EFFECTS OF DESIGN ERRORS ON CONSTRUCTION PROJECTS

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Abstract: There have been extreme issues of building failures and other serious matters as a result of design errors. Construction and engineering professionals have found it difficult to learn from their mistakes, particularly with regards to the prevention, identification of design errors, projects that have wrought disaster after the construction are completed. Yet, design errors have been the root cause of several catastrophic accidents that have resulted in the loss of life and injury of workers and members of the public. So much emphasis is placed on the issue of time and cost that quality takes a back seat. This research justifies several mixed-mode research approaches and prior theoretical knowledge extracted from the literatures, case-study projects, interviews and visitation to construction sites. The paper further examines level of perception among the principle parties in the construction industry and the factors that control design and construction. Type and causes of design errors in the construction industry were identified and classified using a structured questionnaire that explain the relationship between the factors and the elements. Findings were validated and supported by case study projects. This research equally pointed to ways of improving performance and project delivery including ways of curtailing design errors in construction industry and improved understanding of the occurrence.

Keywords: Building projects, civil projects, Design error,

INTRODUCTION

Construction and engineering practitioners have found it increasingly difficult to learn from their mistakes, particularly with regard to the prevention, identification and/or containment of design errors. John. et al, (2001) explained that majority of structural failures and associated damage costs are due to errors in planning, design, construction, and utilization, rather than variability in construction material, strengths and structural loads. It should be recall that design is the first stage of construction and design errors have been the root cause of numerous catastrophic accidents that have resulted in the death and injury of workers and members of the public.
Design errors indicate the total design effectiveness of a project, major design quality problems occur during construction when errors, omissions and ambiguities in plans and specifications become evident (Davis & Ledbetter, 1987). A large amount of country's maintenance resources is being expended on corrective or remedial measures to buildings and their services due to design or construction defects.

This research work examines the effect of design errors in construction projects by identifying the types of existing design errors in building and civil construction projects, examines the causes of design errors in construction projects, assess the impact of design errors on construction projects and propose solutions as a means to reduce uncertainty caused by design errors.

The outcome of this study will benefit public and private sector, design firm and contractors because it intends to identify and expose the severity of faults and defects which are expected to occur in the design and construction stages. In the meantime the owner will minimize maintenance expenditure and the substantial life of the building will increase. The designer will improve the quality of the design by recognizing the faults and avoiding them, and as a result he will have better recognition and liabilities or losses to the owner. The contractor will improve the quality of work and minimize time delay and expenditure on repair work: also, benefit and have a better recognition in the market.

LITERATURE REVIEW

Successful project management is both an art and a science which attempts to control corporate resources within the constraints of time, cost, and performance (Kerzner, 1995) as cited by Rukn (2007). The triangle of time, cost, and performance is a combination that should be continuously pursued by the project team member throughout the life cycle of the project.

The owner, designer and contractor all have different interests in, or uses for the design of a facility. But what they do share is the commitment to complete the project safely and within a given budget and completion time. The major issue is "accuracy of the drawings," or the number of design errors, omissions and ambiguities within the plans and specifications that affect the quality of the facility. Inadequacies in the plans and specifications are the major causes of changes to the contract (George, 1998)

Therefore, the influence of errors in design documents is large, as Koskela (1992) suggests that it "sometimes seems that the wastes caused by design are larger than the cost of the design itself". A survey in Kuwait (Kartam et al., 2001) reported that defective design is one of the most significant risks to project delays. Similar results were also obtained from studies in Japan (Sawada, 2000), the US (Kangari, 1995) and Hong Kong (Ahmed, 1999). Defective design is considered a critical risk in these countries. More specifically, Burati et al, (1992) indicates that deviations on the projects accounted for an average of 12.4% of the total project costs, and design deviations average 78% of the total number of deviations, 79% of the total deviation costs, and 9.5% of the total project cost. He also found that design errors are the result of mistakes or errors made in the project design. He concluded that the deviation costs of the design change categories amounted to an average of 54.2% of the total deviation costs. In another study, Stasiowski et al, (1994) found that most design firms spend 25-50% of design man-hours redoing work that had already been done once, redesigning details that have already been designed on other projects, and correcting errors caught during design reviews.

Similarly, a survey conducted by Nikkei Construction involving 79 Japanese contractors (Anon, 2000) shows that 44% of respondents often experienced a significant number of design documents problems. The common problems experienced were constructability, conflicts in structural designs, inadequate temporary work designs, improper construction methods, and information on differing site conditions. He concluded that these design problems are ongoing issues in the Japanese construction industry and of major concern to many parties within the industry.

However, the occurrence of errors at the design stage is not limited to construction industry only; evidence has shown that errors in design occur in other industries. For example, Phal et al, (1996) stated that up to 80% of all faults in engineering projects can be traced back to insufficient planning and design work. Furthermore, up to 60% of all breakdowns that occur within the warranty period are caused by incorrect or incomplete product development. Also, the recent withdrawal of many cars from the market in order to change some systems in the cars (NHTSA, 6th Dec. 2000) and the court decision against the manufacturer of tyres which proved that the design of the tyres was causing the explosion of some tyres, leading to accidents. This was supported by the press release of the American National Highway Traffic Safety Administration: "the official death toll related to faulty Firestone tires and suspension system: 148 deaths and more than 525 injuries". These statistics are clear evidence that errors in design influence other industries also. Our role in the construction industry is to find the means to prevent errors or at least limit the effect of the errors that occur during the design stages.

RESEARCH METHODOLOGY

In this review, Data were collected using a structured questionnaire; the study area was Lagos State. Sixty questionnaires were administered to both indigenous and multinational construction companies in various professionals in the construction industry. Forty Seven were returned and analyzed using percentage, mean and one-way ANOVA in the SPSS version 12 package. The analyses of the data include determining the effects of design errors on construction projects.

ANALYSIS AND DISCUSSION OF FINDINGS

Types of design and construction errors

Table 1 above shows the types of design and construction errors. Eleven major groups of faults were identified as the major errors in design and construction projects; they are, the defects in civil design, architectural defects in design, design defects in maintenance practicality and adequacy, defects due to consultant firm administration and staff, defects due to construction drawings, defects due to construction inspections, defects due to civil construction, defects due to contractor administration, defects due to construction equipment, defects due to construction materials and defects due to specifications.

Out of the identified errors in construction projects, narrow stairs, passages and doors ranked first under architectural defect as a common design error in construction project with a mean value of`2.85.

Inadequate concrete cover on reinforcement under defect in civil design with mean value of 2.83 was ranked second as another common construction fault that as not being taking care of.

Table 1 also reveals that under defects due to consultant firm administration, Designers ignorance of material properties and Misjudgment of user's intended use was ranked third and fourth among the various types of design errors in construction projects with mean value of 2.68 and 2.62 respectively.

It also shown on the table that not considering the local climate condition when designing exterior shape with mean value of 2.55 was ranked fifth under architectural defect in design and civil defect design shows that improperly locating conduits and pipe openings at critical structural locations was ranked sixth with mean value 2.53.

Specifying inadequate concrete mix design and poor communication with the design firm and the owner are defects due to specification and defects due to contractor's administration with mean value of 1.55 and 1.77 respectively and took 37 and 38 which was the ranked least among the design errors identified.

Table 1: Types of design and construction errors

ARCHITECTURAL DEFECTS IN DESIGN	Strongly Agree	Agree	uncertain	Disagree	Strongly Disagree	Total	Mean	Rank
Narrow stairs, passages and doors Specifying finishing which need to be repaired as a whole.	6	17	10	6	8	47	2.85	1
Inadequate joints between finished face.	8	23	14	0	2	47	2.26	16
Not considering the local climate condition when designing exterior shape.	0	26	16	5	0	47	2.55	5
Not relating exterior material selection to climate condition.	18	21	13	5	0	47	2.32	13
DEFECT IN CIVIL DESIGN								
Inadequate provisions for movement	20	3	15	19	0	47	2.28	15
Ignoring aggressive environment and weather condition effects.	8	14	22	3	0	47	2.43	10
Ignoring biological effects	6	19	17	3	2	47	2.49	7
Inadequate structural design such as foundation.	4	32	3	6	2	47	2.36	12
Ignoring variation in soil conditions	9	21	9	6	2	47	2.38	11
Ignoring load impact on structured stability.	21	15	8	3	0	47	1.85	31
Exceeding allowable deflection.	13	18	11	3	0	47	2.00	26
Ignoring wind effects on the structure	7	21	14	3	0	47	2.19	18
Inadequate concrete cover on the reinforcement.	8	5	16	13	3	47	2.83	2
Improperly locating conduits and pipe openings at critical structural locations	2	24	7	12	0	47	2.53	6
DEFECTS DUE TO CONSULTANT FIRM ADMINISTRATION & STAFF								
Lack of QC/QA program during design.	16	9	20	0	0	47	2.00	26

Poor technical updating or staff training.	12	27	6	0	0	47	1.79	34
Hiring unqualified designers.	17	5	4	19	0	47	2.45	9
Lack of designer field experience.	11	9	14	6	0	42	2.26	16
Lack of designer technical background.	12	23	10	0	0	47	1.87	30
Designer ignorance of materials properties.	3	18	15	3	6	47	2.68	3
Misjudgement of climatic conditions.	4	29	9	3	0	47	2.15	20
Misjudgement of user's intended use.	2	19	17	3	4	47	2.62	4
DEFECTS DUE TO CONSTRUCTION DRAWINGS								
Lack of references	7	34	4	0	2	47	2.06	23
Conflicting details	19	2	0	4	2	47	1.89	29
Lack of details	3	36	6	0	2	47	2.19	18
DEFECTS DUE TO CONSTRUCTION INSPECTION								
Lack of inspection.	13	25	7	2	0	47	1.96	27
Unqualified inspector	7	34	4	0	2	47	2.06	23
Proponent (owner) negligence of the importance of inspection.	14	21	10	0	2	47	2.04	24
Weakness of inspection rule in implementing corrective actions during job	20	11	14	0	2	47	2.00	26
DEFECT DUE TO CIVIL CONSTRUCTION								
Inaccurate measurement.	7	21	11	6	2	47	2.47	8
Damaged form work.	6	27	9	3	0	47	2.11	21
Excavation too close to the building.	6	18	18	3	0	47	2.30	14
Painting in unsuitable conditions or on unsuitable surface.	9	24	6	6	0	47	2.11	21
Inadequate water proofing and drainage.	5	40	0	0	0	45	1.81	33

Insufficient reinforcement concrete cover.	7	31	7	0	0	45	1.91	28
Cold joints	2	41	4	0	0	47	2.00	26
Loss in adhesion between materials.	7	23	12	3	0	47	2.15	20
Early formwork removal.	2	5	28	12	0	47	2.06	23
Poor soil compaction.	2	9	27	9	0	47	1.91	29
Inadequate curing.	3	37	2	3	0	47	2.02	25
Lack of communication.	31	6	2	0	2	47	2.09	22
DEFECTS DUE TO CONTRACTORS ADMINISTRATION								
Not complying with specification.	12	33	3	0	2	47	1.87	30
Inability to read the drawings	15	20	6	2	4	47	2.15	20
Insufficient site supervision.	10	35	0	0	2	47	1.91	29
Poor communication with the design firm and the owner	25	20	0	2	0	47	1.55	38
Unqualified supervision.	10	20	15	2	0	47	2.19	18
Speedy completion or cheap quality work.	17	22	6	2	0	47	1.85	31
Unqualified work force.	17	25	3	2	0	47	1.79	34
Multinational construction experience.	6	17	19	3	2	47	2.53	6
DEFECTS DUE TO CONSTRUCTION MATERIALS								
Different thermal movements in dissimilar material.	2	35	8	0	2	47	2.26	16
Selection of material which is unstable for the existing climatic conditions.	41	0	4	2	0	47	2.00	26
Use of non-durable materials	0	36	6	0	3	47	2.23	17
Use of expired materials.	11	20	8	3	3	47	2.17	19
Poor material handling and storage.	0	38	7	2	0	47	2.06	23

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DEFECTS DUE TO CONSTRUCTION EQUIPMENT								
Wrong use of equipment.	11	34	0	2	0	47	1.68	35
Inadequate performance of equipment.	14	31	2	0	0	47	1.62	36
Lack of required amount of equipment.	6	39	2	0	0	47	1.79	34
DEFECTS DUE TO SPECIFICATION								
Unclear specification.	11	22	12	2	0	47	1.94	28
Not defining adequate materials type.	5	28	12	2	0	47	2.06	23
Not specifying the QA/QC construction procedure.	8	24	13	2	0	47	2.02	25
Not specifying the allowable load limits.	2	13	26	3	3	47	1.83	32
Specifying inadequate concrete mix design.	2	16	29	0	0	47	1.57	37
Unclear specification.	2	7	32	6	0	47	1.89	29

Factors that causes Design Errors

Table 2 shows the result of various causes of design errors in construction projects. The comparisons were done using analysis of variance (ANOVA) to determine the level of significance (SL). The first three on the list are 'Insufficient fund to create quality documents' having P- value of 0.000 and F- value of 14.206, 'Insufficient time to create review quality documents' (0.028) P- value and 3.346as F- value, therefore, it is an indication that there is significant difference among the factors and have significant value < 0.05. They are said to be significant (S). The third is on 'Lack of coordination between principle players and others discipline' with 0.000 as the P- value and 10.062 as f-value. This implies that it is significant.

Ten out of the identified factors that causes design errors were not significant as shown in the table 4 above. Ill-defined or unclear scope of work, speed of work, Use of narrow stairs, passages and doors, Inadequate provision for movement, attempt to produce maximum profit by minimizing staff, Owner changing design criteria late in the design process, Project managers not understanding the scope, Miss-coordination between lead designer and consultants; and confusion created by owner decisions or indecision's, and in turn, Client not coordinating as to what is required, Budget and time pressure on the designer human error were seen not to be significant to the factors that causes of design errors in construction projects.

Table 2: ANOVA Table of Result of causes of design errors

Causes of Errors		**Sum of Squares**	**df**	**Mean square**	**F value**	P	SL
Insufficient fund to create quality documents	Between Groups	24.168	3	8.056	14.206	.000	S
	Within Groups	24.385	43	.567			
	Total	48.553	46				
Insufficient time to create review quality documents	Between Groups	10.961	3	3.654	3.346	.028	S
	Within Groups	46.953	43	1.092			
	Total	57.915	46				
Lack of coordination between principle players and others discipline	Between Groups	18.007	3	6.002	10.062	.000	S
	Within Groups	25.652	43	.597			
	Total	43.660	46				
Ill-defined or unclear scope of work	Between Groups	.089	3	.030	.092	.964	NS
	Within Groups	13.826	43	.322			
	Total	13.915	46				
Human error	Between Groups	3.182	3	1.061	1.706	.180	NS
	Within Groups	26.733	43	.622			
	Total	29.915	46				
Speed of work	Between Groups	2.017	3	.672	.786	.509	NS
	Within Groups	36.792	43	.856			
	Total	38.809	46				
Use of narrow stairs, passages and doors	Between Groups	1.795	3	.598	.504	.682	NS
	Within Groups	51.056	43	1.187			

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	Total	52.851	46				
Inadequate provision for movement	Between Groups	1.383	3	.461	.490	.691	NS
	Within Groups	40.447	43	.941			
	Total	41.830	46				
Attempt to produce maximum profit by minimizing staff	Between Groups	1.384	3	.461	.728	.541	NS
	Within Groups	27.255	43	.634			
	Total	28.638	46				
Government spends too much time reviewing the A &E's work	Between Groups	15.238	3	5.079	5.983	.002	S
	Within Groups	36.506	43	.849			
	Total	51.745	46				
Owner changing design criteria late in the design process	Between Groups	.000	3	.000	.000	1.000	NS
	Within Groups	16.000	43	.372			
	Total	16.000	46				
Low budgets for design	Between Groups	8.753	3	2.918	3.122	.036	S
	Within Groups	40.183	43	.934			
	Total	48.936	46				
Project managers not understanding the scope of the project	Between Groups	5.213	3	1.738	2.120	.112	NS
	Within Groups	35.255	43	.820			
	Total	40.468	46				
Miss-coordination between lead designer and consultants; and confusion created by owner decisions or indecision's, and in turn	Between Groups	4.377	3	1.459	2.373	.083	NS
	Within Groups	26.432	43	.615			
	Total	30.809	46				
Client not coordinating as to what is required	Between Groups	5.722	3	1.907	4.268	.010	S
	Within Groups	19.214	43	.447			

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	Total	24.936	46				
Designer rushes out drawings before proper review	Between Groups	10.706	3	3.569	5.693	.002	S
	Within Groups	26.953	43	.627			
	Total	37.660	46				
Budget and time pressure on the designer	Between Groups	4.377	3	1.459	2.373	.083	NS
	Within Groups	26.432	43	.615			
	Total	30.809	46				
Designers lack of construction knowledge and experience	Between Groups	21.160	3	7.053	5.049	.004	S
	Within Groups	60.075	43	1.397			
	Total	81.234	46				

Effects of design errors on construction projects

Table 3 shows the results of effects of design errors on construction projects using analysis of variance (ANOVA) to determine the level of significance. Most of the respondents revealed that the time it takes to produce a quality set of design documents is clearly not enough. The concern should not be time but rather the quality of the design, it does not matter how long it takes to produce the design in as much that the end result will be a complete and useable design that the contractor will understand and use to meet the requirements of the owner. Also the owner will eventually gets a quality product and reduced costs due to limited changes (except owner scope changes) and virtually no litigation.

The difficult thing to understand is that if everyone knows that time is a major deterrent then why isn't something done about it. Several of the responses stated that profit motive was a factor. Everyone wants to make a profit. And how is this quest satisfied? Finish ahead of time or just get done the necessary items in order to put the project on the street and get it built. If it meets the owner's requirements then obviously they have a quality product. They also have many change orders, additional cost, adversarial confrontations and a construction schedule that grows.

Table 3: ANOVA Table of Result of Effects of Design Errors on Construction Projects

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ANOVA							
		Sum of Squares	**df**	**Mean Square**	**F**	**P value**	**SL**
Client changing design criteria late in the design process leads to project failure	Between Groups	15.031	3	5.010	4.427	.008	S
	Within Groups	48.671	43	1.132			
	Total	63.702	46				
Quality reduction in design details	Between Groups	10.408	3	3.469	5.048	.004	S
	Within Groups	29.550	43	.687			
	Total	39.957	46				
Design errors leads to conflicting specification.	Between Groups	10.141	3	3.380	9.910	.000	S
	Within Groups	14.668	43	.341			
	Total	24.809	46				
Slow down Speed in designer work	Between Groups	4.691	3	1.564	1.495	.229	NS
	Within Groups	44.969	43	1.046			
	Total	49.660	46				
Setback in Quantity of work to be achieved.	Between Groups	1.620	3	.540	.859	.470	NS
	Within Groups	27.019	43	.628			
	Total	28.638	46				
Safety measure drawback	Between Groups	8.150	3	2.717	2.831	.049	S
	Within Groups	41.255	43	.959			
	Total	49.404	46				
Lack of faster implementation of action on site.	Between Groups	3.092	3	1.031	2.551	.068	NS
	Within Groups	17.376	43	.404			
	Total	20.468	46				
Excessive consumption of funds in correction work	Between Groups	1.521	3	.507	1.580	.208	NS
	Within Groups	13.798	43	.321			
	Total	15.319	46				
Minimizing staff to achieve Maximum profit	Between Groups	10.716	3	3.572	2.567	.069	NS
	Within Groups	51.479	37	1.391			
	Total	62.195	40				
Conflicts among the	Between	5.526	3	1.842	2.174	.105	NS

building production team	Groups						
	Within Groups	36.432	43	.847			
	Total	41.957	46				
Conflicts on who should pay for design error	Between Groups	1.472	3	.491	1.106	.357	NS
	Within Groups	19.081	43	.444			
	Total	20.553	46				
Differences/ variation in soil conditions	Between Groups	1.886	3	.629	.482	.696	NS
	Within Groups	56.071	43	1.304			
	Total	57.957	46				
Not relating exterior material selection to climate condition	Between Groups	3.784	3	1.261	1.360	.268	NS
	Within Groups	39.876	43	.927			
	Total	43.660	46				
Ignoring load impact on structured stability	Between Groups	3.100	3	1.033	1.746	.172	NS
	Within Groups	25.453	43	.592			
	Total	28.553	46				
Poor technical updating or staff training	Between Groups	3.092	3	1.031	1.509	.226	NS
	Within Groups	29.376	43	.683			
	Total	32.468	46				
Wrong use of equipment	Between Groups	4.235	3	1.412	4.962	.005	S
	Within Groups	12.233	43	.284			
	Total	16.468	46				
Misjudgement of user's intended use	Between Groups	7.910	3	2.637	9.975	.000	S
	Within Groups	11.366	43	.264			
	Total	19.277	46				
Deformation of building elements	Between Groups	5.380	3	1.793	2.307	.090	NS
	Within Groups	33.429	43	.777			
	Total	38.809	46				
Unqualified work force	Between Groups	10.448	3	3.483	4.358	.009	NS
	Within Groups	34.360	43	.799			
	Total	44.809	46				
Speedy completion or	Between	.849	3	.283	.237	.870	NS

cheap quality work.	Groups						
	Within Groups	51.363	43	1.194			
	Total	52.213	46				

MEANS OF REDUCING UNCERTAINTIES CAUSED BY DESIGN ERROR

Respondents were asked if designers are given adequate time to complete design documents, do they need to develop Quality Control/Quality Assurance plans? The result of the question indicates that firms have introduced different steps in order to reduce the number of design errors. Within the realm of Total Quality Management concepts, firms have developed Quality Control plans as a check and balance system to reduce the number of design errors and reduce contractor rework. The reduction in errors and rework is possible through better coordination within die different disciplines. These plans establish criteria to review all the documents within the package. All the coordination and reviewing can only be totally served through effective communication.

Designers indicated that they have taken steps to develop regular coordination meetings between engineers and contractors enhancing the communication level. They also developed an out-of-house design review with the contractor to discuss not only the current phase of the construction but also the next phase(s). This forward thinking allows the team to foresee any problems that might develop while there is time to correct them without hindering the construction schedule.

Contractors are taking greater steps to review the drawings using system checks. Although still operating under a time limitation, the contractor is devoting more assets to the upfront review. Alter the bid award; the contractor continues to review the drawings early in order to reduce fewer project interruptions.

Conclusion

There are many initiatives being conducted to control the growth of cost and schedule within the construction industry. The major issue is the "accuracy of the drawings," or the number of design errors, omissions and ambiguities within the plans and specifications that affect the quality of the facility. So much emphasis is placed on the issue of time and cost that quality takes a back seat. The quality of the project depends on the conformance of the objectives and requirements. This

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is achieved if the owner establishes and communicates the scope of work to the designer who then clearly stated these requirements in the contract documents. An informative quality management technique will provide an agreement to procedures and definitions among the principle parties for the project. It is understood that the more time established in the design and bidding phase will lead to a quality product that will finish within schedule and within budget. This will minimize litigation and confrontation. The design team should continually educate themselves with the construction techniques performed by the contractor and incorporate that knowledge into the details of the project by integrating quality as the main focus of the design, the design team will be required to deal with communication between the principle parties, coordination of the other disciplines and adequately review the plans and specifications before issue.

The survey produced several feasible recommendations, to improve the quality of design and reduce the design errors to include omissions and ambiguities. First and foremost is resolving the scope definition before starting the project construction. It should be a joint effort between the owners, designer the contractor in the major concepts. Before any contractual agreement, there should be an open line of communication between all the principle parties. Included in that is the understanding of managerial skills and what constitutes a design error that will affect the cost and schedule of the project. The greatest measure of success is the sharing of information. Designers should take full control of the review process, both in-house and out-of-house. Adequate time should be given to complete the design documents including reviews, field investigations and greater involvement in the inspection process. Provide the designer and contractor an avenue to discuss problems and resolve them without intervention of the owner. The cost of doing business is growing every year and the percentage for payment has remained the same. Computer Aided Design(CAD) has not decreased the expenditures but raised them. In promoting the design factor of quality over time and cost all parties will create a win-win scenario and ensure the highest quality of construction.

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