS would cost about 0.1% to 0.5% of total construction cost and produce a saving of a least 3% of total project cost (about five times the original outlay). Studies have shown that more than 25% of the costs can be cut through the use of an effective quality program (Hart, 1994). This clearly points to the importance of knowing how to prevent recurrence, not only benefiting the contractor, but also the client and end-users. Roberts (1991) in Australia found that by spending 1% more on prevention, failure costs could be reduced from by a factor of five. Direct costs are readily measurable, often quoted in evaluating quality of workmanship, and represent a significant proportion of total project costs. Indirect costs are not directly measurable and include loss of schedule and productivity, litigation and claims, and low operational efficiency (Love, 2002b). In addition, labour costs for QM, which includes full-time QM personnel and others occasionally involved with quality-related activities, need to be identified.

PROJECT MANAGEMENT QUALITY COST INFORMATION SYSTEMS

Several quality costing project management IS have been developed and implemented to determine quality costs: Quality Performance Management System (QMPS), Quality Performance Tracking System (QPTS) (Davis *et al*. 1989), and Quality Cost Matrix (QCM). However, these have been restricted to testing in the USA and UK and thus can not be directly implemented in construction projects in countries, such as Australia, with cultural and other differences in the way that projects are procured and information is organized and managed.

Quality Performance Management/Tracking System

Patterson and Ledbetter (1989) used the QPMS to track the cost of QM by activity on four projects. They assumed that direct rework costs were 12.5% of project cost and found that quality costs were 25% of project cost. The cost of rework was then related to the QM cost by the cause of the error. While this system was simple and flexible, it did not consider the effect of failure on time-related cost. In addition, the system did not identify specific causes of failure. The QPTS, an updated version of the QPMS, was developed to characterise quality cost for the purposes of quantitative analysis and tracking deviations. Here deviation costs included rework, impact, liability, and warranty work. To track a quality failure a series of questions needed to be asked, such as: what subcontract? Who was affected? What was the cost? When was it detected? Who was the cause? What QM involvement was there? What type was it? In the QPMS, quality failures are characterised by type, cause, and time of detection. In categorizing QM activities, Davis *et al*. noted that the definition of QM varies from one design firm to another, and the distinction between design practice and QM is blurred. So if any QM activity is repeated because of an earlier failure, its cost becomes part of the failure cost and not QM cost. For example, if formal design and drafting checks/reviews, constructability reviews, and inspections were needed again, then they would be included as a failure cost.

Willis and Willis (1996) used a case study to test the QMPS system on a heavy industrial project. They found that the total quality cost of quality (TQC), the cost of prevention and appraisal plus the cost of failure and deviation correction, was 12% of total labour expenditures for design and construction. This was made up of 8.7% prevention and appraisal and 3.3% deviation correction. Willis and Willis (1996) found that internal and external examinations accounted for 76% and 12% of prevention and appraisal costs, respectively. In addition, the sources of deviation correction causes were attributable to design error (38%), vendor error (30%) and designer change (29%). Willis and Willis (1996) suggest that prevention and appraisal techniques were effective in reducing deviation corrections. They were able to show that more emphasis on prevention activities could reduce appraisal and internal failures. Ultimately, the goal of an organization should be to eliminate failure/deviation correction costs and prevention and appraisal expenditures at the same time.

Quality Cost Matrix

Abdul-Rahman (1993) acknowledged the limitations of the QPTS and developed a quality cost matrix (QCM), which took into account the effect of a failure on time, particularly, the costing of accelerating work and specific causes of a non-conformance. The QCM sought to address the following questions:

- What category of non-conformance should be used and which activity is affected?
- What is the specific problem?
- What is the cause of the problem?
- How long will it take to rectify the problem?
- What is the cost to remedy the situation?
- Is any other cost spread elsewhere?

Each of these formed a category of the QCM. Defect notices, daily reports, site instructions and variation orders coupled with interviews with key site personnel were used to identify non-conformances in selected engineering projects. In a water-treatment plant 62 non-conformances were identified. These were found to account for 2.5% of contract value. Not all non-conformances could be identified due to resource constraints and availability of site personnel. Thus, Abdul-Rahman states, "assuming that the rate at which the cost of non-conformances occur is constant throughout construction then the total cost of non-conformance is estimated to be 6% of the estimated project cost." This figure did not reflect the full extent of rework that occurred, as many client-initiated variations were not included. Design errors or omissions contributed to 30% of the cost of non-conformance. Three construction-related costs were identified. These were associated with, the subcontractor, coordination and planning, and construction.

The three most frequent non-conformance categories were design-related, construction/workmanship, and subcontractor related. As organizations in construction generally do not have information about quality costs, the implementation of a quality cost IS is likely to be met with resistance: it will result in additional work for personnel, especially, the supervisor, project manager, and contract administrator.

DESIGN OF PROMQACS: A PROTOTYPE

The authors approached a contracting organization that was recognised nationally as a leader in the implementation of QM systems. In fact, it was the first building and construction company in Australia to be certified to comply with ISO 9000 (as well as AS 3901 and AS 2990 Category A). A contracting organization was selected as they are the typical interface between design and construction in a project. We assumed that a quality cost IS could be designed from information made available to the researchers by them. The authors contacted senior management to explain the nature and purpose of the research. It was found that the organization was interested in ascertaining the costs of rework and its causes. The national quality manager reported that they had been monitoring these costs since the introduction of their quality assurance system and had managed to reduce them from 5% to less than 0.5% of contract value (Lomas, 1996). The contracting organizations expressed a keen interest in developing a system to determine rework costs but were reluctant to provide information to the world at large, particularly prevention and appraisal costs. Consequently, the information needed was *only* made available to the researchers. Two projects that were about to start were selected to test PROMQACS. These were a *residential building*, that had a contract value $A10.96 million, and construction period of 43 weeks, and a *warehouse building* – which had a contract value of $A4.45 million with a construction period of 30 weeks. The contractor approached the consultants involved with both projects and asked if they would be interested in becoming involved in the research. The consultants were reluctant to divulge information regarding their quality costs. However, they did consider the research to be important and therefore volunteered to assist the researchers identify and categorize rework costs in the selected projects. Before a quality cost software program could be developed for construction projects, the information to support it had to be available within the project system. In addition, accessibility to information from various organizations involved in the projects was another factor to be considered. In collaboration with the site management teams and consultants who had expressed interest in the research, the information to determine rework costs was categorized into a series of modules, as shown in Figure 1.

A database developed in Microsoft Access®, was incorporated into the contractor's project administration software package. All parties involved, prior to its start, agreed that the information contained within PROMQACS was for 'information purposes' only and therefore was by no means contractually binding. The consultants had no information technology (IT) infrastructure in place. Consequently, the database was distributed via e-mail on a monthly basis to each project's client's representative, architect, structural engineer, and quantity surveyor. This allowed each party to check the accuracy and reliability of each rework event identified. In some instances there were discrepancies, but these primarily related to responsibility and costs of rectification. In these, a nominal value was inserted and the organization that was involved with undertaking the rework was considered to be responsible. However, it should be noted that this is not always the case. Ideally, PROMQACS should be supported by a centralised project management IS, whereby all parties have access and therefore can make a contribution to its implementation. However, the low usage of IT by the construction industry has meant that such systems have yet to become part of everyday work practices (Deng *et al*., 2001).

What was the problem?

This was used to describe the specific problem and date when it was recorded. The contract documentation was used to identify this. However, the date does not necessarily show when the rework actually occurred or when it was identified, but is the date it was formally recorded by a member of the site management team.

What subcontract trade?

This information is used to identify areas were corrective action could be undertaken to prevent future problems. It can also identify the number of subcontractor trades involved in a particular quality failure event. Data about each subcontract value and program was can also be found from the contractor, as it is available from the project administration IS.

Who was the cause?

Rework caused by a project team member may add quality costs to other participants. Though, this does not always imply blame. For example, a detailed design without complete information may be considered appropriate, given the degree of uncertainty associated with complex projects, and then it is inevitable that some rework will occur. However, it is also inevitable that some participants will have to take responsibility for the rework and bear its financial cost. The participant who is allocated the direct cost of rework can be identified by examining the contract documentation and the contractor's project administration system. Burati *et al*. (1992) specifically noted that the task (organization) that causes the rework to occur should be charged the costs for rectification, regardless of what other tasks are affected.
How did it affect time?
Non-productive time is waste. It consists of *inactivity* and *ineffective* work. Inactivity includes waiting time, idle time, and travelling. Ineffective work includes rectifying mistakes and errors, working slowly and inventing work. The aim of this category was to determine the amount of non-productive activity associated with rework. In both projects, the project manager's assistance was required to identify the effect that rework had on each project's construction programme. For example, time waiting for design queries to be answered, rectification time, and delay (effect on the project's critical path).

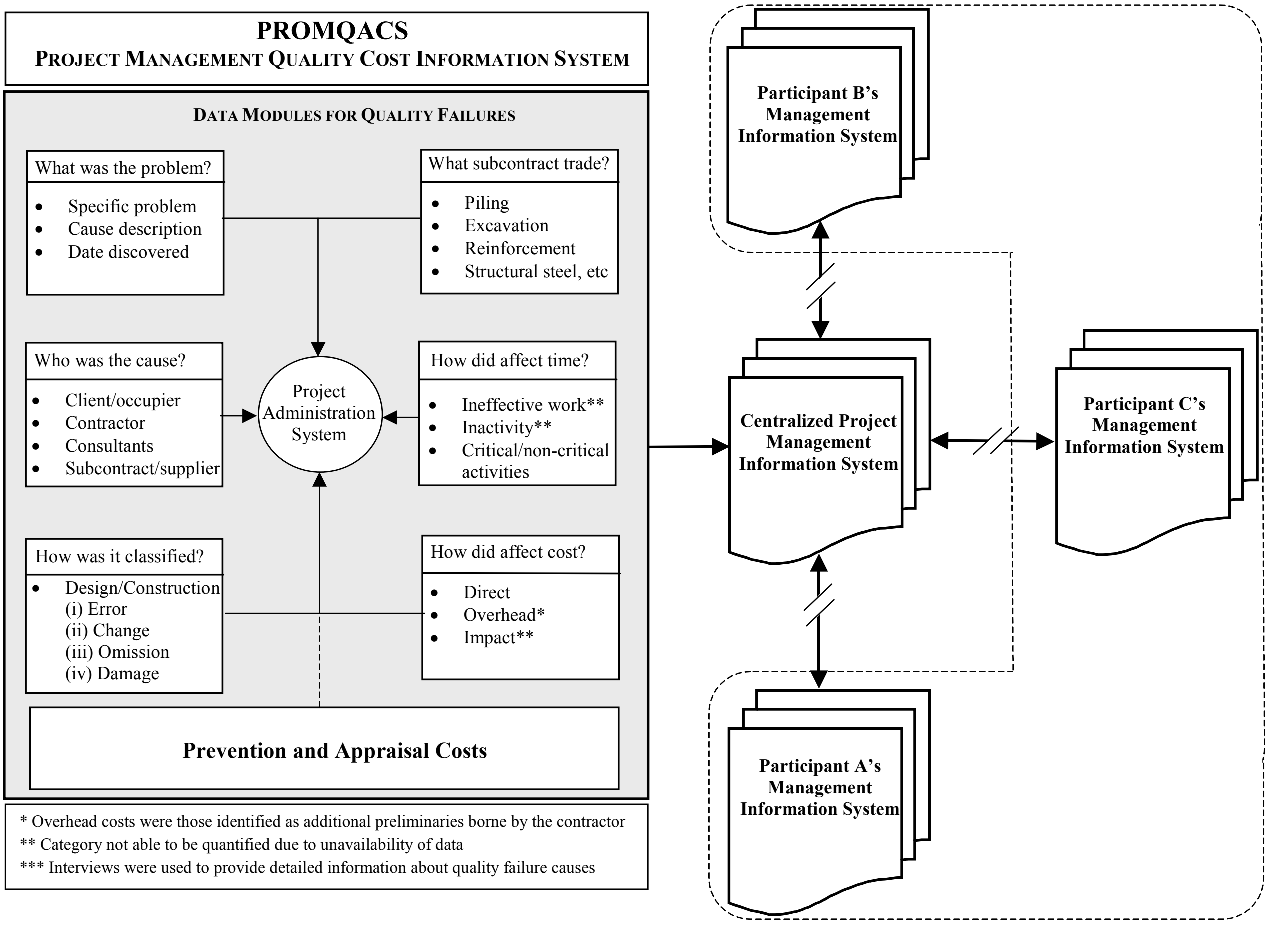

Figure 1. The architecture of PROMQACS

How was it classified?

A three-tiered categorisation system that was adapted from Farrington and Burati et al. (1992) in Table 2 was used to classify the types of rework identified. The first level refers to phases of the project that were affected, that is, pre-planning, design, construction, procurement, construction start-up, operation, and disposal. The second level is used to determine the type of rework, that is, a change or an error. A change is essentially a directed action altering the currently established requirements. Changes can affect the aesthetics and functional aspects of the building, the scope and nature of work, or its operational aspects. A design-change-client, for example, would indicate that a client would initiate a change to the design of the building and therefore results in rework due to a redesign. An error and omission is any departure from correct construction (including checking and supervision) technical inspection; and absence of adequate instructions for maintenance and operation of the building (Knocke, 1992). Each category is mutually exclusive and therefore rework can only be attributed to a single category. In addition to Farrington's initial classification system the categories of construction damage, and construction change improvement were added due to recommendations made by the contractor's project manager.

Table 2 Rework categorisation costing system definitions

Category	Type	Tertiary	Descriptor used
Design	Change	Construction	A change is made at the request of the contractor
		Client/Client Representative	A change made by the client/clients representative to the design.
		Occupier	design change initiated by the occupier
		Manufacture	A change in design initiated by a supplier/manufacturer
		Improvement	Design revisions, modifications and improvements initiated by the contractor or subcontractor.
		Unknown	
	Error		Errors are mistakes made in the design
	Omission		Design omission results when a necessary item or component is omitted from the design.
Construction	Change	Construction	A change in the method of construction in order to improve constructability.
		Site conditions	Changes in construction methods due to site conditions
		Client/Client Representative	A change made by the client/clients representative after some work has been performed on-site.
		Occupier	Occurs when a product or process has been completed
		Manufacture	Process or product needs to be altered/rectified
		Improvement	Contractor request to improve quality
		Unknown	
	Error		Construction errors are the result of erroneous construction methods procedures
	Omission		Construction omissions are those activities that occur due to omission of some activities
	Damage		Damage may be caused by a subcontractor or inclement weather

How did it affect cost?

This category sought to determine the direct cost of rework. They are typically captured in a traditional accounting systems used in projects but are not identified as rework. Thus, rework may appear as a variation, which forms an accrual cost in a contractor's project accounting system. Impact costs are an additional element of rework. A delay or disruption caused by rework may have a detrimental effect on another activity producing a 'ripple effect' (Love, 2002b). According to Besterfield (1979), liability costs may also be associated with rework. This includes legal, insurance, and liquidated and ascertained damage. Overhead costs were those identified as additional preliminary costs borne by the contractor.

Table 3. An example of rework data collected for mechanical subcontract package

Date	Event Description	Comment	Subcontract Trade	Failure	Classification			Non-productive time	Effect on construction programme	Cost of rework incurred	Cost Allocation
				F1 - Internal F2 - External	*Category*	*Type*	*Tertiary*		(*Critical path*)		
24-Jun	Clashes on site between hydraulic and mechanical service ducts and partitions. Ducts were in the line of the partitions. The ducts of two floors were removed.	This occurred because the setout was changed and walls were rearranged.	Mechanical	F2	Design	Change	Unknown	1 day	-	$500	Client
16-Apr	**Variation # 43**: Revised A/C equipment schedule. A/C redesigned. Extra AHU required for air capacity. It had not been deemed sufficient for the initial supply.	Did not affect the programme because the error was detected well in advance of the work commencing.	Mechanical	F2	Design	Error	Unknown	2 days	-	$28 569	Client
1-Oct	**Variation # 184 - Unit 118:** Ventilation to fans in the laundry to duct the dryers. After the apartment was almost complete purchaser requested ducting. At the beginning the client was not informed by the architect that ducting was needed.	Insufficient information.	Mechanical	F2	Design	Change	Improvement	2 days	-	$1 711	Client

TESTING AND OUTPUTS OF PROMQACS

Data was collected from the date when construction started on-site to the end of the defects liability period. Therefore, the rework costs only take account of those that emerged on-site during the production process. A variety of sources were used to identify rework events. Interviews, observations, and documentary sources, such as, variation registers, site instructions, requests for information, final accounts, progress reports, and extension of time claims, in conjunction with the contractor's project administration system, were used to corroborate the data entered into PROMQACS. No liability costs were identified in either project and therefore this category was not included.

The system was able to produce a variety of outputs. An example can be seen in Table 3. Under each main heading there are a series of drop-down boxes that a system user can select when making an entry. The event description and general comments require the user to have acquired some history of the rework event and therefore a brief description had to be inserted. Where possible, reference had to be made to project documentation, so that additional information about the rework incident could be provided. For example, in the case of Variation 43, in Table 3, a user of PROMQACS is directed to additional documentation, should the need arise.

With having a centralized project management IS in place, all information regarding contract variations, requests for information etc., would be stored on a central database that project participants can access. Some contracting organizations such as Bovis-Lend-Lease have developed their own centralized project management system and therefore require subcontractors and consultants to implement their own IS architecture and infrastructure, which is compatible with theirs, if they are to work with them as a part of the project team. As many Australian construction firms have to develop an IT infrastructure and embrace quality costing, the implementation of such a system simply restricts the practice of IS to the task of 'information transfer' in projects and therefore is ineffective in providing means for inter-organizational learning and process improvement.

The system architecture within PROMQACS is be used to determine the various causes of rework that occurred. The output displayed in Table 4 presents a breakdown of the causes and costs of rework in accordance with a pre-defined classification system. Here it can be seen that quantifiable measures (that can be used as benchmark metrics) can be produced from the system, and as a result the causes of rework identified. Furthermore, the subcontract trades were the rework occurs can be identified with those parties responsible for its costs. Knowing such information is vital if the performance of organizations and projects are to improve.

Table 4. Rework costs within each category and type

Category	Type	N	Min	Max	Cost of Rework ($)	Rework Costs (%)	Mean Cost ($)	Std. Deviation ($)
Design	Change	65	150	28 569	182 893	53.70	2 813	5 763
	Error	12	500	37 541	59 233	17.40	4 936	10 440
	Omission	2	3 000	3 837	6 837	2.00	3 418	591
Construction	Change	14	155	43 407	72 979	21.40	5 212	11 484
	Error	120	50	2 000	19 514	5.75	162	339
	Omission	2	380	380	760	0.20	380	-
	Damage	3	500	2 000	3 288	0.97	1 096	796
	Total	**218**			**$345 504**	**100%**		

Table 5. Rework costs within each tertiary level category

	Design (Type)			Construction (Type)					
Tertiary Level	**Change ($)**	**Error ($)**	**Omission ($)**	**Change ($)**	**Error ($)**	**Omission ($)**	**Damage ($)**	**Rework Costs (%)**	**Total**
Improvement	97 125	-	-	10 000		-	-	31.00	107 125
Construction	38 614	-	-	2 400	5 000	-	-	13.31	46 014
Site conditions	-	-	-	-	-	-	-	-	-
Client/ representative	3 047	-	-	1 000	-	-		1.17	4 047
Occupier	44 107	-	-	59 599	114	-	788	30.27	104 608
Manufacture	-	-	-	-	-	-	-		
Unknown	-	-	-	-	-	-	-		
Not Applicable	-	59 233	6 837	-	14 400	760	2 500	24.17	83 370
Total	**182 893**	**59 233**	**6 837**	**72 979**	**19 514**	**760**	**3 288**	**100**	**345 504**

CONCLUSION

The purpose of this paper was to discuss the design of a prototype project management quality costing IS. A review of the quality cost information systems that have been developed was presented and discussed. The development process of PROMQACS included the problem identification, design of the information architecture and the testing of the system to determine the type of information needed so that it could be implemented in practice. While PROMQACS can be used to determine quality costs, the lack of information made available by organizations during the testing phase meant that the research focused on rework (often considered as a quality failure). The information architecture was considered to effective by participating organizations for determining and managing quality costs in projects. In fact, the testing of the system has enabled a series of benchmark metrics to be developed. A challenge facing PROMQACS is its development into an effective software program that all organizations involved with a project can use.

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