An assessment of the causes, cost effects and solutions to design-error-induced variations on selected building projects in Nigeria

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Abstract

Design errors and variations are inherently part of many construction projects and require deliberate effort to combat. The literature reviewed indicates that empirical studies of the cost effect of design-error-induced variations are scarce. This study investigates the causes of variation on building projects, the frequent design errors that lead to variation, the effects of design error on variation cost, and solutions to design-error-induced variation in design documents. A mixed methods research (interviews and 30 case study building projects) was used to collect the necessary data for the study. Interviews were conducted with 25 construction professionals to obtain information on the causes of variation on building projects and solutions to design-error-induced variation on building construction projects. Thirty documents including valuation breakdowns and variation/change order documents were obtained by convenience sampling technique and used for the extraction of design errors leading to variations and their associated costs. The data was analysed with frequencies and percentages. The study found that poor working drawing and lack of coordination among design documents are the major causes of variation. Errors in design calculations and wrong descriptions in specifications are prominent design errors that led to variation. Design errors account for roughly 36% of the variation cost of building projects. Structural and architectural drawings contain the largest number of errors among design documents, but electrical and mechanical documents have the highest contribution to variation cost. The study concluded that variation costs could be minimized if government policies, aimed at ensuring proper contract documentation, were put in place, and construction professionals were limited to their core roles on construction projects. Rechecking of design documents prior to use, knowledge sharing, and use of computer programs were among the recommended solutions to design-error-induced variation in project documents.

Keywords: Construction projects, cost of error, design documents, design error, variation cost, valuation documents

Abstrak

Ontwerpfoute en -variasies vorm inherent deel van baie konstruksieprojekte wat doelbewuste pogings verg om te bestry. Die literatuuroorsig dui daarop dat empiriese studies van die koste-effek van ontwerpfout-geïnduseerde variasie skaars is. Daarom ondersoek hierdie studie die oorsake van ontwerpfout-geïnduseerde variasie, hul effekte op variasiekoste en oplossings vir ontwerpfoute in ontwerpdokumente. Die studie is uitgevoer op geselekteerde bouprojekte in Nigerië. Die gemengde metode van onderhoud- en 30 gevallestudie-bouprojekte is aangeneem in die versameling van die nodige data vir die studie. Onderhoud is met 25 konstruksiekenners gevoer om inligting te verkry oor die oorsake van variasie en oplossings om foute van boukonstruksieprojekte te ontwerp. Dertig dokumente wat insluit waardasie-afbreekpunte en variasie-/veranderingsopdragdokumente is verkry deur die gemaksbepalingstegniek en gebruik vir die onttrekking van ontwerpfoute wat lei tot variasies en hul verwante koste. Die data is geanaliseer met frekwensies, somme en persentasies. Die studie het bevind dat swak werktekening en gebrek aan koördinasie onder ontwerpdokumente die hoofoorsake van variasie is. Foute in ontwerpberekeninge en verkeerde beskrywing in spesifikasies is die prominente ontwerpfoute wat tot variasie gelei het. Ontwerpfoute verteenwoordig tot 36% van die variasiekoste van bouprojekte. Strukturele en argitektoniese tekeninge bevat die meeste foute onder ontwerpdokumente, maar elektriese en meganiese dokumente maak die grootste bydrae tot variasiekoste. Die studie het tot die gevolgtrekking gekom dat variasiekoste in ’n groot mate tot ’n minimum beperk kan word indien regeringsbeleid om behoorlike kontrakdokumentasie te verseker, ingestel word en professionele persone beperk word om die werk van ander professionele persone te doen. Herontwerp van ontwerpdokumente voor gebruik, kennisdeling en gebruik van rekenaarprogramme is onder die aanbevole oplossings om foute van projekdokumente te ontwerp.

Sleutelwoorde: Konstruksieprojekte, koste van foute, ontwerpdokumente, ontwerpfout, variasie, waardasie dokumente

1. Introduction

Construction is, by nature, complex and uncertain. Unlike the manufacturing and other sectors of the economy, the design and production activities of construction projects are usually separate functions. That is, the design and construction of a building are two separate functions performed by different parties working independently (Juliana, Ramirez & Larkin, 2005). However, these parties (contractors and consultants) have different interests in building projects. For instance, while the client wants value for money, the contractor wants to maximize profit. These interests normally lead to design error as a major source of variation, as claimed by Asamaoh & Offei-Nyako (2013).

Variation is any deviation from an agreed, well-defined scope and schedule of construction projects after issuance of variation order (Osman, Omran & Foo, 2009: 142; Alaryan, Emadelbeltagi, Elshahat & Dawood, 2014: 1). Furthermore, while Love, Edwards and Irani (2008: 234) defined errors as unintended deviations from correct and acceptable practice that are avoidable, Dosumu & Adenuga (2013: 677) noted that error entails different meanings and usages depending on how it is conceptualized across different fields of study. With these assertions, design error may be defined as preventable deviations from acceptable standards of practice during the design of construction projects.

Many projects in developing countries suffer from slipped milestone, cost and time overrun, due to variation in construction projects (Ubani, Nwachukwu & Nwokonkwo, 2010: 141). Muhammad, Keyvanfar, Abd-Majid, Shafaghat, Magana & Dankaka (2015: 91) revealed that variation occurs in all types of projects. Muhammad *et al.* (2015: 96) noted three prominent sources of variation: design error and omission account for 65% of variation; design changes account for 30% of variation, and other reasons account for only 5% of variation. To buttress this position, Diekmann and Nelson (1995) affirmed that variation has a 65% likelihood of being caused by design error. Therefore, it can be argued that there is a strong connection between design error and variation. It is on this basis that this study investigates the causes of variation, frequent design errors that lead to variation, cost effects of design errors on variation, and solutions to design-error-induced variation in building projects.

Researchers, including Love & Josephson, 2004; Mohammed, 2007; Long, 2011; Love, Edwards, Han & Goh, 2011; Dosumu & Adenuga, 2013; Dosumu, Idoro & Onukwube, 2017, have worked on the causes, effects and remedies of error in construction documents. Studies have also been conducted on variation and variation orders (Anees, Mohamed & Razek, 2013; Desai, Pitroda & Bhavsar, 2015). Other studies (Al-Dubaisi, 2000; Aljishi & Almarzouq, 2008; Zawawi, Azman & Kamar, 2010) were conducted to affirm that design error is the major source of variation on construction projects. However, there is a paucity of studies investigating the extent to which design errors affect variation cost of construction projects. Without identifying the design errors that have large contributions to variation cost, it may be difficult to reduce the total cost of variation and invariably cost overrun of construction projects.

2. Literature review

Variation is a change or any modification to the contractual guidance provided to the contractor by the owner or consultants (Ismail, Pourrostam, Soleymanzadeh & Ghouyounchizad, 2012: 4969). Changes including changes to plans, specifications or any other contract documents occur after the award of the initial contract or after work might have commenced. The changes may be due to various reasons such as inadequate design, change in design, and misinterpretation of drawings leading to construction error (Memon, Rahmon & Abul-Hasan, 2014: 4495). Similarly, variation order is a formal document that is used to modify an original contractual agreement. It becomes part of the project's documents (Alaryan *et al.*, 2014: 2).

Osman *et al* (2009: 143) and Muhammad *et al.* (2015: 92) classified variation, according to their causes, as design errors and omission (65%), design changes (30%), and unforeseen conditions (5%). Fisk (1997) stated that the two basic types of variation are direct and constructive changes. Direct changes occur when a client instructs the contractor to perform works that are not specified in the contract document or makes additions to the original scope of work. Constructive changes are informal acts or modifications to a contract, due to an act or failure to act. Juszczyk, Kozik, Lesniak, Plebankiewicz & Zima (2014: 285) analysed the errors committed in design and classified them based on error group, person responsible for the error, and place of error in designs.

Variation has been an inherent part of construction projects and usually arises due to the causes attributed to the different stakeholders involved in project execution (Alaryan *et al.*, 2014: 1). Variation is usually regularized by the issuance of a variation order. Various causes of variation have been identified in construction projects and the enormity of these causes indicates that variation is part of construction projects and cuts across various stakeholders (Sunday, 2010: 101). Ibn-Homaid, Eldosouky & Al-Ghamdi (2011: 36) revealed that consultants are mostly responsible for variation order. The reason for this assertion is not known. Oladapo's (2007) study on the significance of variation as a cause of cost and time overruns revealed that changes in specification and scope initiated by clients and consultants are the most frequent causes of variation.

Other causes of variation include inadequate details of working drawings, change in schedule (Memon *et al.*, 2014: 4495); change in scope (CII, 1990); poor workmanship; client's financial problem; change in specification, and design complexity (Mohammad, Che Ani, Rakmat & Yusof, 2010: 75). Alaryan *et al.* (2014: 1) noted that error and omission in design are the main elements of variation, even though there are main causes such as safety consideration, weather conditions, new government regulations, poor planning by contractor, technology changes, and changes in work procedures, among others. Al-Dubaisi (2000) and Zawawi *et al.* (2010) revealed that errors and omission in design are the sources of variation.

Asamaoh & Offei-Nyako (2013: 23) stated that design complexity, change in specification, and lack of knowledge are part of the causes of design errors that lead to variation. Muhammad *et al*. (2015: 93) revealed that impediment to prompt decision-making process, poor workmanship, lack of strategic planning, change in design, non-compliance of design with government regulation, aesthetics, cost, inadequate project objectives, mistake, and plan error are the causes of variation which originated from design error.

Researchers (Jawad, Abdulkader & Ali*,* 2009; Keane, Sertyesilisik & Ross*,* 2012; Olsen, Killingsworth & Page*,* 2012) on the effect of variation in construction projects indicated that changes during construction will affect project performance. Osman *et al.* (2009: 144-145) affirmed that the potential effects of variation on construction projects are increase in project cost, additional payment for contractor, increase in overhead expenses, completion schedule delay, as well as rework and demolition. Increase in project cost and time are the two main effects of variation, according to Aljishi & Almarzouq (2008). It can be deduced from the literature reviewed for this study that design error is a major cause of variation. In order to reduce variation, design error needs to be diminished to the barest minimum.

In addressing the conventional methods of reducing variation, it was suggested that error prevention should be viewed as a continuous process rather than a product of certain activities or behaviours, as it involves people, organisations and project systems (Love, Lopez, Edwards & Goh, 2012: 108). Love, Lopez & Kim (2014: 813, 815, 817) noted that people-related error management includes cognition, behaviour, motivation and learning; organisational error management includes quality, culture and training, and project-related error management includes the use of integrated procurement methods, Building Information Modeling (BIM) and Computer-Aided Design (CAD). Other methods of managing design errors include specialists' involvement in design planning and processing of construction works, preparation of detailed design, provision of elaborate project brief, day-to-day management of the project (Ismail *et al*., 2012: 4971), reports among client, consultant and contractors, establishment of oversight committee, and budgetary allocations (Asamaoh & Offei-Nyako, 2013: 24).

Table 1 summarizes the classifications of design-error-induced variations based on their causes, effects and solutions, as discussed in the literature review of this study.

Table 1: Classification of design-error-induced variations based on their causes, effects and solutions

Classification	*Causes*	*Effects*	*Solutions*
(Alaryan *et al.*, 2014; Osman *et al.*, 2009; Fisk, 1997)	(Muhammad *et al*., 2015; Memmon *et al*., 2014; Alaryan *et al*., 2014; Asamaoh & Offei-Nyako, 2013; Mohammad *et al*., 2010; CII, 1990; Oladapo, 2007)	(Keane *et al.*, 2012; Olsen *et al.*, 2012; Osman *et al.*, 2009; Jawad *et al.*, 2009; Aljishi & Almarzong, 2008)	(Love *et al*., 2014; Asamaoh & Offei-Nyako, 2013; Love *et al*., 2012; Ismail *et al.*, 2012)
Design error and omission	Inadequate details in drawings, lack of knowledge, inadequate project objectives, and design complexity	Completion schedule delay, and increased project cost	Viewing error prevention as a continuous process, organisations and project systems cognition, motivation and learning; quality control, culture and training, use of integrated procurement methods, Building Information Modeling (BIM), Computer-Aided Design (CAD), specialists' involvement in design planning, preparation of detailed designs, elaborate project brief, day-to-day management of the project, establishment of oversight committee, and budgeting allocations

Classification	*Causes*	*Effects*	*Solutions*
Design changes	Change in schedule, change in scope, clients' financial problems, change in specifications, safety consideration, poor planning, technology change, slow decision-making process, non-compliance of design with government regulation, aesthetics, and cost	Additional payment for contractors, rework, demolition, completion schedule delay, increased overhead expenses, rework, and demolition	Quality control, culture and training, Building Information Modeling (BIM), Computer-Aided Design (CAD), specialist involvement in design planning, detailed design, and elaborate project brief
Unforeseen conditions	Poor workmanship, government regulations, and weather conditions	Increased overhead expenses, and completion schedule delay	Motivation and learning

3. Research methodology

This study addressed the causes of design-error-induced variation on building projects, the frequent design errors that lead to variation, the effects of design error on variation cost, and solutions to design-error-induced variation in design documents. The study used a mixed methods design, in which qualitative and quantitative data are collected in parallel, analysed separately, and then merged (Creswell, 2005). In this study, valuation and variation documents from 30 selected case studies of building projects were used to build the theory of human error in designs, predicting that design-induced-errors will negatively affect the variation cost of building projects in Nigeria. The interviews explored causes of and solutions to design-error-induced variation from construction professionals in Nigeria. The reason for collecting both quantitative and qualitative data is to elaborate on specific findings from the breakdown of the valuation and variation documents, such as similar causes of design errors and variation suggested from respondents' groups (Creswell, 2005; Creswell & Plano-Clark, 2007).

3.1 Sampling method and size

Twenty-five construction professionals, consisting of builders, architects, engineers and project managers, were interviewed on the causes of design-error-induced variation and the ways in which design-error-induced variation in construction projects may be minimized. The construction professionals were selected through the stratified sampling technique. The stratification was done according to the respective professional bodies (Nigerian Institute of Building, Nigerian Institute of Architects, Nigeria Society of Engineers, and Institute of Project managers) in the Nigerian built environment. The number of professionals interviewed appears to be small, but the validity of the information supplied was inherent in their wealth of experience on the subject matter and the number of years they have spent in the construction industry. The minimum qualification for corporate membership of professional bodies in the Nigerian built environment is first degree (BSc/BTech/BEng); thus, the minimum qualification of the respondents was BSc/BTech/BEng. Further informal interrogation indicated that the respondents had a minimum of 7 years' work experience in the construction industry.

The case studies selected for the study consisted of building projects that were completed between 2014 and 2016, and that had valuation/variation documents. However, due to the confidentiality of the type of information that was sought, it was necessary to select the building projects to be used for the study based on convenience and availability of the required information. Therefore, 30 case study building projects were selected by non-probabilistic convenience sampling technique and used as the source of data for this study (Etikan, Musa & Alkassim, 2016: 2).

3.2 Data collection

The design-error mitigation topics used in the interview survey were extracted from reviews of the literature. In addition, the myriads of design-error-induced variations discovered in the case study projects prompted the researchers to interview professionals on how the problems may be solved. The interview survey contained one closed-ended and two open-ended questions. Respondents were asked to indicate their role on building construction projects. The options were: (a) Architect; (b) Builder; (c) Engineer (Structural, Mechanical, Electrical), and (d) Project manager. Respondents were asked to mention the top causes of design-error-induced variation in building projects and briefly discuss ways in which design-error-induced variation in construction projects may be minimized. Email messages were sent to respondents via the addresses obtained from the professional bodies, requesting them to grant an interview based on the questions raised in the accompanied interview template, or to reply to the questions in the template, provided they had completed a building project in the past two years and such buildings were not bungalows. A bungalow is a building that is limited to having only a ground floor level. Bungalows do not usually have structural, mechanical and electrical drawings (in Nigeria), which are the major documents investigated in this study. Hence, bungalows were excluded from the study. Professionals who did not meet the stated criteria were not expected to reply to the email invitations; they were automatically disqualified. While 10 of the respondents replied via email by completing the accompanied interview template, 15 respondents granted interviews to the researcher. Further information was requested from those who replied using emails, where clarity was deemed necessary.

For the case studies, the building projects were selected across Nigeria, including commercial, residential and special purpose projects. The selection criteria of the case study projects included suitability of the project for the study (must not be a bungalow), in order to ensure that all case study projects must have all the necessary design documents, valuation/variation documents, and be completed between 2014 and 2016) and the willingness of the custodian of the required documents to release them for the study. It was ensured that projects used for the study were completed between 2014 and 2016 so that recent information could be collected for the study. A breakdown of valuation documents and variation order documents of the selected building projects were examined, in order to determine the design errors that led to variations, and their associated costs and effects on total variation cost of building projects. The valuation and variation documents were obtained from the quantity surveyors of consulting and contracting firms that executed the selected projects. The information extracted from the documents included general information on the types of building projects, design errors that led to variation, cost of each design error, and total variation costs of the building projects.

3.3 Data analysis and interpretation of findings

Using the Excel software program, the responses on causes of design-error-induced variation, the specific design errors that led to variation as well as the responses on the solutions to design-error-induced variation were subjected to content analysis prior to tabulation. Content analysis is a technique that relies on coding and categorizing the data (Stemler, 2001: 137). Once the responses from the interview results were analysed, the causes of variation, specific design errors, as well as the solutions were coded and categorized based on frequency of occurrence.

Since the data collected from valuation and variation documents for the study were mostly related to cost and frequency, they were analysed with sums, frequencies and percentages. To interpret the findings, the following formula was used to calculate the effect of design error on variation cost:

$$\text{Variation cost (\%)} = \frac{\text{Design error cost}}{\text{Total variation cost}} \text{ X } 100$$

4. Findings

This section shows the findings from the analysis and interpretation of the data collected for this study. Tables 2 to 5 show the general information of the case study projects used for the study. Table 6 shows the causes of variation in construction projects. Tables 7 to 8 indicate the frequent design errors that led to variation in the case study projects. Table 9 shows the description of design errors that led to variation on building projects. Tables 10 and 11 show the effects of design error on the variation cost of construction projects. Table 12 presents the data analysis from the report of interviews conducted with construction professionals on the solutions to design-error-induced variation in construction projects.

4.1 General information regarding the type of case study building projects

Table 2 shows the procurement methods used for the building projects investigated in the study.

Table 2: Procurement method used for building projects

Procurement method	*Frequency*	*Percentage (%)*
Traditional	18	60.0
Design and build	12	40.0
Total	30	100.0

Of the projects, 60% were procured traditionally, whereas 40% were procured through management methods (design and build). This indicates that the majority of the projects were procured using traditional methods. Traditional procurement method separates the design from the construction process; a client appoints a main contractor on the basis of competitive or single-stage tendering. Tendering is a process whereby contractors are invited to bid for construction projects based on a competitive fee.

Table 3 shows the types of building projects investigated in the study.

Table 3: Types of building projects investigated

Type of building project(in terms of use)	*Frequency*	*Percentage (%)*
Residential	15	50.0
Commercial	8	26.7
Special purpose	7	23.3
Total	30	100.0

Residential building projects were 50%, commercial buildings, 26.7%, and special-purpose building projects, 23.3%. Special-purpose buildings are buildings with special construction materials and unique designs that restrict its use to what it was built for (that is, they may not be easily converted for other purposes). They are usually single-purpose buildings and include churches, mosques, recreational buildings, theatres, and so on.

Table 4 indicates the sector to which the building projects clients belong.

Table 4: Sector to which building projects clients belong

Type of building project client	*Frequency*	*Percentage (%)*
Private	23	76.7
Government	7	23.3
Total	30	100.0

Projects belonging to private clients were 76.7% and projects owned by government (federal and state) were 23.3%.

Table 5 shows the different contract sums under which the building projects are categorized.

Table 5: Contract sum of building projects

Contract sum (=N=)	*Frequency*	*Percentage (%)*
Below 100 million	15	50.0
100-500 million	10	33.3
Above 500 million	5	16.7
Total	30	100.0

The number of building projects with contract sums above N500 million Naira were 16.7%; 33.3% of the projects cost between N100 million and N500 million Naira, and 50% were below N100 million Naira. It is worth noting that all (100%) the projects investigated were multi-storey buildings.

4.2 Causes of variation in construction projects

Table 6 indicates the result of the interviews conducted with professionals on the causes of variation in construction projects. Once the contents of the interview results were analysed, 15 causes of variation were identified and tabulated as shown. The frequency represents the number of respondents who mentioned the identified causes, and the percentage represents the fraction of the individual frequency to the total frequency of occurrence of the variation. It is important to mention that some of the causes identified by the respondents may be taken as design errors, on the one hand, and they may, however, equally be regarded as causes of variation, on the other.

Table 6: Causes of variation in construction projects

Causes of variation	*Frequency*	*Percentage (%)*	*Rank*
Poor working drawings	24	13.3	1
Lack of coordination during design	20	11.1	2
Change in scope of work by clients	19	10.5	3
Omissions in design	18	9.9	4
Design error	18	9.9	4
Inadequate project objectives	16	8.8	6
Mistakes	15	8.3	7
Inexperience of designers	14	7.7	8
Owner’s financial difficulties	12	6.6	9
Difficult site condition	6	3.3	10
Design complexities	6	3.3	10
Incorrect assumptions	4	2.2	12
Aesthetics	4	2.2	12
Technology changes	3	1.7	14
Fatigue	2	1.2	15
Total	181	100	

Poor working drawing (13.3%) was the most rated cause of variation on construction projects, followed by lack of coordination during design (11.1%), change in scope of work by clients (10.5%), design errors (9.9%), omissions in design (9.9%), inadequate project objectives (8.8%), mistakes (8.3%), inexperience of designers (7.7%), owner's financial difficulties (6.6%), design complexities (3.3%), difficult site conditions (3.3%), aesthetics (2.2%), incorrect assumptions (2.2%), technology changes (1.7%), and fatigue (1.2%), respectively. Many of the causes of variation identified in the study were more design related; this is consistent with the claims made in the literature reviewed in this study. To elaborate on this finding, a breakdown of valuation/variation documents from the construction buildings of this study was done to examine specific design errors that led to variation in construction projects (see Table 7). It was also important to examine the frequency of occurrence of design errors according to the types of errors identified (see Table 8) and to describe the design errors that led to variation on building projects (see Table 9).

Table 7 indicates the design errors that led to variation on construction projects according to the breakdown of valuation/variation documents examined. The frequencies, types of design errors and their descriptions were also obtained from the documents. Due to space, Table 7 presents only the frequencies of design error on construction projects and their corresponding percentages based on design documents and total number of design errors identified; other details are presented in Table 9.

Table 7: Design errors that led to variation based on design documents

Types of errors	*Frequency*	*Total error per document (%)*	*Total design error (%)*	*Rank*
Structural drawings				
Wrong/inadequate description in specification	6	11.5	4.5	7
Error in design calculation	34	65.4	25.8	1
Omission of details	12	23.1	9.0	5
Total	52	100.0	39.3	
Architectural drawings				
Absence of specification	6	15.0	4.5	7
Dimensional error	16	40.0	12.1	2

Types of errors	*Frequency*	*Total error per document (%)*	*Total design error (%)*	*Rank*
Wrong/inadequate description in specification	16	40.0	12.1	2
Omission of details	2	5.0	1.6	12
Total	40	100.0	30.3	
Electrical drawings				
Omission of details	6	27.3	4.5	7
Wrong/inadequate description in specification	14	63.6	10.6	4
Error in design calculation	2	9.1	1.6	12
Total	22	100.0	16.7	
Mechanical drawings				
Omission of specification	6	33.3	4.5	7
Error in design calculation	4	22.3	3.1	11
Wrong description	8	44.4	6.1	6
Total	18	100.0	13.7	
Total of totals	132		100	

A total of 132 errors were found in architectural drawings (40), structural drawings (52), electrical drawings (22), and mechanical drawings (18), respectively. These figures translate to 30.3%, 39.3%, 16.7%, and 13.7% for the design documents, respectively. Table 7 shows further that the frequency of occurrence of design errors in valuation documents based on design documents were in the order of structural drawings (39.3%), architectural drawings (30.3%), electrical drawings (16.7%), and mechanical drawings (13.7%), respectively. This shows that, if variations are to be greatly reduced, more attention needs to be paid to structural and architectural drawings (69.6%) during their preparation, in order to reduce the frequency of error occurrence.

Aside from consideration based on design documents, errors in structural design calculations (25.8%) showed the highest design error that led to variation, followed by dimensional errors in architectural drawings (12.1%), wrong descriptions in electrical specifications (12.1%), wrong descriptions in electrical specifications (10.6%), omission of details in structural drawings (9%), wrong description in mechanical drawings (6.1%), absence of mechanical specification (4.5%), absence of architectural specification (4.5%), wrong/

inadequate description in structural specifications (4.5%), omission of details in electrical specifications (4.5%), errors in mechanical design calculations (3.1%), omission of details in architectural specifications (1.6%), and error in electrical design calculations (1.6%), respectively.

Table 8 presents the frequency of occurrence of design errors according to the types of errors identified.

Table 8: Design errors that led to variation in construction projects based on type of error

Type of error	*Frequency*	*Percentage (%)*	*Rank*
Wrong/inadequate descriptions in specifications	44	33.3	1
Errors in design calculations	40	30.3	2
Omission of details in specification	20	15.2	3
Dimensional errors in architectural drawings	16	12.1	4
Absence of specifications	12	9.1	5
Total error	132	100	

Out of the 132 design errors discovered in the design documents of construction projects, 44 (33%) were wrong/inadequate description in specifications, 40 (30.3%) were errors in design calculations, 20 (15.2%) were omission of details in specifications, 16 (12.1%) were dimensional errors in architectural drawing, and 12 (9.1%) were complete absence of specifications. This shows that errors in design documents of building projects are mostly characterized by wrong/inadequate description in specifications, errors in design calculations, omission of details in specifications, and dimensional errors.

Table 8 also indicates that specification-related errors accounted for 57.6% of the total errors leading to variation in construction projects. This implies that many problems are yet to be solved in the specifications of construction drawings. These problems include provision of clear and detailed specifications for materials, and correct and adequate description of specification, among others. In addition, errors in design calculations constituted 30.3% of the total errors leading to variation in construction documents. In Nigeria, at present, many civil/structural engineers do not use Computer-Aided Designs (CAD) software for their designs; yet they mostly do not carry out manual calculations before providing for numbers and sizes of reinforcement required as main and distribution reinforcement bars of construction projects. They only rely on residual knowledge of seemingly similar projects that have been designed at some point.

Table 9 presents the design errors that were extracted from the valuation breakdown of investigated building projects and their descriptions on how they led to variations in those construction projects. It is clear from Table 9 that all the design documents were characterized by one or other error. Therefore, there is an urgent need to improvise means of preparing design documents that are near error free.

Table 9: Description of design errors that led to variation on building projects

Types of building	*Design errors*	*Description of design errors as stated in valuation breakdowns of investigated building projects*
Residential buildings	Omission of detail on structural drawing. Omission of details on electrical drawing. Omission of specification on mechanical drawing. Absence of specification on architectural drawing. Inadequate specification on structural drawing. Wrong description of specification on structural drawing. Wrong description of specification on architectural drawing. Wrong description of specification on electrical drawing. Wrong description of specification on mechanical drawing. Dimensional errors on architectural drawing. Dimensional errors on structural drawing. Error in structural design calculation.	Omission of 2.8 tons of reinforcement in beams. Absence of specification on architectural drawing. Inadequate specification of retaining wall on structural drawing. Omission of specification of soil and storm uPVC pipes on mechanical drawing. Dimensional error leading to extension of wall on architectural drawing. Dimensional error leading to increment in window dimensions on architectural drawing. Wrong description of bar marks and changing it from Y6 to Y12 on structural drawing. Addition of reinforcement on first-floor slab top and bottom on structural drawing. Dimensional error on architectural and structural drawings, which later led to extension of roof. Omission of garden light on electrical drawing. Error in mechanical drawing, which led to removal of already installed pipes. Omission of electrical fittings, which include fire alarm, internal and external lighting fittings, telephone systems, sub-main cables, and so on. Omission of mechanical appliances, which include air conditioner, plumbing fittings, and so on. Omission of columns on ground floor. Dimensional error on slab, which led to extension of slab. Omission of some details on roof from initial design, which led to re-design of the roof. Error in roof slab, which led to redesign of roof slab. Wrong description of floor tiles. Extension of window sizes, due to dimensional error. Wrong description of electrical cables. Wrong description of plumbing and mechanical fittings.

Types of building	*Design errors*	*Description of design errors as stated in valuation breakdowns of investigated building projects*
		Absence of roof gutters on architectural drawing.
		Extension of living room, due to dimensional error.
		Extension of slab along circular column, due to dimensional error.
		Omission of beams on ground-floor slab.
		Extension of beam 20 to grid line 5A.
		Omission of columns on ground-floor slab.
		Extension of ground beam, due to dimensional error.
		Omission of columns on ground-floor slab.
		Reduction of beam height, due to wrong description.
		Increment of beam height connecting to isolated column.
		Introduction of column, due to omission.
		Introduction of beam, due to omission.
		Inadequate specification of door type.
		Wrong description of paving stone.
		Introduction of Cantilever beam from column C33 & C27 first-floor layout beam.
		Introduction of RC roof gutter to replace original aluminium roof gutter.
		Introduction of column C33 & 27 on first-floor slab layout.
		Introduction of new roof floor beam (Beam 15A).
		Additional reinforcement to roof beam and slab.
		Introduction of columns.
		Addition of beams.
		Additional reinforcement on roof slab.
		Relocation of pipes at various locations.
		Removal of floor screed in maid's room and replacing with floor tiles.
		Breaking of wall on gridline two for bedroom 2.
		Reduction of swimming pool finish level from 1650mm to 1500mm.
		Relocation of water heater and switches in various areas in the utility building.
		Demolition of staircase.
		Increased thickness of external concrete skirting of the main building to conceal pipes.

Types of building	*Design errors*	*Description of design errors as stated in valuation breakdowns of investigated building projects*
Commercial buildings	Wrong description of specification on mechanical drawing. Wrong description of specification on electrical drawing. Wrong description of specification on architectural drawing. Wrong description of specification on mechanical drawing. Absence of specification on electrical drawing. Omission of details on mechanical drawing. Error on structural design drawing. Error on electrical drawing	Extension of wall due to error on architectural and structural drawings. Wrong description on mechanical drawing, which led to removal of duct and relocating it on another spot. Relocating water supply riser on gridline (4, B). Relocation to shaft between gridlines (1, 2) and B on the ground-floor ceiling level. SWP riser on gridline (4, B). Relocation to shaft between gridlines (1, 2) and B on the ground-floor ceiling level. Omission of male and female toilets of 1^{st}, 2^{nd} and 3^{rd} floors and fixing installation between gridlines (3, 5). Redesign of duct, due to design error on mechanical drawings. Relocation of lighting points on electrical drawing. Absence of CCTV, TV, normal and UPS power points on electrical drawing. Relocation of points for light switches, water heater, hand dryers, shaver sockets, normal and UPS power points, due to wrong description of specification on electrical drawing. Redesigning of roof trusses, due to errors on drawing. Redesigning of electrical drawings, due to issues encountered during construction. Wrong specification of drainage pipes and coupling. Wrong description of distribution board to accommodate pumps.
Special-purpose projects	Error in structural design calculation.	Design error in structural calculation. Absence of specifications.

4.3 Cost-effect of design error on variation cost of building projects

Table 10 shows the cost effects of design errors on variation and total cost of building projects based on design documents.

Table 10: Effects of design errors on variation cost of building projects based on design documents

Types of errors	*Cost of error (=N=)*	*Effect on document's total (%)*	*Effect on total cost of error (%)*	*Effect on total variation cost (%)*	*Rank*
Electrical drawings					
Omission of details in specifications	26,475,763.86	20.9	10.6		3
Wrong description in specification	15,183,882.82	12.0	6.2		6
Error in design calculation	85,158,591.04	67.1	34.1		1
Total	126,818,237.71	100.0	50.9	18.3	
Mechanical drawings					
Absence of specification	23,342,763.68	46.3	9.4		5
Error in design calculation	14,931,052.06	29.6	6.0		7
Wrong description in specifications	12,167,522.98	24.1	4.9		8
Total	50,441,338.72	100.0	20.3	7.3	
Structural drawings					
Wrong/inadequate description in specification	831,880.00	2.2	0.3		12
Error in design calculation	33,426,372.06	84.9	13.4		2
Omission of details	3,330,131.66	8.9	1.3		10
Total	37,588,383.72	100.0	15.0	5.4	
Architectural drawings					
Absence of specification	453,810.00	1.4	0.2		13
Dimensional error	5,332,677.76	15.4	2.1		9
Wrong/inadequate description in specification	25,759,565.16	74.4	10.3		4
Omission of details in specifications	3,060,000	8.8	1.2		11
Total	34,606,052.92	100.0	13.8	5.0	
Impact of design error on variation cost (%)				36	

Total cost of error = N249,454,013.07

Total variation cost of investigated projects = N692,723,179.98

According to design documents, electrical drawings had the highest cost effect on total variation cost (50.9%), followed by mechanical drawings (20.3%), structural drawings (15%), and architectural drawings (13.8%), respectively. Individually however, errors in electrical design calculations (34.1%) had the highest effect on total cost of error, followed by error in electrical design calculation (13.4%), omission of details in specifications (10.6%), wrong/inadequate description in specification (10.3%), absence of specification (9.4%), wrong description in electrical specification (6.1%), and error in mechanical design calculation (6%), among others.

Table 10 also indicates that, when design error costs were compared with the total cost of variation (= 692,723,179.98), electrical drawings contributed 18.3% to total variation cost, mechanical drawings contributed 7.3%, structural drawings contributed 5.4%,d and architectural drawings contributed 5%, respectively, to total variation cost of the building projects investigated in this study. In summary, if the works of services engineers (electrical and mechanical engineering works) are correct, 25.6% of the 36% variation cost could be saved.

Table 11 presents the effect of design error on total cost of error and variation cost based on types of errors.

Table 11: Effects of design errors on variation cost based on types of error

Types of error	*Cost of error*	*Effect of error on total error cost (%)*	*Effect of error costs on total variation cost (%)*	*Rank*
Errors in design calculations	133,526,015.16	53.5	19.3	1
Wrong/inadequate descriptions in specifications	53,942,850.96	21.6	7.8	2
Omission of details in specification	32,865, 895.52	13.2	4.7	3
Absence of specifications	23,796,573.68	9.5	3.4	4
Dimensional errors in architectural drawings	5,332,677.76	2.2	0.8	5
Total cost of error	249,454,013.08	100	36	

Total variation cost of investigated projects = N692,723,179.98

Errors in design calculations (53.5%) had the highest effect on total cost of errors. This was followed by wrong/inadequate description in specifications (21.6%), omission of details in specifications

(13.2%), absence of specifications (9.5%), and dimensional error in architectural drawings (2.2%), respectively.

This result shows that there is the need to reduce errors in design calculations to the barest minimum, in order to reduce variation cost. There is also the need to improve specification-related issues that accounted for approximately 44.3% of the types of errors leading to variation. This shows that specification-related issues and errors in design calculation account for approximately 97.8% of the total design error cost leading to variation. This is revealing, as it shows that specifications and calculations are the greatest issues of design errors and variation cost on building projects.

Furthermore, errors in design calculations contributed approximately 53.5% to the total cost of design errors, and errors in electrical design calculations alone took 34.1% (see Table 9). The problem with electrical design in Nigeria may be as a result of building services' works being executed by mechanical and electrical engineers who have hardly any or no knowledge about building construction processes. In view of this, the Nigerian Institution of Building (NIOB), the Council of Registered Builders of Nigeria (CORBON) and the academia in the built environment have been clamouring and encouraging builders to specialise in building services rather than in the saturated construction management, construction technology, and building maintenance.

In addition, Table 11 shows the impact of design error costs on total variation cost of building projects investigated. Errors in design calculation had 19.8%, wrong/inadequate description in specifications had 7.8%, omissions of details in specifications had 4.7%, absence of specifications had 3.4%, and dimensional errors in architectural drawings had 0.8%. The total contribution of design errors to variation cost, according to the investigation in this study, is 36%. That represents the probable net effect of design errors on variation cost of building projects.

4.4 Solutions to design-error-induced variation in building projects

Based on the classification in Table 1, the content analysis method was adopted to categorize measures for minimizing design-error-induced variation in building projects so that variation costs can be drastically reduced. The main points from the interview results were tabulated. Table 12 shows the suggested measures as well as brief explanations of how the measures can be practised.

Table 12: Measures and explanations for minimizing design-error-induced variation in building projects

Classification	*Suggested measure(s)*	*Explanation*
Design error and omission	Visitation to site before designing	Many designs are produced on the assumption that construction sites are of levelled topography and, as such, designs are produced based on that assumption. This unethical practice should be avoided, as it has caused a great deal of design problems leading to litigations, delays, cost overrun, and wastages, among others.
	Proper planning	There should be proper planning and assessment of clients' brief before project design commences.
	Contractors' representatives are important	Contractor's representatives should be represented during the design process of building projects. An interviewee noted that the presence of a builder in the design build-up is of no little importance, as issues of discrepancies in contract documents, buildability and maintainability, methodologies, work programming, health and safety, quality management and building production management would be articulated before the final design is produced. This means errors and their potentials would be pointed out early enough and this would save a great deal of time and cost for the client.
	Use of computer programs	It was suggested that the use of computer programs, software and applications that are available across different disciplines in the built environment should be used for the design of construction documents.
	Pay adequate attention to details	This will improve concentration on projects, reduce oversight problems and negligence on the part of designers. The phrase used by one of the respondents is that designers must take design of building projects as 'their baby'. For this to happen, it was noted that clients must be willing to pay adequately for design jobs.
Design changes	Clients to give more time for designs	This suggestion was believed to be a major way forward if it is religiously followed. Respondents noted that many clients are not aware of the tasks ahead for a project to be well designed. Attempts to explain to clients mostly fail, because many of them lack sufficient education on how building projects are prosecuted. This condition is aggravated when clients believe that they are the financiers of projects and can always engage the services of another designer if a designer fails to abide by the time allocated. This condition is further compounded, as many designers who have been out of job for some time are willing to take up those jobs with a view that problems emanating from the designs will be solved one way or another during the project.
	Construction professionals and their roles	Professionals should not only have adequate understanding of the project to be executed, but also understand the roles to be played.
	Knowledge sharing	There should be a forum for sharing knowledge on the experience of various building projects so that it can be useful for future projects. This is based on the learning curve theory.
	Professionals should have checklists from a collective data bank that can be used for future projects	This suggestion is like that of knowledge sharing. However, the difference is that, in this case, there is a recognized co-ordination point where other designers can furnish themselves with relevant information concerning the type of project to be executed.

Further discussions with professionals indicate that these suggestions will be mostly successful when adopted multilaterally rather than unilaterally.

5. Discussion of findings

This study investigated the causes of variation, design errors that lead to variation, effects and solutions to design-error-induced variation on building projects.

5.1 Causes of variation and design errors in construction projects

The findings of the study show that the main causes of design-error-induced variation are poor working drawings, lack of coordination during designs, change in scope of work by clients, omission in designs, inadequate project objectives, mistakes, inexperience of designers, and owners' financial difficulties. These results are consistent with the existing body of knowledge in the fields of poor working drawing (Mohammad *et al.,* 2010; Ismail, *et al.*, 2012; Asamaoh & Offei-Nyako, 2013; Memmon *et al.,* 2014; Mohammad *et al.,* 2015: 93-94); change in scope of work by clients (CII, 1990); omission in design error (Al-Dubaisi, 2000; Zawawi *et al.,* 2010; Alaryan *et al.,* 2014); inadequate project objectives (Ismail *et al.,* 2012; Mohammad *et al.,* 2015: 95); mistakes (Mohammad *et al.,* 2015; 93); inexperience of designers (Asamaoh & Offei-Nyako, 2013: 22), and owners' financial difficulties (Mohammad *et al.,* 2010: 78).

The results of this study further indicate that errors in structural and architectural drawings constitute approximately 70% of the total design errors that led to variation in the projects investigated. This shows that, if structural engineers and architects can do something drastic about their designs, roughly 70% of design-induced variation could be eliminated. While Muhammad *et al*. (2015) noted that design for aesthetics is a cause of errors in design documents (mostly architectural drawings), experience shows that civil engineers are used to design for reinforcement of construction projects, instead of structural engineers. This is inconsistent with the ethics of construction professional practice and needs to be mitigated.

The findings of the study further indicate that errors in structural design calculations, dimensional errors in architectural drawings and wrong/ inadequate description in specifications are the most occurring design errors in the documents studied. In Nigeria, for instance, there is no clear difference between civil and structural engineers by practice. However, professional structural engineers are statutorily charged with the responsibility of reinforcement designs for all kinds of construction works, whereas civil engineers are simply constructors of engineering projects. Besides, many reinforcement designers base their designs on residual knowledge and make provisions for reinforcements without doing any loading calculations. The result of many of these design practices is over-reinforcement of buildings that could be as dangerous as under-reinforcement. This practice has been found culpable for many cases of building collapses occurring in developing countries following investigations by concerned organisations such as government and professional institutions.

In addition, wrong/inadequate description in specifications and omission of details could lead to delay and cost overrun, which could be due to late reply to Request for Information (RFI), change in scope of work, and clarifications to drawings and specifications. In general, the findings of the study indicate that wrong/inadequate description in specification and errors in design calculations were jointly responsible for approximately 64% of design errors in project documents. Thus, deliberate efforts to improve on the descriptions of design specifications and calculations could lead to a reduction of over half of the total design errors leading to variation in building projects. In addition, it is cause for concern to discover that some large building projects investigated were being constructed without any specifications. This is not only unprofessional, but also dangerous to the cost, time, quality and safety of the building and occupants of such projects. It could also pose risks of buildings collapsing.

5.2 Cost-effect of design error on variation cost of building projects

Much of the literature investigated in this study did not consider the effects of variation on construction projects in quantitative terms. Hence, comparison with the results of this study may be difficult. This study found that electrical and mechanical drawings constitute approximately 71% of the total cost of error in design documents and roughly 26% of the variation cost of building projects. This shows that, even though structural and architectural drawings contain the most number of errors in design documents, those of electrical and mechanical drawings (services) have the most cost effects on variation when compared with other documents. This means that attention must be paid to services drawings if considerable reduction of design error and variation costs are to be achieved. In Nigeria, for example, mechanical and electrical engineers are still responsible for the electrical, plumbing and other services in buildings. The problem is that many of them are not trained building services engineers and this could be a major cause of the problem with services documents discovered in this study. Therefore, young and upcoming builders need to be encouraged to shift focus from construction management and construction technology to building services.

5.3 Solutions to design-error-induced variation in building projects

Lastly, the interview of experts revealed that design error variation can be reduced by rechecking designed documents before presenting them for use, using computer programs rather than manual calculations and designs, knowledge sharing among designers, use of competent designers, clients giving more time to designers, site visitation before designing, having design checklists, paying adequate attention to details, proper planning and assessment of clients' briefs, good understanding of projects and the roles to be played, and representation of contractor in the design phase of building projects. Comparing these suggestions with previous studies indicates that they agree with Love *et al.* (2014) in respect of learning, use of Computer-Aided Designs (CAD) and Building Information Modelling (BIM). The learning corresponds with knowledge sharing among designers and CAD/BIM corresponds with the use of computer programs. The result also agrees with Asamaoh & Offei-Nyako (2013) in respect of reports among consultants and use of oversight committee for designs. Reports among designers goes with knowledge sharing among designers and use of oversight committees goes with rechecking design documents by the committees before presenting them for use. The result of Ismail *et al.* (2012) is consistent with the representation of contractors in the design phase of building projects, as mentioned by the respondents in this study.

It is important to state that one of the suggestions of Love *et al.* (2014) is the adoption of the Integrated Procurement Method (IDP). Even though many developing countries such as Nigeria know all about the procurement method, professionals are still reluctant to adopt the method. The reason for this may be multivariate, ranging from the adoption of computer programs such as BIM to the fear of running out of business for unknown reasons. It is important to clarify that the IDP is adopted on some projects. Many of the construction stakeholders, however, still vest their interests in the traditional procurement method, as is evident in the projects investigated for this study. Therefore, more campaigns and enlightenment may be required to ensure that the IDP is embraced in the construction industry. It is also important to mention that the campaign for sustainable design and construction is hinged on the adoption of IDP, as all the professionals must simultaneously meet and brainstorm on the success of the project.

6. Conclusions

Based on the findings of this study, it was concluded that poor working drawings, lack of coordination during designs, change in the scope of work by clients, omission in designs, inadequate project objectives, mistakes, use of inexperienced designers, and owners' financial difficulties are the main causes of design-error-induced variation. In addition, structural and architectural drawings contain the highest number of errors in design documents of building projects. In these documents (structural and architectural drawings), errors in structural design calculations, dimensional errors in architectural drawings, wrong/inadequate description in specifications, and omission of details were the most implicated.

Furthermore, electrical and mechanical drawings (drawings of services engineers) contained fewer errors in comparison with structural and architectural drawings; they had the most cost effect on variation cost. The most implicated errors in these documents (electrical and mechanical drawings) were errors in design calculations, wrong/inadequate description in specifications, omission of details in specifications, and absence of specifications. Lastly, the suggested methods of minimizing design-error-induced variation were rechecking of documents before use, use of computer programs, knowledge sharing, use of competent designers, giving more time to designers, site visitation before designing, having design checklists, paying attention to design details, proper planning and assessment of clients' brief, understanding projects and the roles to be played, and engaging the contractor's representative during the design phase.

7. Recommendations

All electrical, mechanical and structural design calculations should be verified by dedicated government authorities before proceeding to the site for construction. Hence, legislation towards achieving this feat is recommended. Furthermore, it appears that not much can be done about the current professionals preparing electrical and mechanical design documents, because there are hardly any building services professionals. In view of this, government and higher institutions are advised to sponsor staff in the building profession on building services training. Many schools in Europe and universities in Hong Kong, in particular, are engaging in services trainings and researches including Heating Ventilation and Air Conditioning (HVAC). The Nigerian construction industry and the academia can tap into this wealth of knowledge and experience.

Moreover, all design organisations should be advised to establish quality control departments to verify all designs. Appropriate sanctions should be prescribed for defaulters. In addition, only structural engineers should be allowed to carry out structural designs and detailing. Civil engineers should be stripped from performing that function, as it is outside their professional roles. Structural engineers are trained people who design the reinforcement details of structural construction works. Civil engineers are generally trained construction managers on civil engineering works such as stadium, dams, roads, and so on.

In addition, if any meaningful improvement is to be made on errors in design calculations, government policies or other means should compel structural engineers to use the recommended software to calculate the numbers and sizes of reinforcement required for structural designs. This will prevent the perennial problem of over- and underdesigning that could result in recurrent building collapses. It is important to note that this recommendation is also applicable to other construction documents (architectural, electrical, and mechanical engineers) investigated in this study. Lastly, since designers pay more attention to drawings than specifications, this study recommends that designs with specification-related issues be regarded as incomplete and not be used for construction works until all specifications issues are settled.

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