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EFFECTS OF KNOWLEDGE, EXPERIENCE AND COORDINATIONON COST CERTAINTY FOR STRUCTURAL ENGINEERING DESIGNS OF HIGH-RISE BUILDING PROJECTSIN NAIROBI, KENYA

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ABSTRACT

Clients are increasingly demanding a high degree of cost certainty from their project design teams to ensure that their building projects are completed within the budgeted resources. However, this objective has been negated by various challenges that unfortunately cause budget overruns. This study investigated the effects of experience and project management skills on Change Orders for Structural Engineering High-Rise Buildings in Nairobi County, Kenya. Data was collected from 150 consulting Civil Engineers drawn from the Engineers Board of Kenya register using a web-based structured questionnaire. Analysis of variance and Chi-square tests showed that coordination and experience directly correlated to cost certainty at 5% confidence level. Design coordination significantly helped to narrow gaps for cost certainty as well enhancing better understanding of the project scope. The level of professional experience was found to be critical for problem solving, effective use of design software, quality control of design and documentation and integration. Therefore, professional experience and coordination played a critical role in the reduction of cost overruns during the construction of high-rise buildings in Nairobi.

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INTRODUCTION

Makingcities and human settlements inclusive, safe, resilient and sustainable is the focus of sustainabledevelopment goal (SDG) number 11. To achieve this goal calls for a balanced and integrated approach that takes into consideration economic, social and environmental aspects (UN,2015). This SDG -11 was informed by the projection that over 60% of the global population would live in urban areas and cities by 2050 thereby presenting huge challenges of housing, energy, water and transportation amongst others.In 2019 census, Kenya's population was estimated at 47 million with Nairobi city accounting for about 4.3 million (KNBS, 2019). Worldometer live estimates the current 2023 population of Kenya at 57 million. As a consequence of the population growth, about 2 million people live in slum settlements in Nairobi County, the challenges of such settlements notwithstanding (Amnesty International Publications (2009). As part of the solution to urbanization and settlement challenges, developers are opting for high rise building projects rather than building horizontally, thereby occupying lesser precious land area (Vijayasree, 2019). Vertical expansion also frees much needed land for enhancing the greenness and resilience of urban settlements, thus contributing to their overall health. Many cities across the world including Nairobi are witnessing a surgeinhigh-rise building projects, a trend that is expected to continue into the future (Construction Review, 2019). However, high-rise building projects present numerous complex technical and management challenges that require knowledge and experience to solve(Designing Buildings, 2021). For any project quality, cost, time, scope, risk and benefits are the key performance targets that require detailed planning, monitoring and control in order to achieve the stakeholder's objectives (Axelos, 2017; Gray, 2020).Economic sustainability is an overarching objective for every stakeholder in a building project. The aim is to ensure that the project will be executed to the required standards and completed within the approved budget.

In their study on whether maximizing cost certainty was the overarching objective of project implementation as opposed to minimizing costs, Lopez, Craige and Gransberg (2016) observed that in order to control the overall project costs, the project team had to guard against situations that compel them to seek for more funding from clients. Ensuring that cost certainty for building projects are minimized from the concept to the construction stage was found to be a workable strategy in this regard. More so the research provided evidence on the need to invest in pre-construction activities that mitigate risk and lead to increased cost as opposed to endeavouring to complete the project at the lowest cost possible, thus guaranteeing the overall quality of a project (Gransberg, Lopez and Humprey, 2007). From a project management perspective, it is vital to ensure that these processes are allocated sufficient resources to produce high quality designs and construction documents that can be relied upon for bidding (Brown, 2002). The various professionals involved on the project such as the architect, project manager, structural engineer, services engineer, quantity surveyor and other specialists have the responsibility of planning, coordinating and managing the design and project formulation processes in a manner that adds value and enables achievement of project objectives that revolve around six important aspects, namely scope, time, cost, risk, benefits and quality (Axelos, 2017). Completing the project within the agreed budget is therefore one of the most critical objectives of any project.

Objectives: The objective of this study was to evaluate the effects of knowledge, experience and coordination on cost certainty for structural engineering high-rise building in Nairobi, Kenya.

METHODOLOGY

The methodology of this studyconsidered the research design, instruments, population, samplesizing and sampling, data collection and analysis and results presentation.

Research Design:This research adopted a quantitative sample survey approach to gain greaterunderstanding of how the independent variables influence the quality of structuralengineering design and consequently the cost certainty of building projects.

Research Instruments: This study used structured questionnaires to collect primary data from the respondents.According to Burns and Grove (2009), questionnaires are regarded as being rich forboth quantitative and qualitative research. They also enable thecollection standardized information and are relatively inexpensive to administer andanalyse (Creswell, 2009). For example, Ikechukwu, Emoh and Okoracha (2017) used structuredquestionnaires to study the causes and effects of cost overruns in public buildingconstructions projects delivery in Imo state of Nigeria.

Research Population:This research targeted registered consulting civil engineers with experience instructural engineering design of high-rise buildings as the primary respondents.Structural engineering is one of the core specialized fields in the broader civilengineering profession. The sample frame was drawn from the Engineers Board of Kenya register for consulting engineers. The engineers were the most experienced and they understood well the dynamics of the construction industry. The 337 registered consulting civil engineers formed the initialresearch population for the study.

Sample Sizing and Sampling: The scope of research was restricted to respondents and high-rise projects withinNairobi County. Therefore 243 out of the 337 consulting civil engineers wereselected as respondents. Omair, (2014), Hogg and Tannis (2009) provide the following formula fordetermining a statistically representative sample.The sample size computed using equation 1.

$$n = \frac{m}{1+\left(\frac{m-1}{N}\right)} \qquad \text{…………(1)}$$

Where *n, m* and *N* represent the sample size of the limited, unlimited and available population respectively. *m* is estimated by equation 2.

$$m = \frac{z^2 \times p \times (1-q)}{\varepsilon^2} \qquad \text{……....(2)}$$

Where*z*is the statistic value for the confidence level used, (i.e., 2.575, 1.96, and 1.645, for 99%, 95%, and 90% confidence levels, respectively), *p* is the value of the population proportion which is being estimated; and ε is the sampling error. Since the value of *p* is unknown, Sincich, Levine and Stephan (2002) suggests a conservative value of 0.50 be used so that a sample size that is at least as large as required can be obtained. Most researchers use a 95% confidence level, i.e., 5% significance level and a sampling error ε of 0.05. Therefore, the unlimited sample size of the population, *m*is given by equation 3.

$$m = \frac{1.96^2 \times 0.5 \times (1-0.5)}{0.05^2} = 385 \qquad \text{…………...3}$$

Given that *N*=243, the representative sample, *n* was given by equation 4.

$$n = \frac{385}{1+\left(\frac{385-1}{243}\right)} = 149.2, \qquad \text{..……..…4}$$

Equation 4 was also used by Jarkas and Haupt (2015). Therefore, a total of 150consulting civil engineers were randomly selected using the probability intervalsampling technique from the 243 consulting civil engineers domiciled in NairobiCounty to participate in the survey.

Data Collection:Primary data was collected through structured questionnaires which wereadministered to 150 respondents by the researcher.Before the main survey, a pilot study using an online survey programme was carriedout on 12 respondents out of which 9 (representing 75%) returned their dully filledquestionnaires. The questionnaire focused on capturing the respondent's general particularsg four sections focusedon addressing each of the three independent variables and how theyinfluence cost certainty.

Effect of Coordination of SED on Cost Certainty: From a project's perspective, coordination describes the process of sharing information, being on the same page, harmonizing the different designs prepared by the multidisciplinary members of the project team into a single, fully described project product. Frequency of occurrence of the defects was measured using a Likert scale of 1 to 5 where 1 represented never, 2 represented rarely, 3 represented sometimes, 4 represented often and 5 represented always.

Impact of Knowledge and Experience on SED: In evaluating the influence of knowledge and experience on cost certainty of high-rise building projects, respondents were asked to indicate their level of agreement based on 5 statements on how knowledge and years of experience impacts the quality of structural engineering design. The level of agreement was measured on a scale of 1 to 5 where 1 represented Strongly Disagree, 2 represented Disagree, 3 represented Neutral, 4 represented Agree and 5 represented Strongly Agree.

Data Analysis and Presentation of Results

The web based google forms questionnaire provided a mechanism of automaticallysaving the responses from each respondent in excel format. The data was cleaned, coded and then imported intothe SPPS program for both descriptive and inferential statistical analysis. Descriptivestatistics were used to analyse general respondent's characteristics. They were analysed in terms of frequencies, proportions and percentages and presented usingtables, to summarize the data and give an overview of thedistribution of output. For each of the variables, the analysis illustrates thedistribution of responses (frequency distributions), measures of central tendency (mean, median and mode) as well as measures of dispersion such as variance andstandard deviations. Inferential statistics such as ANOVA, correlation and non-parametric analysis such Chi-square were used to testhypotheses and association between the dependent variable and independentvariables.

RESULTS AND DISCUSSIONS

Effectof Coordination of SED on Cost Certainty: The data collected showed that design coordination had significant effect on the cost certainty since over 50.9% of structural engineers relied on direct and formal contact as a way of sharing information for coordination purposes. Another 32.1% used meetings either physical or virtual to coordinate their designsas shown in Table1. However, only 9.4% employed the use of modern integrated design and coordination technology such as Building Information Modelling (BMI) while a paltry 3.8% rarely coordinated their work. The low uptake of technology is a matter of concern given the benefits of employing such technologies as shown by Nyaga (2016), Mumbua (2016) and Gitee (2018). Over 60.4% of the respondents noted that interface conflicts with other disciplines often and always. Occurredas shown in Table 4. About 33.9% often and always noted errors and omissions in their designs and documentation, while 51% often and always experienced design changes during construction. About 41.5% often and always experienced schedule overruns and 28.3% experienced budget overruns during construction (Table 4).

Table 1. Proportion of Structural Engineers Using different Methods of SED Coordination

Methods for SED coordination	Count	Percentage (%)
Direct formal contact e.g., through letters, emails, reports and drawings	54	50.9
Informal contact e.g., telephone, discussions and social media platforms	4	3.8
Meetings- physical or virtual	34	32.1
Integrated design and coordination technology e.g., BIM	10	9.4
Rarely done. Each professional works independently	4	3.8
Total	106	100

Table 2. Proportion of Engineers using different Methods of SED Quality Management

Methods of SED quality check	Count	Percentage (%)
Review by an experienced engineer within or without the firm	58	54.7
Output from the design software is generally satisfactory	2	1.9
Rely on the designer's level of knowledge and experience	6	5.7
Use of established QMS system such as ISO 9001:2008	12	11.3
Review through established office procedures	28	26.4

Table 3. Benefits of SED Coordination

Benefits of SED coordination	Mean	Max.	Min.	Std. Dev.	Mode
Helped in narrowing gaps, uncertainties and risks	2	5	1	1	1
Enhanced better understanding of the project scope	3	5	1	1	2
Fosters establishment of roles and responsibilities for the design team	3	5	1	1	3
Enables optimization and integration of design	3	5	1	1	4
Promoted monitoring and evaluation of progress and quality of design	4	5	1	1	5

Table 4. Adverse effects of lack of coordination on the quality of SED

Effects of Poor Coordination	Likert scale					Total		
	1	2	3	4	5	Count	Mean	Standard Deviation
Interface conflicts with other disciplines	1.9	3.8	34.0	39.6	20.8	106	4	1
Omissions and errors in design and documentation	0.0	17.0	49.1	24.5	9.4	106	3	1
Design changes during construction	0.0	5.7	43.4	32.1	18.9	106	4	1
Schedule overruns	3.8	20.8	34.0	26.4	15.1	106	3	1
Budget overruns during construction	11.3	15.1	45.3	15.1	13.2	106	3	1

When it comes to quality checks of SED within their firms, 54.7% had their design process and outputs checked by an experienced engineer within or outside the organization. About 26.4% had established office procedures for quality checks while only 11.3% used established quality management systems (QMS) such as ISO 9001:2008 (Table 2). About 5.7% solely relied on the level of knowledge and experience of the engineer and a further 1.9% relied on the output from the design software. The premium placed on the experience of the engineer in assuring quality of SED agrees with findings of Barton (2019) and Barker Structural (2017) as way of mitigating undesirable project outcomes such as defects and budget overruns. The data on the effect of various methods of planning and coordination on enhancement of quality of SED showed that narrowing of gaps, uncertainties and risks on the project were the most critical factors (Table 3). This also had the lowest mean of 2. Better understanding of the scope of the project ranked second while fostering the establishment of roles of roles and responsibilities for the design team ranked third. Optimization of design and better monitoring and evaluation ranked fourth and fifth respectively. These findings support Jain and Singh (2012) theory of cost overruns which postulates that effort helps understand the nature and scope of the project and with sufficient effort from the designers the entire scope of the project can be captured. Gaps and errors in design and documentation can thus be reduced. Considering the adverse effects of poor or lack of design coordination on the building projects, results showed that all the listed adverse effects were significant. The results agree with the rankings of Table 3 where narrowing gaps, uncertainties and risks ranked as number one. The findings also corroborate with Hegazy ***et al***. (2001) and Chiu (2002) who noted that the interdisciplinary nature of the design process lends itself to risks of having gaps and errors, which if unresolved creep into the construction stage and manifest as budget overruns. The more the engineer can narrow the gaps through proper design coordination, the less likely it is for the project to experience the adverse effects

Impact of Knowledge and Experience on SED: The results showed that the level of knowledge and experience of the engineer in charge of the project had a huge bearing on design parameters that ultimately affect cost certainty of building projects. A significant proportion of respondents with a mean of 4 either agreed or strongly agreed that the level of knowledge and experience improved problem-solving capabilities (98.1%), improved effectiveness in use of design software (96.2%), enhanced constructability of design (81.1%), enhanced quality of design and documentation (81.1%) and improved coordination and integration of design (79.2%) as detailed in Table 5. The results agreed with Schwinger and Meyer (2010) and Ahmed, Hacker and Wallace (2005) who acknowledged the place of experience in effective project delivery. High rise building projects are complex and present unique challenges that have a bearing all facets of project delivery such as technical, financial, safety, logistical, and operational.Analysis of the data in Table 5indicates that errors and omissions in design and documentation were tied to the level of knowledge and experience of the engineer in charge of the project. About 41.6% acknowledged that error and omissions were often and always found in their design and documentation. However, only 11.3% of the respondents claimed that their projects rarely or had never been adversely affected.With an exception ofstructural integrity issues which the respondents said that they rarely occur with a mean of 2, all the other adverse effects had a mean of 3 indicating that they sometimes occur (Table 6).

knowledge and experience of the engineer. Thus 50.9% of the respondents reported that they never occurred and 60.4% rarely occurred. These research findings agree with Jain and Singh (2012) that knowledge and experience plays a vital role in capturing the scope and consequently the completeness of design. The effects of the key determinants of the cost certainty of high-rise building projects wastested for statistical significance by cross table analysis.

Table 5. Opinions of respondents on benefits of Knowledge and Experience (%)

Benefit Statement	Likert Scale					No. of Respondents	Mean	StD Dev
	1	2	3	4	5			
Improved problem-solving capability	1.9	0.0	0.0	26.4	71.7	106	5	1
Improved effectiveness in use of design software	0.0	1.9	1.9	52.8	43.4	106	4	1
Enhanced design and constructability	0.0	3.8	15.1	35.8	45.3	106	4	1
Enhanced quality control of design and documentation output	3.8	5.7	9.4	35.8	45.3	106	4	1
Improved the coordination and integration of design	7.5	7.5	5.7	41.5	37.7	106	4	1

Where: 1=Never; 2=Rarely; 3=Sometimes; 4=Often; 5=Always on the Likert scale.

Table 6. Opinions respondents on adverse effects attributed to knowledge and experience (%)

Effect of Poor Design Coordination	Likert Scale					Total		
	1	2	3	4	5	Count	Mean	Standard Deviation
Errors and omissions found in designs and documentation	1.9	9.4	47.2	20.8	20.8	106	3	1
Coordination gaps with other disciplines	1.9	11.3	43.4	34.0	9.4	106	3	1
Contractual disputes	13.2	37.7	35.8	9.4	3.8	106	3	1
Cost escalations due to variations/reworks	1.9	26.4	34.0	20.8	17.0	106	3	1
Delays in project works	7.5	18.9	35.8	26.4	11.3	106	3	1
Structural integrity issues	28.3	32.1	24.5	3.8	11.3	106	2	1

Table 7. ANOVA-Significance testing of Coordination

ANOVA TABLE			Sum of Squares	df	Mean Square	F	Sig. Level
Enhances and better understanding of the project scope * Methods used to coordinate SED issues with project team	Between Groups	(Combined)	14.171	4	3.543	2.792	.030
		Linearity	3.431	1	3.431	2.704	.103
		Deviation from Linearity	10.740	3	3.580	2.821	.043
	Within Groups		128.169	101	1.269		
	Total		142.340	105			
Enables optimization and integration of design * Methods used to coordinate SED issues with project team	Between Groups	(Combined)	17.164	4	4.291	2.920	.025
		Linearity	8.967	1	8.967	6.102	.015
		Deviation from Linearity	8.197	3	2.732	1.859	.141
	Within Groups		148.421	101	1.470		
	Total		165.585	105			
Promotes monitoring and evaluation of progress and quality of design * Methods used to coordinate SED issues with project team	Between Groups	(Combined)	69.875	4	17.469	14.573	.000
		Linearity	12.989	1	12.989	10.836	.001
		Deviation from Linearity	56.886	3	18.962	15.819	.000
	Within Groups		121.068	101	1.199		
	Total		190.943	105			

The study also showed that 43.4% of the respondents acknowledged that their building projects had often and always been adversely affected in terms of having design coordination gaps with other disciplines. These gaps eventually had to be addressed in the course of construction with varying degrees of implications of the project. Variations during construction with resultant cost escalations and delays in project works were similarly noted as significant outcomes related to the level of knowledge and experience of the engineer. Thusabout 37.8% of the respondents acknowledged these adverse effects on their projects as occurring often and always. Contractual disputes and adverse effects on the structural integrity of the building projects were noted to be the least prevalent factors affected by

The various methods of design coordination were statistically significant in so far as enhancing better understanding of the project, enabling optimization and integration of design. The promotion of evaluation, monitoring and quality of design had P- values of 0.03, 0.025 and 0.00 respectively as shown in Table 7. The analysis of the various quality management systems employed by engineers versus the frequency of occurrence of adverse effects on projects also showed statistical significance for constructs such as errors and omissions in design, documentation and budget overruns (Table 8). Analysis of variance showed a significant difference in association and direction of relationship between the methods of quality assurance and omissions and errors in design and documentation as well as budget overruns during construction (Table 9).

Table 8. ANOVA-Significance testing of Adverse impacts due to Design Coordination challenges

ANOVA TABLE							
			Sum of Squares	**df**	**Mean Square**	**F**	**Sig. Level**
Omissions and errors in design and documentation * Quality management systems used in the organisation	Between Groups	(Combined)	7.344	4	1.836	2.678	.036
		Linearity	2.479	1	2.479	3.615	.060
		Deviation from Linearity	4.865	3	1.622	2.365	.075
	Within Groups		69.259	101	.686		
	Total		76.604	105			
Budget overruns during construction * Quality management systems used in the organization	Between Groups	(Combined)	21.435	4	5.359	4.731	.002
		Linearity	9.416	1	9.416	8.312	.005
		Deviation from Linearity	12.020	3	4.007	3.537	.017
	Within Groups		114.414	101	1.133		
	Total		135.849	105			

Table 9. Measures of association of coordination constructs

Measures of Association				
	R	**R^2**	**Eta**	**Eta Squared**
Omissions and errors in design and documentation * Quality management systems used in the organization	-0.180	0.032	0.310	0.096
Budget overruns during construction * Quality management systems used in the organization	-0.263	0.069	0.397	0.158

Table 10. ANOVA- All independent variables vs budget overruns

		Sum of Squares	df	Mean Square	F	Sig. Level
The kind of structural design software/tools used	Between Groups	12.535	3	4.178	3.456	0.019
	Within Groups	123.314	102	1.209		
	Total	135.849	105			
Experience of the structural engineer	Between Groups	17.040	3	5.680	4.876	0.003
	Within Groups	118.810	102	1.165		
	Total	135.849	105			
The amount of structural design fees for the project	Between Groups	11.430	3	3.810	3.123	0.029
	Within Groups	124.419	102	1.220		
	Total	135.849	105			
Coordination of the structural design	Between Groups	10.480	3	3.493	2.842	0.042
	Within Groups	125.369	102	1.229		
	Total	135.849	105			

The negative correlation coefficient (R^2) value revealed that budget overruns and errors in design and documentation decreased when coordination effort geared to enhancing quality of SED was increased. Since the P values from the ANAOVA were less than the level of significance of 5% (α=0.05), it implied that a correlation existed between the constructs. The quality of Structural Engineering Design was found to have effect on the cost certainty of high-rise building projects as shown in Table 10.

Conclusion and Recommendations

The level of coordination and experience in Structural Engineering Designs (SED) affectsthe quality and the cost certainty of high-rise building projects. High-cost certainty can be achieved by exerting tighter control on the factors that have an adverse effect on the quality of structural engineering designs, thereby avoiding the problem of seeking more funding. Further, structural engineering practitioners as well as other professionals in the construction industry should endeavour not only to establish functional quality management procedures within their operations but also to shift from disjointed working and adopt design solutions that allow project teams to work collaboratively on the same model. Experience in structural engineering designs is a premium asset for both the practitioners and clients who employ their services. Developers, project managers and any procurement entities of engineering services should therefore be sensitised on the pitfalls of employing inexperienced engineers on their high-rise building projects.

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