Design Error Costs in Construction Projects

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Abstract: Design errors can adversely influence project performance and can contribute to failures, accidents, and loss of life. Although there has been a considerable amount of research that has examined design error causation, little is known about design error costs. With increasing emphasis placed on the use of nontraditional forms of procurement methods as a result of various government reports and the advent of Building Information Modelling there is a general perception that design error costs will be significantly less than those projects procured by traditional means. By using a questionnaire survey, estimates for design error costs were obtained from 139 projects. The mean direct and indirect costs for design errors were revealed to be 6.85 and 7.36% of contract value, respectively. Design error costs were found not to significantly vary with procurement method and project type used. Although the research provides invaluable insights into practitioners' perceptions of design errors costs, their actual costs remain relatively unexplored. **DOI:** 10.1061/(ASCE)CO.1943-7862.0000454.

CE Database subject headings: Errors; Construction costs; Procurement; Design.

Author keywords: Designers; Errors; Costs; Procurement method; Project type.

Introduction

The prevalence of design errors and their resultant cumulative negative effect upon the financial performance of organizations and projects is a leitmotiv within the construction industry. Design errors dominate the cause of accidents, and it has been revealed that gross errors cause 80 to 90% of failures to buildings, bridges, and other civil engineering structures (Matousek and Schneider 1976; Lopez et al. 2010). Bijen (2003) identified that engineering failures account for as much as 10% of the total investment in new buildings and structures. Importantly, these failures are not restricted to simple direct cost considerations because they are also inextricably linked to less tangible environmental and social costs. Despite the considerable amount of research that has addressed error causation in construction and engineering projects (e.g., Petroski 1991; Busby 2001; Andi and Minato 2003a, b; Love et al. 2009), the actual costs associated with design errors remain unknown because they are not formally measured by organizations. Even at a project level design error costs are rarely measured, although a proclivity exists for them to manifest as change orders or claims. Much of the research that has examined design error costs is anecdotal or based upon a limited number of cases (e.g., Burati and Farrington 1992; Robinson-Fayek et al. 2003; Andi and Minato 2004; Love and Josephson 2004; Love et al. 2011c, d). In addressing this issue, the research reported in this paper sought experts estimate's of design errors from projects that they had been directly involved with. The influences of procurement method and project on design error costs are also examined.

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Design Error Costs

Numerous definitions of error have been identified in normative literature (Lopez et al. 2010). Tucker and Edmondson (2002) define error as "the execution of a task that is either unnecessary or incorrectly carried out" (p. 3). Similarly, Reason and Hobbs (2003) define error as "the failure of planned actions to achieve their desired goal, where this occurs without some unforeseeable or chance intervention" (p. 39). The term failure is often used interchangeably with error; however, a subtle difference between error and failure exists. A failure is "an unacceptable difference between expected and observed performance" (Ayininuola and Olalusi 2004; p. 73). With a failure an implicit expectation, exists; whereas, in the case of an error an unforeseeable or chance intervention takes place. Studies that have examined design errors in construction have often treated interchangeably used the terms changes, omissions, defects, quality deviations, nonconformances, and failures (e.g., Josephson and Hammarlund 1999; Josephson et al. 2002). A lack of definition has resulted in a great deal of confusion pertaining to the underlying causes and costs of errors in projects (Love and Edwards 2004).

According to Love et al. (2009), a number of latent conditions reside within project systems that influence error-provoking activities to take place and, therefore, contribute to design errors occurring downstream during construction. For example, the use of competitive tendering can result in organizations committing to undertake work at a lowest price. This can result in opportunistic behavior whereby design firms omit to undertake design audits, reviews, and verifications to maximize their fee. Moreover, when firms are placed under schedule pressure by clients to design and document, then a propensity exists for them to omit tasks to make work more efficient. This often result in errors in contract documentation, which has been identified as a major cause of disputes within construction projects (Love et al. 2011a). For the purpose of brevity, it is not the intention of this paper to examine error causation because this has been examined elsewhere (e.g., Lopez et al. 2010; Love et al. 2011a, b, c, d).

Once design errors are identified rework is invariably required. The extent of the rework that arises, however, is dependent upon when it is identified in a project's life cycle. Farrington (1987) revealed that design errors occurring in nine case study projects accounted for 19.7% of the total number of deviations that arose. Farrington (1987) also revealed that design changes/errors accounted for 79.1% of the total cost of quality deviations that arose in projects. Similarly, Robinson-Fayek et al. (2003) found the engineering and review processes for an engineering project contributed to 68% of rework costs with 78% of this total attributable to design errors. Barber et al. (2000) found that design errors accounted for 50% of quality failure costs in civil engineer projects. The cost of design errors has been reported to be lower in building projects with Love and Li (2000) revealing that they accounted for 14% of rework costs. Cusack (1992) has revealed that design errors contained within contract documentation alone can contribute to a 5% increase in a project's contract value.

Research Methodology

This research formed part of a broader study that focussed on determining the influences of people, organizations, and projects on design error costs within construction and engineering. For the purpose of this research, Reason and Hobb's (2003) definition of an error is used and applied to the design phase of construction and engineering projects. Instead of developing a survey questionnaire that sought general opinions from respondents about errors in design, respondents were asked to select a recently completed project that they had been involved with and subsequently answer about the perceived causes, associated costs, and organizational and project management practices implemented. In essence, each project was treated as a separate case. In examining design error costs experienced in the selected projects, the following hypotheses were addressed:

1. Significant differences in design error costs exist for various types of construction and engineering projects, and
2. Significant differences in design error costs exist with various procurement methods for construction and engineering projects.

Questionnaire Survey

The study sample was selected from the Yellow Pages online directory by using the stratified random sampling technique. This technique increased the sample representativeness and was useful in enabling general statements on portions of the population to be made. Before the main study sample size was determined, a pilot study was undertaken with 20 selected design consultancy organizations. The pilot study tested the likely response rate, comprehensibility, and suitability of the survey questionnaire. Each organization was contacted and informed about the aim of the research by e-mail with the questionnaire attached. In addition, telephone calls were made to each organization to follow-up on each e-mail that had been distributed approximately a week later. Their consent to participate was expressed when they completed and returned the questionnaire. Respondents were asked to critically review the design and structure of the questionnaire. All comments received were positive, and as a result the questionnaire remained unaltered for the main survey. All 20 questionnaires were returned. The composition of the respondents who completed the pilot questionnaire was architects (45%) and engineers (55%).

In the main survey, 550 questionnaires were emailed to architectural and engineering organizations throughout Australia. 119 valid survey questionnaires were received in the main survey. As the pilot questionnaires required no changes, they were added to the sample, which result in 139 valid responses representing a consolidated response rate of 25%. The response rate is considered acceptable for a survey focusing on gaining responses from industry practitioners (Edward-Gibson and Whittington 2010). Fig. 1 provides a breakdown of valid responses by respondent type. The main types of respondents were architects 55% and structural engineers 24.5%.

Data Reliability

Data reliability is related to the data source and the identification of the position held by the person who completed the questionnaire (Leicht et al. 2010). Thus, it was important that the personnel who had detailed knowledge about the procurement processes associated with a project answered the questionnaire; it was emailed to the senior personnel within the organization identified. Whether they actually answered the questionnaire was impossible to determine, except in circumstances where respondents optionally supplied their contact details. Of the 139 questionnaires used for this research, contact details were provided by 65 respondents, many of which were employed in senior positions. From the positions held by the respondents, emailing the questionnaires directly to individuals within design organizations appeared to have reached those involved closely with the delivery of construction and engineering projects. Additionally, the survey questionnaires were emailed to organizations based in different states and territories within

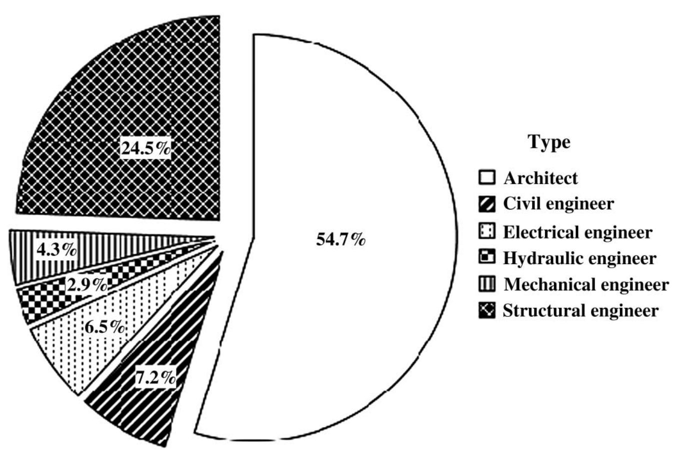

Fig. 1. Respondents by type

Australia. This served to minimize the duplication of projects selected. Fig. 2 provides a breakdown by state and territory of the respondents who answered the questionnaire.

Justification of Method and Data Analysis

Each survey respondent was asked to provide details on the following for the project that they had selected: type of project and facility; procurement method; and original contract value. In addition, direct and indirect estimates of design error costs that occurred during the project were sought. Types of project, facility and procurement methods were measured on a nominal scale; whereas, ratio scales were used to measure design error costs. Respondents were also asked to provide general comments at the end of the questionnaire with respect to design error causes for their selected project. The quantitative data gathered were analyzed by using SPSS (statistical package for the social sciences) Version 17.0 software. Descriptive analysis provided a frame of reference examining the dataset. ANOVA was used to test for significant differences for different procurement methods and project types. ANOVA was also used to examine the perceived consistency of the design error cost estimates that had been provided by respondents within the construction industry. Moreover, to identify where any differences between samples lie, a Tukey's post hoc test was used.

Analysis and Discussion

A variety of project and facility types and procurement methods were identified in the survey. Tables 1 and 2 present a summary of project and facility types and the retrospective procurement methods used to deliver projects obtained from the survey data. Table 1 indicates that traditional lump sum (TLS) methods were used to deliver new build (69.2%), refurbishment/renovation (57.1%), and fit-out projects (54.5%). New build projects accounted for 65% of the total number of projects identified from the sample (Table 2). Refurbishments and renovations were the next most popular project type, accounting for 20% of the total number of projects. Table 2 identifies that survey respondents were involved in procuring various types of facilities. For example, residential buildings (33.8%) were the most popular followed by educational schools (14.4%) and commercial retail buildings (8.6%).

From the results and bearing in mind previous studies, it can be seen that in the last 10 years TLS have remained the primary choice of procurement method within the Australian construction industry (Love et al. 1998, 2008; Love 2002). Because an architect is typically the first point of contact for clients, it is often in their interest to recommend the adoption of this form of procurement method so they can take the lead role and maximize their fee scales by undertaking pre- and post-contract works (Mortledge et al. 2006). Despite calls for the greater use of nontraditional procurement methods to improve the integration of design and construction processes and collaboration between project team members, TLS are still used. Although TLS is a well-known and tried and tested method, particularly for public sector clients, it performs poorly in terms of time performance and delivering value for money (Raisbeck et al. 2010). Moreover, a greater propensity exists for contractual disputes to arise with traditional methods (Cheung and Yiu 2006). With the introduction of building information

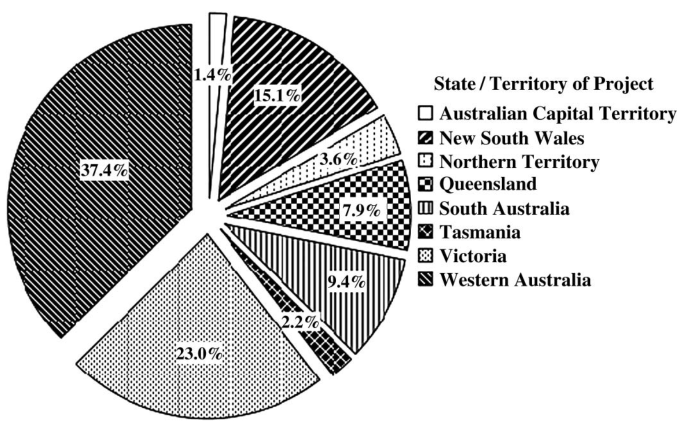

Fig. 2. Respondents by Australian state or territory

Table 1. Procurement Methods

Project type	New build		Refurbishment/renovation		Fit-out		Civil engineering		Total	
Procurement methods	*N*	Percent	*N*	Percent	*N*	Percent	*N*	Percent	*N*	Percent
Traditional: lump sum	63	69.2	16	57.1	6	54.5	2	22.2	87	62.6
Traditional: cost plus	6	6.6	2	7.1	1	9.1	1	11.1	10	7.2
Traditional: provisional quantities	4	4.4	—	—	—	—	—	—	4	2.9
Construction management	3	3.3	3	10.7	1	9.1	1	11.1	8	5.8
Design and build	10	11.0	6	21.4	1	9.1	3	33.3	20	14.4
Design and manage	—	—	1	3.6	1	9.1	1	11.1	3	2.2
Management contracting	3	3.3	—	—	1	9.1	1	11.1	5	3.6
Novation	1	1.1	—	—	—	—	—	—	1	0.7
Turnkey/package deal	1	1.1	—	—	—	—	—	—	1	0.7
Total	91	100	28	100	11	100	9	100	139	100

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Table 2. Facility and Project Type

Project type	New build		Refurbishment/renovation		Fit-out		Civil work		Total	
Facility type	*N*	Percent	*N*	Percent	*N*	Percent	*N*	Percent	*N*	Percent
Administrative: authorities	2	2.2	—	—	2	18.2	—	—	4	2.9
Administrative: civic	1	1.1	—	—	—	—	—	—	1	0.7
Civil works	—	—	2	7.1	1	9.1	5	55.6	8	5.8
Commercial: recreational	5	5.5	3	10.7	—	—	1	11.1	9	6.5
Commercial: retail	9	9.9	2	7.1	1	9.1	—	—	12	8.6
Commercial: offices	4	4.4	—	—	1	9.1	—	—	5	3.6
Educational: school	15	16.5	5	17.9	—	—	—	—	20	14.4
Educational: university	2	2.2	1	3.6	—	—	—	—	3	2.2
Entertainment	2	2.2	2	7.1	—	—	—	—	4	2.9
Hospital/health	2	2.2	3	10.7	—	—	—	—	5	3.6
Hotel/motel/resort	7	7.7	—	—	2	18.2	1	11.1	10	7.2
Industrial: factory	4	4.4	—	—	—	—	1	11.1	5	3.6
Industrial: warehouse	4	4.4	—	—	2	18.2	—	—	6	4.3
Residential	34	37.4	10	35.7	2	18.2	1	11.1	47	33.8
Total	91	100	28	100	11	100	9	100	139	100

modeling, however, there will be a need to switch to using nontraditional methods to maximize its benefits (Love et al. 2011b).

Design Error Costs

The questionnaire survey asked the respondents to provide an estimate of the direct and indirect design error costs that occurred in the project selected. Design error costs are rarely, if ever, measured within Australian construction projects, so estimates provided by respondents were based on their cognizance of the project.

The total costs of design errors were calculated from the sum of the direct and indirect design error costs respondents provided. The mean (M) and standard deviation (SD) of the total design error costs are identified in Fig. 3 for the 139 projects surveyed ($M = 14.2\%$, $\mathrm{SD} = 17.47\%$). Figs. 4 and 5 display the distribution of the respondents estimates for direct ($M = 6.9\%$, $\mathrm{SD} = 12.72\%$) and indirect ($M = 7.4\%$, $\mathrm{SD} = 8.03\%$) design error costs.

The total costs of errors in design were found to considerably vary among construction and engineering projects. Design error costs were reported by some respondents as within 1% of a project's contract value; whereas, others have reported such costs to be over 90%. This degree of estimate variability among respondents suggests that many of them could be uncertain about the actual design error costs incurred in the projects. The mean estimates of practitioners' design error costs that were perceived to have been incurred in their selected projects are presented in Fig. 6.

To test whether there were significant differences between the estimates of the respondents for design error costs (direct and indirect) an ANOVA was undertaken. The descriptive statistics indicated that differences existed in the direct cost estimates provided: architects ($M = 6.8\%$, $\mathrm{SD} = 15.2\%$), civil engineers ($M = 9.7\%$, $\mathrm{SD} = 13.0\%$), electrical engineers ($M = 10.8\%$, $\mathrm{SD} = 9.0\%$), hydraulic engineers ($M = 4.4\%$, $\mathrm{SD} = 7.1\%$), mechanical engineers ($M = 7.6\%$, $\mathrm{SD} = 13.6\%$), and structural engineers ($M = 5.2\%$, $\mathrm{SD} = 6.4\%$). However, Levene's homogeneity of variances test was not violated ($p < 0.05$), indicating that variances among designer group populations were approximately equal. The ANOVA analysis revealed similarities among practitioners in their direct design error cost estimates, $F(5{,}133) = 0.416$, $p < 0.05$. Tukey's post hoc honestly significant difference (or HSD) test was performed to support the findings from the ANOVA results. The HSD test did not identify significant differences in direct design error costs between designer types.

Indirect design error costs generally cover those associated with the resultant increases in resources required to address rework (Sun and Meng 2009). These costs can include losses in working efficiency, productivity and time, as well as contractual claims and litigation that may arise. The indirect costs of design errors may often unknowingly be absorbed by project team members (Love 2002). The descriptive statistics indicated differences in the indirect cost estimates provided: ($M = 6.5\%$, $\mathrm{SD} = 6.2\%$), civil engineers ($M = 12.6\%$, $\mathrm{SD} = 16.2\%$), electrical engineers ($M = 10.9\%$, $\mathrm{SD} = 10.1\%$), hydraulic engineers ($M = 3.9\%$, $\mathrm{SD} = 4.2\%$), mechanical engineers ($M = 8.6\%$, $\mathrm{SD} = 13.5\%$), and structural engineers ($M = 7.0\%$, $\mathrm{SD} = 6.5\%$). Levene's homogeneity of variances test was not violated ($p < 0.05$), indicating that variances among practitioner group populations were approximately equal. The ANOVA analysis also revealed similarities among practitioners in their indirect design error cost estimates, $F(5{,}133) = 1.615$, $p < 0.05$.

When respondents were asked to compare design error costs of their selected project with others with which they had been involved, 6% believed they were "to a very great extent" comparable, 10% for "to a great extent," 49% for "to some extent," 17% for "to a small extent," and 19% for "not at all." The mode was found to be "to some extent," thus, it can be concluded that the reported design error costs accurately represent industry practice. The mean reported direct and indirect design error costs could be considered benchmarks to guide the pursuit of Australian construction industry best practice. However, a systemic approach to determining the cost of design errors is required. Several approaches have been developed but their implementation requires a considerable amount of cooperation and collaboration between project team members (e.g., Farrington 1987; Low and Yeo 1998; Robinson-Fayek et al. 2003; Love and Irani 2003).

Design Error Costs and Procurement Methods

Boxplots are presented within Fig. 7 where univariate and multivariate outliers are presented for procurement methods and total

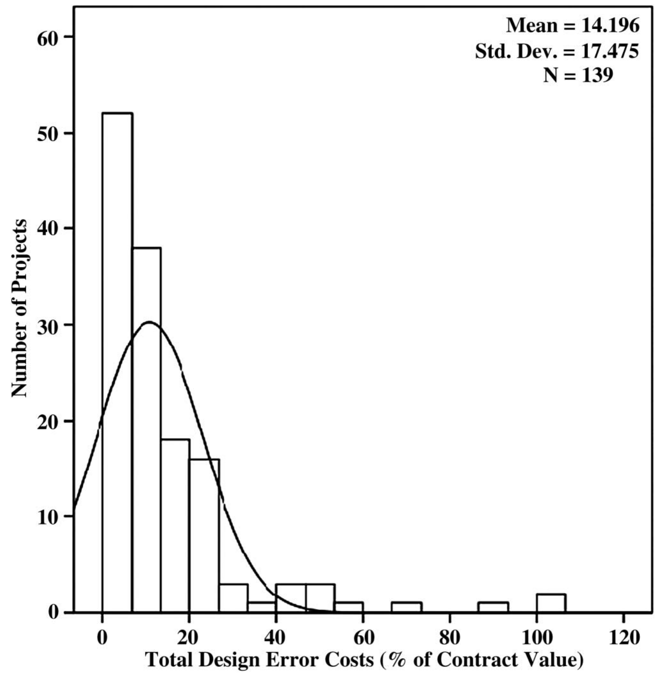

Fig. 3. Total design error costs as percent of contract value

design error costs. Most of the design error cost outliers occurred on traditionally procured projects. A civil engineering consultant stated that their selected project, which had been undertaken by using a traditional cost plus method, had experienced a year's delay because of design errors. In two of the outlier projects that were procured by using a TLS, architects suggested that clients established unrealistic timelines for preparing contract documentation and as a result design errors occurred.

To determine if a significant difference existed between design error costs and procurement methods, an ANOVA was undertaken. Levene's homogeneity of variances test was not violated ($p > 0.05$), indicating that variances among designer group populations were approximately equal. The ANOVA analysis revealed similarities among practitioners in their direct design error cost estimates, $F(5,133) = 0.416$, $p < 0.05$, and indirect design error cost estimates, $F(5,133) = 1.615$, $p < 0.05$. Tukey's post hoc HSD test

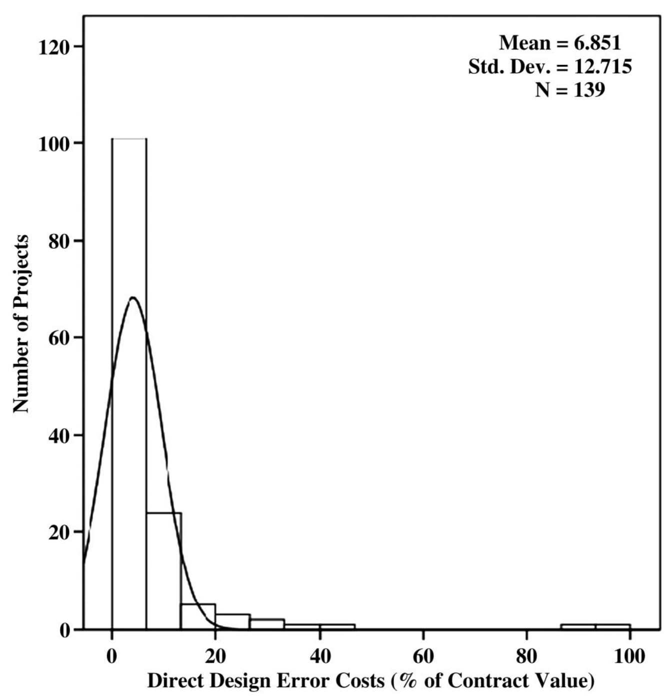

Fig. 4. Direct design error costs as percent of contract value

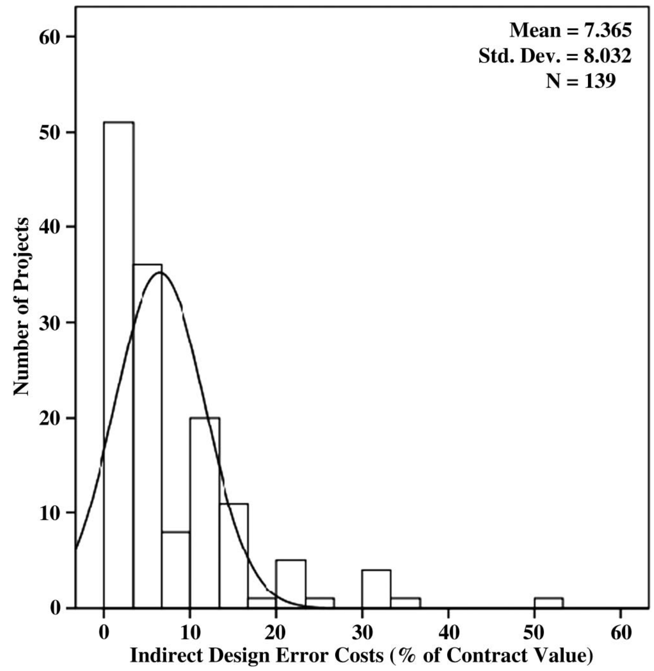

Fig. 5. Indirect design error costs as percent of contract value

was performed to support the findings from the ANOVA results. The HSD test did not identify significant differences in both direct and indirect design error costs between designer types ($p < 0.05$). However, as more than one project procurement method category had less than two cases, they were categorized further as either traditional or nontraditional.

A t-test was performed to determine whether a difference exists between the traditional and nontraditional procurement methods in the total costs of design errors (direct and indirect design error costs) experienced within the selected projects. The means and standard deviations for the total design error costs for both traditional and nontraditional procurement are presented in Table 3. Table 4 presents the t-test results. No significant difference exists at the 95% level of confidence between traditional and nontraditional methods in total design error costs within projects. Hence, it is concluded that there are no significant differences between the project procurement methods employed in their design error costs.

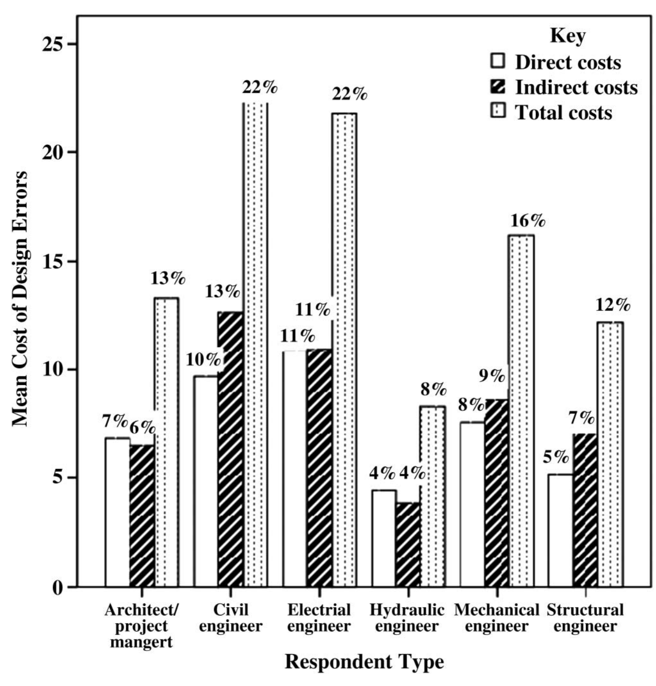

Fig. 6. Mean estimated design error costs for each designer type

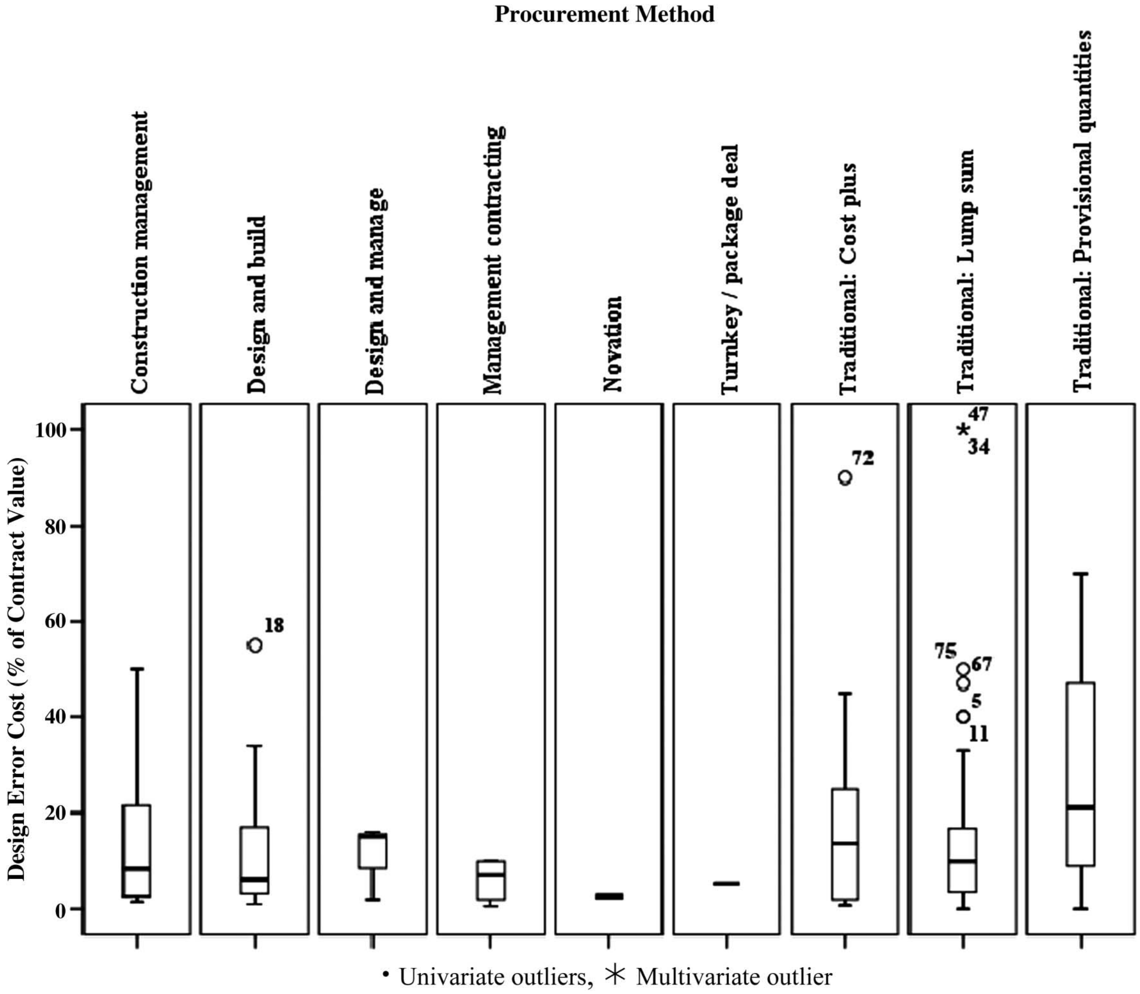

Fig. 7. Boxplots for procurement methods and design error costs

Design Error Costs and Project Types

Table 5 identifies the direct and indirect design error costs for the project types sampled within this research. ANOVA was performed to determine whether significant differences existed among project types in their design error costs. Levene's homogeneity of variances test was not violated for direct and indirect design error costs ($p < 0.05$), indicating that variances among each project type's populations were approximately equal. The ANOVA analysis revealed similarities among project types in their direct design error costs, $F(3{,}135) = 0.572$, $p < 0.05$, indirect design error costs, $F(3{,}135) = 0.000$, $p < 0.05$, and total design error costs, $F(3{,}135) = 0.019$, $p < 0.05$. The ANOVA results did not identify significant differences in direct design error costs between project types.

Table 3. Total Design Error Costs for Project Procurement

Procurement method	N	Mean	Standard deviation	Standard error mean
Traditional	99	15.19	19.01	1.91
Nontraditional	40	11.74	12.79	2.02

Conclusions

The research presented within this paper sought to determine whether significant differences in design error costs existed for various project types and procurement methods. A questionnaire

Table 4. Total Design Error Costs for Project Procurement Independent Samples Test

	Levene's test (Equality of variances)		t-test (Equality of means)						
Equal variances	F	Significance	t	df	Significance 2-tailed	Mean difference	Standard error difference	95 percent CI of difference	
	0.974	0.325						Lower	Upper
Assumed			1.055	137.000	0.293	3.451	3.273	−3.020	9.923
Not assumed			1.240	106.042	0.218	3.451	2.783	−2.065	8.968

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Table 5. Direct and Indirect Design Error Costs for Project Types Descriptive Statistics

	Direct design error costs						Indirect design error costs					
Project type	*N*	Mean	Standard deviation	Standard error	Minimum	Maximum	*N*	Mean	Standard deviation	Standard error	Minimum	Maximum
New build	91	5.98	11.54	1.21	0.00	98.00	91	6.71	7.02	0.74	0.00	35.00
Refurbishment/renovation	28	7.08	17.13	3.24	0.50	93.00	28	5.84	5.21	0.98	0.00	20.00
Fit-out	11	10.32	7.90	2.38	2.00	30.00	11	12.18	8.29	2.50	0.00	30.00
Civil work	9	10.67	13.46	4.49	1.00	40.00	9	12.78	17.40	5.80	0.00	50.00
Total	139	6.85	12.72	1.08	0.00	98.00	139	7.36	8.03	0.68	0.00	50.00

survey was used to obtain data from 139 Australian construction projects. It was revealed that TLS remains the most popular form of procurement method in Australia despite continual calls for the use of integrated methods such as design and build. The mean direct and indirect design error costs were found to 6.9 and 7.4% of a project's contract value, respectively. Nevertheless, design error costs were not found to significantly vary among the project types and procurement methods adopted. Although this research provides insights into the design error cost estimates of industry practitioners, their actual costs remain relatively unexplored.

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