MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN ART AND TECHNOLOGY

SCHOOL OF BUILT ENVIRONMENT

ASSESSMENT OF VARIATIONS IN DESIGN SPECIFICATIONS AND THEIR IMPACT ON BUILDING FAILURE AND COLLAPSE IN UGANDA:

A CASE STUDY OF KAMPALA CITY

BY

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A REPORT SUBMITTED TO MAKERERE UNIVERSITY SCHOOL OF BUILT ENVIRONMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF THE BACHELOR OF SCIENCE IN QUANTITY SURVEYING

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Declaration

I, Samuel Mugabi, do hereby declare that this project report titled "***Variations in design specifications and their impact on building failure and collapse in Uganda: A case study of Kampala City***" in its entirety is purely a product of my synthesis and analytical interpretation of variations in design specifications as one of the engineering malaises responsible for failure and collapse of high-rise buildings in Uganda. The dissertation has never been submitted to Makerere University as well as other institution of higher learning either in bit or full for any award. The dissertation is built on related views of other scholars. However, their works have been duly annotated and paraphrased and consequently listed down in the section for references towards the close of this manuscript.

-------------------------- 1/2/2022 --------------------------

Samuel Mugabi **Date**

(Student)

Approval

I certify, that this project report titled "***Variations in design specifications and their impact on building failure and collapse in Uganda: A case study of Kampala City***" has been duly compiled by Samuel Mugabi and is now ready for submission for the award of the degree of Bachelor of Science in Quantity Surveying of Makerere University.

-- · 04 - 02 - 2022

Ms. Namakula Hidaya **Date**

Makerere University

College of Engineering Design and Technology

Dedication

To my lovely parents, Mr. and Mrs. Mugabi Milton, we have won an academic guerilla war; thank you for every sacrifice you have made to see me graduate into a professional Engineer. To my siblings; Peter, Elijah and Shadia, I have left footmarks for you; keep racing to fill them. The battle is won and so now is the time to harvest unlimited dividends!

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A journey worth travelled must successfully come to an end, goes an old adage. So is my four-year journey that I embarked on in the year 2017 at CEDAT. This project being the last straw, has successfully been accomplished, courtesy of the invaluable support of a score of people. Top of the list is my supervisor, Ms. Namakula Hidaya for her selfless support. Despite the national, institutional and international obligations that divide her work time apart, she immensely supported the processes leading to the final accomplishment of this project by among others providing me prompt feedbacks, guiding me on how to correct any digressions that arose in my work from time to time and above all, ensuring that I stayed focused to completing it by always telling me, Samuel, I am optimistic you will finish this project in time! Madam Hidaya, you are a gem. I actually relish an opportunity of furthering my career and siphoning more knowledge from your intellectual store.

Mr. Mugabi Milton, my lovely dad, I will always sing your name because minus you, minus me. Little would I have achieved if you never laid your back down as a structural bridge for me to connect between points that were seemingly parallel and impossible to reach. Happily, enough, we have defeated all the precipices and won the battle. As an old adage goes that behind any successful man, lies a woman, Mrs. Kyomugisha Imeridah Mugabi worked tooth and nail with you to ensure that our system was always efficient. I can testify that your synergies have made life enjoyable on planet earth. Thank you indeed.

A great vote of thanks goes to all CEDAT staff. Throughout the academic journey, you have all been very phenomenal to me. Thank you for your support. In the same footing, I salute my friends for your invaluable contribution towards my overall success. Your discussion points have made me an open book in Quantity Surveying.

To my respondents, this project report would have been more or less a mere sketch minus your inputs! You are cornerstones in this research.

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List of Acronyms and Abbreviations

BIM	:	Building Information Modeling
BoQs	:	Bills of Quantities
CEDAT	:	College of Engineering, Design and Technology
CSI	:	Construction Specifications Institute
ERB	:	Engineers Registration Bureau
GIGO	:	Garbage In, Garbage Out
KCCA	:	Kampala Capital City Authority
MEP	:	Mechanical Electrical and Plumbing
MoWT	:	Ministry of Works and Transport
n.d	:	Not Dated
R&D	:	Research and Development
RII	:	Relative Importance Index
STEM	:	Science Technology Engineering and Mathematics
UIPE	:	Uganda Institution of Professional Engineers
USA	:	Uganda Society of Architects

Abstract

Kampala is the premiere city in Uganda, a status it has possessed since independence in 1962. Given this strategic advantage as well as historical fame during colonial period, it has continued to be a magnet of Uganda as well as a preferred center for expatriates. This has led to shortage of land and housing units compelling investors to establish high rise buildings. However, in the last one decade, many high-rise buildings have collapsed and caused loss of lives and property. While there are many contributory factors, variations in design specifications could be among. No studies have been carried out to provide this linkage. Thus, the purpose of the study was to assess the variations in design specifications and how these have led to failure and collapse of high-rise buildings in Kampala city. The study was guided by the following specific objectives, to assess: Design errors common on high rise buildings in Kampala City, the factors leading to increase in design errors on high rise buildings in Kampala city; and the effects of the design errors on the structural performance and sustainability of the high-rise buildings in Kampala city. The study collected both primary data that was both quantitative and qualitative. Primary data were collected using questionnaires and interviews. Questionnaires were administered to staff of selected institutions and companies while interviews were administered to top management of KCCA, UIPE, USA, ERB and MoWT as well as contractor companies. Quantitative data were analysed at univariate levels using SPSS while qualitative data were analysed using narrative text and verbatim quotations. Findings of the study established various design errors common on high rise buildings including wrong estimates and them omissions and ambiguities among others. The study equally established factors leading to rise in design errors including poor workmanship, lack of effective coordination, among others. Consequently, the errors have led to concrete failure, loading failure and collapse of buildings. The study concluded that design errors are very common on high rise buildings in Kampala city and yet they are not given emphasis as prime causes of building failure and collapse in high rise constructions. The study recommended need careful screening of design engineers, use of BIM technology among others to eliminate computational errors and wrong estimates for better performance and sustainability of high-rise buildings.

Keywords: *Design errors, High rise buildings, Building failure and collapse, Kampala city,*

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Introduction

1.1 Background to the study

In the construction of the high-rise buildings, there are various design specifications that have to be followed (Peansupup & Ly, 2015). In Kampala, Uganda, Alinaitwe and Ekolu (2014) counted 54 building collapse deaths and 122 injuries in just four years (between 2004 and 2008). The frequency of building failure and collapse in Kampala city has attracted the attention of scholars and audits aiming at establishing the causes of the mayhem. Design specifications are highly detailed, specific requirements regarding the design that has to be closely adhered to till completion of a construction project (Trenchlesspedia, 2020). They specify design requirements of a particular project and is prepared by the client after exhaustive research. For the sustainability of high-rise buildings as is the case with other construction projects, design specifications should be strictly observed. Failure to observe design specifications leads to design errors (Okeke et al., 2020; Trenchlesspedia, 2020). Design errors refer to design mistakes, design omissions, and design conflicts (Peansupap & Ly, 2015). Design mistakes are the human errors that occur naturally and are unavoidable. An inexperienced designer may apply the design information incorrectly. These mistakes can be lapses (memory failures) or slips (when failure arises even if knowledge is correct). Design omission occurs if any part of a system has been forgotten in the design while design conflicts are the overlapping items that cannot be constructed at the same time. However, the contribution of design errors has remained inconclusive and are believed to be among the key causes of building failures and collapse in different contexts (Okeke et al., 2020; Waziri, 2016) including Uganda.

Table 1. 1: Cases of building failures and collapse in Kampala city (2000-2020)

Year	Place	Number of Death/Injured	Estimated property lost
May 2020	Makindye	Storeyed building collapses killing 16 workers and injuring many others	Property in neighborhoods lost, value not reported

Year	Place	Number of Death/Injured	Estimated property lost
October 2019	Bakuli, Rubaga Division	Building collapsed killing one and injuring two	No property damages reported
April 2016	Makerere Hill	Storeyed building under construction collapsed killing 6 people and injuring many others	Property and cars parked in the neighborhood destroyed
December 2015.	Kansanga	Five construction workers died, while five sustained injuries when a storeyed building collapsed	Not reported
August 2014	Kansanga	Two people sustained severe injuries when a six-storeyed building under construction collapsed	The debris damaged a vehicle (Mercedes Benz) and some houses in the neighborhood.
June 21, 2013	Nakivubo Mews (KCBD)	Nice Time Arcade caved in, ten people were injured when a building caved in	Not reported
July 2012	Nakawa	Lugogo construction site, Two construction workers were killed when a building under construction on Lugogo- Bypass (Rotary Avenue) collapsed.	Not reported
July 2011	Ntinda	Seven people sustained injuries after a building under construction collapsed.	A lot of property, including three cars, were damaged.

Year	Place	Number of Death/Injured	Estimated property lost
January 26, 2010	Luwuum Street	Two people died and five others sustained severe injuries on, when a storeyed building under construction caved in.	Not reported
October 2008	Nakasero, Lumumba Avenue	NSSF Pension Towers , at least seven people died after a wall collapsed at a National Social Security Fund (NSSF) construction site	Not reported
February 2008,	St. Peter's Secondary School, Naalya	In 10 people were killed when a building under construction collapsed	Not reported
January 2008.	Mini-Price Bata, Namirembe road	Three people died when the walls of the building collapsed.	Not reported

Source: ***Masaba et al.(2016), Sejjoba (2018), KCCA (2020), Ngwomoya (2020)***

1.2 Problem statement

Since 2010 to present, many parts of Kampala city such as Buziga, Makerere hill, Makindye and Kampala Central Business District have been affected by building failures and collapse (Anguyo, 2013; Manishimwe, 2017; Masaba et al., 2016, Ngwomoya, 2020). The increasing number of cases of collapsing buildings has brought about a plethora of challenges prompting stakeholders in the building industry and the government to establish the causes of problem (Masaba et al., 2016; Ngwomoya, 2020). While these studies have identified the causes of building failure and collapse such as negligence, deficient foundations, inadequate or faulty steel reinforcement, hasty construction, greed, failure to carry out soil tests, poor supervision and non-adherence to the building codes, none has labored to provide an extensive analysis of the effect of design errors and yet according to Błaszczyński and Sielicki (2019), Kobielak et al. (2015) and Peansupap and Ly (2015), design errors greatly contribute to building failure and collapse. The lack of empirical data about the extent to which non-conformance to design specifications has caused building failures and collapse in Kampala city has motivated the researcher to conduct this study and fill the knowledge gap.

1.3 Objectives

1.3.1 Main objective

The impact of design errors in structural and other building components has not been yet studied in detail and well-understood as a major cause of building failure and collapse in Kampala city. Therefore, the purpose of this study was to evaluate the impact level of design errors in structural and other building components in building construction projects.

1.3.2 Specific objectives

Specifically, the study assessed to;

(i) Identify design errors common on high rise buildings in Kampala City.

(ii) Determine the factors leading to increase in design errors on high rise buildings in Kampala city

(iii) Establish the effects of the design errors on the structural performance and sustainability of the high-rise buildings in Kampala city.

1.4 Research questions

The study sought to provide answers to the following research questions;

(i) What are the common design errors on high rise buildings in Kampala City?

(ii) What are the factors leading to the frequency of the design errors on high rise buildings in Kampala city?

(iii) What are the effects of design errors on the structural performance and sustainability of the high-rise buildings in Kampala city?

1.5 Scope

1.5.1 Content Scope

This study assessed the effect of variations in design specifications on building failure and collapse in Kampala city. Content wise, the study aimed at identifying the common design errors on high rise buildings in Kampala city, the factors leading to a high frequency of the design errors and the effects of the design errors on the structural performance and sustainability of the high-rise buildings in Kampala city.

1.5.2 Geographical Scope

The study was conducted in five Divisions of Kampala city; this is because most of the buildings that have collapsed are located in these divisions with relatively high construction activities. The divisions are: Nakawa, Lubaga, Central, Kawempe and Makindye Divisions.

1.5.3 Time Scope

The study covered the period between 2010 and 2020. As earlier shown in Table 1.1, frequent cases of collapse of buildings and structural failures have been reported in the same period.

1.6 Significance

The study findings provide in-depth information to KCCA, Minister for Kampala City and Ministry of Lands, Housing and Urban Development on the institutional weaknesses existing in the current strategies implemented to eliminate the problem of collapsing buildings and other structural failures. This provides them with the necessary information that will inform their decisions when revising or amending the control guidelines. The findings will also provide key information to policy makers and planners on the likely benefits of involving grass root-based authorities such as Local Council 1 about the potential of serving as a conduit through which the possible defects that are feared to happen to a construction site in a given area can be reported and addressed before it develops into a major structural failure.

To future researchers and scholars, this study provides documented evidence of design errors and their contribution to structural failures in Kampala. This could pave way for identification of the most plausible strategies that could mitigate and or lead to elimination of design errors given the toll of loss of lives and property that occurs after collapse of high-rise buildings.

The accomplishment of the study will equip the researcher with an assortment of research skills (such as literature review, conducting field-based surveys and data analysis) that will enable the researcher to execute research related projects with ease out.

1.7 Justification

One of the things that make a city very catchy, attractive and stand out are the outstanding high-rise buildings, usually tall or big enough to be made out. The construction process, right away from planning, design specifications are involved as they guide the whole process to completion. There are always variations in these design specifications and these variations lead to design errors in both architectural and structural designs.

The biggest factor that leads to failure and collapse of buildings in Kampala city are design errors due to variations in design specifications. these variations have a high bearing on the total project cost, taking up approximately 15-20% of the total project cost, people ought to know why they spend that much money and their structures are still failing and collapsing.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents review of literature related to variations in design specifications and the effects on the quality of building constructions. Specifically, emphasis is placed on how the variability of design specifications gives rise to design errors and how these translate into building failure and consequently design. The review of literature is made under themes that were developed from specific objectives of the study relayed in Chapter one.

2.1 Design Specifications

According to McMahon (n.d), design specifications refer to detailed information about entire plan that ought to be followed in the execution of a construction project. Pringle (2021) conceives design specifications to mean the detailed description of the dimensions, construction, workmanship, materials etc., of work done or to be done, prepared by an architect, engineer etc According to Tymkiv (2021), design specifications outline the design needs of a construction project or any other product development and serve as a compass on which the successful implementation of a project hinges or rotates. Usually, they are written down as a document and describe the set criteria that must be met by the developers of a construction project. McMahon (n.d) proffers that design specification are defined with the need to eliminate design problems. The design specifications provide a description of the specifications, including dimensions, weight, overall cost, and so forth. Tymkiv (2021) provides an illustrative rationale of design specifications when they argue that design specifications provide detailed description of the desired solution hence enabling the design engineers to move from the abstract to the concrete solution in order to achieve the product's goal. According to Definitions Dot Net (2021), a design specification provides explicit information about the requirements for a product and how the product is to be put together.

Design specifications are the minimum acceptance criteria and are developed from customer needs. Without clear customer needs, every design solution could be either accepted or rejected on a whim (Jahan et al., 2016). Design Specifications may include: Specific inputs, Calculations/code used to accomplish defined requirements, Outputs generated from the system, explanations of the technical terms and identifications of how the product meets the applicable regulatory requirements (Definitions Dot Net, 2021). The design specification should provide a clear and unambiguous definition of the outcomes to be achieved. Design requirements are formally defined; often in terms of constraints that must be met for the solution to be feasible, and objectives by which the performance of a feasible design is ranked (Leary, 2019). According to Pringle (2021), design specifications are very vital on three prongs: 1) are required during the design stage; 2) form part of the contract documentation and; 3) play a key role in project fulfillment. Trenchless (2020) notes that design specifications together with technical drawings and bills of quantities (BoQs) provide a complete blue print to the contractor regarding the directions they should follow while executing a given construction project.

2.2 Types of specifications

2.2.1 Prescriptive Specifications

Prescriptive specs focus on the details for the types of materials used and the installation of said materials. Architects or engineers tend to take over the job of project design in prescriptive specs. Prescriptive specs give a better image of what the final product will look like compared to other specs. Prescriptive specs can be broken up into three separate parts: general, products, and execution. General consists of information such as national quality standards, product handling, design requirements, and keeping quality control. The products phase will go over the different products necessary for each task as well as the individual performance levels of each product. The execution phase will go over how to prepare materials and go through with installing them. This process also involves testing the quality of the materials and checking if they were installed correctly.

2.2.2 Performance Specifications

Performance specs discuss the operational requirements of a project. It details what the final installed product has to be capable of doing. In this phase, the owner or general contractor does not give a subcontractor specs detailing how to finish the job. Instead, designers and architects give contractors details on how the final product has to work in this phase. For example, a contract asks the team to make a pump that pumps 300 gallons per minute. There are no directions on how to make the pumping system go that fast, so it is up to the contractor to figure it out. Of the three types of construction specifications, this phase involves most of the testing to make sure a project meets all of its operational requirements. The architect or engineer describes the project outcome, and trusts the trade contractor's experience to get there. Since the contractor has to figure out what to do, decisions about materials and strategy move away from the architect and engineers and shift towards the contractor.

2.2.3 Proprietary Specifications

Proprietary specs are used when you need to use a single type of product for any kind of installation. These are the least common of the three types of construction specifications, but they are for jobs involving existing equipment and already completed installations. When the owner or client wants to be consistent with their materials or just prefers a specific type of material, use proprietary specs. Contractors use proprietary specs when their section of the project is dependent upon the performance of a specific product. Architects and engineers tend to try and avoid proprietary specs because it can lead to promoting a specific manufacturer. Favoring a manufacturer can discourage competition during the bid phase of the project, which may increase the total cost of the project. Architects and engineers will give the contractor a list of reliable suppliers to choose from to stop this.

2.3 Design Specifications in Construction projects

Webster (2017) defined construction as a process that consists of the building or assembling of infrastructure. Far from being a single activity, large scale construction is a feat of human multitasking. Normally, the job is managed by a project manager, and supervised by a construction manager, design engineer, construction engineer or project architect. The building process involves three major phases: the conception / design phase, construction phase, and operation or use phase (Horsely, Chris & Barry, 2010). Therefore, design specifications are indispensable in the fields of architecture and civil engineering. According to Definitions Dot Net (2021), design specification is the most traditional kind of specification, having been used historically in public contracting for buildings, highways, and other public works, and represents the kind of thinking in which architects and engineers have been trained. Its use is called for where a structure or product has to be specially made to meet a unique need. Further, Definitions Dot Net (2021) posits that a design specification must include all necessary drawings, dimensions, environmental factors, ergonomic factors, aesthetic factors, cost, maintenance that will be needed, quality, safety, documentation and description.

When design specifications are well defined, design quality is realized (CSI, 2020; Hou et al., 2020). Design quality is defined as the sum of meeting the client's expectation through the design process, providing quality design documents which meet relevant codes, social requirements, functions, purposes of the buildings, etc (Hou et al., 2020). Scholars such as Georgy et al. (2005) observed that design quality has two criteria. One is the direct quality of the design documents, and the other is the expected quality of the building itself. For cost control, the most important decisions regarding the quality of a complete facility are made during the design and planning stages rather than during construction. It is during these preliminary stages that component configurations, material specifications, and functional performance are decided. It is widely acknowledged that the expected quality of a project is typically codified in specifications, such as those produced by the CSI, and referenced by design and constructions documents. CSI (2020) states that, 'Design professionals rely on CSI standards to produce buildings that are safe, up-to-code and long-lasting. This statement suggests that the standards provide a tool that designers can use to define building quality. One of the major challenges facing implementation of construction projects are the variations in design specifications (Zakariya et al., 2020). Variations are most common on construction projects in developing countries compared to the developed world (Hou et al., 2020). Where the design specifications are not followed on a construction project, it results in design errors.

2.4 Construction design errors

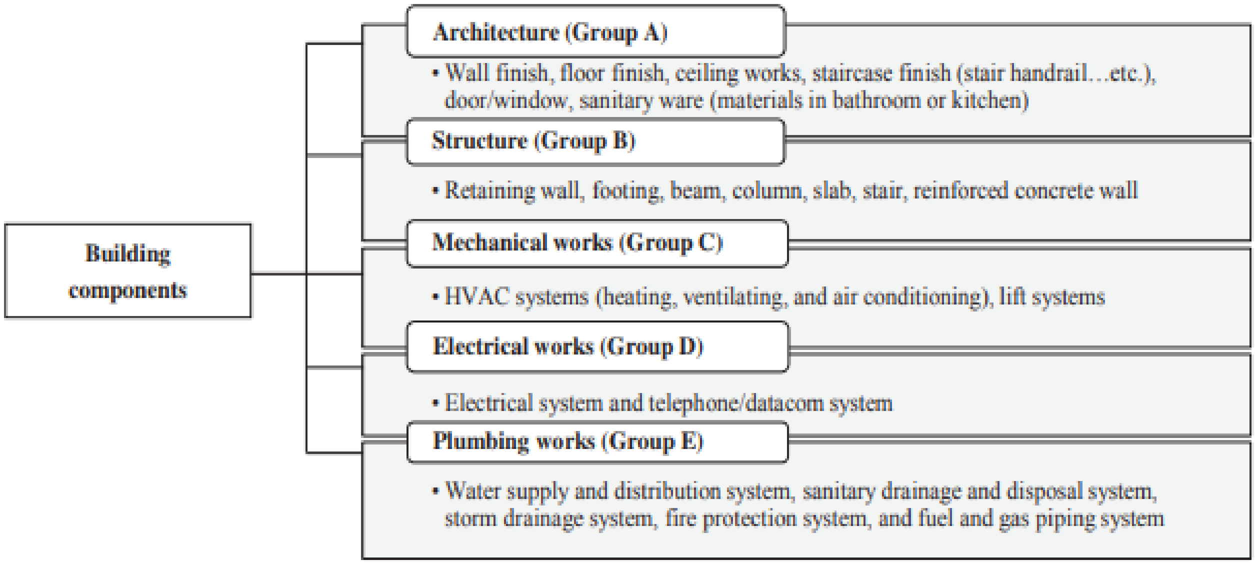
An error is defined by Webster (2017), as a deviation from accuracy or correctness; a mistake, as in action or procedure; an inaccuracy, as in speaking or writing. According to Dosumu and Aigbavboa (2017) & Suryaho (2019), design error is a deviation from a drawing or specification, also including omissions and ambiguities. Simply, a design error is any deviation from an agreed well-defined scope and schedule of construction projects after issuance of variation order or any unintended deviations from correct and acceptable practice that are avoidable. There are various types of errors in construction projects. Ham et al. (2018) categorizes them into three families: simple design (Type 1); rework-related (Type 2) that may lead to demolition and rework; and delay-related (Type 3) likely to prolong the construction period.

There are basically three types of errors: imperfections, non-conformance and omissions. Imperfections are deviations in details that have no effect on the assembly or facility (Vasista, 2017). They require very little correction or can be left as an acceptable condition. There is no initial cost adjustment or time delay. These errors are generally not recorded, only identified in the As-built drawings for future knowledge. Nonconformance errors are those that do not meet the specifications and require corrective action (Sreenivasulu, Ramalinga & Gyanen, 2017). In terms of design only, it is necessary to determine if the errors were due to negligence by the designer, which will determine if he is responsible financially for any Initial Cost impact due to the errors. It used to be that designers were handled with kid gloves and not held financially responsible for any errors or omissions in the construction documents. Rarely did the owner look to the designer, but would simply pay for the change and tell the contractor to make it happen. According to Vasista (2017), owners and even some contractors are going after the designer for errors, omissions and ambiguities to the drawings and why it would be beneficial to reduce design errors. The rate of occurrence of design errors on building projects is becoming alarming by the day, this have had several adverse effect on the construction industry such as cost overrun, in extreme cases and prolonged delay in the completion time of construction project which will prevent building projects to achieve sustainability in development through increasing the final cost on construction project.

Design errors are an inevitable and important issue which have negative impact on project management efficiency and effectiveness. They are the important contributors to reworks, cost overruns, schedule delays, and unsafe environments which affect project performance. In practice, owner, designer, contractor, and other stakeholders have different interests in the design (Peansupap & Ly, 2015). These various interests certainly lead to design errors which can arise at any time. The occurrence of these errors can increase many difficulties in construction management. These difficulties can lead to between 80% and 90% of the failures occurring in civil engineering projects. They can also incur more cost that adds a project's value around 14.2% (Peansupap & Ly, 2015).

Ham et al. (2018) noted that design and construction firms do not usually make extra efforts to count the number of inadvertent design errors and do not perform adequate design review, validation, and inspection. Ham and colleagues argued that in instances when management of a multipurpose complex construction project such as a high-rise building fails to pay attention to the design specifications, it has this failed to eliminate or manage risk factors properly in the preparation stage and this can fatally affect the success of the project. Notably, the contractors are at risk of incurring additional costs including rework (Han et al. 2013). Since high-rise construction project involve stakeholders from different fields of expertise, such as architecture; structure; and mechanical, electrical, and plumbing (MEP) (Won et al. 2016; Moon et al. 2017), design errors often remain undetected in the design phase and are then identified and corrected in the construction phase (Won et al. 2016; Moon et al. 2016b). It is therefore essential for contractors to manage design errors in the preconstruction phase.

Detailed building design process consists of five disciplines: architectural design, civil design, structural design, mechanical design, and electrical design (Peansupap & Ly, 2015). Mechanical, electrical, and plumbing systems (MEP systems) have caused many problems related to limited space for MEP system installation. According to the detailed building design process and the necessity of MEP systems, design errors between structural and other building components involve five different groups, such as design errors between structure and architecture (Group A), design errors between structure and structure (Group B), design errors between structure and mechanical works (Group C), design errors between structure and electrical works (Group D), and design errors between structure and plumbing systems (Group E) as illustrated in Figure 2.1 below;



Source: Peansupap and Ly (2015).
Figure 2. 1: Building components and their sub elements

2.5 Causes of design errors on building construction projects

The prevalence of design errors in construction projects is attributed to a cornucopia of factors (Zakariya et al., 2020). These include: ineffective use of quality management practices, ineffective use of information technology, poor coordination between different design team members, time boxing/fixed time for a task, poor planning of workload, lack of manpower to complete the required task, design team turnover/reallocation to other projects, not enough time to prepare contract documents; and insufficient client brief to prepare detailed contract document. Ayodele (2018) documented the causes of errors in construction documents to be: non – availability of information, poor communication, inadequate project brief, poor salaries of professionals, non – identification of project risks, inadequate consultant professional education, inadequate consultant professional experience, inadequate project manager experience, time scheduled pressure, inadequate project planning, complexity of project, concurrent documentation, heavy work load of consultant, poor consultancy fees, inadequate document preparation time and inadequate document manager experience. The study also identified the various types of error in construction documents as: unnecessary additions, non – conformance to client requirement, non – conformance to design code, absence of specifications, dimensional error, miscalculation, scanty specification, wrong specification, omission of necessary item and incorrect details.

Design errors arise from poor workmanship. A study by Falade (2017) established that the frequent cause of design errors on construction projects in Abuja, Nigeria was largely concerned with the designers as the principal cause. The same study established that the inexperience of designer is a major contributing factor to design errors. According to Dosumua and Aigbavboa (2017), construction is complex and uncertain in nature; and unlike manufacturing and other sectors of the economy, the design and production functions in construction process are usually separated. That is, the design and construction of a building are two separate functions performed by different parties working independently. However, these parties (contractors and consultants) have different interests in building projects. These interests normally lead to design error which is a major source of variation.

Design errors also arise from direct and constructive changes. Direct changes occur when client instructs the contractor to perform works that are not specified in the contract document or makes additions to the original scope of work (Dosumua & Aigbavboa, 2017). Oberlender, David and Anwar (2012) reported that there is a tendency for some designers to make changes during design in order to please clients. Constructive changes are informal acts or modifications to a contract due to an act or failure to act. Other causes of variation are inadequate details of working drawings, change in schedule, change in scope, poor workmanship and client's financial problem (Dosumua & Aigbavboa, 2017). Changes in specifications and design complexity as well as a lack of knowledge are part of the causes of design errors which lead to variation (Dosumua & Aigbavboa, 2017). Impediment to prompt decision making process, poor workmanship, lack of strategic planning and inadequate, 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.

Failure to match computer software with human expertise is one of the causes of variations in design specifications. According to Hanson (2022), today's competition in the marketplace and complexity of structural designs necessitate the use of computers for structural analysis and design. With the introduction of computers, however, came the ability to make errors faster than ever before. Hanson noted that Junior engineers are increasingly placing blind trust in computer generated structural analysis results, but the evaluation skills used by experienced engineers must have been learned at some point. By this, Hanson professes that design errors are likely to be minimized when the use of computer systems is augmented by the experiential knowledge of the engineering team as they are able to reason back and forth about the authenticity of the design specifications. This holds true from the parlance of computer science since the computer systems operate on the principle of GIGO (Garbage In, Garbage Out). Human judgment is very critical.

2.6 Effect of design errors on quality of building constructions

During their economic lifetime, buildings may face partial and sometimes complete collapse due to errors made during the design or construction phase (Pekgokgoz et al., 2021). This implies that quality of construction is very important. The quality of a construction work is decided mainly in the construction and completion phase of the works (Do et al., 2019). However, in order to serve the best for the construction phase, the design work plays a very important role for all construction works, regardless of the big or small construction size or items. The design work helps the works to be constructed in accordance with technical standards, ensuring safety and environmental sanitation. In addition, the quality of design also plays an important role in determining the effectiveness of investment capital (Do et al., 2019). In the preparation phase of investment, the design quality determines the use of economical, reasonable and economic investment capital. If the quality of design work in this phase is not good, it will lead to waste of capital investment, affecting the following design phases because the following design phases are developed based on the previous design

The designing cost usually accounts for only 2% to 4% of the construction cost, but it can have 75% of the influence on the project cost (Ling & Li, 2012). Design errors in construction projects indicate affect project performance. The imaginable effects include: increase in project cost, additional payment for contractor, increase in overhead expenses, completion schedule delay, rework and demolition (Dosumua & Aigbavboa, 2017). While these may not have serious effects on the communities where the affected building constructions are located, the worst-case scenario happens when the design errors induce building failure and consequently collapse. According to Love, Lopez and Edwards (2013), design errors can severely jeopardize safety and contribute to failures in construction and engineering projects. Such failures can have devastating economic, environmental and social consequences. Specifically, design errors induce potential failures and accidents especially with defective building constructions. Defective constructions are prone to collapse. Ham et al. (2018) defined defective construction works as works that fall short of complying with the express descriptions or requirements of the contract. Building structures with design errors face the possibility of defects and defective work, which generally result in structures that cannot perform their originally intended roles (Ham et al., 2018).

According to Surahyo (2019), errors in design and detailing are one of the common causes of failure and cracking in concrete structures. A study by Building Research Advisory Service, UK, was carried out for analysing the reasons for causes of failures in buildings, which indicate that 58% of all failures are attributed to faulty design; 35% defects are attributed to faulty execution, and the rest to material failures or poor performance. Surahyo (2019) further noted that errors in design and detailing may include improper design of foundations resulting in differential movements and foundation settlements, lack of adequate movement joints and proper detailing of construction joints, improper detailing of reinforcement, restraint of members subjected to thermal volume changes, improper grades of slab surfaces, and overlooking the considerations of groundwater pressure and earth pressure while designing basements and water-retained structures and inadequate design loads. The design errors and discrepancies can thus adversely influence project performance and can contribute to failures, accidents, and loss of life (Choudhry et al., 2017).

In Nigeria, Qurix and Doshu (2020) established that faulty architectural and engineering designs; induced building failures and collapse. They recommended need for use of use of Building Information Modelling to predict behaviour of buildings under various loading and environmental conditions. Also, only certified professionals should carry out design of projects. In relation to this, Chatterjee et al. (2017) established that recently, structural failure due to defective building designs has become a potential threat. One of the main causes of structural failure is the inaccurate assignment of loading conditions, which can cause imperfect design. Low quality construction material may have similar effect as the inaccurate loading conditions. Suddenly, applied load on RC buildings beyond its design load results in failure of the beam and column, which ultimately directs to failure of the RC buildings. Cracking and falling of walls have been the major structural damages observed in reinforced concrete structures. These types of damages are highly expected due to structural failures in multi storied buildings.

Using the case study of Nizhny Novgorod in Russia, Tamakov et al. (2021) established in-situ concrete ceiling of the building under construction in the Sormov highway that collapsed covering an area of 540 sqm. During the investigation of the accident, it was found out that no Method statements (MS) for construction and installation works (for the installation of the formwork, installation of reinforcement cages, pouring concrete) had been developed. There was no substantiation of the choice of service poles (calculation of actual loads acting on the poles) and their arrangement pattern for the floor formwork. At the moment of the accident, the poles failed (broke) because they were installed improperly either with a vertical deviation after installation above the permissible (safe) values, or with a pitch above the permissible due to the lack of the pole arrangement pattern and MS for installation work. As a result of the collapse, six construction workers suffered injuries of varying severity, two construction workers died. In a related incident, Tamakov et al. (2021) also included the study of collapse of reconstructed building of hypermarket "Big dipper" in Novosibirsk and concluded that they had collapsed because of the buckling of the formwork shores. According to the conclusion of the Technical Commission that investigated the collapse, the cause of the collapse of the formwork while installing the floor, was the loss of stability of the shores. According to the Commission, the main violations caused the accident committed by the contractor were failure to comply with the requirements of technological documentation and the lack of necessary control by the responsible officials of the execution of construction works.

Pekgokgoz et al. (2021) examined partially or completely collapsed buildings and investigated the reasons for the collapse. The context of the study was South East Anatolia Project, Renewable Energy and Energy Efficiency R&D Center (GAP YENEV) building located in the Osmanbey campus of Harran University, where a partial collapse occurred in the cantilever flooring system. As a result of the examinations and analyses made, it has been observed that load situation of the building and the load analysis in the approved reinforced concrete application project never coincided with each other. This situation revealed that the collapse occurred because of serious mistakes made during both the project phase and the manufacturing phase of the building. With the ABAQUS program, the unit-width cantilever of the building was modeled and analyzed both as it should be and in its current form, and its moment carrying capacities were compared. The analysis revealed that the moment capacity of the cantilever slab was considerably lower than the capacity it should have been.

Alemdar and Alemdar (2021), used the context of the steel structure of the factory that partially collapsed under expected snow loads in the western part of Turkey. The authors indicated that the structural design process has many vital roles in preventing the collapse of structures and should be conducted according to national obligatory standards. However; structural failures or even catastrophic collapses based on improper design, underestimated design loads, unexpected extreme loads, and improper erection are reported worldwide on large-span structures. The possible reasons for the collapse of the system were examined by visual inspections and analytical results. The load-carrying capacities of the main girders and purlins were determined using the buckling analyses of the structural member. The nonlinear geometric analysis of the entire steel structural system was defined to evaluate the vertical load-carrying capacity of the main girder. The progressive collapse mechanism of the system was determined. The obtained results indicate that the snow load was not the main reason for the collapse but the mistakes in the project design, constructional defects and inadequate capacity of structural elements are the primary reasons behind the collapse.

2.7 Summary of Literature reviewed

The literature reviewed in the foregoing sections has revealed that variations in design specifications leads to design errors which lead to building failures and collapse and consequently a toll on life and socio-economic livelihoods. However, the case studies reviewed are citing examples from other contexts other than Uganda and Kampala city in particular and yet the study area has had a high spate of building failures and collapse in the last decade as shown in Chapter One. In the next chapter, the study methodology is described.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

According to Okesina (2020), methodology is a broad term which covers the research philosophical approach, design, method, and procedures used to carry out an investigation including data gathering, participant selection, instruments use, and data analysis. The chapter presents the methodology adopted by this study. This chapter presents the research design, study population, sample size and selection techniques, data collection methods, data collection instruments, data quality control, measurement of variables, data processing and analysis techniques and ethical considerations.

3.1 Research design

A research design is an overall plan or strategy for conducting research. It is a master plan specifying the methods and procedures for collecting, analyzing and interpreting the data in order to get the desired information. This study adopted a cross sectional survey design. Ritchie et.al. (2013) contend that cross sectional study design gathers data from the sampled population at a particular time and provides in-depth understanding of the variables under study. This approach affords researchers, the opportunity to acquire broad understanding of the study variables and a justifiable means of investigating assumed relationships between the variables.

3.2 Study population

Population refers to an entire group of persons or elements targeted in a study (Valencia-GO, 2015). The population for this study included: KCCA physical planning department, KCCA Division construction units, Contractor companies, Uganda Society of Architects, Engineers Registration Board (ERB), Uganda Institution of Professional Engineers (UIPE) and Ministry of Works and Transport (MoWT).

3.3 Sample size and Sampling Techniques

Kumar (2019) defines a sample as part of the target population that has been procedurally selected to represent it. In this study, both probability and non-probability sampling techniques were used. Using Krejcie and Morgan (1970) Table of sample size determination from finite or known populations, a sample of 108 respondents was drawn and engaged in the study as shown in Table 3.1.

Table 3. 1: Research respondents by category and sample

Category	Target population	Sample size
KCCA	24	23
ERB	10	10
USA	10	10
UIPE	10	10
MoWT	15	13
Contractor companies	20	19
Consultant Engineers	24	23
Total	**113**	**108**

3.4 Data Collection Methods

3.4.1 Face-to-face interviews

Interviews were administered to ERB, USA, UIPE and MoWT officials. According to Kumar (2019), interviews are a better method of collecting data from a small section of the entire population and yield detailed data. Further, the method was used because it is flexible in a way that the researcher is able to paraphrase the questions for clarity in order to tap all the intended responses from the participants (Amin, 2005; Katebire, 2007; Odiya, 2009).

3.4.2 Questionnaire survey

Questionnaire survey method was applied on KCCA, contractor companies and consulting engineers. The choice of this method was informed by Bryman (2011) that questionnaire method facilitates cheap collection of relevant data. Questionnaire survey was administered because it provides efficient means of collecting data on a large-scale basis (Hyman et.al., 2018). Besides, data collected using closed-ended questionnaires is easy to code and analyse (Kumar, 2019; Odiya, 2009), while the method also enables the collection of primary data from a big number of respondents at a very cheap cost (Kronenberger et.al., 2018).

3.5 Procedure for Data Collection

The researcher obtained a cover letter from CEDAT, Makerere University allowing him to proceed to collect data and process the dissertation thereafter. Questionnaires were administered to the respondents. Regarding face-to-face interviews, the researcher contacted the key informants and provided them with an overview of what the study is about and thereafter, request for their consent to participate in the study. Arrangements were made and interviews administered as planned. The researcher was meticulous to capture all the proceedings of the interviews by opting to use a voice recorder as well as making notes during the process of interviews. The interviews were later transcribed before actual data analysis begins.

3.6 Data analysis of the study

3.6.1 Qualitative data analysis

Qualitative data analysis entailed organizing data into thematic constituent parts in order to obtain answers to questions. Analysis of qualitative data involved translating the narratives into a set of themes by paying attention to actual voices as used by interviewees and other key informants (Feig & Stokes, 2011). Each interview findings were transcribed into themes and verbatim quotations. Thematic qualitative data analysis focused on the identifiable themes and patterns of the variables under study.

3.6.2 Quantitative data analysis

Quantitative data analysis involved generating descriptive statistics for the study variables. These were displayed using tabular devices. Quantitative data were analyzed using SPSS version 25. The contribution of each statement was examined with the ranking of the attributes in terms of their criticality as perceived by the respondents. This was done by use of Relative Importance Index (RII). The five-point Likert scale (that ranged from 1 to 5) was adopted and transformed to relative importance indices (RII) for each statement using the RII formulae below;

$$RII = \frac{\sum W}{A \times N} \quad (0 \leq RII \leq 1) \quad \text{..........Equation (3.2)}$$

Where;

W= weighting given to each factor by the respondents (ranging from 1 to 5),

A = highest weight (5 in this case)

N = total number of respondents

The following equation by Khaleel and Nassar (2018) was used in this study;

$$RII\ \% = \frac{5*(n5)+4*(n4)+3*(n3)+2*(n2)+1*(n1)}{5*(n1+n2+n3+n4+n5)} \quad \text{..........Equation (3.3)}$$

Where n1, n2, n3, n4 and n5= number of respondents who selected:

n1= the number of respondents who selected "Strongly Disagree"

n2= the number of respondents who selected "Disagree"

n3= the number of respondents who selected "Not sure"

n4= the number of respondents who selected "Agree"

n5= the number of respondents who selected "Strongly Agree"

According to Akadiri (2011), five important levels are transformed from RII values: high (H) ($0.8 \leq RII \leq 1$), high-medium (H–M) ($0.6 \leq RII \leq 0.8$), medium (M) ($0.4 \leq RII \leq 0.6$), medium-low (M-L) ($0.2 \leq RII \leq 0.4$) and low (L) ($0 \leq RII \leq 0.2$). In this study, two major labels were used in interpreting the findings as borrowed from Muhwezi et.al. (2014) and Khaleel and Nassar (2018). These are: significant for statements with RII > 0.599 and insignificant for statements with RII< 0.599.

3.7 Ethical considerations

The study followed a series of research ethics protocols. It started with obtaining a letter of authorization from CEDAT after successfully defending the proposal before my supervisor. This was followed by seeking consent from the targeted respondents for questionnaire administration and interviews. The review of literature also involved annotations and paraphrasing to avoid plagiarism. Lastly, pseudonyms were used to cite the voices of the respondents who participated in interviews especially where there are verbatim quotations.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The study examined variation in design specifications and their impact on building failure and collapse in Uganda. The context of the study was Kampala given its historical, geographical, locational and political advantages that account for why it accommodates over 80% of the entire population of high-rise buildings in Uganda. The findings are presented quantitatively using tabular devices and qualitatively using narrative text and verbatim quotations. The findings are presented and discussed under themes in the gist of the three objectives of the study, namely: To identify the design errors common on high rise buildings in Kampala city; To determine the factors leading to increase in design errors on high rise buildings in Kampala city; and To establish the effect of the design errors on the structural performance and sustainability of the high-rise buildings in Kampala city. As earlier declared in chapter three in the subsection on ethical considerations, this study involved collection of data using interviews. To fulfill the academic ritual of ensuring protection of the identities of the respondents, pseudonyms (not real names) have been used where direct quotations (verbatims) are used to illustrate the findings of the study. The actual findings of the study are preceded by results on the response rate as well as the background characteristics of the respondents in that respective order.

4.2 Response rate

The study actual study findings for this study were preceded by presentation of the results on the participation of the targeted respondents. This is called response rate by this study. According to Krishnan and Poulose (2016) and Morton et al. (2012), response rate refers to the number of the usable questionnaires used in analysis divided by the number of all the questionnaires administered by the study. Generally, a high response is suggestive of how the study attracted the attention of the targeted respondents (Dillman, 2020; Krishnan & Poulose, 2016; Odiya, 2009). This study never expected to realize 100 percent response rate, given that the questionnaires and interviews were not administered to a captive audience. Below are the results of response rates computed for all categories of respondents

Table 4. 1: Results of respondent participation in the study

Data collection tool	Number targeted	Number involved	Response rate
Questionnaire	108	97	89.8%
Interviews	4	4	100.0%
Total	**112**	**101**	
Overall response rate			**89.9%**

Source: Field data, (2021 October)

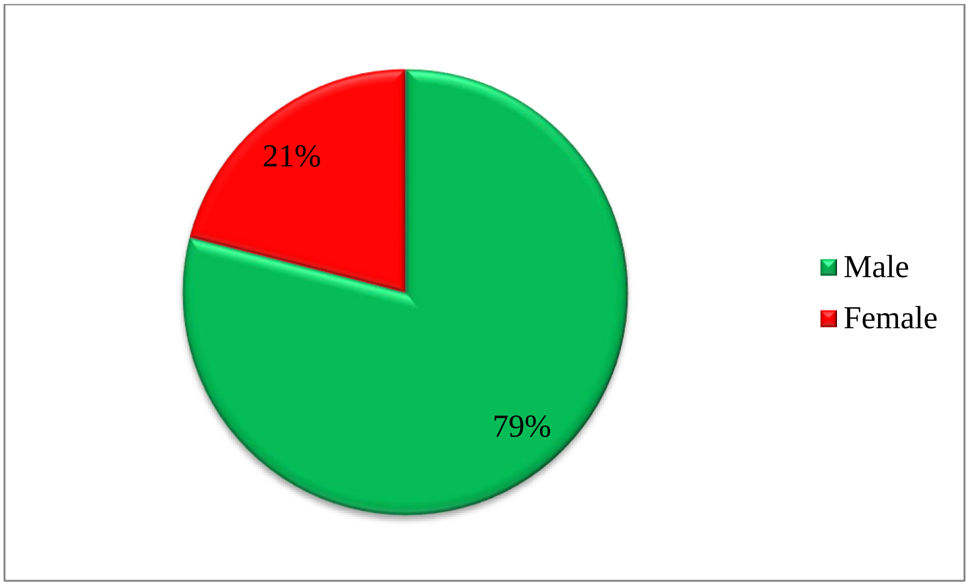
As shown by Table 4.1, initially, the study had targeted 112 respondents in total, 108 for survey questionnaire and 4 for interviews as key informants. Of the 108 respondents targeted for questionnaire survey, only 97 participated giving rise to a response rate of 89.8%. For interviews, all the targeted respondents participated producing a high response rate of 100%. The average response rate was 89.9% which was high enough to warrant high credibility of the results obtained. The high response rates reported in this study imply that all the targeted respondents were interested in the study. This inference is in consonance with Morton *et al.* (2012) that in events when the response rates are higher, say on the 70% and above region, it is indicative that all categories of respondents were interested in the study and so, the results are accurate. The findings on high response rate are a clear testimony of the findings of Krishnan and Poulose (2016) and Matthiesen et al. (2021) that the study findings based on the sample can even be generalized to the study population.

4.3 The Demographic Characteristics

This study collected data on sex, age range, highest education level and working experience. The following results were obtained

4.3.1 Sex of the respondents

Results on sex of the respondents is shown in Figure 4.1 below;



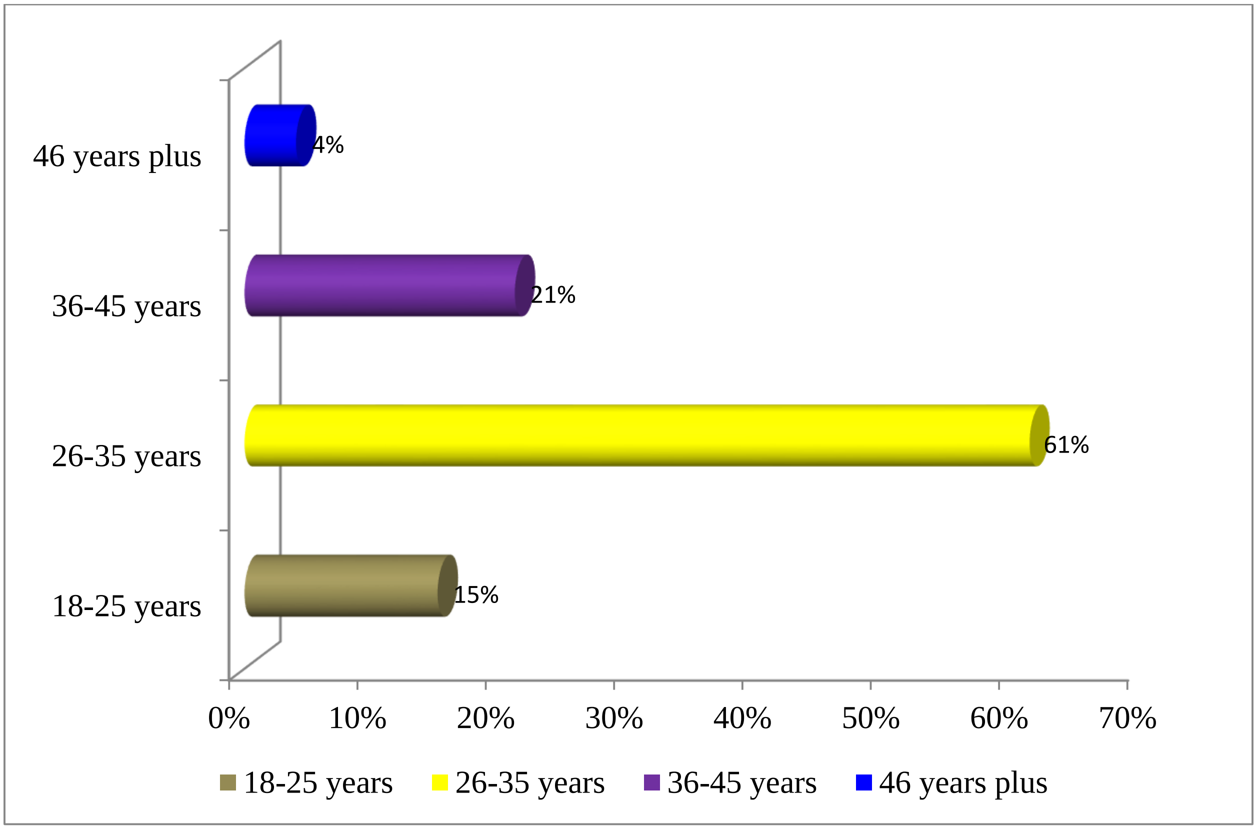
Source: Field data, (2021 October)

Figure 4. 1: Description of the respondents by sex

Figure 4.1 shows that more males participated in the study compared to females. The males comprised 79% and females, a small number at 21%. The high proportion of male respondents is reflects the gender inequalities in science, technology engineering and mathematics (STEM) professions with a greater proportion of males pursuing STEM at higher education compared to females. However, the participation of both males and females shows that both categories of gender were interested in the study given that failure and or collapse of high-rise buildings affected all categories of gender more or less equally especially when it has obstructed lifelines such as power shutdowns, disruption in flow of piped water and blocking of roads which leads to gridlock (intense traffic jam) in alternative routes hence raising the ire of both male and females.

4.3.2 Age-bracket of the respondents

The age ranges to which the respondents belonged were also assessed by the study. Figure 4.2 shows the results obtained;



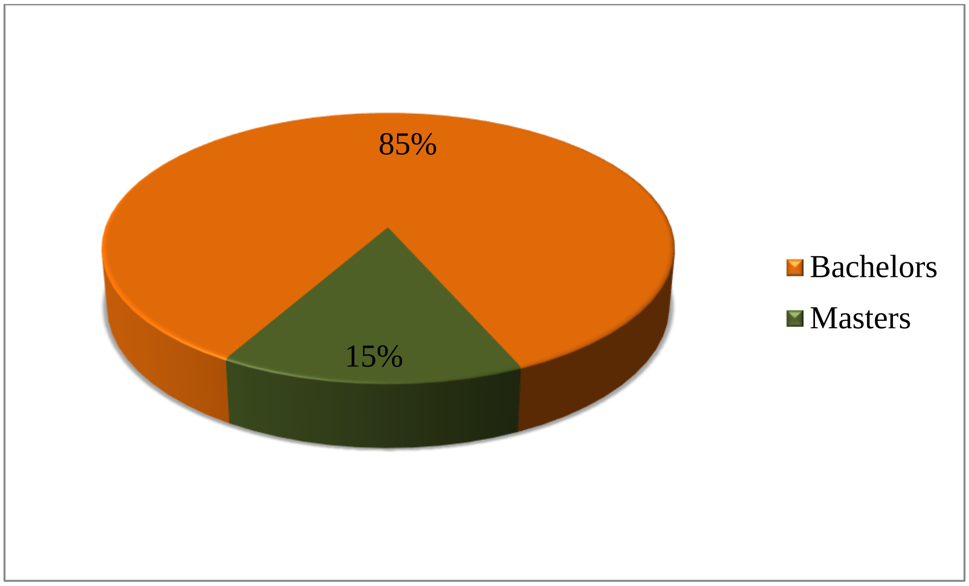
Source: Field data, (2021 October)

Figure 4. 2: Description of the respondents by sex

As seen from Figure 4.2, a negligible number of the respondents, (4%) belonged to the age bracket of 46 years and above. The majority of the respondents, 82% (61% + 21%) fell in the age range between 26 and 45 years. This finding shows that the institutions from which the respondents were picked have a high preference for most staff in the early years of their career. The early career practitioners are believed to be very creative and innovative. At advanced age in career, say 45 and above, majority of the respondents are considering to retire for private practice or engagement in lucrative income generating projects using the savings accumulated over their work life.

4.3.3 Level of Education

Responses on the highest levels of education pursued by the respondents were equally sought by the study as shown by results in Figure 4.3

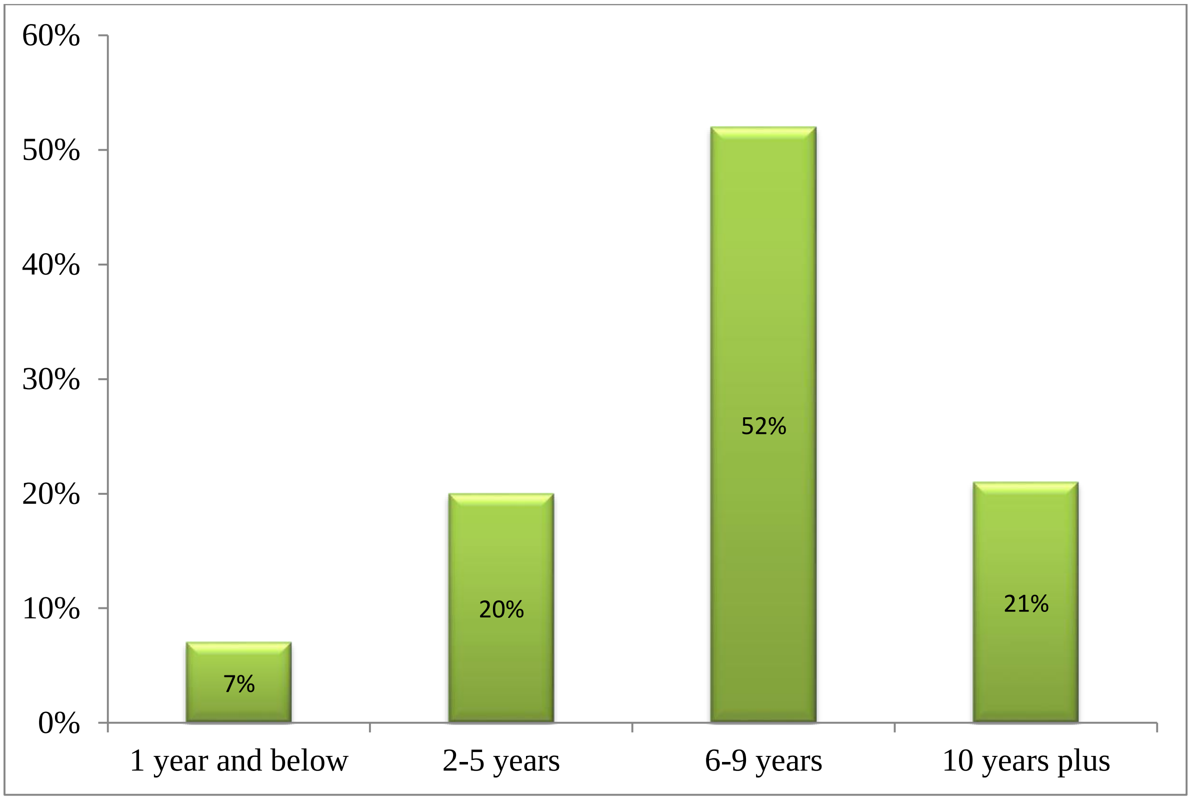


Source: Field data, (2021 October)

Table 4.4 shows a high level of literacy among the respondents. A very high proportion of the respondents were educated to bachelors' level (85%) while the rest (15%) had pursued master's degree. The statistic shows that all the respondents were functionally literate and had a high level of understanding to best interpret the statements used to assess or measure different dimensions of the questionnaire before opining. The findings are therefore based on well thought opinion given the high level of literacy.

4.3.4 Working experience of the respondents

The experiential knowledge of the respondents was also tapped into by this study. The respondents were asked to indicate the number of years they have served in their respective institutions. Results obtained are shown in Figure 4.4



Source: Field data, (2021 October)

As shown in Figure 4.4, an insignificant number of the respondents, 7% were assumed to be less informed about the issues examined by the study since they had worked in their respective institutions for less than one year. Thus, they were less equipped with experiential knowledge about variations in design specifications and how they have cause problems in the stability and sustainability of engineering structures in Kampala city in particular and Uganda in general over time due to their short tenure in office. In comparison, majority,73% (52%+21%) had served for 6 years and beyond and hence in a far better position to describe the scope and magnitude of variations in design specifications and how these have been part and parcel of the correlates or determinants of failure and collapse of high-rise buildings in Kampala city. The study findings are credible since they captured the views and opinions of long serving staff of the institutions.

4.4 Design errors common on high rise buildings in Kampala city

Objective one (1) assessed to identify the design errors common on high rise buildings in Kampala city. The errors were assessed using close ended questions measured at a 5-point Likert scale. The researcher provided a graphical illustration of the common design errors before delving into discussing the common individual design errors.

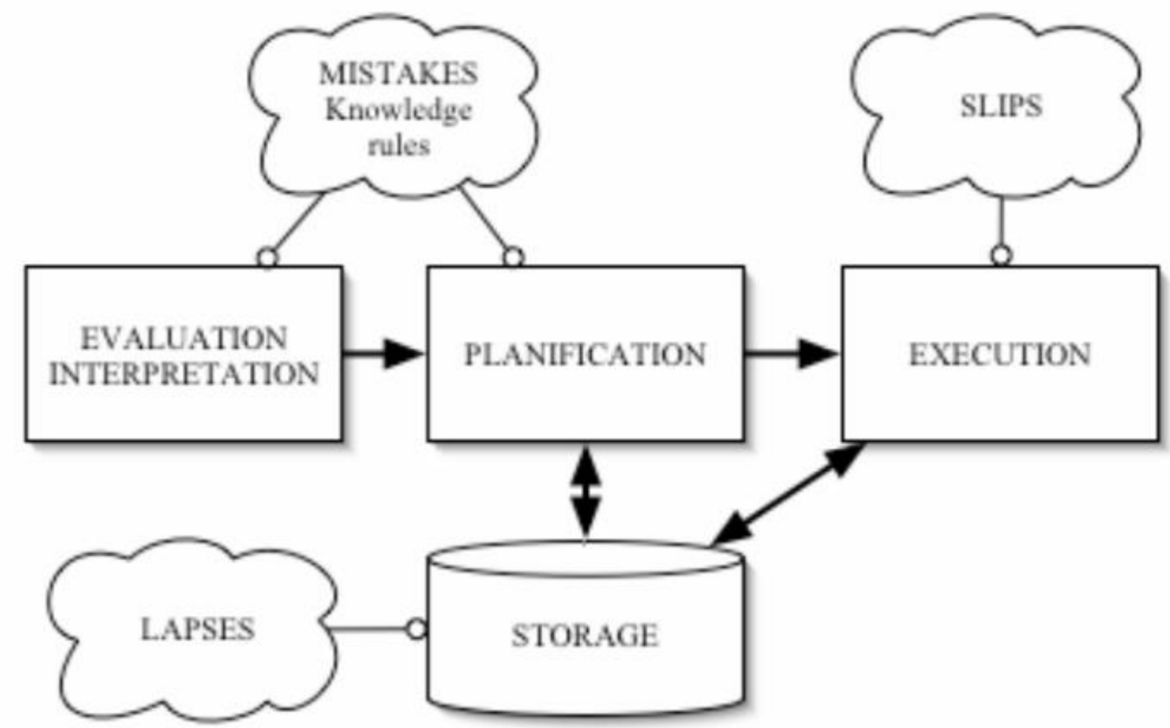


Figure 4. 3: Graphical abstract of the nature and types of design errors common on high rise buildings.

The findings were condensed using Relative Importance Index (RII) as earlier specified in Chapter Three. The findings are populated in Table 4.2 below

Table 4. 2: Description of common design errors

Design errors common on high rise buildings in Kampala city		RII	Rank
1.	Incomplete drawings are commonly observed on structures appearing in trouble	0.838	1st
2.	It is common for designers to omit some detailing during the design process,	0.806	2nd
3.	Use of different teams to prepare building designs	0.704	3rd
4.	Variations between drawn information and written information	0.672	4th
5.	Incorrect or inconsistent scales being used across drawings	0.647	5th
6.	Poorly detailed junctions or abutments between different components or systems	0.630	6th
7.	Omissions and ambiguities from drawing or specifications	0.622	7th

Source: Field data, (2021 October)

Item 1 in Table 4.2 shows that majority of the respondents agreed that the most common design error on high rise buildings in Kampala city was incomplete drawings (RII=0.838). Incomplete drawings are common on building sites where the designers lack adequate experience to warrant them to have the diligence of producing quality design specifications for high rise buildings. The key informants from KCCA and UIPE during interviews revealed that this was the most and frequently reported source of design errors of high-rise buildings in Kampala City especially those whose construction has been suspended after whistleblowing from the communities. The same views were shared by respondents from contractor companies and USA who revealed that in events where a structure especially high rise is commissioned basing on Incomplete drawings, the stakes are high that requests for information and change orders are made most of the time when the work starts on site consequently leading to illicit alterations and hence design errors. The findings are supported by Ham et al. (2018) who noted that design and construction firms do not usually make extra efforts to count the number of inadvertent design errors and do not perform adequate design review, validation, and inspection. Ham and colleagues argued that in instances when management of a multipurpose complex construction project such as a high-rise building fails to pay attention to the design specifications, it has this failed to eliminate or manage risk factors properly in the preparation stage and this can fatally affect the success of the project.

Item 2 shows that majority of the respondents agreed that omission of details in the design plans was also commonly observed on some high-rise buildings in Kampala city (RII=0.806). The respondents illustrated their submission by attesting those surveys carried out by KCCA and Ministry of Lands, Housing and Urban Development have established that some structures ongoing in the city miss design details such as window details or roof construction details with the engineering teams claiming that they were intending to complete them later. From interviews with KCCA and ERB, while the contractors show commitment to completing the design plans before carrying on with construction, it has become a common malaise for design teams to merely provide notes about what that portion of the construction should consist of which culminates into design errors especially when they have failed to honor their obligation before the commencement of the construction exercise.

Another common design error are conflicting specifications. This scored a high RII of 0.704 and a 3rd rank by the respondents. This type of error normally arises when the drawings are not coordinated especially when there are different design teams deployed to produce the design specifications for the same building. This leads to inconsistences resulting in 'clashes'. The key informants revealed that such clashes may be hard when for example when ventilation ducts are running through structural beams. As well, they may be soft especially when there is insufficient space for installation works or access for maintenance. Key informants from KCCA and contractor companies revealed that use of different teams to produce design specifications brings about conflict of interest consequently leading to design errors. Detailed building design process consists of five disciplines: architectural design, civil design, structural design, mechanical design, and electrical design (Peansupap & Ly, 2015). When there is a failure to strike a fit between the actants, design errors arise.

Item 4 shows another major design error on high rise buildings in Kampala city was inconsistencies between drawn information and written information (RII=0.672). According to key UIPE, KCCA, USA and ERB officials, the inconsistences normally arise when the design team choose to duplicate information between different types of documents. For example, a drawing may include notes referring to additional details in specification clauses.

Item 5 shows that majority of the respondents cited notational and computational design errors as common on high rise buildings in Kampala city (RII=0.647). These design errors, the respondents recounted were often committed when the designers hurriedly compile the computations quickly to meet the set deadline for the design to be finished. As a result of hurry and haste, the designers come up with these errors largely because they have failed to invest adequate time for examining the design and guarantee that all values are written correctly. When numerical calculations are conducted, the design engineers are supposed to write results with three important figures. The final result would have two significant figures provided that numerical computation is done with three significant figures. As far as rounding of values are concerned, there are recommendations which should be used to carry out rounding numbers and prevent errors in the design. These are shown in Appendix C. The finding is an amplification of the observations made by Hanson (2022) that failure to match computer software with human expertise is one of the causes of variations in design specifications. According to Hanson (2022), today's competition in the marketplace and complexity of structural designs necessitate the use of computers for structural analysis and design. With the introduction of computers, however, came the ability to make errors faster than ever before. Hanson noted that Junior engineers are increasingly placing blind trust in computer generated structural analysis results, but the evaluation skills used by experienced engineers must have been learned at some point.

Item 6 in Table 4.2 shows that majority of the respondents agreed that design errors are also manifested on high rise buildings in Kampala in the form of poorly detailed junctions or abutments between different components or systems (RII=0.630). Abutments, commonly used on bridge constructions in this study was borrowed in the survey to mean masonry used to resist the lateral forces of a vault. It also referred to the impost or abacus of a column. Columns are key components of high-rise buildings. The findings are supported by Falade (2017) who established that the frequent cause of design errors on construction projects in Abuja, Nigeria was largely concerned with the designers as the principal cause. According to Dosumua and Aigbavboa (2017), construction is complex and uncertain in nature; and unlike manufacturing and other sectors of the economy, the design and production functions in construction process are usually separated.

Item 7 shows that majority of the respondents agreed that most high-rise buildings in Kampala especially those under serious investigation by KCCA for flouting the building codes and institutional standards were also characterized by a high degree of omission and ambiguities from drawing or specifications (RII=0.622). The key informants provided comporting views during interviews and revealed that omission occurs when something required to complete the building or comply with the building codes is not shown on the plans and or in the specifications while ambiguities arise when the write-ups carry digressions and confusing information not easy to decipher by the project management team. Such errors affect the quality of the construction deliverable. This finding rhymes Dosumua and Aigbavboa (2017) and Oberlender et al. (2012) who noted that design errors also arise from directed and constructive changes. Direct changes occur when client instructs the contractor to perform works that are not specified in the contract document or makes additions to the original scope of work (Dosumua & Aigbavboa, 2017). Oberlender, David and Anwar (2012) reported that there is a tendency for some designers to make changes during design in order to please clients. Constructive changes are informal acts or modifications to a contract due to an act or failure to act. Other causes of variation are inadequate details of working drawings, change in schedule, change in scope, poor workmanship and client's financial problem (Dosumua & Aigbavboa, 2017). Changes in specifications and design complexity as well as a lack of knowledge are part of the causes of design errors which lead to variation (Dosumua & Aigbavboa, 2017).

4.5 Factors leading to increase in design errors on high rise buildings in Kampala city

Objective two (2) assessed the factors leading to an increase in the occurrence of design errors on high-rise buildings in Kampala city. Similar to sub section 4.4, the findings of the study on the 5-point Likert scaled statements used in the assessment were condensed using RII. The findings are shown in Table 4.3 below;

Table 4. 3 : Views of the respondents on increase in design errors on high rise buildings

S/N	**Causative factors**	**RII**	**Rank**
1.	Improper coordination between the stakeholders.	0.797	1st
2.	Using unqualified engineers	0.700	2nd
3.	Frequent design changes during construction process.	0.687	3rd
4.	Improper documentation of drawings and design data.	0.674	4th
5.	Unclear scope of work.	0.666	5th
6.	Improper site investigation data	0.647	6th
7.	Incorrect estimates.	0.641	7th
8.	Incompetent designs	0.630	8th

Source: Field data, (2021 October)

Item 1 from Table 4.3. shows that majority of the respondents (RII=0.797) attributed the occurrence of design errors on high rise buildings to the improper coordination between stakeholders. The major stakeholders considered by this study were the owners of buildings, contracted construction companies as well as the supervising entity-KCCA. As a result, the laxity on coordination creates an environment for the construction companies to deviate the standards given the fact that they are working for higher profits. Therefore, they will always ensure that they spend minimally by compromising the standards.

Item 2 from Table 4.3 shows that design errors have become common on high rise buildings in Kampala city largely due to the tendency of deploying unqualified engineers (RII=0.700). As a result, it is obvious that the entire design specifications are either faulty, incomplete or wrong while the buildings are also poorly constructed. The seriousness of this problem has also been published on many occasions in the local newspapers. The problem of incompetent engineers was raised by the key informants from ERB and UIPE who revealed that Incompetent engineers are liable to engaging in substandard work right from the time they are designing the structural plans of the high-rise buildings. This accounts for why there has always been a mention of poor workmanship as a key determinant of the collapse of failure of high-rise buildings in Kampala city. The key informants from KCCA and USA revealed that incompetent engineers are usually afraid of large data and therefore resort to manual computations and yet these are normally prone to human error. Such issues, would be eliminated if the staff resorted to software automation. The findings are supported by those of Oloyedde et al. (2010) who noted that the skill, experience and personal ability of the workmen involved in the building construction is of utmost importance in creating value and has a multiplier effect on the quality of constructions. Not only does it become a necessity at the construction sites, but also in the phases preceding the actual construction itself. Oloyede and colleagues for example cite the example of the decision by construction companies to use the so-called ready-made hollow sandcrete blocks sold by some block-making industries that at times, do not measure up to standard as a result of anticipated abnormal profits. Once these lapses are tolerated intentionally or otherwise, the quality of the sub-structure or super-structure cannot be guaranteed. The quality of the workmen is a measure of their effectiveness and efficiency at all times during construction while the level of building maintenance after its occupation depends on the performance of workmen. In addition, he must be willing to deliver high quality building materials to site in required quantities coupled with strict supervision of workmen by the Site Supervisor

Similarly, results in Table 4.6 show that the majority of the respondents (RII=0.687) attributed the increase on occurrence of design errors on high rise buildings in Kampala city to lack of proper documentation of drawings and design data. As a result, the design plans outputted are always complicated and can hardly be defined using the available data. This factor provides concrete evidence of the observation made earlier that many construction design plans were drawn by incompetent engineers. These findings were in line with Kumalasari (2017) whose study revealed that deficiency in design detailing is considered a cause of structure failure. It includes errors, mistakes, omissions, and discontinuity/loss of design concept. Construction deficiency occurs as problems with workmanship and deviation of results from the specifications. Kumalasari (2017) findings gave examples of such deficiencies as improper installation and inadequate temporary structure to support the permanent structure, maintenance deficiencies are corrosive and damaged components that take place during post construction or the service life of the buildings which all contribute to failure of buildings.

As further indicated in Table 4.3, majority of the respondents (RII=0.674) cited unclear scope of work as another major cause of design errors on high rise constructions in Kampala city. This factor was equally mentioned by the key informants from UIPE and KCCA who revealed that complaints of unclear scope of work were raised in most of the ground-based investigations on some of the past high-rise buildings that have collapsed in Kampala city. They reiterated that with unclear scope of work, the crew charged with preparation of the construction design plans lack systematic information on which they can base to produce clear design plans. The interruptions disrupt their work yet preparation of design plans is incremental.

Item 5 in Table 4.3 shows that majority of the respondents also raised the issue of improper site investigation data as another major factor leading to increased occurrence of design errors on high rise buildings (RII=0.666). This was common on buildings that relied on design plans bought or produced from the open market. The ERB officials on this factor mentioned that some site owners are very negligent to the extent that they engage structural engineers to produce buildings plans for high rise buildings without engaging the engineering team to make a physical tour of the site. The UIPE and KCCA respondents also symptomized this factor as a major manifestation of design errors but attributed it to failure of the proprietors of the high-rise buildings to carry out soil tests. Collectively, these give rise to improper site data that affects the quality of the design plans. The respondents from USA revealed that as the city population continues to swell, the need for additional housing space becomes more pertinent. In the expansive city suburbs, developers are competing to erect high-rise buildings to respond to the housing deficit. In pursuit of provision of better housing and working spaces, developers are flouting critical construction procedures and hastily erecting buildings, several of which have collapsed before completion.

Item 7 shows that majority of the respondents (RII=0.647) agreed that the design errors have occurred continuously due to incorrect estimates. Key informants in agreement, revealed that while estimating is less glamorous and more behind the scenes than other parts of the construction process, it is one of the most critical factors leading to increased occurrence of design errors. This error is frequent as a third of construction companies are making less than projected. The major reason for incorrect estimates raised by KCCA and ERB officials was insurmountable pressure from the owners of the buildings under plan who are anxious to start construction leading to less attention on the computations made in the design plans. Given this scenario, the design engineers are not given ample time to examine fees for labor, materials, and potential risks and to comb through the data to make sure that any errors are detected and corrected forthwith. Consequently, this leads to production of design plans with flawed timelines and potential equipment failures.

Item 8 shows that majority of the respondents cited incompetent designs as a major cause of design errors on high rise buildings (RII=0.630). Where bad designs were found, project conflicts and onsite errors were inevitable. The cause of bad designs as mentioned by UIPE and ERB officials was common on high-rise buildings where the designs were rushed. This caused early hiccups and work-order changes that could have been prevented with cross-team communication or optimized processes. The UIPE officials revealed that failure to verify the site with a laser scanner breeds human error from the measurement process leading to provision of wrong information to the drafters. Based on this scenario, the respondents from USA proposed that one way to avoid bad designs was emphasizing digitizing the plans created from those measurements with Building Information Modeling (BIM).

4.6 To establish the effect of the design errors on the structural performance and sustainability of the high-rise buildings in Kampala city

Objective three (3) sought to establish the effect of the design errors on the structural performance and sustainability of high-rise buildings in Kampala city. As earlier noted in Chapter one (Table 1.1), the problem of collapse of high-rise buildings has become a perennial problem in Kampala City. Based on this observation, the respondents were asked to provide opinion on the extent to which design errors observed in the preceding sections contributed to the problem of collapse of buildings and building failures with emphasis on high rise ones. The results obtained are shown in Table 4.4 below;

Table 4. 4 : Effects of design errors on structural performance and sustainability of high-rise buildings

S/N	**Effects of design errors**	**RII**	**Rank**
1.	Failure of concrete structures	0.999	1st
2.	Negation of air and moisture barriers	0.967	2nd
3.	Ignoring load impact on structured stability	0.941	3rd
4.	Ground settling	0.932	4th
5.	Oxide Jacking	0.927	5th

Source: Field data, (2021 October)

Item 1 shows that majority of the respondents (RII=0.999) revealed that when there is inadequate structural design, the concrete is exposed to greater stress than it can handle. Besides, the concrete may be strained beyond its strain capacity. When such occurs on a high-rise building, there is spalling or cracking of concrete. The officials from ERB and UIPE provided consolidating views on this aspect when they revealed that excessively high compressive stress due to inadequate structural design results in spalling of concrete. As well, they revealed that many of the collapsed buildings in Kampala city in 2020 and 2021 succumbed to high torsion or shear stresses which resulted in spalling or cracking of concrete. One of the causes of cracking as observed on some high-rise buildings occurred due to abrupt changes in sections hence causing stress concentrations. For instance, on some buildings inspected, the officials of KCCA Physical Planning Unit mentioned that some construction projects use relatively thin sections rigidly tied into massive sections or patches and replacement concrete that are not uniform in plan dimensions. Other notable defects mentioned by KCCA officials included:1) insufficient reinforcement at corners and openings which causes stress concentrations,2) inadequate provision for deflection which results in loading of members or sections beyond the capacities for which they were designed, 3) inadequate provision for drainage leading to ponding and leakage that may result in damage to the interior of the structure or in staining and encrustations on the structure, 4) incompatibility of materials whereby there is use of materials with different properties (modulus of elasticity or coefficient of thermal expansion) adjacent to one another resulting in cracking or spalling as the structure is loaded or as it is subjected to daily or annual temperature variations, 5) neglect of creep effect in prestressed concrete members may lead to excessive prestress/ loss that in turn results in cracking as loads are applied, 6) rigid joints between precast units leading to cracking or spalling, 7) unanticipated shear stresses in piers, columns, or abutments; and 8) inadequate joint spacing in slabs.

Item 2 shows that majority of the respondents agreed that the existence of design errors in the construction plans often leads to negation of air and moisture barriers which provide antecedents of building collapse (RII=0.967). The respondents revealed that enclosure issues can allow moisture intrusion into the building if air/moisture barriers are not included, are not correctly placed within wall details, or are not continuous throughout wall sections. They related this defect to the possibility of building failure and collapse in the long run.

Item 3 shows that the respondents agreed that design errors are likely to cause issues on load bearing of the high rise building eventually leading to failure and collapse (RII=0.941). According to ERB, KCCA and UIPE officials, defective designs are among the major causes of failure and collapse of buildings in Kampala city. With defective designs, it is practically impossible to determine the actual loading conditions on the structural elements. Inferior construction materials may also be the cause since the loads are calculated for materials of specific characteristics. Structure may fail even if the design is satisfactory, but the materials are not able to withstand the loads. The USA officials in complement reasoned that on high rise buildings where for example too many people are made to operate on a balcony or deck than is supposed to be, the potential for failure and collapse are very high.

Collapsed building: How KCCA abandoned its watchdog role

Tuesday, September 14, 2021

New Content Item (1)

By Amos Ngwomoya

Item 4 shows that majority of the respondents (RII=0.932) agreed that design errors lead to ground settling. While ground settling or sinking of buildings is common with very old buildings, the key informants in this study (UIPE and USA) revealed that ground settling has become a common manifestation of design errors on newly constructed high-rise buildings in Kampala city. Complementing this observation, key informants from KCCA chimed in and revealed that many design engineers have committed a mistake of disregarding the site data or even visiting the proposed sites. Consequently, they prepare designs which are not supposed to be erected on certain terrains (such as soft soil, marshland, etc.). As a result, the foundation begins sinking shortly after construction and get worse as time progresses. The USA officials also provided a resonating view that at times, due to design errors, the high-rise buildings sink only a few millimeters each year which cumulates after years making the foundation unstable. As a result, once the foundation fails, the building can collapse from the bottom. In large, multistory buildings, this often result in a "pancake effect" where the upper floors slam down on top of the collapsed foundation.

Item 5 shows that majority of the respondents (RII=0.927) agreed that design errors are responsible for oxide jacking on high rise buildings in Kampala city. Oxide jacking or rust burst commonly occurs when there is poor choice of materials as specified in the design documents. It involves corrosion of metal components (such as rebar) which results in the expansion of surrounding structures (such as concrete). This expansion can make the high rise building unstable. On high rise structures, the officials from UIPE and ERB revealed that the best materials would be stainless steel rebar and rebar that has been treated for corrosion resistance since these are not vulnerable to oxidation, although they may be a little expensive. USA and KCCA officials revealed that much as some constructions have been using carbon steel rebar in the interest of saving money, the materials are poor quality and inferior and may be vulnerable to oxide jacking.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter presents the summary of the study, conclusions drawn and recommendations made.

5.2 Summary of the study

The study on establishing variations in design specifications and its effect on building failure and collapse was carried out in Kampala city. Emphasis was on high rise buildings. The motivation for the study was basically the increased spate of building collapse in different parts of Kampala city and more so, the high-rise buildings which has cause unspeakable property loss, grievous body injuries and to the worst death of both construction crew members and neighboring homesteads and passersby. While it was anticipated that various in design specifications could have been one of the prime causes of the problem, there was paucity of empirical evidence about the same. Variations in design specifications especially on high rise buildings has been proven elsewhere to result in design errors leading to building failure and collapse. Given this research gap, the study aimed to come up with evidence about variations in design specifications and specifically, the types of design errors common on high rise buildings in Kampala city, the factors leading to the increased occurrence of design errors on high rise buildings in Kampala city; and the impacts of the design errors on the performance and sustainability of high-rise buildings in Kampala city.

The study involved respondents from UIPE, ERB, KCCA, USA, MoWT, contractor companies and consultant engineers. Data was collected using questionnaires, interview guides and participant observation and analysed using quantitative and qualitive means. Quantitative analysis involved use of tabular devices and Relative Importance Index (RII) while qualitative analysis used narrative text and verbatim quotations. Findings revealed that design errors common on high rise buildings include omissions of key information, variance between drawings and written information, incorrect computations, missing or sketchy site environmental data, among others. The contributing factors included poor workmanship, limited supervision, lack of coordination between stakeholders, unclear scope of work, bad designs, among others. The study established that the design errors have resulted in collapse of high buildings. This has occurred through concrete failures, jacking out of structures, loading imbalance and ground settling. These effects were identified as common denominators on all the high-rise buildings that have collapsed in Kampala city in the last five years before this study.

5.3. Conclusion

Building projects have design phases and construction phases. In the design phase, there is architectural design, which deals with space partition and building appearance, and structural design that deals with safety, stability and durability. Its structural design that ensures that a structure will safely carry the loads it has been subjected to. When a building collapses, its because it has been overloaded. Therefore, the design flaws that can led to building collapse are structural flaws, not architectural. Every structural design that is approved by KKCA or other local authorities bears the stamp of a registered engineer. Therefore, if a building collapses due to faulty structural design, it is easy to identify and punish the responsible engineer. Most of the time when clients get approved drawings, they cut off the professionals that did the design and do their own thing with their foremen. They ignore the design, use different material mixes etc. this was probably the case on the kisenyi project.

If we strictly go by the building control act, we'll ask why the building control officers don't monitor construction sites and ensure that the engineers that designed the buildings are supervising the construction phase. In reality, KCCA may not have enough staff to monitor all the buildings being constructed in the city. To be more realistic, the technicians that serve as foremen shouldn't fail at their responsibilities.

5.4 Recommendations

There is need for adoption of computerized building construction information systems such as BIM for purposes of eliminating the obvious design errors such as incorrect computations. High rise buildings involve expenditure of colossal sums of money and have a wide expanse of details that must be made before the onset of construction work. However, as earlier noted, deployment of computer systems operates on GIGO principle which implies that human ware must equally be given adequate attention. Therefore, the deployment of technology should be twinned with rigorous training of the design engineers to keep them abreast with the trending developments and advances in the sector of building constructions.

KCCA should work hand in hand with the professional bodies and construction and building unions in order to address the problem of deployment of non-professionals at sites of high-rise buildings in the city. The professional bodies are necessary in this strategy as they will help to enforce standards by favoring only certified groups but again through competitive bidding processes.

The deadly practice of sourcing for design engineers who are very green about the site configurations as is commonly practiced in Kampala should stop forthwith. The government through UIPE, KCCA MoWT and USA should peg clearance of the site designs by first subjecting the design teams to cross examinations in order to establish clearly that the designs made have been informed by the adequate knowledge of the sites through physical visits.

There is need for periodic refresher courses on safe building planning and management practices for staff in the construction sector. Capacity building is necessary because it will enable the personnel in the construction industry to keep abreast with best practices in the management of buildings. To make the trainings comprehensive, the study recommends KCCA to integrate professionals from all relevant bodies concerned or related to building construction so that a full dose of necessary and relevant information is disseminated and fed to the concerned groups in the construction industry.

5.5 Areas for further research

Although the findings reported in the study are informative, they are not conclusive. Specifically, they are tied to only Kampala city. Other urban centres such as municipalities and town councils where cases of collapsed buildings such as Wakiso, Jinja and many others are not reported in this study, which makes the findings to lack a comparative and comprehensive coverage. To draw more valid generalizations, this study should be extended to cover other urban settings in Uganda. Specifically, the study should be broadened to cover the entire building process in Uganda as a means of unraveling other proximate and underlying causes of structural failure of buildings. Equally there is need for a longitudinal study in order to qualify and corroborate some of the causes and implementation failures reported in this study.

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Appendices

Appendix A: Questionnaire

Dear respondent,

My name is Samuel Mugabi, a student of Makerere University, College of Engineering, Design and Technology pursing a Bachelor of Science in Quantity Surveying. As part of the requirements for the award of this course, I am obliged to carry out a research study. That said, I am undertaking a study on ***"Variations in design specifications and their impact on building failure and collapse in Uganda: A case study of Kampala City".*** This research is purely for academic purposes; however, the findings will have potential to help policy planners and makers to formulate sound management strategies that are capable of improving on performance and sustainability of high-rise buildings in Kampala city and other urban and peri-urban centres of Uganda. Your participation is voluntary. There are no monetary benefits. The responses obtained from you are strictly required for academic purposes. Any one moment, they can never be used against you. After all, the questionnaire is anonymous and does not mandate you to write down your personal details.

If you agree to participate in this study voluntarily, please sign below

……………………………… ……………………………………

Signature/Thumb print of respondent Date

Enumerator:

In observance of the Ministry of Health COVID-19 Control Standard Operating Procedures (SOPs),

(i) Make sure you observe the 2-meter distance between you and the respondent

(ii) Ensure that you and the respondents are putting on a face mask. For ethical reasons, since June 2020, MoH obliges you to provide face masks to respondents without.

(iii) Make sure you sanitize your hands and those of the respondent before you give out a pen or a questionnaire booklet.

(iv)Before starting the interview, inform the respondent the essence of this study. Read the consent form and ask them to sign on the **TWO** consent forms after accepting to participate. Leave one with the respondent and keep one with you.

Section A: Background information

Your gender

Male	Female

Age bracket

18 -25 years	26-35 years	36-45 years	46 years and above

Your highest educational Qualification

Diploma	Bachelors	Masters	PhD	Other (Please specify)

Number of years working with your organization/company

Less than1 year	1-5 years	6-10 years	Above 10 years

Section B: Common design errors on high rise buildings

B1: Internal controls

Using the key provided, please tick the alternative that you think most suits your opinion.

1) Strongly Disagree 2) Disagree 3) Not sure 4) Agree 5) Strongly Agree

Statements		**1**	**2**	**3**	**4**	**5**
1	Incomplete drawings are commonly observed on structures appearing in trouble					
2	It is common for designers to omit some detailing during the design process,					

Statements	1	2	3	4	5
3 Use of different teams to prepare building designs					
4 Variations between drawn information and written information					
5 Incorrect or inconsistent scales being used across drawings					
6 Poorly detailed junctions or abutments between different components or systems					
7 Omissions and ambiguities from drawing or specifications					

Section C: Factors leading to increased occurrence of design errors on high rise buildings

Using the key provided, please tick the alternative that you think most suits your opinion.

1) Strongly Disagree 2) Disagree 3) Not sure 4) Agree 5) Strongly Agree

Statements	1	2	3	4	5
1 Improper coordination between the stakeholders.					
2 Using unqualified engineers					
3 Frequent design changes during construction process.					
4 Improper documentation of drawings and design data.					
5 Unclear scope of work.					
6 Improper site investigation data					
7 Incorrect estimates.					
8 Incompetent designs					

Section D: Effects of design errors on performance and sustainability of high-rise buildings

Using the key provided, please tick the alternative that you think most suits your opinion.

1) Strongly Disagree 2) Disagree 3) Not sure 4) Agree 5) Strongly Agree

Statements		1	2	3	4	5
1	Failure of concrete structures					
2	Negation of air and moisture barriers					
3	Ignoring load impact on structured stability					
4	Ground settling					
5	Oxide Jacking					

Feel free to provide any general comment about design errors on high rise buildings in Kampala city.

Thank you for participating in the study

Appendix B: Interview guide for top management of selected institutions

Introduce the topic of study. Then request that the proceeds of this interview be audio taped so that it becomes easy to capture all the details since the writing speed might not match conversation speed.

Thank you

1. Tell me a bit about yourself and what you do.
2. In your opinion, how are high rise buildings performing in Kampala city?
3. How about their sustainability?
4. Why are variations in design specifications common on high rise buildings in Kampala city?
5. How have the variations affected the quality of constructions in Kampala city?
6. What are the effects of the design errors arising from variations in design specifications?
7. How can these challenges be addressed?

Thank you for participating in the interview

Appendix C: Recommendations for Rounding Off Design Computations

Types of calculation	Record/ round to the nearest	Type of element designed
Loading	0.1 kPa	Slabs
	1 KN/m	Beams and girders
	0.1 KN	Point loads
	5 KN	Column and footing loads
Dimensions	10 mm	Span length and location of load
	5 mm	Effective beam and slab depth
Computations	10 KN.m	Bending moments
	10 mm^2	Reinforcement areas
Design selection	5 mm	Slab thickness
	25 mm	Beam depth and width
	25 mm	Column cross sectional dimensions
	25 mm	Bar spacing in slabs and walls

Source: The Constructor (n.d). Building Ideas. Retrieved on 30 October 2021 from

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