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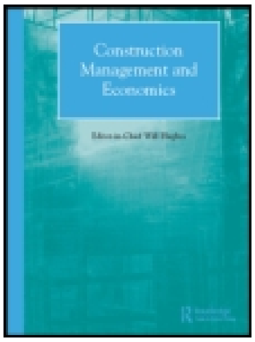

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Quantifying the causes and costs of rework in construction

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Very few construction companies and consulting firms in Australia measure their costs of quality. Consequently, it is difficult for them to prove that systems for preventing quality failures are cost-effective. Although the direct costs of a quality system can be quantified with some accuracy (salaries, costs of documentation, audits, etc.), the corresponding benefits are far more difficult to assess. Indeed quality failures have become an endemic feature of the procurement process in construction and invariably lead to time and cost overruns in projects. Thus, in order to improve the performance of projects it is necessary to identify the causes and costs rework. The research presented in this paper quantifies the causes, magnitude and costs of rework experienced in two construction projects that were procured using different contractual arrangements. The causes and costs of rework projects are analysed and discussed. The findings reveal that the cost of rework for the case study projects was 3.15% and 2.40% of their project contract value. Changes initiated by the client and end-user together with errors and omissions in contract documentation were found to be the primary causes of rework. It is recommended that construction companies and consultant firms (particularly design consultants) implement quality management practices as well as place emphasis on coordinating project documentation during the design development process so that the amount of rework in projects can be reduced or even eliminated.

Keywords: Australia, QA, quality costs, prevention, rework

Introduction

To improve the performance of construction organizations and reduce costs, Davis *et al.* (1989), Abdul-Rahman (1993) and Low and Yeo (1998), have stressed the need to measure quality costs. In Australia, however, very few construction companies and consulting firms have in place systems for assessing their quality costs (Bhuta and Karkhanis, 1995). Moreover, quality tools and techniques that can be used for improving performance are rarely used. This is because many construction companies and consulting firms have embraced that concept of quality solely from the perspective of quality assurance (QA) as it is a requirement for government related contracts (Love and Li, 1999). In fact, recent research has found that effectively, QA does not improve an organization's competitiveness and performance (Terziovski *et al.*, 1997). Only when a continuous improvement philosophy is used in conjunction with an effective QA system will organizational performance improve significantly (Oakland and Aldridge, 1996). Without an effective quality cost system in place, performance improvements can be very difficult to identify and measure.

The Construction Industry Development Agency in Australia (CIDA, 1995) has estimated the direct cost of rework in construction to be greater than 10% of project cost. Thus, if a 10% rework value applied to the annual turnover of the Australian construction industry which in 1996 was estimated to be $43.5 billion per annum (DIST, 1998), then the cost of rework could be estimated to be $4.3 billion per annum. Unfortunately the lack of attention to quality in construction has meant that quality failures have become endemic features of the construction process. This paper extends the research reported by Love *et al.* (1999a) which determined the causal structure of rework by quantifying the causes, cost, and magnitude of rework that were experienced in two construction projects.

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Previous research

Research undertaken by Cnuddle (1991) determined the failure costs in construction by investigating the amount of non-conformance that occurred on-site. Cnuddle (1991) found the cost of non-conformance to be between 10% and 20% of the total project cost. Furthermore, it was found that 46% of total deviation costs were created during design, compared with 22% for construction deviations.

The Building Research Establishment in the UK (BRE, 1981) found that errors in buildings had 50% of their origin in the design stage and 40% in the construction stage. In 1987 the National Economic Development Office conducted a survey (NEDO, 1987) which aimed to identify ways of improving quality control in building projects. It was revealed that the main factors that influenced quality were attributed to design (e.g. lack of coordination of design, unclear and missing documentation) and poor workmanship (e.g. lack of care and knowledge). A further study was undertaken by NEDO in 1988, and these findings were almost identical to the previous year's study.

Burati *et al.* (1992) collected data on quality deviations from nine industrial engineering projects. The aim of their study was to determine the causes and degree of quality problems in both design and construction. According to Burati *et al.* (1992), the cost of quality deviations can be as high as 12.4% of project cost. In fact, they suggest that the additional cost to construction caused by rework may be even higher because often these do not include schedule delays, litigation costs and other intangible costs of poor quality. They found from their research that 79% of total deviation costs were created during design, compared with 17% for construction deviations.

Hammarlund and Josephson (1991) suggested that a large part of the failure costs found in construction projects are attributable to the poor skills of site management. From their study they found the major causes of quality failures in order of precedence to be: defective workmanship, defects in products, insufficient work separation, inadequate construction planning, disturbances in personnel planning, delays, alterations, failures in setting-out and coordination failures. Hammarlund and Josephson (1991) estimated quality failures that occur after a project has been completed to be as high as 4% of actual project production cost. Interestingly, it was found that 51% of these failure costs were design related, while 26% were related to poor installation of materials and 10% to material failure.

Quality costs

Quality costs are just one type of measurement that can provide management with information about process failures and the activities that need to be designed to prevent their occurrence. With this in mind, the measurement of quality costs taken throughout a project can be used to help transfer lessons learned to the next.

Love *et al.* (1998) defined quality costs as the total cost derived from problems occurring before and after a product or service is delivered. Figure 1 identifies quality costs in terms of control and failure. Costs associated with failure arise from both internal and external sources. Internal poor quality costs increase an organizations cost of operations, for example, rework, material waste, and other avoidable process losses. However, external poor quality costs result in loss of profits: for example, contractual claims, defect rectification (rework), and the loss of future business. Quality costs can be used to identify the causes of poor quality and to develop estimates of their direct and indirect costs. Then this information can be used to determine quality improvement initiatives, which can be directed at achieving significant cost savings and quality breakthroughs for organizations.

There are numerous methods for calculating quality costs. For example, costs can be classified as the 'cost of conformance' and the 'cost of non-conformance'. Conformance costs include items such as training, indoctrination, verification, validation, testing, inspection, maintenance, and audits. Non-conforming costs, on the other hand, include items such as rework, material waste, and warranty repairs. Another way of calculating quality costs is proposed by Feigenbaum (1991), who classifies them according to failure, appraisal and prevention. (i) Failure costs can be either internal or external. The internal failure costs are those incurred rectifying an error or defect before a product leaves the organization or while it is still under its

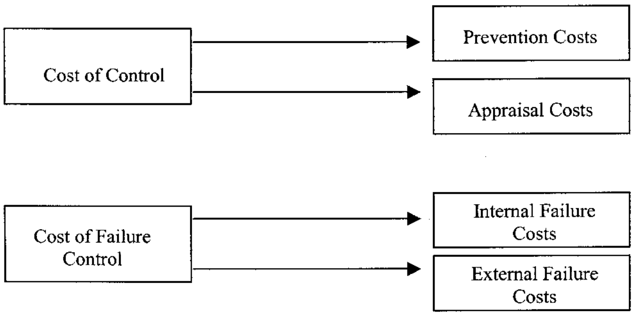


Figure 1 Quality costs: cost of control and failure (Feigenbaum, 1991)

control. Conversely, external failure costs are those incurred due to errors or defects in the product detected when the product has left the organization or is no longer under its control. (ii) Appraisal costs include all monies spent on the detection of errors or defects by measuring the conformity of different items to the required level or specifications of quality. Items include, issued architectural and structural drawings, work in progress, incoming materials (e.g. reinforcement, door hardware etc.) and finished products. (iii) Prevention costs include the sum of all amounts spent or invested to prevent or at least significantly reduce errors or defects, that is, to finance activities aimed at eliminating the causes of possible defects and errors before they occur.

These quality costs relate only to preventing and correcting errors of a poor product/service quality. In fact, they represent only the direct, tangible, and visible portion of the real and total quality costs. Such costs include those that are direct as well as indirect, be they tangible and measurable or intangible and estimated.

An example of expected quality costs for an organization can be seen in Figure 2. According to Banks (1992), actual prevention costs are expected to rise, as more time is spent on prevention activities throughout the organization. As processes improve over a period of time, appraisal costs should reduce, as the need for inspection is no longer necessary. Thus, the greatest savings could be derived from reducing internal failure areas (Figure 2).

According to Davis *et al.* (1989), without a formal systematic quality management system in place quality deviations may not be identifiable. Consequently, information is lost and activities that need to be improved in order to reduce or eliminate rework cannot be ascertained. Similarly, the BRE (1982) in the UK has demonstrated that significant cost benefits can be achieved by implementing a quality management system. The BRE stated that 15% savings on total construction costs could be achieved through eliminating rework, and by spending more time and money on prevention. For example, additional time spent upstream by designers (architects and engineers) on coordinating project documentation could reduce downstream quality costs significantly during on-site production, which may ultimately improve project performance (Love *et al.*, 1999b). It is suggested that learning to design quality into internal processes may enable designers to yield first-time quality on a regular basis, which may reduce their external failure costs and thus improve interorganizational processes.

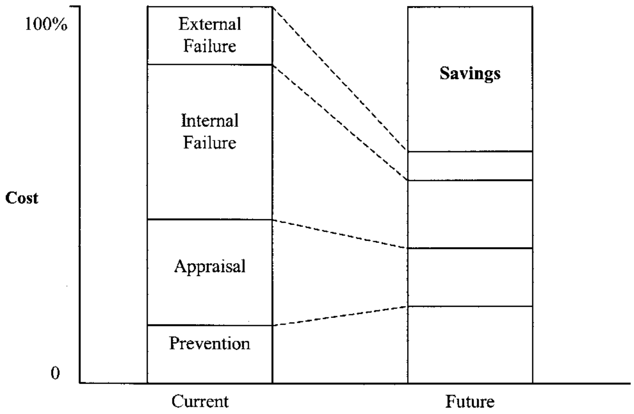


Figure 2 Total quality cost

The importance of prevention costs is illustrated in Figure 2. Campanella and Corcoran (1983) state that increases in expenditures for prevention and appraisal will not show immediate reductions in failure costs, primarily because of the time lag between cause and effect. Prevention and appraisal costs are unavoidable costs that must be borne by construction companies and consultant firms if their product/service are to be delivered right the first time. Failure costs on the other hand are almost avoidable. By eliminating the causes of rework, substantial reductions in appraisal costs can be achieved (Low and Yeo, 1998).

Numerous systems have been developed to capture the quality costs in construction. For example, Patterson and Ledbetter (1989) developed a system called the 'quality performance management system' to track the costs of quality by activity. This system was used on four industrial projects when the costs of rework were assumed to be 12.5% of the project cost. By implementing the system it was found that rework was almost 25% of the project cost. Similarly, Abdul-Rahman (1995) developed a quality costs matrix for determining the cost of nonconformance for civil engineering projects. Abdul-Rahman found in his research that the total cost of nonconformance was 5% of the tender value. Abdul-Rahman notes that the contractor had a quality system in place and suspected that the quality failures could have been considerably higher as material wastage and head office overheads were excluded from this figure.

To date there has been limited research undertaken in Australia that has attempted to identify the quality costs in building projects. In the next section case studies are presented which attempt to quantify the causes and costs of rework (quality failures) from two projects that were procured by the same contracting organization.

Research methodology

The contractor used for the research was the first building and construction company to be certified to the dual standards of ISO 9001/AS 3901 and AS 2990 Category A in Australia. Since becoming certified in 1991, the company has developed and implemented an effective continuous improvement programme that has been able to reduce the amount of rework experienced in its projects as well as improve its position in the market place.

The authors established personal contact with senior management within the contracting organization to explain the nature and purpose of the research, which was to determine the magnitude, causes and costs of rework in construction projects. Meetings were conducted with site management and the consultants involved with the projects to explain the nature of the research and information required. A detailed description of the methodology used in this research can be found in Love *et al.* (1999a) and Love and Li (1999). Two projects were used in this study. Project A consisted of two 6-storey residential apartment blocks, which contained a total of 43 units. Underground parking, a landscaped podium and a swimming pool are among the facilities incorporated in this development. The contract value for the development was A$10.96 million, with a contract period of 43 weeks (Table 1). The project was procured using a traditional lump sum contract, with the client employing a project manager to act as their development representative. Project B consisted of a 2-storey industrial warehouse. The contract value for the development was A$4.45 million, with a contract period of 30 weeks (Table 1). The project was a negotiated document and construct contract with a guaranteed maximum price (GMP) and savings participation incentive. A project manager was employed by the client to act as their representative. A conceptual design was developed and the contractor took responsibility for documenting and constructing the facility.

Data collection

Data were collected from the date on which construction commenced on-site to the completion of the defects liability period. Therefore, the rework costs presented take account only of those costs that emerged on-site during the production process of the project. The authors used the same procedure for collecting data for each case (Love *et al.*, 1999a; Love and Li, 1999). Bearing in mind the array of evidence that was accumulated, great care was taken to ensure that the data collected converged on similar facts.

The data collection procedure has followed the major prescriptions by most textbooks in doing fieldwork research (Dane, 1990). A variety of sources were used to collect the rework data, these included interviews, observations, and documentary sources such as variation registers, site instructions, requests for information (RFI), final accounts, progress reports, and extension of time claims. The authors collected information that related to the date when the rework occurred/when it was first identified, its cause, the work involved, its effect on the project's critical path, costs incurred, the trade package type and the magnitude of events.

Classification of rework

The classification system used in this research for categorizing the cause of rework was based on the work undertaken by Burati *et al.* (1992), which can be seen in Table 2. Nonproductive time or noncontributory work (Serpell *et al.*, 1997) refers to the loss of time due to waiting, being idle, travelling, and re-doing work. The data collected for this research were limited to the construction phase of the project; however, additional rework due to re-designs was recorded when it was possible to do so. Examples of the data collected for particular subcontract packages in project A can be seen in Tables 3. The data collected included only the

Table 1 Details of case study projects

Project details	Project A (residential development)	Project B (industrial development)
Original contract period	43 weeks	30 weeks
Extension of time	5 weeks	8 weeks
Original contract value	$10 960 000	$4 450 000
Revised contract value	$12 065 900	$4 876 316
Variations (client initiated changes)	$806 356	$319 333
Rework – Variations	$299 544	–
Rework – Non-variations	$40 960	$64 078
Rework – Defects	$5 000	$42 905
Overall cost of rework % contract value	3.15%	2.40%

Table 2 Rework classification system (adapted from Burati *et al.*, 1992)

Category	Type	Tertiary	Description used
Design	Change	Construction	A change is made at the request of the contractor
		Client/ Client rep	A change is 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	The source of the change could not be determined, as there was not enough information available. Discussion with project manager does not reveal the cause
	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 rep	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	The source of the change cannot be determined, as there is not enough information available. Discussion with project manager did not reveal the cause
	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

direct costs of rework and therefore do not constitute the total cost associated with the rework event. Burati *et al.* (1992, p. 36) state that the indirect costs of rework can be significant and that the direct costs are only the 'tip of the iceberg'. Due to the limited amount of data available on direct costs, only the direct costs of rework experienced in the projects are presented in this paper.

Findings and discussion

Table 1 presents the details of the projects that were used for the research, and it can be seen that the direct costs of rework were found to be 3.15% and 2.40%, respectively, for project A and project B. The overall cost of rework includes variations and defects. In project A, rework caused by variations accounted for 86% of the total costs of rework. Examples of variations, which were categorized as rework, can be seen in Table 3.

In project B there were no rework costs as a result of variations. This was primarily because the contract was based on a GMP, and additional costs caused by design errors and omissions were deemed to be the contractor's responsibility. Rework had a dramatic effect in the time performance of both projects. With the assistance of the contractors' project managers, it was estimated that rework had adversely affected the critical path of project A by 4 weeks and of project B by 3 weeks.

The project managers in both projects did not use a project quality system because it was considered that the site team had too heavy an administrative workload. Moreover, they considered their own cost control system was adequate enough to detect potential cost overruns and to act as an expenditure versus budget indicator. Time pressures and fixed preliminaries hindered the implementation of the quality cost system (Abdul-Rahman, 1993). If the system had been implemented most of the rework that did occur could not have been avoided because it was outside each project manager's control.

Table 3 An example of rework data collected for mechanical subcontract package in project A

Date (1996)	Event description	Comment	Trade	Failure (F1, internal; F2, external)	Classification			Non-productive time	Effect on construction programme (Critical path)	Cost of rework incurred	Cost Allocation
					Category	Type	Tertiary				
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 set-out was changed and walls were rearranged	Mechanical	F2	Design	Change	Unknown	1 day	–	$500	Client
16 April	**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 effect the programme because the error was detected well in advance of the work commencing. Two days to rectify the design error	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

Rework (non-variations)

It can be seen in Table 1 that non-variations in project B accounted for 59% of the total cost of rework, compared with only 12% in project A. Although this may appear a significant finding, the additional costs borne by the contractor for variations in project B have been allocated under this section because the contractor agreed to deliver the project for a GMP. This difference highlights the additional costs caused by consultant's errors and omissions, as they stated that they were not given enough time to design and document the project by the contractor. Consequently documentation was not checked before the subcontract trade packages were let.

In project B the design consultants stated that their fees were too low, which limited their capacity to design and document the project fully. The design consultants had 10 weeks to document and develop the specification for the project prior to commencement on-site. Interviews with the architect revealed that recent graduates with less than 2 years experience were being used to document the project, so that their fee income could be maximized. The engineers, on the other hand, worked on the project only for the time they had allowed in their fee. Consequently, dimensional errors and omissions occurred during construction (Table 4), especially at the interface between subcontract trades, for example, changes to partition and ceiling layouts due to clashes with services.

Defects

Those defects that were identified are those items that needed to be rectified after practical completion had been awarded. It was found that damage by subcontractors and poor workmanship were the primary cause of defects. In project A defects accounted for 1.5% of the total cost of rework, whereas in project B they accounted for 40%. Interestingly, there were no nonconformances issued on either project, despite the large number of minor defects that occurred.

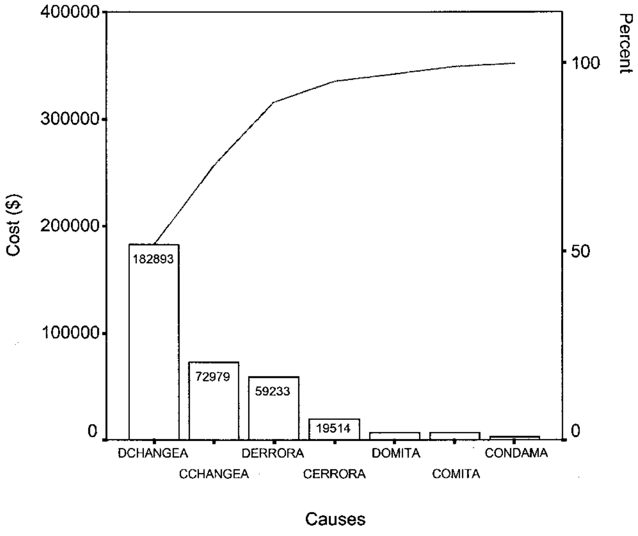
Causes and costs of rework

Table 4 presents the spread of costs within each rework category and type for the two projects. A comparison of the two projects at the category level reveals that design related rework costs accounted for 72% of total rework costs in project A and 20% in project B. Similarly, construction related rework costs accounted for 28% of total rework in project A and 80% in project B. Pareto graphs for the causes and costs of rework can be seen in Figures 3 and 4. In project A, design changes (53.7%), construction changes (21.40%) and design errors (17.0%) are the major factors contributing to rework accounting for 92% of rework costs. In project B construction changes and errors were the causes for 50% of rework costs.

In project A, occupiers/end-users of the apartments

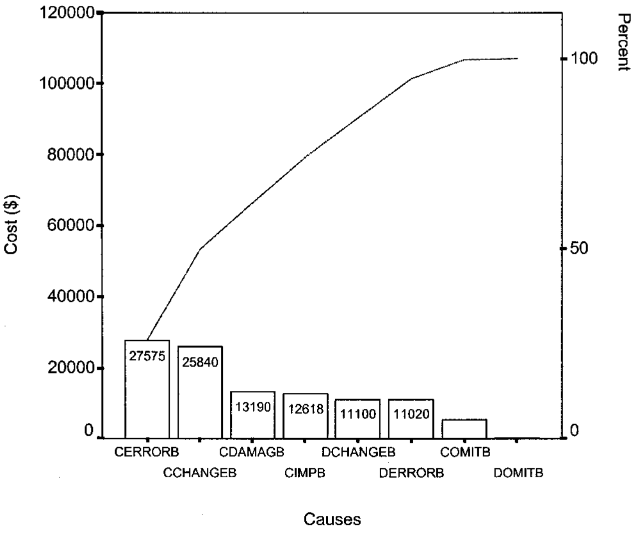
Table 4 A summary of rework causes, costs and their magnitude in project A and B

Category	Type	*N*	Range($) Min	Range($) Max	Sum ($)	% Total rework costs	Mean ($)	Std deviation ($)
Project A								
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%		
Project B								
Design	Change	10	200	3 500	11 100	10.38	1 110	1 285
	Error	6	650	5 500	11 020	10.30	1 836	1 836
	Omission	1	300	300	300	0.28	300	–
Construction	Change	25	40	6 500	25 840	24.15	1 033	1 798
	Error	36	50	3 500	27 575	25.78	765	827
	Omission	20	50	1 250	5 340	4.99	267	379
	Damage	29	50	7 500	13 190	12.33	454	1 433
	Improvement	38	50	5 000	12 618	11.79	332	853
	Total	165			$106 983	100%		



Key: DCHANGEA – Design Change, CCHANGEA – Construction Change, DERRORA – Design Error, CERRORA – Construction Error, DOMITA – Design Omission, COMITA – Construction Omission, CONDAMA – Construction Damage

Figure 3 Pareto chart for the cost of rework causes in project A



Key: CERRORB – Construction Error, CCHANGEB – Construction Change, CDAMAGB – Construction Damage, CIMPB – Construction Improvement, DCHANGEB – Design Change, DERRORB – Design Error, COMITB – Construction Omission, DOMITB – Design Omission

Figure 4 Pareto chart for the cost of rework causes in project B

generally initiated the design changes. This was because the apartments were sold-off the plan and occupiers were not able to visualize the final product. The other source of construction changes was direct from the architects, as they wanted to improve the functionality and aesthetics of the building. Figure 5 indicates that changes due to occupiers and operational improvements, whether initiated through design or construction, formed a significant proportion of rework costs in project A. In project B, construction changes occurred as a result of improvements to the functionality of the building and from the client's representative. Changes initiated by the client's representative resulted from requests made by end-users. These changes arose because they had not been asked about their specific requirements during the design development process. The aggregate cost of changes initiated by the contractor for operational improvement and by the client's representative can be seen in Figure 6.

In both project A and project B, design and construction changes could have been significantly reduced if occupiers and end-users had some input into the design brief. In addition, errors and omissions appear to be major factors that contribute to rework. It was found in both projects that poor coordination and integration between design team members hindered the flow of information among design team members. This resulted in RFIs being raised by the contractor and subcontractors, which caused significant amounts of nonproductive time to be experienced in both projects. This was exacerbated further by the fact that engineers used CAD technologies and the architects used manual systems to document their designs. Thus, when a change was required, documentation was difficult to update because of system incompatibility between designers. Consequently, some drawings were issued with dimensional errors and missing information.

Causes of nonproductive time

Nonproductive time is comprised of work inactivity and ineffective work. Work inactivity includes waiting time, idle time, and travelling. Ineffective work on the other hand includes rectifying mistakes and errors, working slowly and inventing work (Serpell *et al.*, 1997).

Table 5 provides a breakdown of the causes of nonproductive time experienced in both projects. A total of 69 and 39 nonproductive days were recorded in project A and project B respectively, as a result of waiting for information, travelling, cleaning, rectifying mistakes and damaged items. This loss of time predominately was attributable primarily to those categories that experienced a large number of rework events. Examples of the type of rework that caused the occurrence of nonproductive time can be seen in Table 5.

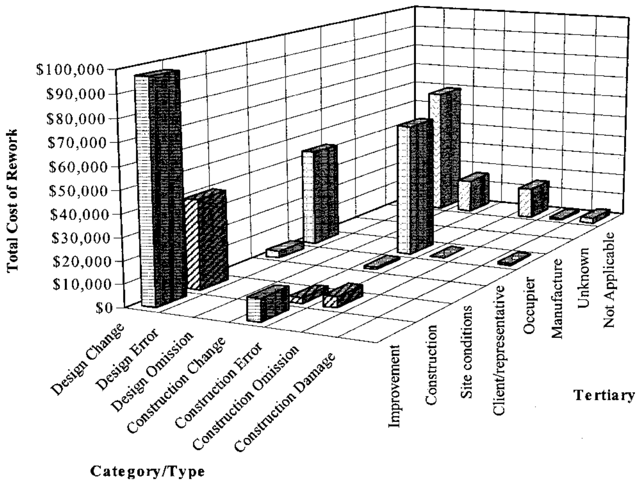


Figure 5 Breakdown of category/type and tertiary causes of rework in project A

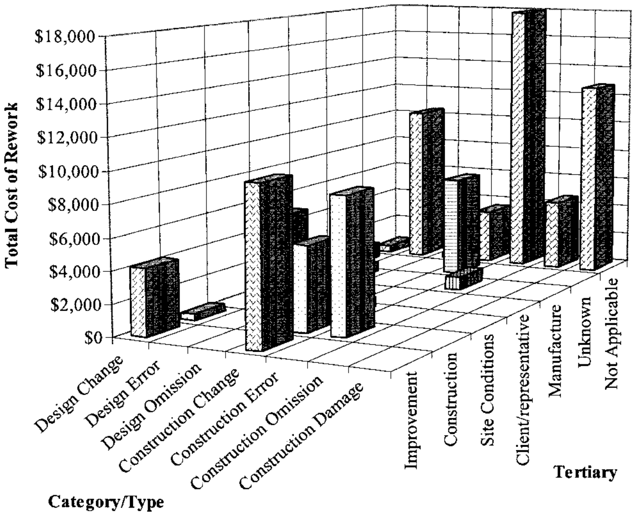


Figure 6 Breakdown of category/type and tertiary causes of rework in project B

Design generated nonproductive time was found to be greater in project A (57%) than in project B (23%), and vice versa for construction. It is suggested that this difference was greater in design in project A because more RFIs were raised due to discrepancies in the contract documentation and the changing requirements of occupiers. In project B, however, construction errors and damage were the primary causes of nonproductive time. For example, doors were painted the wrong colour as the painting subcontractor simply misread the finishes schedule. On another occasion pre-cast panels needed to be repaired because they had been damaged during their installation.

Allocation of rework costs

Tables 6 and 7 identify the costs of rework attributable to each subcontract package as well as the cost of rework as a percentage of subcontract value. In Table 6 the structural steel subcontract package experienced additional costs of 35%, which were borne by the client. A detailed investigation into why and how rework occurred revealed that the cause of rework was attributable to the sequential nature of the supply chain, which resulted in poor communication and decision-making being experienced. This was found to be further exacerbated by the absence of a quality focus during the design process. The costs of having a crane and the scaffolding on-site for an additional 4 weeks due to the rework that was experienced in the structural steel roof were significant, and consequently taken up under the contractor's preliminaries. The ceilings and partitions trade also experienced a significant amount of rework, which was charged back to the client and contractor (Table 6). The architect's documentation for the ceilings and partitions package contained dimensional errors and missing information, and thus affected the set-out of the internal walls. In order to meet the construction programme the contractor subsequently had to hire an additional foreman for 4 weeks to help with the set-out of internal walls. At times the subcontractor had to demolish partitions because they clashed with services.

The mechanical subcontract package also experienced considerable additional cost, which again was charged back to the client. Design changes made by purchasers (end-users) (Table 3) together with errors made by the design engineer and architect due to poor coordination were the major factors that contributed to an additional cost of 10% being allocated to this package.

In Table 7, the only immediate subcontract packages that experienced rework costs in excess of 10%, were

Table 5 Causes of nonproductive time

Cause	Project A	Project B
	(% total time)	(% total time)
Design		
Change	28	5
Error	19	18
Omission	10	–
Construction	3	13
Change	20	33
Error	–	–
Omission	–	–
Damage	20	23
Improvement	–	8

Table 6 Allocation of rework costs in project A

Subcontract package	Value ($)	Cost to subcontractor ($)	Cost to contractor ($)	Cost to client ($)	Rework % sub/c value
Balustrades	111 165	300	–	1 912	1.9
Blockwork	391 230	3 400	–	8 000	2.9
Carpentry	145 596	–	–	5 121	3.5
Ceiling and partitions	768 841	750	8 900	51 062	7.9
Concrete	572 735	–	1 500	1 431	0.5
Doors	53 649	300	–	1 788	3.8
Electrical and fire	694 401	1 250	2 000	29 250	4.6
Formwork	830 277	2 950	1 000	–	0.4
Joinery	399 729	500	–	–	0.1
Landscape	332 976	250	–	10 434	3.2
Lifts	338 704	–	–	708	0.2
Mechanical	488 520	1 000	–	50 735	10.5
Metalwork	139 304	300	–	1 192	1.0
Painting	446 892	450	–	1 338	0.4
Piling	251 795	2 800	–	–	1.1
Pluming and drainage	914 862	450	500	32 000	3.6
Reinforcement	578 236	2 260	500	6 503	1.6
Roofing	40 795	200	–	–	0.4
Structural steel	90 481	300	–	32 006	35.7
Tanking	221 775	–	2 000	–	0.9
Tiling	485 078	1 000	–	4 757	1.2
Contractors preliminaries etc.	Unknown	–	73 345	–	–

Table 7 Allocation of rework costs in project B

Subcontract package	Value ($)	Cost to subcontractor ($)	Cost to contractor ($)	Cost to client ($)	Rework % sub/c value
Blockwork	185 559	50	1 775	625	0.99
Carpentry	16 492	–	1 250	–	7.6
Carpet and vinyl	915	–	150	100	27.3
Ceiling and partitions	140 269	2 275	–	6 500	6.3
Concrete	1 032 626	700	5 083	100	0.57
Doors	33 445	250	3 775	125	11.7
Electrical and fire	571 750	550	5 860	3 960	1.8
Excavation	181 712	–	7 500	–	4.1
Lifts	111 000	500	150	–	0.6
Mechanical	288 200	750	–	–	0.6
Metalwork	36 380	1 920	–	–	5.9
Painting	70 420	300	4 895	195	7.7
Piling	156 243	3 500	–	–	2.2
Plumbing and drainage	320 000	3 495	1 950	–	1.7
Roofing	135 464	2 900	1 500	250	3.4
Specialist shelving	151 795	250	6 825	10 375	11.5
Structural steel	230 273	1 850	3 100	–	2.15
Tiling	10 307	50	350	–	3.9
Windows and glazing	30 345	50	345	50	1.5
Contractors preliminaries etc.	Unknown	–	22 155	–	–

the carpet and vinyl (27.3%), doors (11.7%), and specialist shelving (11.5%). It was difficult for the contractor to identify who was responsible for the damage. As a result, the contractor had to bear the costs of rework. The ceilings and partitions package faced very similar problems to those experienced in project A, that is, dimensional errors in the documentation.

With the assistance of the contractor and design team members, the authors were able to identify most of the direct rework costs that occurred in the projects. Due to the limited data that were available, the indirect costs could not be quantified, though the authors suspect that they were considerable. The costs of rework reported are significantly lower than any other reported study to date and therefore the authors do not consider them to be indicative. The authors suggest that it would be inappropriate to compare these findings with previous studies as levels and interpretations of quality will differ between each country. In addition, local practices, industry culture and contract arrangements also may have a significant influence on the incidence and cost of rework in any situation and locality.

Conclusion

Quality management is a critical component in the successful management of construction projects (Hellard, 1995; Abdul-Rahman, 1997; Love *et al.*, 1999c). Yet, in the case studies presented the lack of a quality focus by design consultants and to some extent the contractor (as they did not implement their project quality plan and inspection and test plans) significantly affected project performance. The prevention of poor quality was not considered as an issue and, as a result, external failures occurred downstream during production. Though, it may well be argued that measuring quality in the design phase of a project is difficult because all too often the designer is not the final user assessing the quality performance of the product.

Contractors in many ways act as quality buffers, that is, they check contract documentation before construction commences, so that they can determine their construction programme as well as identify errors and foresee potential problems that may occur. Contractors invariability act as managers of the production process and therefore need to be provided with 'the right' information, which enables them to manage their subcontractors more effectively.

The findings presented in the case study demonstrated that during construction, rework arose out of incomplete and erroneous information. Every time a change was made in design, it had to be reworked by the design team, which in turn affected their fee. Contractors' QA systems are not able to stop errors and omissions, which originate from consultants, nor can they prevent changes, but they can act as a prevention mechanism and give early warning of poor quality.

Generally, quality management techniques have not been well received by the Australian construction community primarily because the short-term benefits are considered to be intangible (Jaafari, 1996). However, if the industry is to improve its performance, all organizations involved in the project supply chain should implement quality management practices. In order to ensure quality in design documentation, construction companies and consulting firms should give greater attention to the following quality management practices: (a) the requirements of the client and end-users; (b) producing correct and complete drawings and specification; (c) coordinating and checking design documentation (including interorganizational coordination; (d) conducting design verification through design analysis reviews; (e) controlling changes (e.g. scope freezing); and (f) committing to providing a quality service. Also, special emphasis should be placed on the constructability of the project, so as to minimize design changes and errors that may arise during construction. It is suggested that giving attention to these preventive items may help improve design quality assurance and therefore minimize changes, errors, and omissions. If rework is to be reduced then significant improvement in the understanding of quality is required by both construction companies and consulting firms.

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