AN INVESTIGATION INTO THE ROLE OF BUILDING INFORMATION MODELLING IN REDUCING COST AND TIME OVERRUNS EXPERIENCED IN 2-DIMENSIONAL BASED CONSTRUCTION- A SURVEY OF CONSTRUCTION PRACTITIONERS IN NAIROBI COUNTY.

BY

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RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN CONSTRUCTION MANAGEMENT IN THE DEPARTMENT OF REAL ESTATE AND CONSTRUCTION MANAGEMENT, SCHOOL OF THE BUILT ENVIRONMENT, UNIVERSITY OF NAIROBI, NAIROBI.

AUGUST, 2018

DECLARATION

I declare that this is my original work and has not been presented to any other university or institute of higher learning for examination or academic purposes

Signature ______________________ Date____________________________

Reg. No. B53/82741/2015

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SUPERVISORS' DECLARATION

This research project has been presented for examination with our approval as the University supervisors;

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DEDICATION

I dedicate this to;

My Family; To my father, David Maina, for his continued support and for doubling up as a mother and father since the passing on of my late mum. To my mother, the late Lucy Imanene- Maina, who always believed in me and took so much pride in my achievements. To Fred and Flora Maina, for their support.

Allan Rono, without whose encouragement and persistent follow up I would not have completed this endeavor.

My peers and colleagues in the construction industry.

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My special thanks to my family, for their love and support which gave me the energy to complete this work successfully.

Nonetheless, I take full responsibility for this study. Any shortcomings or errors herein do not in any way reflect the contribution of the aforementioned

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

BIM………. Building Information Modeling

CAD…........Computer Aided Design

IM…………. Information Management

CRC………. Cooperative Research Centre

CSG………. Constructive Solid Geometry

AIA…………American Institute of Architects

IFC…………Industry Foundation Classes

IDP…………Integrated Design Process

ICE…………Integrated Concurrent Engineering

UML………. Unified Modeling Language

CPM………...Construction Project Manager

CM…………..Construction Manager

ACMK………Association of Construction Managers of Kenya

ICPMK…….. Institute of Construction Project Managers of Kenya

BORAQS……Board of Registration of Architects and Quantity Surveyors

EBK…………Engineers Board of Kenya

ABSTRACT

Construction is a costly and labor-intensive activity which requires efficient management of resources for successful delivery. This delivery is however hampered by cost and time overruns, a prevalent phenomenon evidenced both locally and internationally in the industry.

It can be argued that the impediments to enhanced efficiency in the building industry are no longer predominantly technical. An organization's efficiency greatly depends on its ability to manipulate and synthesize information pertinent to its processes for its benefit. The sets of information generated from and absorbed into the construction process keep spiraling, so much so with numerous participants feeding into the process. The conventional two-dimensional information management model of construction is however not adjusting to these convolutions, resulting in difficulty in coordination of this information. The ability to relay information in consistent and compatible formats is crucial to achieving reduced downtime and increased quality and efficiency of the construction process. This has resulted in the development of Building Information Modeling (BIM), a process and tool through which a project's lifecycle information is streamlined and manipulated to improve the effectiveness of the construction delivery process.

This study sought to evaluate the role of BIM in reducing cost and time overruns experienced in 2 dimensional (2D) based construction. It was guided by four objectives: to determine the cause(s) of cost and time overruns in construction projects, to identify the significance of information management challenge(s) in 2D modeling in contributing to time and cost overruns, to establish the level of BIM maturity at which construction professionals are operating within Nairobi county as well as to identify the role of BIM and its effectiveness in reducing time and cost overruns experienced in 2D based construction. The study area was limited to Nairobi County considering a study sample across three construction profession strata; Architects, Engineers and Construction Managers. Purposive sampling of construction professionals with knowledge or experience in BIM as well as experience working in Nairobi County was done for an exhaustive study. The total sample size of 99 was considered. Data was collected through use of structured questionnaires distributed via Survey Monkey®. Descriptive summaries such as frequencies and means were derived from Survey Monkey® analytical tools. Z test and regression analysis were conducted using SPSS software. The data was then presented in form of tables and charts.

The study determined the causes of cost and time overruns in decreasing order of frequency including frequent design changes, poor project scheduling, slow client decision making, poor team collaboration, poor contract duration estimation, inadequate design, contractor inexperience, complexity of projects, project risk and uncertainty, material shortages, accidents on site, designer inexperience and poor scope definition. Challenges in 2D modeling which are significant in contributing to cost and time overruns were further established and ranked in decreasing order of significance. Lack of interlinking of changes made on one document which relate to other documents are not interlinked was ranked as the most significant 2D challenge. This was followed by tedious and error prone element clash detection, lack of multidisciplinary interaction resulting in information loss and repetitive work, inability to simulate actual scenario on site and lack of interlinking between 2D drawings with cost and time schedules. The use of lines and symbols to represent 3D objects which leads to ambiguity and misrepresentation was identified as another challenge in addition to the difficulty in confirming completeness of 2D drawings without a reference model.

The role of BIM in reducing cost and time overruns experienced in 2D based construction was identified as collaboration and coordination among project team members, detection and elimination of errors and omissions in design, design management of complex projects, design or order management change, speedy stakeholder decision making, reduction of requests for information, schedule estimation and monitoring, cost estimation and monitoring, material scheduling and project risk management. Further, BIM was confirmed to be effective in playing all these roles.

The study recommends government support in the implementation of BIM through national policy frameworks sanctioning and formalizing BIM implementation procedures. It further endorses investment of construction professionals in training on BIM procedures and software since full benefits of BIM can only be achieved if all construction participants operate within the platform. A review of construction tertiary school level curriculums to include BIM training is also recommended for generation of BIM savvy graduates.

CHAPTER ONE

INTRODUCTION

1.0. Introduction

The construction industry accounts for about 10% of the World's gross domestic product (Styhre, 2009). The Global Construction 2030 Report estimated that by 2030, construction output volume will rise to $15.5 trillion globally: an 85% growth rate. China, US and India were placed at the frontline of this growth, accounting for 57% of the growth.

According to the Kenya National Bureau of Statistics Economic Survey of 2017, the construction industry grew by 9.2% in 2016 with a resultant increase in employment in the division from 148,600 jobs in 2015 to 163,000 jobs in 2016. The survey further indicated that the total development expenditure in the sector was expected to grow from Ksh 87.8 billion in 2015/16 to Ksh 115.6 billion in 2016/17 reflecting a 31.7% growth rate. This indicates the core position held by the construction industry in contribution to national development and economic growth. The industry is not without its challenges, the most consequential being time overruns which cost the economy large loses in lost revenue from incomplete facilities and extended construction budgets.

Construction project time and cost overrun is a prevalent phenomenon. The Boston underground tunnel project coined the 'Big Dig', for example, ran $12 billion over budget. Additionally, the project which was scheduled for completion in 1998 ran through to December 2007. The Boston Globe faulted Bechtel Corporation of San Francisco and Parsons Brinckerhoff of New York, the project managers, for mistakes and waste which cost over $1 billion (LePatner, 2007).

Delays in Kenyan projects are said to be a common and re-occurring phenomenon and are experienced in any sector that delivers services through project constructions. The government of Kenya and its developing partners continue to allocate huge financial resources to infrastructure development. However, the benefits intended for the developments are partly or never realized due to unsuccessful project implementation (Kimwele and Kimani, 2014) which reflects poor project time management practices (Talukhaba, 1999). According to Chitkara (1998), a study conducted in India for 350 projects as reported by the yearly 1989-1990 report of the Ministry of Programme Implementation indicated that 56 percent of the projects had cost overruns and 49 percent faced a time overrun from 1 to 157months. Talukhaba (1988) in his study demonstrated that time performance of construction projects is poorest whereby about 70 percent of projects initiated in Kenya have a chance of overrunning in time with a magnitude of up to about 53.3 percent as compared to the chance that about 53.7 percent can overrun in cost with the magnitude of about 20.7 percent.

Tardif and Smith (2009) point to the fact that the impediments to construction have since graduated from technical challenges. He suggests that they are mostly related to inability to make strategic decisions fueled by lack of dependable and appropriate information. Information management (IM) bears significance for the construction industry considering its sheer weight and influence in the economy. Information and Communication Technology (ICT) and Building Information Modeling (BIM) promote effective construction management, serving as resourceful information and diagnostic tools (Forbes and Syed, 2011).

As demonstrated by the Guggenheim Museum in Bilbao, the Gherkin in London by Foster & Partners, The Bird's Nest Beijing National Stadium by Herzog & de Meuron and other projects, modeling systems can be used to produce buildings of astounding complexity, structures that could not have been completed using drawing-based methods achieving higher quality, more efficiency and more economic construction than with conventional methods (Crotty, 2012). Simulation using BIM software to construct and coordinate the various components ahead of production facilitates more efficient management of the vast information that the construction process generates (Eastman et al., 2011).

The UK BIM Mandate, a strategy necessitating that all centrally procured public sector projects implement BIM at Level 2 as from April 4th, 2016 (UKBIMA, 2016), further asserts the need for more efficient and collaborative ways of working in the construction industry. The Kenya Vision 2030 underscores the importance of ICT under the second medium term plan. The ambitious development plan emphasizes that ICT will promote Kenya's universal competitiveness and will serve to improve efficiency and effectiveness in all sectors of the economy. The 2006 National ICT Policy was further articulated to improve information management and circulation.

This study sets out to investigate challenges which contribute to time and cost overruns in 2D modeling as well as how these challenges can be overcome through adoption of Building Information Modeling.

1.1. Problem Statement

Construction project success is often measured based on cost, time and quality (Pinto and Morris, 2007). Time and cost overruns are, however, two common and interrelated challenges (Sambasivan and Soon, 2007) associated with construction projects both in Kenya and worldwide.

Gupta (2017) documents the Sydney Opera House to have been completed at 1457% over budget. The original cost and scheduling estimates in 1957 projected to be 7 million dollars while the completion cost is documented as 102 million dollars. Further, it took sixteen years to complete the project whose estimated time was five years. Closer home, the Kenya National Assembly Official Record (2011) details the National Construction Authority Bill indicates that the industry faces many challenges. These include project delays, or even worse, stalled projects, cost overruns, unresolved bills.

Construction project delivery entails managing a fragmented process with disintegrated participants seamlessly to deliver client satisfaction. Communication is a key aspect in any organization and comes into play in building construction projects. The increased number of professionals and organizations contributing a construction process further serves to add to organizational complexity of the process (Fewings, 2013). Managing complex dependencies between different project tasks and components as well as subcontractors is yet another challenge encountered in construction projects. The temporary nature of their interaction further propels the challenge of development of a seamless means of communication.

The construction industry is further faced with problems arising from the fact isolation of the design process from the realities on site (Onyenobi et al., 2012). Over the years, buildings have also become increasingly complex. With this increasing complexity, the information generated, exchanged and absorbed by the building process is intense (Betts and Brandon, 1995). The two-dimensional information management model of construction is however not adjusting to these intricacies, resulting in difficulty in coordination of this information. Keeping information consistent and compatible across the various project participants is difficult. Design revision using 2D CAD systems can be difficult, time consuming and expensive (Eastman et al., 2011). Visualization of any changes applied to the design is yet another problem. Idealizing a 3D scenario into 2D drawings is the root cause of the problem in the 2D setting. The tasking nature of this process bears into the construction process, prolonging it as well as propelling the costs involved.

Change orders have become an acceptable component in construction projects even when these are avoidable by exploring constructability issues at the design stage (Forbes and Syed, 2011). Vietnam Interim Review (2015) alludes to the fact that change orders, requests for information (RFIs), rework, and design clashes that are not found until construction begins contribute to 25 per cent of infrastructure project costs in the country. Waste of material and labor on impractical designs is yet another challenge experienced in traditional construction. Although most design defects may be remedied by modifications in the work, some detailed design may be impossible to perform (Callahan, 2005).

There is a growing awareness within construction practice of the significance of information effectiveness for increased efficiency (Betts and Brandon, 1995). Clients have also become aware of the advantages of visual representation of their projects at the design stage in this era where fiscal control has largely been transferred from suppliers to clients (LePatner, 2007).

With increased globalization, the world has become an open market for the client to access construction consultancy services. The trend of outsourcing international consultants for multibillion local projects has become common in Kenya, citing major building projects such as Britam Tower where GAPP Architects from South Africa and ChapmanBDSP (building services engineers) from the United Kingdom were contracted, Two Rivers Lifestyle Mall where Boogertman and Partners (Architects) from South Africa and ChapmanBDSP (building services engineers) from the United Kingdom were contracted, to name but a few. Notably, these consultants have embraced BIM technology as has been evidenced during the interaction with the researcher.

The need for sophisticated methods of project delivery and management of this vast information is evident (Fewings, 2013). Effective project management can only be achieved if the quality of this information is not compromised during transfer and application. Poor information management affects the processes in construction, ultimately resulting in cost and time overruns as well as undermining the quality of the output (Rocha et al., 2017). The efficiency of information transfer as well as use of formats compatible across the project participants is therefore crucial. This need for a common language across participants in the construction process has led to the advent of BIM.

BIM is the intentional management of information through the whole life cycle of an infrastructure project. It entails considering the intended use for an asset at the beginning of the project and how it will be integrated, ran and sustained. The BIM platform offers an avenue for the simulated construction of building components as well as coordination of all elements and processes before production (Eastman et al., 2011). This serves to address challenges long before they are experienced on site where they are traditionally encountered at the construction stage as well as improve communication (Vaux et al., 2016). The cost of making changes at the design stage is much less than that at construction (Tardif and Smith, 2009). Underwood and Isikdag (2010) outline BIM benefits including improved design consistency, more yield, and building information standardization, improved quality and improved proceeds, adding that the cost and time involved in BIM implementation is recovered through savings made from its application.

1.2. Study Hypothesis

Null hypothesis (H_0): Building Information Modeling is not effective for management of cost and time overruns experienced in 2D based construction.

Alternate hypothesis (H_A): Building Information Modeling is effective for management of cost and time overruns experienced in 2D based construction.

1.3. Study Objectives

1. To determine the cause(s) of cost and time overruns in construction projects.
2. To establish the significance of information management challenge(s) in 2D modeling in contributing to time and cost overruns.
3. To establish the BIM Maturity Level at which construction professionals are operating within Nairobi county.
4. To identify and evaluate the effectiveness of BIM in reducing time and cost overruns experienced in 2D based construction.

1.4. Research Questions

1. What is/are the cause(s) of time and cost overruns in construction projects?
2. How significant are information management challenge(s) in 2D construction in contributing to time and cost overruns?

3. What BIM Maturity level are construction professionals operating at within Nairobi county?
4. How effective is BIM technology in reducing cost and time overruns in 2D based construction?

1.5. Area and Scope of the Study

The study was conducted within Nairobi County which is Kenya's capital city and economic centre. The Kenya National Bureau of Statistics Economic Survey of 2017 lists Nairobi City County's completed private buildings' index as one of the key economic indicators for the nation at 407.1 for the year 2016. This is indicative that the county is at the forefront of building construction.

This study concentrates on information transfer among the construction project teams during the construction process and how this relates to delays. Business processes in all organizations are centered on information flow (Winch, 2010). Construction is about information transfer, exchange and use, and it follows that information flow is a key concern of the project manager, as is the transfer and control of knowledge. Information technology can improve communication but its development must consider the social complexity in which information is exchanged (Emmitt and Gorse, 2003). This pleads the case for choice of research on Information Management and Building Information Modeling.

External and internal factors which cause time and cost overruns in construction are identified in the study. Battaineh and Abdallah (2002) note that external factors are those over which the project team has no control over which affect the delivery of the project while Fugar and Agyakwah-Baah (2010) are cited in defining internal factors as those that arise from the parties to the contract or from within the project which can be altered in favor of the project. External factors are often uncontrollable and can only be monitored (Battaineh and Abdallah, 2002) and would not be easy to evaluate for the purposes of this research.

This study sheds light on the deficiencies in information management in the traditional disjointed 2-dimensional model and shows how BIM can be used to overcome these deficiencies. Review of literature on BIM mainly highlights BIM capacity to curb challenges that cause cost and time overruns. Ultimately, BIM cannot address all challenges encountered in construction which result in time and cost overruns. The study addresses the issues of failed communication, poor information management, as well as collaboration between the project participants because of increased fragmentation of individuals involved.

This study however requires purposive sampling of a population that is well conversant with both phased 2D construction and BIM enabled construction to establish if an information management niche exists in the 2D setting and if this niche can be addressed through adoption of BIM. Musyimi (2016) in her study determined that only 25% of construction project management practitioners in Kenya have implemented BIM in construction project management. This indicates a low level of adoption of BIM in the Kenyan construction industry. The researcher therefore included international expatriates who have penetrated the local market in addition to local construction professionals for an exhaustive study. This information was collected through questionnaires distributed via SurveyMonkey®.

1.6. Research Methodology

Since this study intends to explore the capability of BIM to overcome cost and time overruns in 2D based building construction, a qualitative research design is adopted. Stratified purposive sampling was applied for a sample of 99 elements encompassing construction professionals across the three strata with experience using BIM for projects within Nairobi county. Data was collected through use of structured questionnaires designed and distributed via Survey Monkey®.

1.7. Significance of the Study

This study bears relevance to many stakeholders in the construction industry. The results of this study will avail information on the challenges that are traditionally encountered at the construction phase due to inadequate consideration of constructability at the design stage as well as due to lack of proper communication and collaboration among the varied participants. It also gives a detailed account of how these challenges can be surmounted through the adoption of BIM as well as additional benefits that can be derived.

This study will be important for investors in the construction industry to understand the overall project savings that can be made by investing more time and effort at the design stage to avoid abortive works at the construction stage. This is in recognition of the fact that a certain additional cost is pegged on adoption of BIM but also that the cost associated with project time overruns can be much more intense. The understanding of the clients that the benefits of adoption of this technology outweigh the cost of adopting it is crucial. Direct advantages to the client/ investor include BIMs ability to offer high level summary information about their facilities, planning, budgeting as well as decision support avenues available.

For consultants, this study will promote a critical examination of methods currently in use for determination of project schedules as well the extent of collaboration among themselves as well as with the site team. The study also avails information on direct potential benefits from adoption of BIM. Designers can take advantage of the modeling aspects of the technology as well as to plan appropriately. Cost and Quantity Estimators can obtain more accurate quantities from the electronic model as it simulates the real project.

Contractors often give their time and cost estimates under the pressure to submit timely and competitive bids. This study encourages an investigation into the methods used to give these estimates as they tie the contractor down to figures stated in some cases. Many consultants have adopted the use of BIM in projects design globally. However, this has not been adopted as much by contractors. This could perhaps be related to lack of information. This study avails this information to contractors to create awareness on this effective simulative tool which if adopted properly can enable them to develop accurate schedules and thus maintain their profit margins.

At a national level, decisions on funding for projects is based on strategic plans which depend on information and estimates derived by the committees in charge. The funds are raised through different fiscal methods and must be supported by expert estimates. The case of incomplete facilities and extended construction budgets is a common occurrence in Kenya. This happens when budgets are not adhered too, thus exhausting the funds allocated to various public projects and can be corrected through effective scheduling of costs. For planners, this study will promote an understanding on BIM ability to provide accurate ways to determine program needs.

1.8. Study Assumptions

The study assumes that the sample identified gave honest and reliable feedback to represent the population. The introductory section of the questionnaire encouraged voluntary participation noting that all responses would be anonymous and confidential. Additionally, reliability tests were conducted to confirm internal consistency of the data.

1.9. Limitations of the Study

Questionnaires were distributed via Surveymonkey® using an email collector which enabled delivery notifications. Nonetheless, some targeted respondents did not respond despite sending out several reminders. This accounts for the 9.1% non-response rate noted in chapter 4 of this study.

1.10. Definition of Terms

Constructability- The ability of a structure to be built effortlessly (Ogunlana, 1999).

Global project- This refers to projects whose project teams are situated in multiple locations across different time zones and countries. These kinds of projects exhibit unique challenges due to the varying cultures, languages, organization structures and time zones (Binder, 2007).

Construction process- The American Institute of Architects defines the construction process to entail the schematic design phase, design development, construction documentation, tendering and finally construction (AIA, 2016).

Construction stages- In the Kenyan context as per BORAQS CAP 525, construction stages include the inception stage, outline proposals stage, scheme design stage, detailed design and production stage, tender action and finally completion

1.11. Organization of the Study

This study is organized into five chapters.

Chapter one covers the introduction to the study which defines the problem statement, lists the objectives of the study as well as the hypothesis to the study. This is guided by research questions also outlined herein. The chapter also defines the area and scope of the study, significance of the study and finally outlines the organization of the study.

Chapter Two entails a review of literature on the challenges that lead to time and cost overruns in traditional 2D paper based construction. Information Management in the construction industry is also reviewed. Additionally, it gives a detailed account of the abilities of BIM, as documented in literature, in overcoming the challenges identified previously in the chapter. Moreover, it gives an account of the documentation available on projects where this technology has been adopted and how this affected time and cost schedules in the projects where it was implemented. Challenges to the adoption of BIM are also studied in this chapter.

Chapter Three outlines the area of research and research methodology for the study. This served to give a systematic process which guided the research process. This chapter recounts the philosophy, approach, strategy and data collection methods applied to interrogate the hypothesis posed. The capacity of BIM to address the time and cost overruns experienced in 2D building construction was interrogated. Data collection was carried out through structured questionnaire survey amongst the respondents. Purposive sampling was applied to identify a sample of building construction project managers; construction project managers/ construction managers, architects and engineers with experience in Building Information Modeling for a detailed study. The questionnaires were designed using Survey Monkey® and distributed via email or in person among targeted correspondents. Data analysis entailed derivation of frequencies and means as well as use of z test and regression analysis for testing of the hypothesis. Conclusions, recommendations and suggestions for future study were then then made

Chapter Four encompasses analysis of data collected as well as testing of the hypothesis. All the data analyzed is presented herein as well.

Chapter Five summarizes the study findings and concludes on the hypothesis. It also includes recommendations informed by the literature and data analyzed in previous chapters, in addition to acknowledging sources of information.

CHAPTER TWO

LITERATURE REVIEW

2.0. Introduction

This chapter reviews the causes of time and cost overruns in construction projects from literature. Both external and internal causes are identified. It narrows down on specific internal causes of cost and time overruns in the 2D setting which can be managed through adoption of BIM technology. The chapter also reviews literature on the importance of information management. Finally, it gives an account of 2D methods applied prior to the adoption of BIM in the industry, the history of BIM, definitions, applications in addressing the specific challenges established in the traditional setup as well as benefits and challenges associated with the adoption of BIM.

Construction project delays are a common occurrence, both in the local and international scene. Surprisingly, although the capabilities of scheduling software have grown tremendously, project delays remain a rampant spectacle in construction (Trauner et al., 2009). Time overruns signify delay in the completion of a project, deviating from schedule of implementation originally anticipated. Cost overruns signify increase in the cost of the project originally assessed though there may be no time overrun. Time overruns however have inbuilt attributes of cost overrun due to increase in preoperative expenses, mainly interest during construction period and increase on the cost of non-firm fixed assets (Gupta, 2017).

Construction has been compared with the factory industries where mechanization, replacing craft with machines and with semi-skilled labor has been achieved resulting in success with large scale methods. Prefabrication, system building, mechanization and the rationalization of the building process is an attempt to emulate this (Talukhaba, 1988). Arguably, research and development work in the manufacturing industry has reinforced advancements in construction industry (Forbes and Syed, 2011).

Nonetheless, it would be deceptive to imply that the same sort of dramatic change might be about to happen in construction as has happened in manufacturing over the past two decades. Smith and Morledge (2013) relate the presence of a permanent and controlled environment where the product can be designed, prototyped and tested prior to final production to the success of the manufacturing industry. This promotes quality assurance, reduction of wastes and value addition as well as enabling potential clients to view and try the product prior to purchase. A fragment of this has been achieved in mass residential construction development. However, a critical study into the inefficiencies and wastes in the construction process is necessary as these are prime targets for greater profit (Tardif and Smith, 2009). Efficiency and productivity in the industry can only be achieved if building information can be developed, exchanged, evaluated and manipulated in a reliable manner.

BIM presents an opportunity for a semblance of this prototyped designing and simulation to be achieved in construction, like the manufacturing scenario described above. Data is embedded on the model, intelligently linking it to objects summarizing the vast content into forms that are easier to extract and analyze. This expedites the facility delivery process and promotes speedy decision-making by relevant stakeholders (Forbes and Syed, 2011).

2.1. Cost and Time Overruns in the Construction Industry

Building and construction projects in general are very sensitive to the nature of the organizational structure of the implementation team. The efficiency of combining their various participants' activities generally determines the success of the project (Mbatha, 1986). There are always failures such as cost overrun and time overrun in construction projects, common to both developed countries with sophisticated delivery systems and developing countries (Ameer, 2015). Since most construction projects tend to overrun on cost and time, the ability to minimize the extent of overruns and contain them within the cost and time contingencies is a challenge for any construction manager (Loosemore and Uher, 2004). LePatner (2007) alludes to the fact that construction is possibly the only venture where business savvy owners struggle with the inability to understand and control the process. He submits that construction will always cost more and always take longer than was anticipated. Brooker and Wilkinson (2010) suggest that cost and time overruns are among the main areas that give rise to construction disputes, fueled by the uncertainty about who is liable for the overruns and why they occurred.

2.1.1. Types of Delays

Sunjka and Jacob (2013) classify delays into four categories;

2.1.1.1. Excusable non-compensable delays;

These are delays that the owner and contractor cannot control. However, this kind of delays warrant an extension of time for the contractor. These would include acts of God, extreme weather conditions and labor disagreements. (Kushnick, 2010).

2.1.1.2.Non-excusable delays;

These are delays which are as a result of action or inaction from the contractor. Cushman et al. (2001) describe these as delays caused by the contractor's negligence or fault, delays that were foreseeable, or delays for which the contractor assumed the risk. These are commonly caused by predictable weather conditions, delays by the contractor or their agents, contractor's poor site management, contractor's financial challenges, labor or material shortages and poor workmanship

2.1.1.3.Excusable compensable delays

These are delays caused by the client or their agents (Sunjka and Jacob, 2013). These entitle the contractor to seek not only a time extension, but also monetary compensation. Damages are recoverable even if the owner grants the contractor a time extension for the compensable delay. Common compensable delays caused by the client include poor management of nominated contractors, failure to provide access to the site, intermission of the contractor's performance, issue of change orders, interference with contractor's delivery or delays caused by a third party under the control of the client such as the consultant (Cushman et al., 2001)

2.1.1.4.Concurrent delays

These are delays caused by both the contractor and the owner (Sunjka and Jacob, 2013) or when two events occur simultaneously resulting in delay of the project. Where an event out of the control of the client and contractor occurs simultaneously with an event in the control of the contractor, it can be argued that the event out of the control of the project participants would have prevented the contractor's performance either way (Kushnick, 2010).

2.1.2. Causes of Cost and Time Overruns in the Construction Industry

Construction cost and time overruns are caused by external and internal risk factors (Gupta, 2017). External risks are generally considered uncontainable and can only be monitored while internal risks can be managed in favor of the project (Fugar and Agyakwah-Baah, 2010).

2.1.2.1. External Causes

External causes are those over which the project team has no control over which affect the delivery of the project. According to Jackson (2010) and Battaineh and Abdallah (2002) these include weather conditions; work proceeds much more slowly under adverse weather conditions, changes in regulations, government taxes and levies, issue of permits and licenses by relevant authorities; delays in issue of permits and license for construction affect the overall construction process, Currency fluctuations, natural factors such as landslides, earthquakes and floods, problems with neighbors, site conditions and accidents on site. Import policies and bans which affect materials and equipment are also external factors that can affect a project since a change in policy or ban can result in additional lead times and repeat approval processes.

2.1.2.2.Internal Causes

Internal Causes arise from the parties to the contract or from within the project (Fugar and Agyakwah-Baah, 2010) which can be altered in favor of the project. They may be related to the client, contractor, consultant, materials, labor, equipment, project uniqueness and complexities as well as project management and communication strategies adopted. As highlighted by Sharma and Prabdeep (2014), Battaineh and Abdallah (2002) and Fugar and Agyakwah-Baah (2010), these factors include;

2.1.2.2.1. Client Related Causes

The construction process is often delayed due to reasons tied to the client. These include;

i. Slow decision making,

Slow internal reviews and decision making by clients, especially where more than one client is involved, can result in project delay. In addition, this sets a precedence for other project participants that the time management is not a key concern for the project. Lack of clear communication and determination of decision points and decision makers can also cause further delay (Heilman and Andrle, 2012).

ii. Interference by owner,

Situations where a there is a specific and affirmative task to be performed by the client by the terms of the contract and is subsequently not performed by the owner can be termed as active interference. One of the motives of interference by the owner is the prospect of figuring out a shorter critical path for performance. A directed change in the contractor's method of performance that results in greater efficiency can result in a deductive change order. This interference however often has opposite effect through disruption, delays and increased expense to the interfering party (Callahan, 2005).

iii. Unrealistic contract durations imposed by owners

Often, clients impose impractical expectations and schedules on contractors which results in disputes as well as general negative relations which slow down the construction process. (Marco, 2011).

iv. Slow payment of completed work

Construction work payments are ideally based on progressive complete works for each section of the works as per the agreed payment plan. The owner should have the funding in place to match the contractor's estimated progress payments. Contractors have since formed forums raising awareness for legislation to accelerate payments from owners (Callahan and Bramble, 2011). These delays may stall construction progress as they strain the contractor's cash flow.

2.1.2.2.2. Contractor Related Causes

Construction progress is dependent on the contractor's capability to handle the project both technically and financially. These are both critical aspects assessed during tendering to evaluate the contractor's ability to deliver the project. Delay factors which relate to the contractor include;

i. Poor planning and scheduling

Chitkara (1998) links insufficient time plan, equipment plan, poor organization and poor cost forecasting to project delays. Ashworth (2012) states that without accurate time and resource allocation is necessary for execution of a project. Use of sequencing and scheduling tools to monitor process flow highlights dependency between the activities and the effects of delays in turn.

ii. Lack of experience

Where a contractor does not have the prerequisite knowledge to undertake a task, the possibility of errors in the constructed facility increases. This has the possibility of creating low quality works, reworks, variations and delay in the project completion (Ameer, 2015).

iii. Financial challenges

The contractor's financial resources may be strained, resulting in project delays. Generally, the contractor's restrained resources do not entitle them to poor performance, but results in delays (Callahan and Bramble, 2011).

iv. Poor site management

The contractor is tasked with the responsibility to ensure that all site activity is coordinated to deliver the project. This calls for effective planning of all processes and facilitation of subcontractors as well. Where this is not done, delays are experienced and these come with cost implications (Masterman, 2002).

v. Dispute on site

Disputes between the parties to a contract or between laborers on site can arise resulting in strained relationships (Greenhalgh 2013). More and more projects end up in arbitration, litigation, or some form of dispute resolution because of these disputes (Trauner et al., 2009). Labor disputes are listed under excusable delays which implies an entitlement for extension of time and excuses the contractor who cannot meet their contractual deadline from their breach of contract (Cushman et al., 2001). The cost of idle labor and lost time when disputes are encountered is worthy of note. Where these disputes result in litigation or arbitration, this results in an additional incurred cost on the project.

2.1.2.2.3. Consultant Related Causes

These relate to delays instigated by the consultant or designer which include;

i. Poor contract management

Covering how delay and disruption should be considered at each stage of a project, from inception to completion and beyond is one of the most important aspects of contract management (Chitkara, 1998). Contract management entails controlling, by contracts, a project's program. This provides a practical and legal recourse for any eventuality along the project lifecycle (Powell, 2016). Technical expertise is required in analyzing extension of time entitlements under the construction contract (Caletka and Keane, 2008). Effective contract administration and management is therefore necessary to keep a construction project on track from a commercial and contractual point of view (Greenhalgh 2013). Powell (2016), Chitkara (1998), Greenhalgh (2013) all link poor contract management to construction project delays.

ii. Inspection and test delays

These delays occur where the contractor has performed all contractual tasks required prior to inspection or testing of equipment/ materials, including invitation of the consultants for the inspection but the consultants delay in attending to the same. This has an obvious delay on the time schedule (Greenhalgh, 2013).

iii. Inaccurate time and cost estimates

Cost estimates are derived at various phases during the project. Each phase interacts with and affects the cost estimation practice. Initially, project costs are derived as estimates which are finetuned along the course of the project (Stuart et al, 2007). The appropriate estimation approach varies based on the project scope definition, design development and complexity. Increasing the quality of initial estimates is one of the methods of preventing delays (Yates, 2007). It is impossible to estimate costs accurately without ensuring a preliminary definition of risk management procedures, quality management procedures, management team structure and their costs. It is important to ensure that no costs are overlooked (Massimo, 2015).

iv. Inadequate experience

Consultant's lack of experience, like the contractor's increases risks of errors in construction. This has the potential of increasing variations and delay in the project completion (Ameer, 2015).

2.1.2.2.4. Design Related Causes

These relate to the design of the project as per the consultants' specifications. Where flaws are inherent in designs or information is not adequately represented in the designs this can result in delays. These factors play in in the following aspects;

i. Frequent design changes and variations

These can be very expensive since they disrupt both the design and construction process (Powell, 2016). Cheung (2014) indicates that design changes are the primary basis of construction disputes as they increase cost. He notes that even though the resulting disputes can be resolved in the end, they may extend the construction process and result in hostile relations which endanger project collaboration.

ii. Improper/Inadequate design

This is determined based on whether the proper level of detail has been provided or whether the work elements are constructable. A detail omitted from a drawing may be because of design error or omission. Either situation may result in numerous requests for information (RFIs) from the contractor during the construction process. This may delay and disrupt the process while the contractor awaits clarification on how to proceed. It is not unusual for contractors to make claims citing the number of RFIs on a project as justification for lost productivity and/ or delays in completion and to allege that inadequate design performance was the culprit (Callahan and Bramble, 2011).

iii. Delay in design approval

The design professional has a duty not to delay the construction project (Cushman et al., 2001). The AIA Standard Agreement Document B141 states that the designer will review and approve contractor submittals with such reasonable promptness so as not to delay the process. Betts and Brandon (1995) highlight the need for proper management of the multi-discipline project regarding design and drawings approval delays to avoid project delays.

2.1.2.2.5. Material Related Causes

This relates to the efficiency in supplying materials to the construction as and when needed. Late deliveries often cause delays in schedules and cost growth in the construction process. The contractor has very little influence over the manufacturing or fabrication process. However, the stakes can be very high when items arrive late. The construction manager must therefore be vigilant and on the lookout for disruptions and inefficiencies that would derail plans. Having prior knowledge on material requirements to plan is therefore crucial (Jackson, 2010). Greenhalgh (2013) lists shortage of material and late delivery of materials among the top ten factors that cause construction delays according to the contractor. Changes in material specification also affect the project schedules especially where lead time must be allowed for shipment (Cushman et al., 2001).

2.1.2.2.6. Labor Related Causes

The contractor needs to carefully assess demand levels throughout the construction period. This information is necessary for provision of adequate resources for the site (Loosemore and Uher, 2004). Shortage of labor, lack of skilled labor, high cost of labor and low level of labor productivity are some of the labor factors associated with delays in construction as well as inflation of costs (Sharma and Prabdeep, 2014).

2.1.2.2.7. Equipment Related Causes

Equipment in construction often improves productivity on site by reducing the number of workers performing a task. However, equipment needs to work properly for this efficiency to be achieved. Time consumed getting equipment to work where breakdown occurs can cause delays in projects especially where the project is heavily dependent on this equipment. The availability of major items of plant and equipment should be considered when developing the project schedule (Loosemore and Uher, 2004).

2.1.2.2.8. Communication and Information Management Related Causes

Communication with different parties is an important factor in any construction project as it involves many entities. Complicated variations which occur down the line can be avoided through strong and sustained communication in the initial project stages. Where this communication is non-existent, major variations and delay in completion can be experienced (Ameer, 2015). Poor interdisciplinary coordination and inefficient or lack of information flow between parties have been identified as causes of project delays by Fewings (2013) and Ameer (2015).

2.1.2.2.9. Project Related Causes

Every project bears its own unique attributes which can contribute to cost and time overruns. These include the project complexity as well as project risk. Gudnason and Scherer (2012) submit that project uniqueness and complexity calls for bespoke managerial actions. Project cost, time, quality and objectives are influenced by project complexities. These complexities and uncertainties further contribute to the project risk element and vary from project to project.

2.1.3. Studies Ranking Causes of Cost and Time Overruns

Sharma and Prabdeep (2014) steered a study ranking the causes of cost overruns in Nigeria, Indonesia, Ghana, Kuwait, Vietnam, Pakistan, UK, Malaysia and Egypt. Slow decision making was found to have the highest frequency in the owner group. Poor project planning and scheduling, contract management, frequent design changes, had the highest frequency of occurrence in the contractor, consultant and design group respectively. Another study by Battaineh and Abdallah (2002) sought to identify the level of importance of the causes of delay of projects in Jordan. The study ranks interference by the client, inadequate contractor experience, delayed payments by client, low workforce productivity, poor site management, slow decision making, inefficient construction methods, poor planning and subcontractors among the top ten ranked factors of both groups. Fugar and Agyakwah-Baah (2010) also sought to identify the ten most important causes of delay out of a possible 32 causes of delay of construction projects in Ghana. The study ranked the causes as follows; delay in honoring certificates, underestimation of cost of project, underestimation of complexity of project, difficulty in accessing bank credit, poor supervision, underestimation of time for completion of projects by contractors, shortage of materials, poor professional management, fluctuation of material costs and poor site management. According to Chitkara (1998), the main causes of project failure are attributed to cost estimation failure and management failure. The study further links these time and cost overruns to inadequate project formulation: inadequate project information, bad cost estimates, poor investment decisions, inadequate project analysis, poor planning for implementation: inadequate time, resource and supply plans, poor cost planning and organization, lack of proper contract planning and management: improper pre-contract actions and poor post award contract management as well as lack of project management during execution: ineffective and inefficient working, delays, change orders.

These studies provide a background and context for ranking of causes of cost and time overruns that is undertaken in chapter 4 of this project.

Further, information management has been cited as a challenge that cuts across the internal causes of cost and time overruns (Rocha et al., 2017). Project information serves to produce details for setting of project cost and time targets which are then applied to monitor the progress of the project (Loosemore and Uher, 2004). For construction projects, time and cost elements require information and details from all the participants in the process for comprehensive schedules to be developed (Betts and Brandon, 1995). The manner in which this information is generated, synthesized and distributed among participants in the construction process either serves to mitigate or propel client related causes, contractor related causes, consultant related causes, material related causes, project related causes as well as communication related causes as discussed in the section that follows.

2.2. Information Management in the Construction Industry

The construction industry absorbs information coming in from different project participants and stakeholders. Integration of this information is therefore necessary (Ogunlana, 1999). Information management should be a necessary function, one that is key to the efficient management of a project (Betts and Brandon, 1995). It is the acquisition of information from different sources, the custodianship and circulation of that information to different addressees. It is concerned with identifying the critical functions-the critical success factors for services and the organization and the information that is needed to support them (Langford and Retik, 1996).

Information drives the construction process thus an intricate balance must be realized between too little and too much information for achievement of the owner's objectives of cost, time and quality. Data entails raw figures while information is synthesized data and knowledge is valid, processed and substantiated information. Data becomes information when they analyzed and placed in a context applicable to the recipient (Zhou and Nunes, 2015). The recipient then interprets the information giving it a context based on their beliefs and understanding, then knowledge is born.

Poor management of information in the construction industry has born cost, time and quality problems. This is mainly so given the heavy reliance on traditional methods of information transfer such as paper-based drawings and details as well as physical site meetings (Rocha et al., 2017). Emmitt (2007) submits that conflicting construction documentation can mislead the project team in charge of the budget and result in errors that can end up in reworks while lack of information can stall the project entirely.

2.2.1. Types of Construction Project Information

Construction projects produce large and complex sets of information at various stages of the construction process. Accuracy and availability of this information is key to efficient project management. Project failure or delay can result from poor decisions escalated by poor or missing information (Hendrickson, 1998). The various types of information generated in the construction process include;

2.2.1.1. Intermediate analysis results during planning and design,

Prior to production of design documentation, intermediate analysis is conducted. Traditionally, this sets off in the form of the concept design, which is developed into the schematic design and further into the detailed design. Proper management of all this information is necessary to ensure that the project team is working on current data.

2.2.1.2. Design documents, including drawings and specifications,

This is the ultimate output from the detailed design process which forms the basis for tender as well as for construction. Detailed drawings and specifications provide project specific information which gives a clear direction to the project team and ties into the client brief..

2.2.1.3. Construction schedules and cost estimates,

Construction schedules break down the project deliverables into work packages with time details assigned. It is necessary therefore, that these schedules give a reflection of the anticipated project deliverables. Similarly, cost estimates are born from the design scheme and form the interest of all project participants. It is crucial that every deliverable on a project is pegged to a cost; hence clarity of project details is key.

2.2.1.4. Quality control documentation

Quality control and assurance is ensured by developing a clear definition of quality standards to be upheld for a project which are periodically monitored to ensure compliance. This is often done through conducting of tests to measure standards achieved against standards set, following which test certificates are issued where compliance is confirmed. Any field activity or inspections conducted are also followed up with monitoring logs for record purposes.

2.2.1.5. Chronological files of project correspondence and memorandum,

The construction process entails communication among the various participants involved. This correspondence is maintained through emails, letters, memos and meetings which further form part of project documentation.

2.2.1.6. Legal contracts and regulatory documents.

Legal contracts are intrinsic to the construction process given the numerous parties involved, each with a binding responsibility towards accomplishment of the project. Regulatory documents such as environmental impact assessment, practicing documentation, approvals by local authorities add to the list of documentation generated from the construction process.

2.2.2. The Importance of Information Flow and Management in Construction

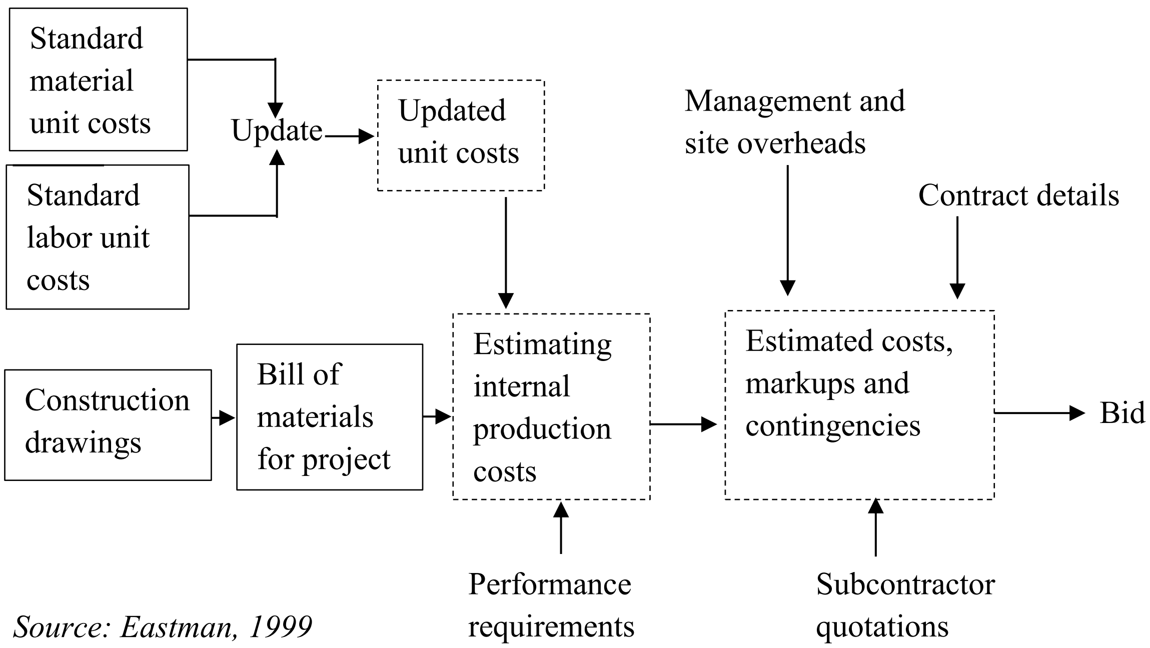
Information flow is crucial for any organization and is driven by organization structure (Winch, 2010). Winch (2010) further suggests that uncertainty from lack of information is a critical management challenge. He links uncertainty to complexity and unpredictability defining complexity as the condition where the information is available impossible to analyze while unpredictability is a condition where past events are not dependable for decision making.

Cheung (2014) points to the fact that effective information flow can maximize on project time, cost and quality. He advocates for effective management of information flow as a pragmatic way to minimize project risk and alleviate project delays or inefficient decisions. This is in recognition of the fact that with effective flow of information, potential disputes can be identified and resolved earlier. He further calls for creation of collaborative work environment to facilitate information sharing between practitioners. Information management further relates to several of the causes of construction delays identified previously in section 2.1.2 of this study as described below;

i. Information management for cost estimation

Sufficient cost information is required for a project planner to be confident that the cost commitments for a project can be realized. Eastman (1999) summarizes building project cost estimation information flows as shown in Figure 2. 1 below. Cost estimation ideally starts with a cost unit and average price per unit is supplied by construction industry information suppliers. These are further updated to account for varied weather conditions, specific site, and contingencies to derive the exact cost to be applied for the project.

Figure 2. 1: Building Project Cost Estimation Information Flows

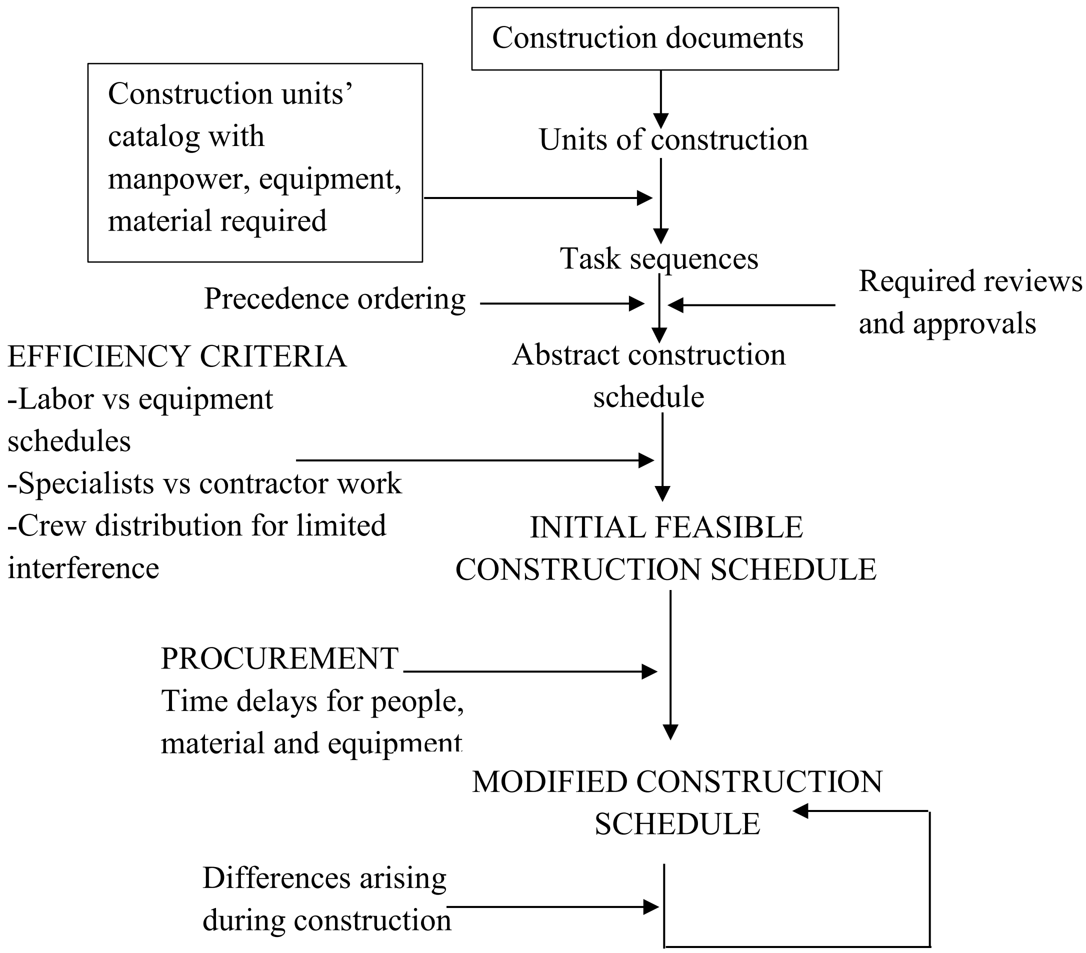


Source: Eastman, 1999

ii. Information management for project scheduling

Eastman (1999) explains that construction schedules are derived from sequenced units of work. Necessary reviews and approval must also be identified and planned for. He summarizes the information flows required for development of a comprehensive schedule as shown in Figure 2.2 below. Comstruction documents are broken down into units of construction following which a sequence of activities is developed and thereafter, the construction schedule.

Figure 2. 2: Information Flows for Construction Schedule Development



Source: Eastman, 1999

iii. Information management for change order and design change management

Information flows constantly between project participants through a variety of media. This is done through drawings, field instructions, change orders, RFIs, among others. It is necessary to ensure that the transmittal forms used expedite the process but also ensure that the exact information required is provided (Callahan, 2005).

iv. Information management for design adequacy

Uncertainty as a result of poor information; information that is missing, untrustworthy, erroneous and inconsistent leads to reactive changes and reworks. Poor transfer of information further results in errors, omissions and assumptions. The degree of confidence for information tools depends on the quality and amount of input data. Visualization allows interrogation of designs to confirm their suitability (Masera et al., 2014).

v. Information management for project risk and uncertainty management

Risk refers to possible unfavorable outcomes while uncertainty refers to lack of certainty involving variability or ambiguity (Chapman and Ward, 2011). Risk arises from the results of an event and the probability of the event occurrence (Kendrick, 2009). Proper information management can be an effective tool for risk management. Information management thus serves as an instrument for project information integration to control risks as well as project information sensitivity management through appropriate classification and designation to relevant managers (Ogunlana, 1999).

vi. Information management for prompt decision making

Effective information management tools keep all stakeholders aware of project challenges for prompt decision making. Decision making depends on availability of accurate and relevant information (Meier et al, 2017). Slow decision making as a prime contributor to time and cost overrun. Increasing the range, detail and flexibility of information flows can profoundly improve the decision-making process.

vii. Information management for complex projects management

Efficient information flow between the designers and contractor is a key aspect for productivity in complex projects (Fewings, 2013). There is a specific need to relay the complex design in a manner that is relatable and constructable. Construction projects today are not only very large and complex, but entail numerous and complex relationship between fragmented participants. Communication and efficient information flow should be enhanced to eliminate information gaps that result in errors and reworks (Kimmons, 1989).

viii. Information management for material scheduling

Management of information flow among the supply chain can make or break the chain. Material shortages and late delivery are highly ranked causes of delay in a project. Information on quantities of material required and when these are due is important to take into consideration any lead times involved (Ribbers and Papazoglou, 2006).

ix. Information management for effective project team collaboration

Collaboration refers to working together as a team towards a common goal. This entails sharing of information relevant to other participants and coordinating the different elements of the project to rid it of clashes promoting integrated value (Shen et al.). Efficiency and accuracy of information flow is important in exchanging construction information including design revisions, change orders, RFI's and procurement details so as to ensure that the project's objective for cost, time and quality are achieved (Gudnason and Scherer, 2012).

2.2.3. Information Technology and Systems in the Construction Industry

The first attempts of harnessing the benefits of information technology (IT) in the construction industry in the developed world began in the late 1970s. So far IT has not had the sort of effect on construction that it has had on, for example, industrial engineering. This is possibly due to the fragmented nature of the construction industry, the one-off nature if its product (Fisher and Yin, 1992). Cheung (2014) states that there has not been much research on effects of communication in the construction management, adding that the two key components of communication study in construction management would include document communication pattern and computerized communication system.

Interestingly, Tardif and Smith (2009) state that the effective technology streamlines process flows reducing redundancies and irrelevant tasks, thereby increasing value. Technology cannot therefore replace communication, but, accentuates it. He argues that performance in the building industry is being boosted and leveraged by advancements in technology, advocating for a systems approach.

As outlined by Underwood and Isikdag (2010), incompletely coordinated and 2D construction information which consisted of inconsistencies and inaccuracies has resulted in many challenges. He encourages information modeling to improve construction information noting that with reduced abortive works, project delivery can be achieved on time and with reduced post construction claims and penalties.

Ogunlana (1999) attributes poor information management in the construction industry to the lack of integrated solutions and automation in planning and control as well as the underutilization of information technology.

2.3. Pre-BIM Status; Disjointed 2-Dimensional Information Management Model

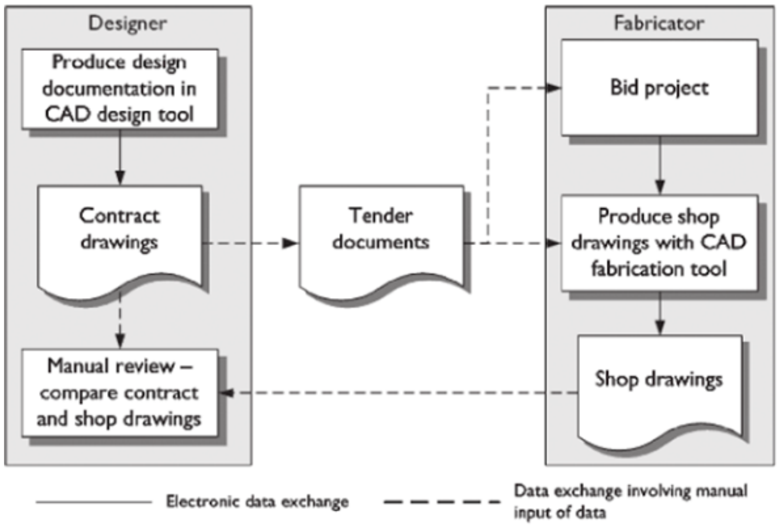
Technical drawings form the basis of the construction process (Eastman et al., 2011). These drawings are a formal language with their own syntax and semantics serving to communicate between project shareholders (Shen et al., 2009). In traditional practice, information generated in the construction process is detailed in paper drawings (Eastman et al., 2011) which are considered adequate for relaying of all information required by the contractor to deliver the design. Even where a 3D model is prepared, it is not generated from or interlinked to the 2D drawings which form the basis of the construction process under this setting. This form of information representation relies on use of lines and symbols to illustrate 3 dimensional objects. Areas of design not properly coordinated or included as information in the drawings often lead to design errors that only became apparent in construction (Epstein, 2012). 2-Dimensional drawing initially started out through manual drafting, which entailed use of stencils, pencil and paper to produce construction details. With the advent of CAD technology, 2D drafting became easier and faster and has since developed as described in the section that follows.

2.3.1. Historical Development of 2D Modeling

Construction has evolved from the Iron Age construction periods in Ancient Mesopotamia, Ancient Egypt and Ancient Greece where construction entailed small buildings with simple locally available materials and relatively rudimentary technology to the nineteenth and twentieth century industrial revolution. This era was characterized by manual drafting. During the 1990s 2D computer aided tools took over manual 2D drafting. This offered significant productivity and quality improvements. It made it easier to share and reuse drawing information between different sheets, visually coordinate consultant information using CAD as a digital light table, share details between multiple parties, reuse the same base building plan for multiple projects and in general, reduce much of the redundancy of manual drafting (Binggeli and Greichen, 2011).

Although use of 2D CAD reduced some of the redundancies of manual drafting, the process also entails manual input of data as is illustrated by Eastman et al. (2011) in Figure 2.3. The designer produces design documentation using CAD programmes following which they develop this into contract drawings which are used for tender. The contractors/ fabricators invited to tender manually derive information from the drawings which they use to tender for the project. Production of shop drawings then follows using CAD fabrication tool, a process independent of the contract drawings.

Figure 2. 3: Traditional 2D Based Design and Review Process



Source: Eastman et al., 2011

This results two different models for design and fabrication. Shop drawings are then manually compared to the contract drawings, for example, through overlaying the two drawings, often done on a light table (Eastman et al., 2011). Since the two sets of drawings assume different layouts and formats, these comparisons can be grueling and conventionally take a week or more.

2.3.2. Challenges Causing Cost and Time Overruns in 2D based Construction

Talukhaba (1988) points out that traditional building is inefficient in joining together the large number of small units involved. Buildings have become intricate in detail over the years. As the construction process progresses, the number of participants increases and the information includes more and more details (Shen et al., 2009). Long and tedious cycles are involved in 2D based construction which contribute to cost and time overruns experienced in the setting. Arguably, the inherent challenges in 2D based construction relate to how information is relayed; using 2D documentation only to describe 3D objects. Conventional paper based construction has been found to have the following deficiencies;

i. 2D drawings are not interlinked with cost and time schedules

In the 2D model, the quantity surveyor and contractor are required to translate a pile of drawings into cost and time schedules. This process relies on various assumptions and is time consuming. For complex projects entailing a lot of information, this process can be prone to errors as various elements can easily be missed out without a visual aid (Pittard and Sell, 2016). The Boston Central Artery, 'The Big Dig', for example, employed a dynamic milestone manager process to forecast delays and reactive adjustments to work schedules. This system eventually resulted in the project running $12 billion dollars over budget and 9 years late (LePatner, 2007).

ii. Inability to simulate the actual scenario on site

The main problem with traditional documentation is that it reduces a complex 3D building, into multiple 2D representations, the drawings (Shen et al., 2009). This dependence on 2D documentation to describe a 3D reality brings forth problems which cascade further downstream in the construction process. Even when some 3D visualization is generated, these are often disjointed and reliant on two-dimensional documentation and detailing (Eastman et al., 2011). Greiman, one of the risk management personnel employed on the 'Big Dig', noted that large projects are often ambiguous and a substantial amount of time is spent in trying to understand the design intent which can also be an expensive process (Greiman, 2013).

iii. Use of arbitrary lines and symbols to represent 3D objects

In the 2D setting, a line_ for example, on a door_ is just a line predefined by the document originator and may not necessarily communicate this to the document recipient. This is unlike in object oriented modeling where all lines are linked to an object, thus selecting the line automatically selects the object, avoiding any misrepresentation (Epstein, 2012). This makes understanding the design intention difficult and can easily result in construction mistakes which are not only expensive to remedy but also cause delays. At the very least, these misconstructions can result in requests for information which can result in delays as well. The National Library of Australia (2011) recognized the Danish Sydney Opera architect, Jorn Utzon, who in realization of the ambiguity related to his ambitious shell roofs created a wooden model in 1957. This resolved design problems encountered in developing the structural stability of the building. However, creation of this handmade model took a long time despite being a monumental achievement in the era before the entry of CAD in construction. The world of Wonders (2015) further reveals that Utzon eventually resigned from the project due to technical challenges which required unconventional technology, a requirement that was ignored by the government and not available at the time, which eventually resulted in the project running 11 years behind schedule and 15 times over budget.

iv. Changes made on one document which relate to other documents are not interlinked

Ensuring that individual document sets are properly internally consistent is difficult in 2D documentation (Crotty, 2012). This means that the same elements must be repeated in several documents. Additionally, even changes within a document which relate to another part of the same document and/or drawing may not reflect. This complicated and fragmented documentation creates a challenge since a change can affect numerous other documents and it is difficult to keep track of all the documents to be updated (Shen et al., 2009).

v. Element clash detection can be a tedious and error prone process

Coordination of different discipline document sets can be difficult in the 2D setting (Crotty, 2012). This ideally entails use of a light table to manually compare the various related document sets. The clash detection process can be time consuming and requires critical review as clashes not detected are carried forward to site with adverse repercussions. Greiman (2013) alludes to the fact that the fast track approach adopted for the 'Big Dig' would have been more efficient for such a complex project if the impact of work segments on other segments could be anticipated, which suggests that no simulation tool was applied to predict outcomes. Instead, this resulted in increased claims and design changes.

vi. Lack of a multidisciplinary interface resulting in information loss and repetitive work

The design project is handed down from the architect who comes up with the overall concept to the services and structural engineers who feed their discipline specific details to the design. The comprehensive design is then costed by the quantity surveyor and used by fabricators and the contractor to derive construction drawings. The traditional design review process does not allow the various professionals to build on the existing designs but requires them to develop their own sets of drawings (Eastman et al., 2011). This results in various drawings sets, a process which can result in information loss and is redundant in its own way.

vii. It is difficult to confirm completeness of 2D documents without a reference model

In 2D based construction, the construction project is not drawn in its entirety. It is therefore difficult to ensure that documents are complete (Crotty, 2012). Incomplete designs are often only identified on site as there is no reference model to confirm all elements whose details are required. The Sydney Opera's shell shaped roof, for example, proved to be a more complex design than Architect Utzon had anticipated. Different options were considered for the roof composition as construction progressed, with an eventual design in 1962 which was too heavy for the already constructed podium structural columns. Shofner (2007) recounts that this was a major setback for the publicly scrutinized project and that demolition had to be conducted in hiding since there was a general uproar over the soaring costs and extended period of the project.

With the vast information exchanged in the construction industry as well as the increased complexity of the process, automation of the process wherever possible is necessary (Cotterman et al., 2005). Change orders have become an acceptable component in construction projects even when these are avoidable by exploring constructability issues at the design stage (Forbes and Syed, 2011). Waste of material and labor on impractical designs is yet another challenge experienced in traditional construction. Although most design defects may be remedied by modifications in the work, some detailed design may be impossible to perform (Callahan, 2005). Systems for planning, cost assemblage, status reporting, earned value, technical performance, personnel management, material procurement and scheduling are required for projects to be within cost and time constraints. This is however not entirely possible without achieving some semblance of the actual scenario to be experienced on site. Building information modelling serves to address this niche.

2.4. Building Information Modeling

BIM is a collaborative technique of simulating the design and planning of a construction project. It offers a coordination platform for construction project participants thereby offering a collaborative process which encompasses design advancement, detailing and integration. BIM entails beginning a project with the end in mind. The virtual building models are created mimicking the real buildings they portray. This is unlike traditional and automated drafting where the 3D models were created from the information contained in the 2D drawings.

2.4.1. Historical Development of BIM

Solid modeling began with SAGE graphical interface and the Sketchpad program developed by Ivan Sutherland's in 1963. In the 1970s and 1980s shape information began to be chronicled and presented using constructive solid geometry (CSG) as well as boundary representation (Quirk, 2012). Although BIM has been in existence for decades, it has only gained popularity in the recent past. Until the initiation of BIM, relay of the designer's visual project concept depended on application of individual experience and judgment of project participants to surmount the characteristic insufficiencies in 2D documents. The designer could only hope that the contractor could infer their correct intent (Crotty, 2012).

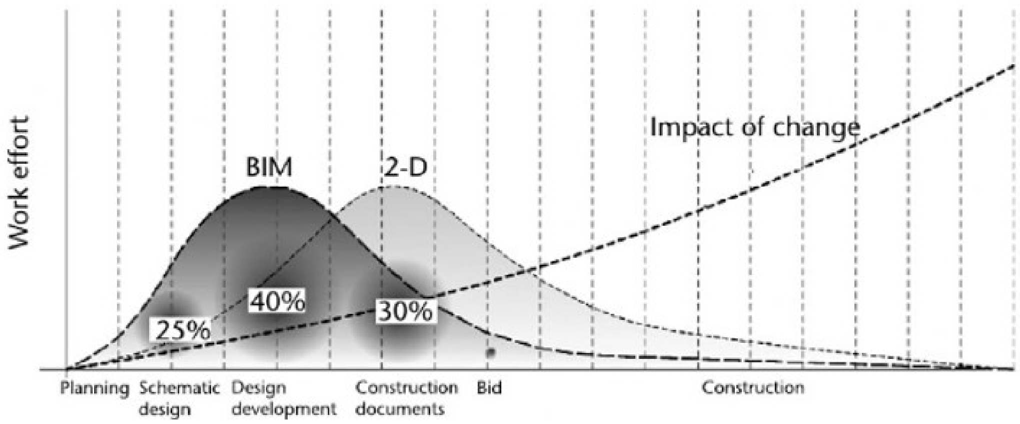
2.4.2.BIM Dimensions

BIM combines width, height and depth_3D with time, cost and facility management, thereby encompassing six dimensions. It serves as a tool as well as a process since the tool defines the process flow of information with increased precision and productivity (Forbes and Syed, 2011). 2D modeling is the process of developing an object through mathematical representation on a Cartesian plane. 3D modeling is the process of developing a virtual representation of an object's surfaces or forms (AIA, 2016). 4D modeling refers to the intelligent linking of individual 3D CAD components with time-related information. 5D modeling denotes intelligent linking of 3D CAD components with time constraints and then with cost-related information (Villella, 2009). 6D modeling refers to the intelligent linking of 3D CAD components with cost, time and facility management (AIA, 2016).

2.4.3. The BIM Concept

The use of BIM promotes a work shift with designers' work efforts being intense during design and documentation unlike in the traditional 2D setting as shown in Figure 2.5. Majority of the consultant's work in the construction documentation stage, which traditionally entailed 50% of the work effort and billings, moves to the schematic and design development stages. Building components are simulated and verified in the BIM setting before manufacture and assembly commences (Crotty, 2012) hence more work effort is concentrated to the beginning stages of a project.

Figure 2. 4: Planning, Design and Construction Schedule

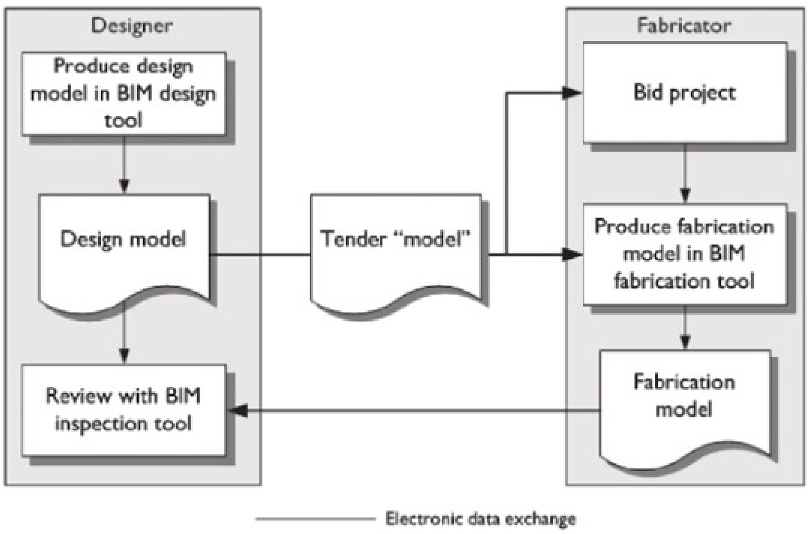


Source: Epstein, 2012

BIM represents the development of computer aided simulation of the actual construction product. Here, CAD technology is used to represent building components as intelligent information-bearing objects. This information includes manufacture, installation details, labor and maintenance requirement, cost as well as replacement value of the various components and enabling the user to monitor these elements easily (Tardif and Smith, 2009). Additionally, cost estimates, material schedules, special relationships, building element schedules and geometry, geographical information and project schedules are embedded on the smart object: BIM. This empowers the model to establish the complete building life cycle (Bazjanac, 2006). The different building components, work packages and their related sequences are easily identifiable. Construction drawings and quantity schedules are readily extracted from the model (Khemlani et al., 2006). A BIM model represents real-world components of actual buildings transforming data into identifiable components such as door, walls windows. Each component has all parameters detailed comprehensively. A change in design is made to the virtual building (Epstein, 2012).

Eastman et al. (2011) illustrate the model based design process as shown in Figure 2.4. In the BIM enabled scenario, the designer produces a design model using the BIM design tool. The model is applied as is for tendering and later upgraded to include fabrication details. Collaboration between the designer and fabricator is enabled in this system with the design and fabrication 3D models being reviewed under a clash detection enabled software. This reduces the times and effort required for clash detection.

Figure 2. 5: BIM Enabled Design Process



Source: Eastman et al., 2011

BIM promotes lean management of project by addressing design limitations early in design which would otherwise only be identified on site (Forbes and Syed, 2011). It encourages continuous reviews and decision making as challenges are identifies. This is unlike the traditional setting where these decisions are deferred until construction which results in errors and omissions which can become time consuming and expensive.

Through BIM, increased prefabrication made possible by intensified integration of the design process as well as reduction of project lead times (Eastman et al., 2011). It also makes it possible to simulate the building process prior to setting up on site. This aids in identifying and resolving of errors that would easily go unnoticed on 2D drawings only to cause impediments during construction. Revisions done within a computer model are cheaper to accommodate than rectification on the ground (Tardif and Smith, 2009).

2.4.4. BIM Maturity Model

The landscape institute, UK, (2016) describes BIM levels 0 to 3 as a notional scale indicating the level of BIM adoption within a practice. The Bew-Richards Maturity Model in Figure 2.6 illustrates the indicative levels as follows;

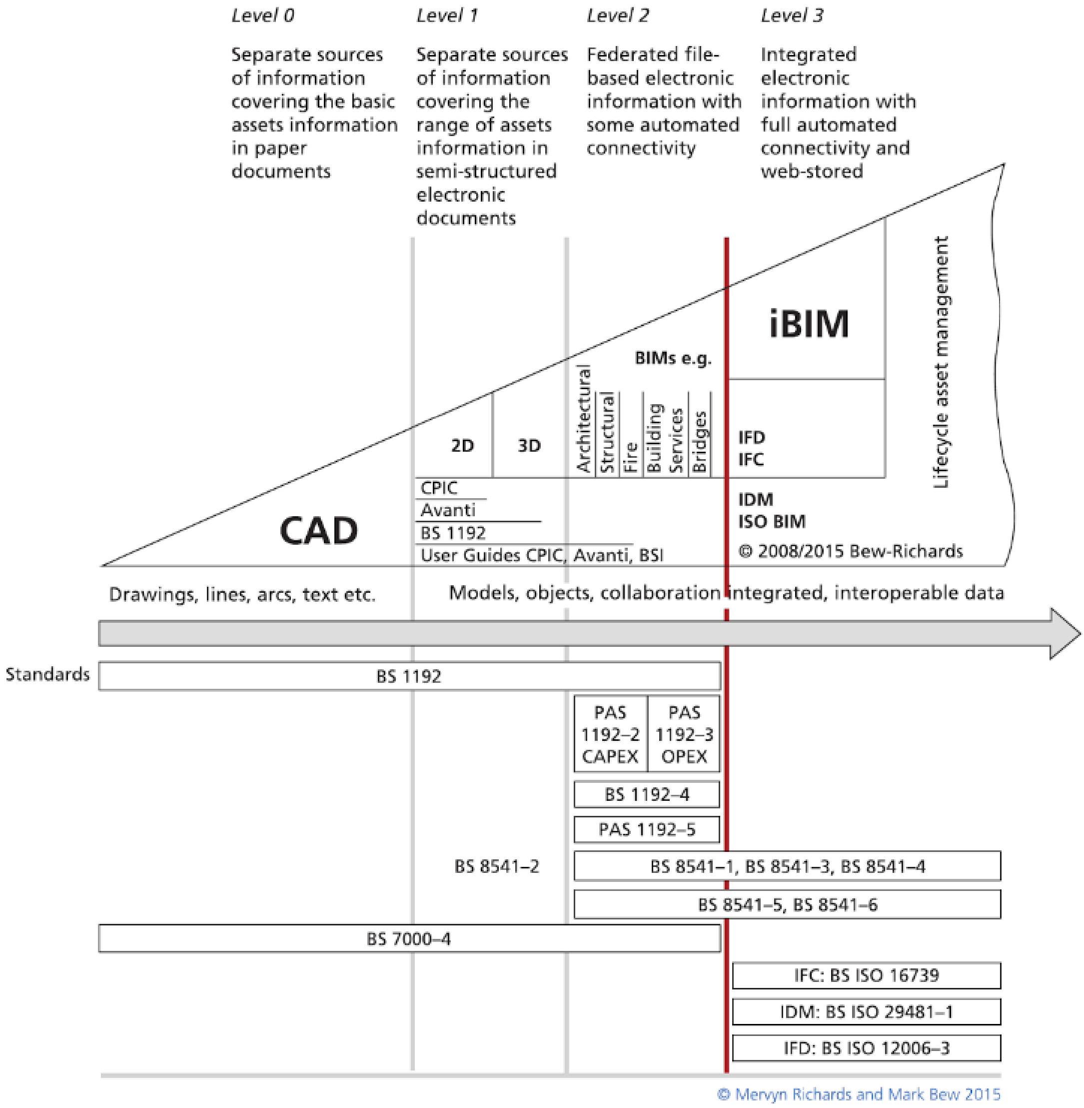
BIM Level 0: Information is exchanged in two dimensional, uneditable documents such as PDFs

BIM Level 1: This level entails managed CAD in 2D or 3D. A Common Data Environment (CDE) is often provided by a cloud based collaboration tool with BS 1192: 2007 being applied to describe project roles and file-naming strategy. Information is structured in standardized formats and may include 2D information and 3D information such as visualizations or concept development models.

BIM Level 2: This entails separate data embedded BIM tools managed in a 3D setting. An enterprise resource planner is incorporated to manage commercial data with cost and time scheduling features as well.

BIM Level 3: This level enables data integration through the Industry Foundation Classes (IFC) file format as well as the International Framework for Dictionaries (IFD This level is yet to be achieved in most countries.

Figure 2. 6: BIM Maturity Model



Source: Landscape Institute, 2016

2.4.5. Capabilities of BIM Technology

i. Visualization

This is done through 3D simulation of the final (Forbes and Syed, 2011). BIM facilitates generation of a digital representation of design intent and construction specifications including a facility's physical and functional characteristics (AIA, 2016). The design is therefore easily relatable to non-construction savvy individuals through walk-throughs in a simulated environment. This kind of presentation demystifies the concept thereby promoting the client's understanding of the project and enabling decisions to be made with greater certainty (Crotty, 2012). This aspect also reduces cases of reworks at construction stage.

ii. Data management

Embedding information and data in the virtual model provides a centralized location to much of the information that defines the building. BIM entails managing the data that defines a project. The virtual models are constructed using parametric objects in which data can be embedded. This data is then used by the project team as it applies to their scope of work (Epstein, 2012). This coupled with the ability to continuously and automatically update all interlinked information within the model allows the entire team to work on a harmonized platform.

iii. Fabrication drawings

Most BIM software can produce fabrication drawings for various structure components. Once the model is complete, 2D interfaces are available which enable the designer to populate layouts in addition to sections and elevations. BIM improves on the 2D CAD process by eradicating the need to cross check multiple drawing files manually for consistency. This redundancy purging increases productivity and encourages prefabrication (Eastman et al., 2011). The advent of Computer Numerical Controlled (CNC) machines, fabrication equipment that accepts and reads precise geometric information, has further automated fabrication and sequencing instructions to cut, drill, mill etc. Geometric information defining a 3D fabrication model can be generated from BIM (AIA, 2016).

iv. Code reviews

BIM technology like most other engineering and construction technology makes use of standard codes. These include British Standards, Eurocode as well as fire and safety regulations and codes (Forbes and Syed, 2011).

v. Interoperability and open standards

Interoperability is the ability of different systems to work together. Open standards on the other hand are a commonly agreed set of definitions which facilitate development of software. Industry Foundation Classes (IFCs) are the open standards for the development of BIM. IFC standards define elements of the building industry allowing transfer of data between applications without losing their integrity. BIM employs open standards which facilitate interoperability and flow of information between applications (Epstein, 2012).

vi. Asset management

Clients can take advantage of BIM to support intelligent operation and maintenance of the building. This includes space planning, reconfiguration and refurbishment exercises (Forbes and Syed, 2011). The model allows the owner to maximize on use of the facility by simulating various scenarios for optimization (Crotty, 2012).

vii. Automated cost estimation

An additional feature of BIM software includes cost data which can be extracted and updated automatically. Since the models by different professionals are interrelated, cases of omissions of such changes are eliminated (Forbes and Syed, 2011).

viii. Quality control

Review of the project to confirm compliance with various requirements in a 2D environment is a tedious and repetitive task which is prone to errors. BIM allows automation of these tasks thereby eliminating many errors and omissions. Virtual resolution of these issues early in the design process is far less costly than later in the design and construction phases (Epstein, 2012).

ix. Construction sequencing

Improved visualization through 4D prototyping can help practitioners to better understand the construction sequence to identify potential conflicts and optimize it. This promotes effective development of procurement and fabrication schedules on a timely basis. 4D location-based scheduling methods can optimize the construction sequence reducing waste during the construction process. These wastes are related to idle labor, reworks and disruptions (Vaux et al., 2016).

x. Conflict, interference and clash detection

Frequently led by BIM managers or coordinators, clash detection is the use of BIM applications to aggregate discipline specific models into an aggregated or federated model to detect undesirable geometric or special conflicts among various building systems or assemblies. This includes not only direct special conflicts but also objects that violate acceptable clearances required for construction or proper installation (AIA, 2016). BIM models scale, in 3D space, thus enabling visual checks for interferences within major systems. This enables the different professionals to confirm that their facilities are placed in accordance with their designs without interfering with other facilities (Forbes and Syed, 2011).

xi. Collaboration and communication

BIM promotes an Integrated Design Process (IDP) which provides types of communication among the project team members which eliminate the need for physical meetings. This decreases project and decision-making time (Epstein, 2012). Tardif and Smith (2009) note that with the adoption of BIM, information exchange shortcomings are surmounted, enhancing collaboration.

xii. Scientific analysis

The simulative model can be used to identify the eventualities of a security breach. This can be done by assessing the evacuation routes and their accessibility, as well as likely failures in security design (Forbes and Syed, 2011).

xiii. Risk management

Reducing the potential for errors and omissions can significantly minimize risk (Epstein, 2012). When managed appropriately, BIM has the potential to reduce construction risks especially since it enables the project team to simulate construction early in the design phase hence enabling identification of potential risks at construction (Tardif and Smith, 2009).

2.4.6. The role of BIM in Reducing Time and Cost Overrun Challenges Experienced in the 2D Setting

BIM reduces direct costs through automation of the design and analysis process, automation of drawings production as well as material take offs. Further, it creates an avenue for reduction of reworks since it improves quality control and design coordination (Eastman et al., 2011). Two dimensional drawings only relay details relating to spatial arrangements and building geometry while cost and time information is assembled manually which is a time-consuming process which is based on various assumptions. BIM surmounts the challenges experienced in conventional 2D based construction. It improves document coordination and consistency besides being a powerful project management tool. Altogether, this results in more reliable and profitable project delivery (Crotty, 2012).

In section 2.1.2. of this study, factors which contribute to cost and time overruns in construction were identified. These included client factors, contractor factors, consultant factors, design factors, material factors, labor factors, equipment factors, communication factors and project specific factors. The section below discusses how BIM can be used to curb cost and time overrun factors identified.

i. Poor cost estimation

Building cost estimation is an attempt to determine the likely cost of building works before the work is done (Pratt, 2012). These estimates do not guarantee that the works will be delivered at the stated cost. They serve to guide the process (Greenhalgh, 2013). Building cost estimates are often derived by comparing them with previously constructed buildings. Differences however exist due to differences in materials used, time of construction as well as project location and complexity. This is a major cause of cost overruns, delays and change orders that plague many owners (LePatner, 2007).

BIM technology makes it possible to derive accurate cost estimates (Eastman et al., 2011). Unlike the traditional paper-based system where cost estimation is performed using square-foot calculations of the overall size of the building, BIM provides the ability for models to be far more accurate in their estimation by looking at individual components. Creating actual cost data for the entire project requires the architect to ensure that every single component is associated with an associated cost for accuracy. Each component is evaluated and assigned either a budgetary value or an assumed value based on weighted cost average. Weygant (2011) submits that cost information is input in the model considering the manufacturer's suggested retail price as well as the labor cost for installation. The visual capacity of BIM further promotes identification of components which have not been measured, avoiding errors of omission (Pittard and Sell, 2016).

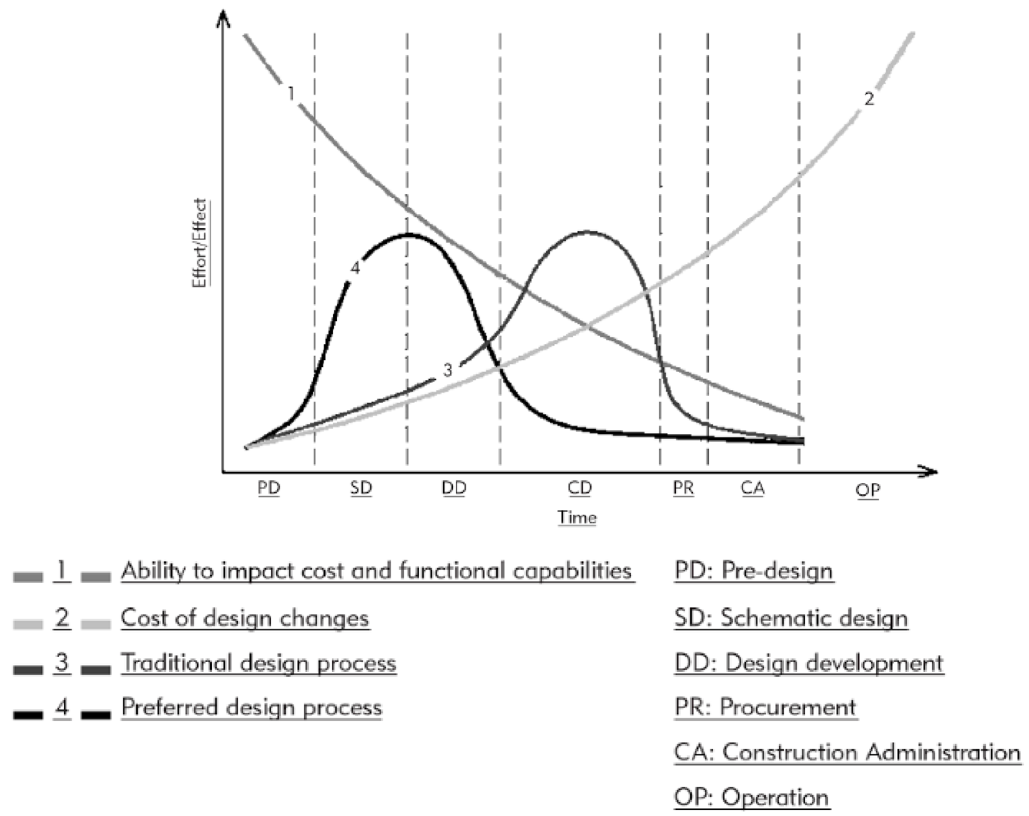
Project and asset management teams can use this process to better understand the cost implications of changes made during any phase of the life cycle of an asset to curb excessive cost overruns due to project modifications (Vaux et al., 2016). Australian Government Productivity Commission which reported 80 per cent reduction of time required to generate cost estimates with an accuracy of 3 percent achieved through use of BIM. These time savings allow reports to be generated more frequently, helping improve cost control and earlier detection of potential issues that may generate cost overruns as well as signal other unplanned events

ii. Design changes and poor change order management

Contractors are often not able to properly price bids due to the uncertainty of impending design changes. This results in inflation of quotations to cover the risk of substantial design changes (Callahan and Bramble, 2011). Changes in design may easily invalidate cost and schedule estimates (Forbes and Syed, 2011). Change orders are typically in writing and signed by the owner and construction manager, engineer or architect. The owner may also issue deductive change orders reflecting elimination of a scope of work from the project or incorporation of an alternative material or construction method into the project (Susong and Klinger, 2006). Disputes often occur between the contractor and owner as a result of these change orders. This can cause long delays and legal battles especially where no change order tracking mechanism is in place. Under the BIM setting, every design professional adds their discipline specific information to the central model, a collaborated effort which reduces the loss of information during transfer (Forbes and Syed, 2011). Changes are also automatically coordinated within the model.

Use of BIM technology provides the advantage of manipulating a model which simulates the actual building prior to construction enabling early detection of the need for design changes. Design changes at the design development stage cost much less than they do when realized during construction (Tardif and Smith, 2009). Figure 2.7 below illustrates the cost of changes at various stages of the construction process in the traditional 2D based construction process and in the BIM enabled setup. Line 3 indicates that in the traditional setup, effort is concentrated in the construction process while in the BIM setting it is concentrated on the design phase as in Line 4. Line 2 indicates that costs incurred when changes are made at the design stage (as promoted by BIM) are lower than when they are made during construction (as in the traditional 2D setting)

Figure 2. 7: Comparison of Cost of Changes in the Traditional 2D based process and the BIM Enabled Process



Source: Eastman et al., 2011

The contribution to change order management by technology is minimal (Adeli and Karim, 2001). However, BIM can be used to avoid errors as well as replication of claims by the contractor.

iii. Inadequate design and design errors

This was identified as a design factor. Inadequate design or design errors often appear during field construction, but in many cases the designer does not have a presence in the field that would allow them to expeditiously resolve design problems (Callahan and Bramble, 2011). Gudnason and Scherer (2012) notes that inadequate design can cause serious delays.

Where a design relays insufficient or wrong information, this design is erroneous. This leads to execution of design errors in construction as well as when estimating the project cost as the design is an inaccurate representation. This results in extra works and change orders which result in delays and cost overrun (Francois, 2015). Effective communication is necessary to avoid these errors. The design and review process must flow seamlessly. It also requires effective project planning, monitoring and controlling throughout the project life cycle. Delays in design are often a result of fast track construction where design of a portion of the work proceeds concurrently with construction of the same portion on site (Callahan and Bramble, 2011).

BIM reduces design errors and inadequate design through predefined views and model navigation which allows virtual walk-through the space. This allows exploration of sections of the design in a more intuitive 3D environment which makes visible issues and attributes that had been traditionally difficult to see in 2D documentation (Vaux et al., 2016). Clash detection between various elements is also made possible through this virtual simulation unlike the 2D scenario where such clashes may be easily missed out and only noticed during construction. As previously noted, the cost of rectification of inadequate design at the design stage is cheaper than reworks required during construction.

iv. Project risk and uncertainty management

This was identified as a project specific factor. With effective project risk management, more projects would be successful (Jobling et al., 2006). Events in the past and experience often serves to predict future occurrences. Cost risk analysis requires comprehensive consideration of all factors that could result in a variation in construction (Hulett, 2016). It enables the project manager to respond to unforeseen events that may occur and that could negatively affect project performance and consequently lead to re-base lining of the project cost or schedule (Massimo, 2015).

Understanding and managing the sources of variation in projects enables a team to maximize opportunities. Traditionally, a project cannot be repeated enough times to develop all the risk data, thus risk analyses depends on projections and range estimates (Kendrick, 2009). BIM enables development of a risk register which records, assesses, prioritizes and mitigates risks. This risk register is dynamic and more interactive. BIM has the potential to make this exercise more dynamic through collection and analysis of data collected or created as part of the project information delivery process, thereby shifting focus from data collection to analysis and assessment, leading to more informed decision making and action. The collaborative nature of BIM provides the environment and ethos to support improved risk management (Pittard and Sell, 2016). Additionally, the project simulation in BIM gives an avenue for the construction process to be virtually simulated, a process which can be repeated numerously correcting any challenges identified, thereby reducing the risk exposure.

v. Poor project scheduling

This was established as a factor cutting across the client, contractor and consultant. Estimating contract duration is based on determination of activity intervals. An understanding of factors that affect time estimates is crucial. Ideally, determination of durations even with the knowledge of these factors depends on past experience and a track record in similar construction. This process involves many assumptions in determination of activity relationships (Caletka and Keane, 2008). This entire process can be time consuming and prone to errors since there is no way to confirm that the durations are accurate and that the sequencing of activities is correct. BIM enables linking of modeled information and Gantt charts promoting more accurate estimation since the time periods are linked to actual activities which are simulated within the model confirming time required for completion of tasks.

Additionally, use of BIM resolve scheduling conflicts, record material movements and cross check overall progress is possible (Holzer, 2016). 4D scheduling used to visualize the construction sequence is another BIM feature. This enables the project manager to compare effects of different sequences to optimize the process. Comparison of the schedule to the baseline schedule is easier than when using traditional scheduling methods and it is easy to spot late or early activities. With a well-organized model, some activity can be automatically generated which speeds up the process (Farrell et al., 2016).

vi. Slow decision making

This was identified as a client factor. Failure to make critical decisions in a timely manner results in delays. This often occurs where decision points are not scheduled or decision makers are not made aware of their responsibilities in time (Yates, 2007). It is therefore important to establish project decision gate which allow for review of lapsed activities prior to approval of subsequent events (Cotterman et al., 2005). The PMBOK Guide sec 2.1.2 defines phase-end gates as transfer points between project phases where key decisions are made.

BIM enables Integrated Concurrent Engineering (ICE) which incorporates a rapid combination of expert design for advanced modeling, visualization, simulation and analysis of specialized design facilities. This enables radical project acceleration by enabling the decision makers visually understand designs and the effects of changes which promotes speedy decision making. ICE relies on concurrent design tasks to reduce design duration and integrates many project stakeholders to reduce decision and response latency and properly account for the needs and performance of a product during all phases of its lifecycle (AIA, 2016).

vii. Management of complex projects

This was identified as a project specific factor. Ochieng et al. (2013) quoted Baccarini stating that the construction process could be the most complex undertaking in any industry. Complexity is defined as consisting of many interrelated parts (Pittard and Sell, 2016). Increasing complexity in construction projects has led to problems such as poor communication and information flow between disciplines, lack of data or missing information, poor coordination, unbalanced allocation of resources as well as poor role definition (Gudnason and Scherer, 2012). Generally, the greater the project complexity, the greater the cost and time required. BIM is useful for complex projects such as Daniel Libeskind's Denver Art Museum which bears extremely complex geometric configuration (Demchak et al., 2009).

Plate 2. 1: Daniel Libeskind's Denver Art Museum, Colorado

Source: *Homesthetics.net*

Simulating the mechanical and structural forms of complex buildings brings out a clear picture of the intended design and aids in resolving errors at the design stage (Demchak et al., 2009). Additionally, these models can be passed on to the contractor thereby reducing the need for requests for information. Through Computer Numerical Controlled machines, parts of the building structure can be used to produce fabrication details straight off the model without the need for production of 2D drawings. This further promotes the accuracy and speed of construction.

viii. Management of Requests for Information

Delays in approval of design was identified as a design factor. These approval delays often happen when the party required to approve a design does not have adequate information to do so. This has given rise to Requests for Information, commonly known as RFIs in the industry. BIM has been responsible for a reduction of between 10 percent and 40 percent of unbudgeted changes and 60 per cent requests for information (Vaux et al., 2016).

ix. Material Scheduling

Material factors were identified to include challenges in determining exact quantities of materials required and exact timings for their delivery as well as delays in delivery. Further, changes in material specifications during construction was also identified as another material factor that can result in overall disruptions and delays.

Through use of BIM, an accurate model of the design is developed to include materials required for each task (Vaux et al., 2016). This allows for just in time arrival of staff, equipment and materials as well as advance purchase of materials and better inventory management based on less schedule uncertainty.

x. Communication and coordination between design and site team

Many projects fail due to communication challenges (Cotterman et al., 2005). These is further intensified for global projects where virtual communication through emails and telephone is the most feasible solution (Yates, 2007). Delays are often realized by management much later after they have happened at which point cost and time overruns have already taken their course (Callahan and Bramble, 2011). Mitigation of these delays therefore requires a team effort as well as proper communication and coordination.

Any communication media that promotes exchange and feedback is considered vital for communication during construction reviews. Construction language entails graphical and diagrammatic representation through flowcharts and behavior diagrams to express ideas and designs. Unified Modeling Language (UML) has emerged as a response to the need for more accuracy in articulating requirements and concepts for complex projects. Use of BIM is an efficient means to share project information (Cotterman et al., 2005).

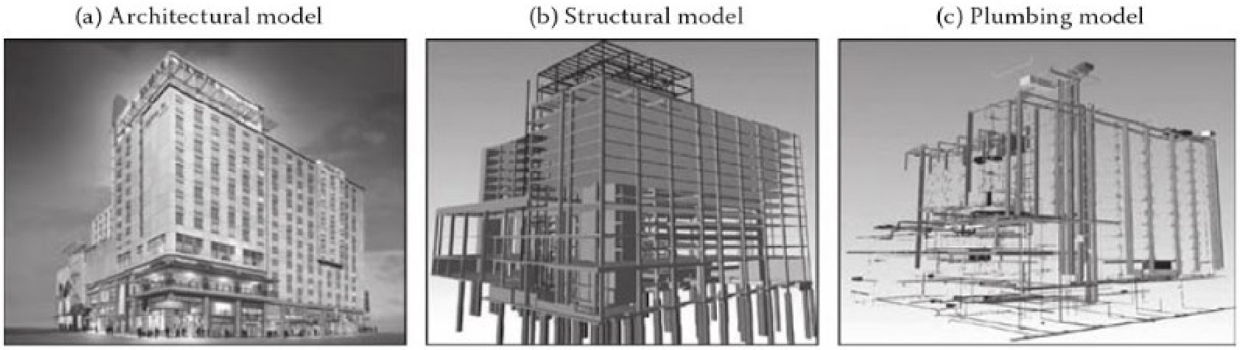
BIM creates a virtual project office with the advantage of high project team collaboration. It avails a BIM database with accurate, coordinated information to all project stakeholders. This promotes prompt collaboration of project decision makers (Underwood and Isikdag, 2010).

2.4.7. Examples of projects illustrating BIM enabled Cost and Time Savings

i. Case 1: Hilton Aquarium, Atlanta, Georgia

Azhar et al. (2008) conducted a study to demonstrate the cost and time savings available with BIM on an actual construction project by Holder Construction Company in Atlanta, Georgia. The Hilton Aquarium project entailed construction of a $46Million hotel and parking structure occupying 484, 000 square feet. Plate 2.2. shows BIM used for design coordination, clash detection and work sequencing with Navisworks being used as a common file sharing platform.

Plate 2. 2: Interdisciplinary Building Information Models for Hilton Aquarium, Atlanta



Source: Forbes and Syed, 2011.

The project team reported to have identified and resolved 590 clashes between structural and MEP components which enhanced design coordination and avoided rework costs. The need for design changes was identified early in the process enabling the client to accept revisions without the need for change orders. Improved communication and trust between stakeholders was reported to facilitate rapid decision making. A cost benefit of $600, 000, equivalent to 1.3% of the project cost, attributed to elimination of clashes in addition to reducing the construction period by 1143 hours (Azhar et al., 2008) The cost of BIM to the project was $90, 000 with $40, 000 paid by the owner.

ii. Case 2: Savannah State Academic Building

BIM was incorporated for planning, preconstruction services and value analysis of this $12 million health education facility. Three different design options were availed to the client by the architect. Client decision was made easier through enabling a walk through the simulated models for selection of their preferred design. The cost of BIM to the project was $5000 while a cost benefit of $1, 995, 000, equivalent to 16.6% of the project cost, was realized at the design concept stage by selecting the most economic option (Forbes and Syed, 2011).

iii. Case 3: Stanford University Centre for Integrated Facilities Engineering Survey

This survey on 32 major projects implementing BIM conducted by the Stanford University Center for Integrated Facilities Engineering (CIFE) established that the project teams managed to eradicate up to 40% of unexpected project changes as well as achieve 3% accuracy for cost estimation. Further, it was noted that the time taken to generate a cost estimate was condensed by 80% using BIM technology. Clash detection and elimination saved up to 10% of the contract cost. Altogether, the projects were found to be completed at 7% less the time required for similar projects run in the traditional setting.

2.4.8. Challenges to use of BIM

i. Initial cost of acquisition

This includes software cost, hardware cost, training cost or the cost of hiring new employees with BIM competence as well as the time lost as the company rolls out new processes (Rogers et al, 2015). This is especially the case for small scale firms since it scales up their cost overheads by a greater proportion than big firms. BIM typically requires new software and regularly requires new software and supporting hardware which is expensive to acquire (Eastman et al, 2011).

ii. Resistance to Change

Construction players are comfortable with the traditional processes and therefore resist change (Bouras et al, 2016). BIM enables and requires new processes. Gudnason and Scherer (2012) argue that an open-minded culture is required for effective BIM implementation. BIM also imposes strict guidelines and processes on project managers, which further fuels this resistance to change (BIMhub, 2013). BIM works effectively when all participants are on the collaboration platform, a process which will require intensive investment in training of stakeholders, but most importantly, a shift in attitude towards technology (Eastman et al., 2011).

iii. Decision-Intensive software

A BIM contains a lot of information. Construction methodologies must be considered when developing the model, thus the modeler makes consequential decisions that impact the project every step of the way. The model is only as useful as the quality of information put into it as per the garbage-in-garbage-out principle (Deutsch, 2011). An experienced design team is therefore required to ensure that value is generated through optimization of available options (Gudnason and Scherer, 2012).

iv. Lack of expertise

For effective use of BIM, expertise on use of the same is required. BIM is considered a complex and delicate system. Lack of knowledge and skill on BIM (Bouras et al., 2016) therefore poses a challenge in the implementation of BIM as a day-to-day tool in design. Effective use of BIM would require all participants involved to be on this platform. Where some of the participants are not on this model, errors can be introduced in the project (Eastman et al, 2011).

v. Managing expectations

Another challenge to successful adoption of BIM entails managing expectations. Setting realistic expectations for BIM is thus useful to address this challenge. Robert Green, a CAD programmer and consultant insists that with the many benefits outlines for the adoption of BIM, it is necessary to educate management on challenges that should be anticipated especially with the initial roll out and training phases so as to manage expectations (Deutsch, 2011).

vi. The need for frequent communication

Through BIM, project team members communicate more frequently, clarifying discrepancies and resolving problems before they occur in the field. Professionals have generally been found to lie on the introverted end of the disposition scale thus the requirement for constant communication and information sharing is a challenge worth noting. However, with time, and as the project progresses, team members feel more comfortable speaking before others and trying to figure out how to accomplish the task at hand together (Deutsch, 2011).

vii. Document and model ownership legal issues

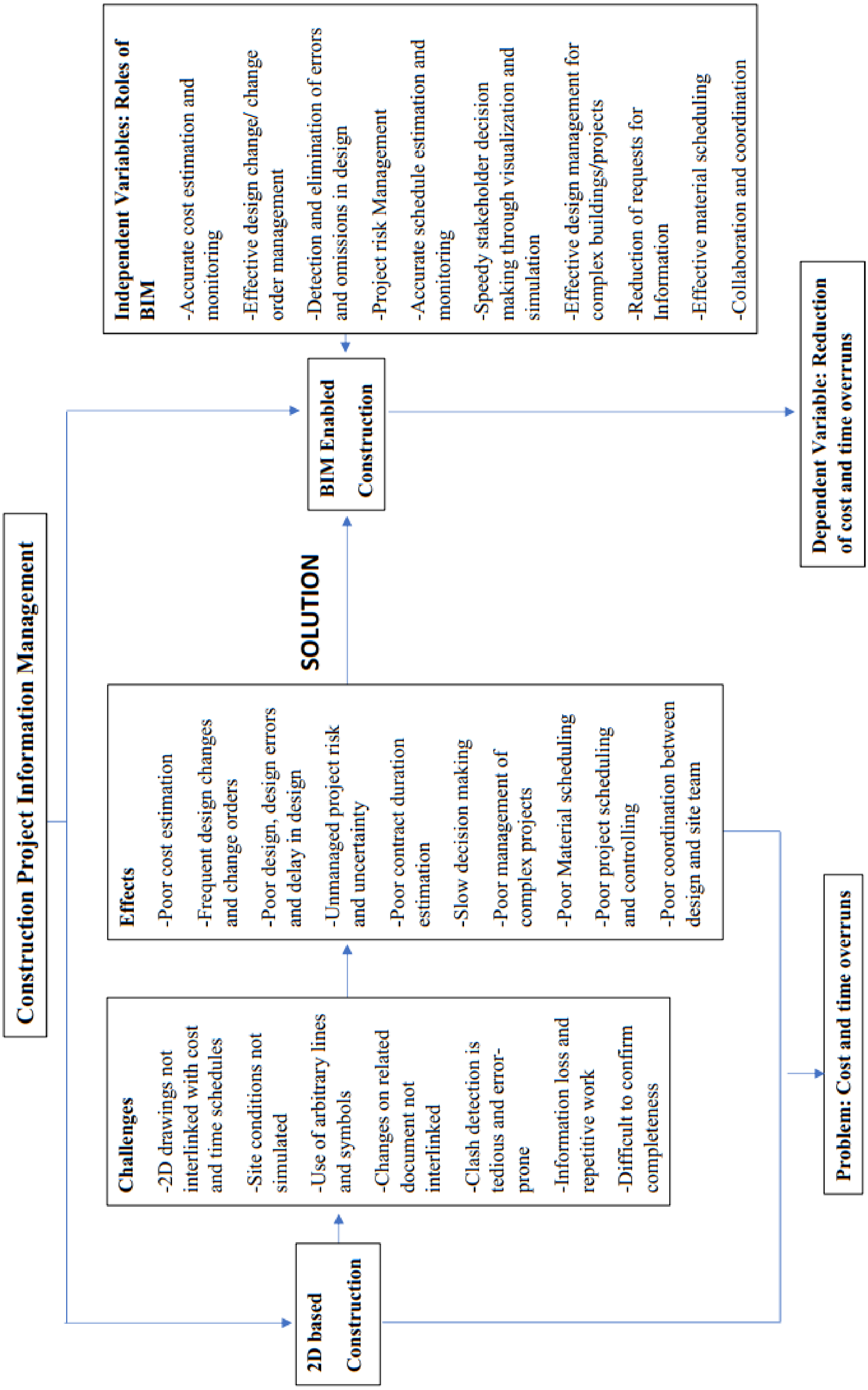
Since each participant feeds their discipline specific information to the model, it is difficult to define ownership of the final collaborated model. Responsibility for the accuracy of the numerous data sets produced is also not clear especially where a BIM Manager is not appointed. Clients have also become aware of the powers of BIM in facility management and will often require an operational model to support refurbishments and upgrades. The question as to whether the client has the right to modify the model or use it for any other purposes is an intellectual property rights battle whose restrictions have not been defined. The American Institute of Architects (AIA) and Associated General Contractors (AGC) in USA are however working towards a solution to this problem (Eastman et al., 2011).

The next section presents the conceptual framework adopted for the study condensed from pertinent issues discussed within this chapter.

2.6. Conceptual Framework

Conceptual Framework: The Role of BIM in Reducing Cost and Time Overruns Experienced in 2D Based Construction

(Source: Author, 2018)



2.5. Summary

The construction industry has been found to experience time and cost overruns both locally and internationally. These cost and time overruns are caused by internal and external factors. Effective management of information within the project ensures that it is availed to the right parties at the time best fit for critical decisions to be made at minimum costs to the overall project. Changes in design executed at the design stage are cheaper to accommodate in comparison to changes made during construction.

Traditionally, a phased 2D paper-based model has been adopted but has been found to result in inconsistent and disjointed information, pleading the case for a more sophisticated approach to information management in the construction industry. This is especially the case given the increasing complexity of architectural building designs in the recent past. BIM has been identified as an effective construction information model which enables simulation of the construction process at the design stage, allowing for exploration of constructability issues virtually. This gives an approximate analogy to the actual construction process thereby providing more accurate time and cost estimates as well as providing a tool for referencing and comparison of actual and scheduled resources, reducing change orders and requests for information, reducing reworks, among others.

Literature reviewed indicated that effective use of BIM has the potential to reduce the time and cost overruns traditionally experienced in the construction industry. Nonetheless, several challenges to the adoption of this technology are also identified. BIM adoption advocates for a process overhaul, which is bound to be met with some level of resistance given that the practitioners are already accustomed to a different approach to the process. Altogether, the benefits of adoption of BIM however outweigh the challenges that come along with BIM technology adoption as detailed in literature. The conceptual framework for the study is presented on the next page.

CHAPTER THREE

AREA OF STUDY AND RESEARCH METHODOLOGY

3.0. Introduction

This chapter details the systematic process adopted in carrying out the research. The study included literature review, data collection and discussion, and conclusion. Through literature review, factors leading to cost and time overruns were established. Information management within the construction industry was then reviewed, identifying the traditional 2D construction methods and the relatively new approach of Building Information modeling. Several deficiencies in information management were identified in the 2D setting.

For this study, the capacity of BIM to address the time and cost overruns experienced in 2D building construction was interrogated. Data collection was carried out through a structured questionnaire survey amongst building construction project managers identified as local consultants and expatriates working in Nairobi. These professionals included construction managers, architects and engineers with experience in use of Building Information Modeling. The questionnaires were designed on Survey Monkey® and distributed via email among targeted correspondents. Data analysis was done to arrive at conclusions, recommendations and suggestions for future study.

3.1. Area of Study

The study was conducted within Nairobi county which is considered as the hub of building construction as per the completed private buildings' index presented by the Kenya National Bureau of Statistics in their economic survey of 2017. Mwakikagile (2010) further describes Nairobi as a bustling capital which has positioned itself as the capital of East Africa in terms of commercial activities. He notes that the city grew as an administrative centre during the colonial period and has since hosted a lot of the construction development, growing rapidly with modern buildings and good infrastructure in comparison to other towns in Kenya. As evidenced by a survey conducted by the Architectural Association of Kenya and the National Museum of Kenya for the Daily Nation which ranked the top 15 iconic buildings in Kenya in September 2012, Nairobi is at the forefront of Kenyan building construction. All fifteen buildings are located within Nairobi County. In more recent years, the county boasts of even more historic building projects such as BRITAM Tower in Upperhill at 200m; currently the second tallest building in Africa and Pinnacle Tower in Upperhill; which will surpass the tallest building in Africa- Carlton Centre in Johannesburg by 77m at 300m upon completion. All the targeted respondents were required to have experience working on a project in Nairobi county and were established through the researcher's contacts.

3.2. Research Design

This encompasses the sets of methods and procedures used in collecting and analyzing the various variables to this research. Research design addresses the objectives of the project within available resources (Creswell, 2014). Since this study intends to explore the capability of BIM to overcome cost and time overruns in 2D based building construction, a qualitative research design is adopted. Qualitative research is majorly investigative research which provides insights into the phenomenon under study (Wyse, 2011).

3.3. Target Population

The target population for this study encompasses project managers handling building construction projects, specifically Construction Managers, Architects and Engineers with experience in BIM to determine the efficiency of BIM in addressing time and cost overruns. The accessible population was identified through the relevant professional bodies in October 2017 as summarized in Table 3.1. The population was divided into 3 strata based on professions.

Table 3. 1: Target Population

Strata	Professional Body	No of Elements
Construction Managers, including expatriates	ACMK and ICPMK	294
Architects, including expatriates	BORAQS	793
Professional Engineers, including expatriates	EBK	2174
TOTAL		3261

Source: Author's Field Survey, 2017

3.4. Sampling Procedures

Struwig and Stead (2001) argue that it is impractical to obtain information from an total universe, thus a sample serves to give an accurate representation. The target population for this study was determined as detailed in section 3.3. above. Stratified sampling technique was applied to ensure that each stratum sample size was proportional to the universal size of the stratum. Musyimi's (2016) study of the uptake of BIM in Kenya indicates a low uptake of 25% which pleads the case for purposive sampling (Daniel, 2012).

Tashakkori and Teddlie (2009) propose use of stratified purposive sampling to discover and describe the phenomenon in question in detail and where the sample is small. Stratified sampling is similar to probability while the required small sample size is an attribute of purposive sampling. Houser (2012) postulates that purposive sampling exposes the researcher to bias. However, she indicates that where the researcher is aware of this likelihood, this limits the concerns. Das (2009) notes that purposive sampling is useful when the sample size is small, and that as the sample size increases the estimate becomes unreliable due to accumulation of bias. Naburi (2017) argues that a minimum of 30 samples per strata is suitable for stratified sampling. For each strata, a sample of 30 was selected across, resulting in a total of 90samples. Additionally, 3 elements per strata were further added to the sample to cater for non-response challenges. The total sample size therefore included 99 elements as shown in Table 3.2. Since the study adopted a purposive sampling strategy, this sample was identified from within the researcher's networks from interaction during BIM execution in building construction projects.

Table 3. 2: Sample Size

Strata	Sample Size
Construction Managers, including expatriates	33
Architects, including expatriates	33
Professional Engineers, including expatriates	33
TOTAL	99

Source: Author's Field Survey, 2017

3.5. Identification of Variables

In chapter Two of this study, a detailed review of literature on external and internal factors that cause cost and time overruns in construction was conducted. External factors were found to be those that the project team has no control over and would not be possible to evaluate for the purposes of research. However, internal factors can be altered or managed in favor of the project. This study attempts to establish the efficiency of BIM in altering the internal factors established to overcome cost and time overruns experienced in 2D modeling. Further, Eastman (1999), Callahan (2005), Masera et al.(2004) Chapman and Ward (2011), Meier et al. (2017), Fewings (2013), Ribbers and Papazoglou (2006) as well as Gudnason and Scherer

(2012) link the effective management of some of the internal factors to effective information management. In this chapter, the researcher attempts to establish a relationship between the reduction of cost and time overruns experienced in 2D modeling and the effectiveness of BIM in influencing the internal challenges identified to cause these overruns in 2D modeling.

3.5.1. Independent and Dependent Variables

A variable is an element that can vary or change. An independent variable refers to the variable that can be controlled or manipulated. The dependent variable refers to the variable that shows the effect of the introduction of the independent variable. It is observed and measured as the independent variable is changed during the experiment. Each independent variable can be manipulated by the researcher and observed as it affects the dependent variable (Chandra and Sharma, 2007). The dependent variable is therefore a function of the independent one.

Cost and time overruns have been identified as a prevalent challenge in the construction industry which pose a socio-economical problem. The variables were identified through literature review. For this study, reduction of cost and time overruns experienced in 2D modeling was identified as the dependent variable. BIM was identified as an information management tool to be evaluated for efficiency in reduction of cost and time overruns. Further, in section 2.4.6., the specific role of BIM in reducing cost and time overruns experienced in 2D based construction was discussed. The effectiveness of BIM in playing these roles form the independent variables for the study; Cost Estimation, Change Order Management, Inadequate Design Detection and Resolution, Project Risk Management, Project Scheduling, Decision Making, Project Complexity Management, Management of Requests for Information, Material Scheduling and Project Collaboration. These variables formed the basis of the questionnaire design.

3.6. Data Collection

Data was collected through administration of semi- structured questionnaires. A pilot test was done to ensure that content validity and clarity of the questions posed. A likert scale was designed to rate the opinions of the respondents. Secondary data for the study was obtained from published literature as well as unpublished scholarly works available. This was used as a benchmark for the study.

3.6.1. Questionnaire Design and Distribution

The questionnaire was designed to identify the respondents' opinions on the effectiveness of BIM for management of the various internal factors causing cost and time overruns identified. As is the case with qualitative research approaches, the questionnaire comprised of structured questions (Creswell, 2014). The data required for this study was mainly collected through use of structured questionnaires via Survey Monkey®. This medium was selected since it offers advantages such as increased administration speed, lower cost since there are no personnel or delivery costs, minimized data entry errors thus more accurate. It also supports easy access to respondents as it can easily be circulated to different geographical regions (Chaudhuri and Cabau, 2017).

3.6.2. Pilot Testing of the Questionnaire

A maiden study was conducted by cross-examining 6 experienced construction professionals; 2 architects, 2 engineers, 1 construction project managers and 1 Land Economist, to validate the clarity and contents of the questionnaire for exhaustive findings on the study. Table 3.3 summarizes the profiles of the professionals involved in this review.

Table 3. 3: Profile of Respondents Interviewed for Questionnaire Content Validity

No	Profession	Years of Experience
1	Architect	10 Years
2	Architect	7 Years
3	Civil/ Structural Engineer	10 Years
4	MEP Engineer	17 Years
5	Land Economist	4 Years
6	Construction Manager	16 Years

Source: Author's Field Survey, 2017

Following the pilot survey, questions found to be ambiguous were edited, incorporating relevant suggestions by the respondents. Responses received varied from Not Significant to Very significant for challenges experienced in 2D modeling and Not effective to Very effective for the efficiency of BIM in management of the various causes of cost and time overruns identified.

3.6.3. Likert Scale Design

The study mainly concentrates on expert opinion from the various professionals identified for the study, thus a numerical scale to quantify their judgment was established. In general, an ordinal scale of measurement was applied. For rating of the significance of various challenges in 2D modeling, a four- point significance scale ranging from 1-4 adopted from Talukhaba's (1999) study was thus established as follows;

- 1= Not significant
- 2= Less significant
- 3= Significant
- 4= Very significant

Further, this scale was modified as in Naburi (2017) to measure the effectiveness of BIM

- 1= Not effective
- 2= Less effective
- 3= Effective
- 4= Very effective

This rating scale was preferred because it is efficient in gathering and processing responses and given that it is a relatively common scale for surveys hence it is respondent friendly. Furthermore, it supplies a large amount of information in a short amount of time with the advantage of data which uses values rather than mere categories (Edwards, 1997).

3.7. Data Analysis and Presentation

Data collected as described above was organized to adopt the most efficient and effective presentation techniques. The questionnaires were first analyzed for completeness and a summary of this data was presented in the next chapter. Statistical Package for Social Sciences (SPSS) software was applied for data analysis. Ms Excel was also used for easy computations. The data was analyzed in form of charts, tables, graphs and percentages, some of which was adopted from Survey Monkey® summary presentation tools.

Descriptive statistics was applied to derive the frequencies and mean for data. Z-test and regression analysis was used to assess and establish the relationship between the independent and dependent variables identified in section 3.5.1. This aided in testing of the hypothesis as discussed in section 3.7 below. The results of this analysis were presented in summary tables in chapter 4.

3.7.1 Mean score and Z-Statistic Analysis

Given that the sample selected was greater than 30 and a test for significance of the null hypothesis was required, the z test was applied (Syagga, 2015). Since the study entails the direction of interrelation between the variables, a one tailed z test was applied. The z Value was calculated based on the equation;

$$z = (\dot{x} - \mu)/(\frac{\delta}{\sqrt{n}})$$

Where;

- z =calculated z-value
- $\dot{x}$=mean score for each variable
- μ=population mean score (2.5)
- δ=sample standard deviation
- n =sample size

Talukhaba (1999) notes that any score above the population mean score of 2.5 is already significant. The z-value arrived at using the above equation was then compared to the Critical z-value for a one tailed z-test at 95% confidence level, identified as 1.64 (Rumsey, 2005).

3.7.2. Regression Analysis

The study further rated the significance of the independent variables with regard to their contribution in reducing cost and time overruns experienced in 2D based construction. This was achieved through application of regression analysis using the SPSS software. It was assumed that the relationship between the independent and dependent variables is linear (Talukhaba, 1999). The dependent variable was reduction of cost and time overruns experienced in 2D modeling. The independent variables were the various roles of BIM found to be significant in reducing cost and time overruns. Each variable was considered one at a time since the combined variable model was inconclusive. The step wise process began with the most auspicious variable in reducing cost and time overruns as established using means score and Z score. Similar to the Z statistic, a confidence level of 95% was set. Multicollinearity of the variables was tested through correlation analysis. The results of the regression analysis are attached in Appendix C. The first stage of the analysis entailed derivation of the correlation coefficient R which measures the correlation between the two variables and R^2 which indicates the percentage of values that lies on the obtained linear model or the % variation of the variables. Rumsey (2005) presents the following interpretation of the R value;

Table 3. 4 Interpretation of Regression Analysis R value

R Value	Interpretation	R Value	Interpretation
-1	Perfect negative linear relationship	+1	Perfect positive linear relationship
-0.7	Strong negative linear relationship	+0.7	Strong positive linear relationship
-0.5	Moderate negative relationship	+0.5	Moderate positive relationship
-0.3	Weak negative linear relationship	+0.3	Weak positive linear relationship
0	No linear relationship		

Adopted from Rumsey, 2005

The next stage of the analysis entailed determination of the statistical significance of the regression model between each independent variable and the dependent variable. This was done by comparing the calculated significance figures to the level of confidence set, i.e 0.05. Therefore, for the regression model to be statistically significant, the calculated significance figure should be less than the 0.05.

The final stage entailed derivation of the components of the linear regression equation $y=mx+c+\varepsilon$ where;

- y = Dependent variable (reduction of cost and time overruns in 2D based construction
- m =Regression coefficient
- x =Independent variable (efficiency of BIM in playing the different roles identified)
- c =Regression constant
- ε=Standard error of the estimate

A positive regression coefficient implies that as the independent variable increases, the dependent variable increases as well while a negative regression coefficient implies an inverse relationship between the two variables. The regression constant simply represents the y intercept on an x-y graph. It serves to account for overall positive or negative bias within the model.

3.8. Hypothesis Testing

Hypothesis testing allows for measurement of sample data against a claim regarding a population parameter (Rumsey, 2005). The null hypothesis (H_0) stated that BIM is not effective for management of cost and time overruns experienced in 2D Modeling while the alternate hypothesis (H_A) stated that BIM is effective for management of cost and time overruns experienced in 2D Modeling. The rejection of the null hypothesis meant accepting the alternative hypothesis.

Talukhaba (1999) identifies two types of errors that can occur in hypothesis testing. Type 1 error_ False positive_ where it is concluded that there is an effect while there isn't or type 2_False negative_ where it is concluded that there is no effect while there is one. He further states that type 1 error can be avoided by setting a confidence level of 95% while Type 2 error can be avoided by setting a confidence level of 99%. Frechette (1994) notes that scientists usually make the judgement to prefer Type 2 errors over Type 1 errors while consumers and the public, for social economic studies, prefer Type 1 errors. Naburi (2017) further asserts this position. A confidence level of 95% was therefore assumed for this study.

For purposes of testing the hypothesis, establishment of a decision point is essential. It was assumed that the population was normally distributed, thus implying that the 4 scores (Not Effective/ Significant, Less Effective/ Significant, Effective/ Significant, Very Effective/ Significant) had an equal chance of occurring, thus the population mean score is 2.5 on the rating scale. This formed the decision point. Consequently, where the significance of a challenge in 2D modelling in contributing cost and time overruns was found to achieve a mean score of above 2.5, it was considered as a significant challenge. Similarly, where BIM efficiency in managing causes of cost and time overruns achieved a mean score of above 2.5 it was considered that BIM is effective for management of cost and time overruns

3.9. Reliability of Test Scores

Reliability tests in statistics evaluate the extent to which an evaluation tool produces consistent results. Cronbach's alpha was applied to test internal consistency of test scores and served to measure the scale reliability.

Table 3. 5: Reliability Scores Interpretation

Cronbach's alpha	Internal Consistency Interpretation
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor

Adopted from Dumsey, 2005

3.10. Summary

The chapter started by detailing the methodology and research design adopted for the study. The target population for the study was identified to include building construction project managers, particularly; construction managers, architects and engineers with experience in use of BIM. These professionals included both local practitioners and expatriates identified in the local Kenyan building construction market. Since a specific audience was targeted from among these various professionals, stratified purposive sampling was determined to be the appropriate sampling method. Data collection was facilitated through structured questionnaires distributed through Survey Monkey® for ease of distribution and information gathering. The data was then analyzed to derive conclusions on the research questions and further test the hypothesis. Frequencies, means and z scores for the data were derived to the significance of challenges in 2D modeling as well as the efficiency of BIM in playing different roles identified to reduce cost and time overruns. Regression analysis was further conducted to establish a relationship between the independent and dependent variables which assisted in concluding on the hypothesis. Cronbach's alpha test was also conducted to confirm the reliability of the scores established.

CHAPTER FOUR

DATA ANALYSIS AND PRESENTATION

4.0. Introduction

This chapter presents the data as well as interpretation of the data analyzed. The statistical methods used for analysis aimed at evaluating the effectiveness of BIM in reducing cost and time overruns experienced in the two-dimensional information model of construction. The survey was administered via Survey Monkey® and was conducted in February 2018. 99 questionnaires were distributed to building construction project managers, specifically 33 architects, 33 engineers and 33 construction managers.

4.1. Respondents' Background Information

4.1.1. Response Rate

Survey Monkey® allowed real-time receipt of respondents' input. Several reminders were sent to non-responsive recipients and the survey was closed off once each strata attained 30 responses at which point it was determined that this was an ideal response rate.

Table 4. 1: Response Rate

Strata	Targeted Respondents	Responses	Response Rate
Architects	33	30	90.9%
Construction Managers	33	30	90.9%
Engineers	33	30	90.9%
Average	**33**	**30**	90.9%
Total	**99**	**90**	**90.9%**

Source: Author's Field Survey, 2018

Rumsey (2005) notes that the ideal response rate is 70% or a value above 70%. The response rate for this study falls well above 70% at 90.9%.

4.1.2. Respondents' Years of Practice

Table 4.2 below shows a summary of the professional experience of the respondents. The highest proportion of the respondents had 5-10 Years of experience at 40.00%, followed by 2-5 years of experience at 22.22%. 21.11% of the respondents had above 15 years of experience while 14.44% and 2.22% of the respondents had 10-15 and 1-2 years of experience respectively.

Table 4. 2: Respondents' Years of Practice:

Years of Practice (Post Graduation)	Responses	Frequency
1-2 Years	2	2.22%
2-5 Years	20	22.22%
5-10 Years	36	40.00%
10-15 Years	13	14.44%
Above 15 Years	19	21.11%
Total	**90**	

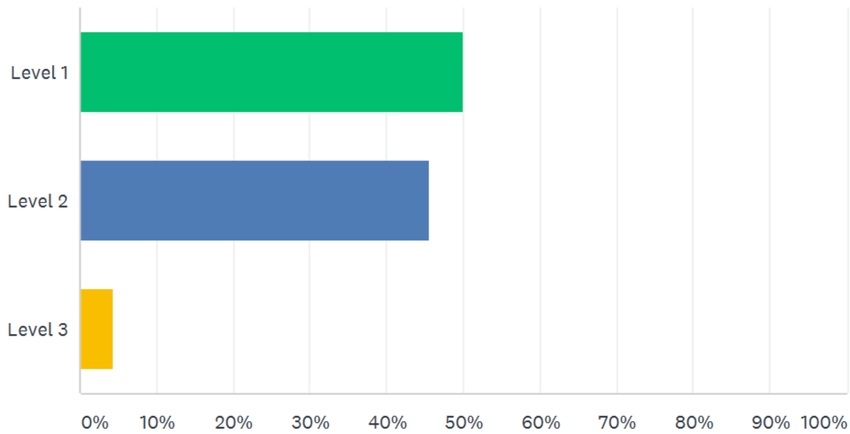
Source: Author's Field Survey, 2018

The study respondents were identified through purposive sampling of construction professionals with experience using BIM for projects within Nairobi county. From the above tabulation, it was found that there is a significant representation of professionals with knowledge of BIM across professionals with various years of experience post-graduation. It was therefore considered that construction professionals with various years of experience post-graduation would be adequately represented by the sample selected.

4.1.3. Respondents' BIM Maturity Level of Operation

Data obtained from the respondents indicated that 50% of the respondents are operating at BIM Maturity Level 1. 45.56% of the respondents are operating at Level 2 while 4.44% are operating at Level 3. Figure 4.2 below shows a graph indicating the BIM Maturity Level of the respondents at an individual or organizational level.

Figure 4. 1: Respondents' BIM Maturity Level of Operation



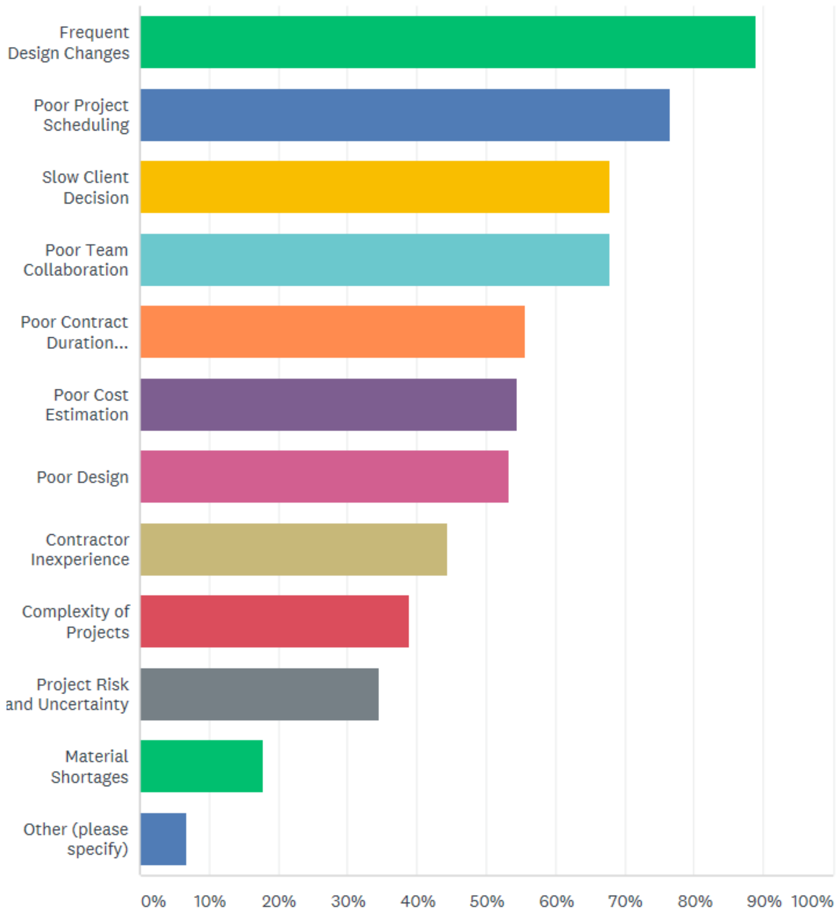
Source: Author's Field Survey, 2018

From the above, majority of the respondents (50%) were found to be operating within BIM maturity Level 1 which entails use of a mix of 2D and 3D methods with partial collaboration between teams. 45.56% were found to be operating within BIM Maturity Level 2 which promotes full collaboration between project teams in a managed 3D environment with separate data embedded BIM tools. 4.44% indicated that they are operating within level 3 which in general entails full data integration. As such, all the respondents were found to be operating within BIM Maturity levels adequate for exhaustive and reliable response.

4.2. Causes of Cost and Time Overruns in Construction

The respondents identified causes of cost and time overruns. These are summarized in Figure 4.3 below.

Figure 4. 2: Causes of Cost and Time Overruns in Descending Order



Source: Author's Field Survey, 2018

Out of the 90 respondents, 88.89% identified frequent design changes as a common cause of cost and time overruns. 76.67% identified poor project scheduling, 67.78% identified slow client decision and poor team collaboration, 55.56% identified poor contract duration estimation, 54.44% identified poor cost estimation, 53.33% identified inadequate design, 44.44% identified contractor inexperience, 38.89% identified complexity of projects, 34.44% identified project risk and uncertainty while 17.78% identified material shortages. Additionally, 6.67% of the respondents identified other causes not listed in the questionnaire. These included accidents on site, designer inexperience and poor scope definition.

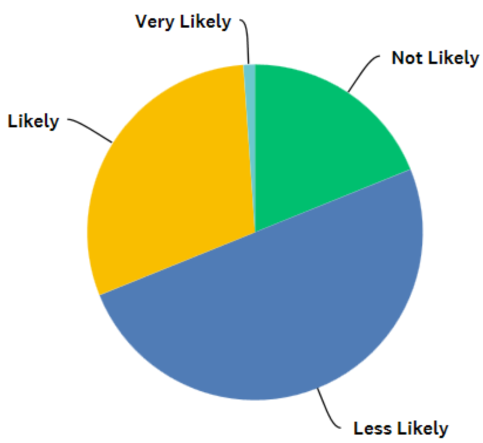
4.3. Challenges Experienced in 2D Based Construction

The respondents were further required to identify and rate the challenges experienced in 2D Based construction to determine the significance of these challenges. First, the researcher sought to find out the respondents' opinions on the probability of occurrence of cost and time overruns in the 2D based model. Next, the challenges were identified and their significance was rated on a four-point Likert scale.

4.3.1. Probability of Completion of Construction Project within Cost and Time Constraints in 2D Based Construction

Figure 4.5 illustrates that 50% of the respondents considered it less likely for a project to be completed within time and cost constraints in the 2D model while 18.89% considered it not likely for a project to be completed within time and cost constraints in the 2D model. However, 30% of the respondents considered it was likely for a project to be completed within cost and time constraints in the 2D model. Additionally, 1.11% considered it very likely respectively for a project in the 2D model to be completed within time and cost constraints.

Figure 4. 3: Likelihood of Completion of a Project Within Cost and Time Constraints in 2D Based Construction



Source: Author's Field Survey, 2018

4.3.2. Significance of Challenges Experienced in 2D Modeling in Contributing to Cost and Time Overruns

The mean value of the ratings for significance of each of the challenges experienced in 2D modeling in contributing to cost and time overruns was determined as tabulated in Table 4.2 below. The mean values (ẋ) for the challenges were ranked in descending order to identify the order of significance. The challenge of changes made on one document which relate to other documents not being interlinked was found to be the most significant challenge (ẋ= 3.58). Tedious and error-prone element clash detection was ranked as the second most significant challenge of 2D modeling (ẋ= 3.52). Lack of multidisciplinary interaction resulting in information loss and repetitive work was ranked as the third most significant challenge of 2D modeling (ẋ= 3.38). Inability to simulate the actual scenario on site was ranked as the fourth most significant challenge of 2D modeling (ẋ= 3.29). The fact that 2D drawings are not interlinked with cost and time schedules was ranked as the fifth most significant challenge of 2D modeling (ẋ= 2.91). The use of lines and symbols to represent 3D objects which leads to ambiguity and misrepresentation was ranked as the sixth most significant challenge of 2D modeling (ẋ= 2.84). Difficulty in confirming completeness of 2D documents without a reference model was ranked as the least significant challenge of 2D modeling (ẋ= 2.76).

Table 4. 3: Significance of Challenges in 2D Modeling in Contributing to Cost and Time Overruns

Challenge in 2D Modeling	**1**	**2**	**3**	**4**	**Total**	**Weighted Average (Mean)**
Changes made on one document which relate to other documents are not interlinked	0	3	32	55	90	3.58
Element clash detection can be a tedious and error prone process	2	6	25	56	89	3.52
Lack of multidisciplinary interaction resulting in information loss and repetitive work	2	4	42	42	90	3.38
Inability to simulate the actual scenario on site	0	10	43	36	89	3.29
2D drawings are not interlinked with cost and time schedules	3	24	41	22	90	2.91
Use of lines and symbols to represent 3D objects leads to ambiguity and misrepresentation	1	27	46	15	89	2.84
It is difficult to confirm completeness of 2D documents without a reference model	7	22	44	15	88	2.76

Source: Author's Field Survey, 2018

Notably, the mean rating values for the significance of all the challenges in 2D modeling in contributing to cost and time overruns were found to be above the population mean of 2.5. Consequently, it was considered that all the challenges in 2D modeling identified and rated in Table 4.2 are significant in contributing to cost and time overruns in construction.

4.4. Role and Efficiency of BIM in Reducing Cost and Time Overruns in Construction Projects

The researcher first sought the respondent's opinions on whether BIM has the capacity to reduce cost and time overruns experienced in construction. 89 out of the 90 respondents considered that BIM can reduce cost and time overruns in construction. One respondent did not give a response to this question. As illustrated in Figure 4.6, 100% of the responses received therefore indicated that BIM can reduce cost and time overruns.

Figure 4. 4: Opinion on BIM's Ability to Reduce Cost and Time Overruns in Construction Projects

Source: Author's Field Survey, 2018

The respondents then identified the following roles played by BIM in reducing cost and time overruns experienced in 2D based construction;

i. Collaboration and coordination among project team members
ii. Detection and Elimination of errors and omissions in design
iii. Design management of complex buildings/projects
iv. Design change/ change order management
v. Speedy stakeholder decision making through visualization and simulation
vi. Reduction of Requests for Information
vii. Schedule estimation and monitoring

viii. Cost estimation and monitoring
ix. Material scheduling
x. Project risk management

However, the efficiency of BIM in playing these roles varied considerable across the respondents. The mean values (ẋ) of rating for the efficiency of BIM in playing the different roles to reduce cost and time overruns were identified and then ranked as shown in Table 4.4 below. BIM was considered to be most effective in collaboration and coordination among project team members (ẋ= 3.84). It was considered effective in detection and Elimination of errors and omissions in design (ẋ=3.73). It was considered effective in design management of complex buildings/projects (ẋ=3.71). It was considered effective in design change/ change order management (ẋ=3.39). It was considered effective in speedy stakeholder decision making through visualization and simulation (ẋ=3.39). It was considered effective in reduction of requests for information (ẋ=3.27). It was considered effective in schedule estimation and monitoring (ẋ=3.17). It was considered effective in cost estimation and monitoring (ẋ=3.07). It was considered least effective in material scheduling (ẋ=2.99) and project risk management (ẋ=2.74).

Table 4. 4: Efficiency of BIM in Reducing Cost and Time Overruns Experienced in 2D Based Construction

Role of BIM	**1**	**2**	**3**	**4**	**Total**	**Weighted Average (Mean)**
Collaboration and coordination among project team members	0	1	12	77	90	*3.84*
Detection and Elimination of errors and omissions in design	0	1	22	67	90	*3.73*
Design management of complex buildings/projects	0	2	22	66	90	*3.71*
Design change/ change order management	3	6	34	47	90	*3.39*
Speedy stakeholder decision making through visualization and simulation	1	11	29	48	89	*3.39*
Reduction of Requests for Information	0	12	41	36	89	*3.27*
Schedule estimation and monitoring	1	14	40	31	86	*3.17*
Cost estimation and monitoring	1	16	48	24	89	*3.07*
Material scheduling	1	20	44	21	86	*2.99*
Project risk management	3	28	47	11	89	*2.74*

Source: Author's Field Survey, 2018

All the above mean values for efficiency of BIM in playing roles identified to reduce cost and time overruns were found to be above the population mean rating of 2.5. The population mean score, however, does not, apply confidence level as required for minimization of errors to conclusively confirm the effectiveness of BIM in reducing cost and time overruns. This therefore calls for the need for a test for significance, identified as the one-tailed Z-test for this study. Being a socio-economic study, this study gives presence to minimization of Type 1 errors where the researcher concludes that BIM is effective in reducing cost and time overruns experienced in 2D based construction while it is not. A confidence level of 95% was assumed. The calculated Z score for each variable was compared to the critical Z value identified as 1.65.

Table 4.5: Descriptive Statistics

Role of BIM in reducing cost and time overruns in 2D based construction	**N**	**Min**	**Max**	**Mean**	**Population mean**	**Std. Deviation**	**z-stat**
Collaboration and coordination among project team members	90	2	4	3.84	2.5	.394	32.26
Detection and elimination of errors and omissions in design	90	2	4	3.73	2.5	.469	24.88
Design management of complex projects	90	2	4	3.71	2.5	.503	22.82
Design or order management change	90	1	4	3.39	2.5	.760	11.11
Speedy stakeholder decision making	89	1	4	3.39	2.5	.748	11.22
Reduction of requests for information	89	2	4	3.27	2.5	.687	10.57
Schedule estimation and monitoring	86	1	4	3.17	2.5	.739	8.41
Cost estimation and monitoring	89	1	4	3.07	2.5	.704	7.64
Material scheduling	86	1	4	2.99	2.5	.728	6.24
Project risk management	89	1	4	2.74	2.5	.716	3.16

Source: Author's Field Survey, 2018

As per the analysis above, the calculated Z score for BIM efficiency in playing the ten roles identified was found to be statistically greater that the critical Z value for a one tailed z test at 95% confidence level, i.e, 1.65. In all the above roles of BIM, the null hypothesis was rejected and the alternate hypothesis was accepted. A conclusion was made that BIM is efficient in playing the ten roles.

Further, regression analysis was conducted to determine the relationship between the dependent variable, ie. Reduction of cost and time overruns experienced in 2D based construction and the independent variables, ie, Efficiency of BIM in playing the above ten roles identified to reduce cost and time overruns in construction. A summary of this analysis is presented in Table below.

4.6 Regression Analysis Summary

Independent Variable (x)	Regression coefficient (m)	Regression constant (c)	Std error of the estimate (ε)	Correlation coefficient (R)
Collaboration and coordination among project team members (C)	1.148	-2.28	0.566	0.627
Detection and elimination of errors and omissions in design (DE)	1.082	-1.905	0.516	0.703
Design management of complex projects (DCP)	0.999	-1.574	0.522	0.695
Design or change order management change (CM)	0.707	-0.263	0.485	0.744
Speedy stakeholder decision making (DM)	0.733	-0.373	0.435	0.785
Reduction of requests for information (RRI)	0.874	-0.746	0.358	0.860
Schedule estimation and monitoring (SEM)	0.836	-0.573	0.309	0.895
Cost estimation and monitoring (CEM)	0.948	-0.795	0.206	0.956
Material scheduling (MS)	0.869	-0.515	0.278	0.916
Project risk management (PRM)	0.745	0.069	0.453	0.764

Source: Author's Field Survey, 2018

Regression equation: $y=mx+c+\varepsilon$; e.g. $y= (1.148) *(C) - 2.28+0.566$

For all the ten independent variables, a positive value was derived for the correlation coefficient. This indicates a strong positive correlation between the dependent and independent variables. Regression analysis assumes a linear equation between the variables taking the form $y=mx+c+ \varepsilon$, where y represents the dependent variable (reduction of cost and time overruns experienced in 2D based construction), m represents the regression coefficient, x represents the independent variables, c is a regression constant and ε represents the standard error of the estimate. As is illustrated in Table above, the regression coefficient for all the independent variables was found to be a positive value which indicates that reduction of cost and time overruns experienced in 2D modeling increases as management of the independent variables through BIM increases. The null hypothesis was therefore rejected and the alternate hypothesis was accepted.

4.5. Reliability of Test Scores

Reliability tests were conducted using Cronbach's alpha to determine the consistency of the data collected on; causes of cost and time overruns, significance of 2D model challenges in contributing to cost and time overruns, and the effectiveness of BIM in reducing cost and time overruns in construction. The results obtained indicated Cronbach's alphas of 0.948, 0.946, and 0.939 respectively. The values are greater than 0.9 which implied that the data collected had excellent internal consistency and was hence reliable for application in the present study.

4.6. Hypothesis Testing

This study sought to determine BIM efficiency in reducing cost and time overruns experienced in 2D based construction. The Null hypothesis (H_0) was that BIM is not effective for management of cost and time overruns experienced in the 2D based construction. The alternate hypothesis (H_A) was that BIM is effective for management of cost and time overruns experienced in the 2D based construction.

From the results, it was established that BIM is efficient in playing ten roles identified to reduce cost and time overruns experienced in 2D based construction. The mean value rating for BIM efficiency in playing these roles ranged from 3.84 (Highest) to 2.74 (Lowest), all higher than the population mean of 2.5, indicating that BIM is effective in playing the roles identified. Further, the Z statistic asserted this finding. The calculated z scores for the ten independent variables were found to range from 32.26(Highest) to 3.16 (Lowest), all higher than the Critical Z value for a one tailed z test at 95% confidence level; 1.65. Finally, the regression analysis results illustrate the direct relationship between the dependent variable, reduction of cost and time overruns experienced in 2D based construction and the independent variables, BIM efficiency in playing the ten roles identified to reduce cost and time overruns experienced in 2D based construction. The summary demonstrated in Table

4.6 indicates positive regression coefficients for all the independent variables, which indicates that reduction of cost and time overruns experienced in 2D modeling increases as management of the independent variables through BIM increases. The Null hypothesis is consequently rejected and the Alternate hypothesis is accepted.

4.7. Summary

This chapter presented data analysis as well as interpretation of the results. The response rate for the study was 90.9% with an equal number of responses from the three professional strata identified; Architects, Engineers, Construction Managers. Most of the respondents were found to be operating at BIM Maturity Levels one and two. 68.9% of the respondents held the opinion that it is Not likely or Less likely for a 2D based construction project to be completed within cost and time constraints while 31.1% felt that it is likely or very likely for a 2D based construction project to be completed within cost and time constraints. Causes of cost and/ or time overruns in construction were then identified. Additionally, the significance of challenges experienced in 2D modeling in contributing to cost and time overruns was determined. All the respondents agreed that BIM can reduce cost and time overruns experienced in construction projects. The roles played by BIM in reducing cost and time overruns experienced in 2D based construction were then identified, following which the efficiency of BIM in playing these roles was established.

The calculated z scores for the ten independent variables were found to range from 32.26(Highest) to 3.16 (Lowest), all higher than the Critical Z value for a one tailed z test at 95% confidence level. Moreover, through regression analysis, a positive relationship between the dependent and independent variables was established, indicating that reduction of cost and time overruns experienced in 2D modeling is achieved through management of the independent variables using BIM. The Null hypothesis was subsequently rejected while the Alternate hypothesis was accepted.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0. Introduction

In this chapter, a summary of major findings, discussions, conclusions and recommendations are deduced from the findings of the study. Areas for further research are also suggested herein. This section is guided by the study objectives as stated in chapter 1.

5.1. Summary of findings

From the study the causes of cost and time overruns in construction projects was determined. Additionally, the significance of challenges in 2D modeling in contributing to time and cost overruns was identified. The BIM Maturity level of operation of the participants was also established. Further, the role of BIM in reducing time and cost overruns experienced in 2D based construction was identified and evaluated. Ultimately, BIM was found to be effective in reducing cost and time overruns experienced in 2D based construction.

The study findings are summarized in the Table 5.1 below, linking them with the study objectives

Table 5. 1: Summary of Study Findings

Study Objective	Study Findings
i. To determine the cause(s) of cost and time overruns in construction projects.	The causes of cost and time overruns were identified as follows in decreasing order of significance; frequent design changes, poor project scheduling, slow client decision making, poor team collaboration, poor contract duration estimation, inadequate design, contractor inexperience, complexity of projects, project risk and uncertainty and material shortages. Additionally, 6.67% of the respondents identified other causes not listed in the questionnaire. These included accidents on site, designer inexperience and poor scope definition.
ii. To establish the significance of information	Moreover, challenges in 2D modeling which are significant in contributing to cost and time overruns were identified as follows in order of significance; changes made on one

management challenge(s) in 2D modeling in contributing to time and cost overruns.	document which relate to other documents are not interlinked, element clash detection can be a tedious and error prone process, lack of multidisciplinary interaction resulting in information loss and repetitive work, inability to simulate actual scenario on site, lack of interlinking of 2D drawings with cost and time schedules, use of lines and symbols to represent 3D objects which leads to ambiguity and misrepresentation as well as difficulty in confirming completeness without a reference model.
iii. To establish the BIM Maturity Level at which construction professionals are operating within Nairobi county.	Majority of the respondents, i.e., 50%, were found to be operating at BIM Maturity Level 1, 45.56% of the respondents at Level 2 and 4.44% at BIM Maturity Level 3.
iv. To identify and evaluate the effectiveness of BIM in reducing time and cost overruns experienced in 2D based construction.	The role of BIM in reducing cost and time overruns experienced in 2D based construction was identified and ranked in terms of efficiency as follows; promoting collaboration and coordination among project team members, enabling detection and elimination of errors and omissions in design, facilitating design management of complex projects, improving design or order management change, promoting speedy stakeholder decision making, reduction of requests for information, automated schedule estimation and monitoring, automated cost estimation and monitoring, facilitating material scheduling and promoting project risk management.

Source: Author's Field Survey, 2018

5.2. Conclusions

From the study frequent design changes, poor project scheduling, slow client decision making and poor team collaboration were ranked as the top four causes of cost and time overruns in construction projects. This is consistent with Sharma and Prabdeep's (2014) study, discussed in chapter two of this study which ranked the causes of cost overruns in 9 countries identifying slow client decision making, poor planning and scheduling, poor contract management, frequent design changes as the factors with the highest occurrence. This indicates the need for improved overall project management to reduce cost and time overruns.

Of the respondents, 69.89% felt that it was not likely or less likely for a 2D based project to be completed within cost and time constraints while 31.11% felt that it was likely or very likely. This highlights a cost and time management niche in the 2D based model. Further, challenges in the 2D model which contribute to cost and time overruns were identified. Changes made on one document which relate to other documents are not linked. Any changes on a layout, for example, have to be updated manually in related sections and elevations. Element clash detection can also be a tedious and error prone process. The lack of multidisciplinary interaction resulting in information loss and repetitive work is yet another challenge, coupled with the inability to simulate the actual scenario on site. The lack of interlinking of 2D drawings with cost and time schedules as well as the use of lines and symbols to represent 3D objects which leads to ambiguity and misrepresentation were also found to be significant challenges. All these challenges relate to how construction information is managed, manipulated and relayed in the 2D model and plead the case for the need for more sophisticated methods of information management in the industry.

Of the respondents, 50% were found to be operating at BIM Maturity Level 1, 45.56% at level 2 while only 4.44% were found to be operating at Level 3. This supports The Landscape Institute, UK, (2016) citation that Level 3 BIM Maturity is yet to be achieved in most countries. This indicates that 50% of the construction professionals' population is still applying 2D methods of construction information management within Nairobi county.

The role of BIM in reducing cost and time overruns was identified as enabling collaboration and coordination among project team members, facilitating detection and elimination of errors and omissions in design, facilitating design management of complex projects, design or order management change, promoting speedy stakeholder decision making, reduction of requests for information, automated schedule estimation and monitoring, automated cost estimation and monitoring, proper material scheduling and project risk management. Further, BIM was found to be most efficient in coordination and communication among project participants, detection and elimination of errors and omissions in design as well as design management of complex projects (85.56%, 74.44% and 73.33% respectively). This was then followed by design change/ change order management, speedy stakeholder decision making through visualization and simulation and reduction of requests for information. Although efficiency of BIM in schedule and cost estimation and monitoring, material schedule and project risk management scored values above the population mean and critical z scores for the test, these had the lowest mean and z scores. Altogether, BIM was found to be efficient in playing the ten roles identified for reduction of cost and time overruns experienced in construction.

5.3. Recommendations

Based on the findings of the study, most of the causes of cost and time overruns in construction can be addressed through effective adoption of BIM. This would aid in reduction of these cost and time overruns. The Kenya Vision 2030 acknowledges the importance of ICT in improvement of efficiency and effectiveness in all sectors of the economy. The government, through national policy frameworks should sanction the implementation of BIM and formalize BIM implementation procedures. The UK BIM mandate sanctioned in 2016 is a good example of such implementation.

Further, information management challenges in the 2D model are significant in contributing to cost and time overruns. There is a need to apply information management tools and processes that ensure that information flows in a seamless and coherent manner across the project participants. From the study, BIM has been established to be an effective information management tool that would host all the professionals on a common platform.

A significant population was found to be applying 2D methods of construction, based on the 50% of the population found to be operating at Level 1 BIM Maturity level. From the literature reviewed, it was acknowledged that full benefits of BIM can only be experienced if all participants are on the BIM platform. Construction professionals should take up the initiative to push the BIM agenda across the industry. Training on BIM is an investment that construction professionals should also consider.

Finally, BIM was found to be efficient in playing all the roles identified for reduction of cost and time overruns in construction. This indicates the crucial need for a mind shift from traditional methods of construction information management. This thought leadership would best be implemented at the undergraduate training level. BIM training should be incorporated in the tertiary level education curriculum to develop a crop of BIM savvy construction graduates.

5.4. Areas for further research

This study limited its review of case studies where BIM has been used to reduce cost and time overruns to an international scope since documented literature on actual projects was available. However, this type of information has not been compiled locally despite the entry of BIM into the Kenya construction market. Further research into effects of BIM on cost and time schedule in the local scene would serve to provide relatable data for decision making on adoption of BIM in Kenya.

Additionally, a considerable number of the study respondents felt that BIM is less efficient in schedule and cost estimation and monitoring, material scheduling and project risk management despite literature cited supporting its efficiency. This perhaps indicates an aspect of BIM not well actualized in Kenya. Studies to shed more light on how benefits can be derived from these BIM capabilities would avail more information to construction professionals.

From the study finding that most construction practitioners in Nairobi county are operating at BIM Maturity Level 1, there is need to look into strategies that can enhance penetration of BIM application in the industry. Studies into how this can be done would aid in getting the industry to operate at BIM Maturity Level 2 as a minimum requirement.

For effective BIM implementation, development of policies and framework for application is necessary. Research into models implemented in countries that have already rolled out BIM strategy policies would aid in facilitating implementation of BIM in Kenya.

This study has shed light on BIM, an information management tool and process with the potential to reduce cost and time overruns, as well as given propositions on the direction for research. Nonetheless, any research undertaken is only useful if the findings of the research are incorporated into the processes or fields under study.

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APPENDIX A

QUESIONNAIRE FOR RESEARCH ON THE ROLE OF BUILDING INFORMATION MODELING IN REDUCING COST AND TIME OVERRUNS EXPERIENCED IN 2D BASED CONSTRUCTION

Dear Respondent,

My name is Pauline Maina. I am a master's student at the University of Nairobi, Department of Real Estate and Construction Management, currently at the thesis level of my M.A. Construction Management. I am conducting an academic research titled: **An Investigation into The Role of Building Information Modeling (BIM) in Reducing Cost and Time Overruns in 2D Based Construction- A Survey of Construction Practitioners in Nairobi County.**

I humbly request your assistance with the details requested on the attached document. Your honest participation in the research would be highly appreciated, with an assurance of confidentiality and anonymity. Any identifiable information received via this survey will only be used at the data analysis stage. You will not be individually identified with your questionnaire or response. Your contribution to this study will contribute to greater understanding of the capacity of BIM in management of cost and time overruns experienced in the construction industry.

SECTION A: BACKGROUND INFORMATION

1. What is your profession?
   - ☐ Construction Project Manager
   - ☐ Architect
   - ☐ Engineer
2. Which statement below best describes your current practice?
   - ☐ Local Consultant
   - ☐ Expatriate
   - ☐ International Consultant with experience working in Nairobi, Kenya
3. Number of Years of Practice (Post graduation)?
   - ☐ 1-2
   - ☐ 2-5
   - ☐ 5-10

- 10-15
- Above 15

SECTION B: EXPERIENCE USING BIM

4. Mervyn Richards and Mark Bew identified BIM Maturity levels including; Level 1: Managed CAD. This may include 2D information and 3D information such as visualizations or concept development models. Level 2: Managed 3D environment with data attached, but created in separate discipline-based models. Data may include construction sequencing (4D) and cost (5D) information. Level 3: A single collaborative, online, project model with construction sequencing (4D), cost (5D) and project lifecycle information (6D). At what level is are you utilizing BIM as an individual or organization?
   - Level 1
   - Level 2
   - Level 3

SECTION C: CAUSES OF COST AND TIME OVERRUNS

5. How likely is it for a project to be completed within expected time and cost constraints?
   - Not Likely
   - Less Likely
   - Likely
   - Very Likely
6. In your experience, which of the following are responsible for cost and time overruns in construction? (Select all appropriate options)
   - Poor cost estimation
   - Frequent design changes and change orders
   - Inadequate design, design errors and delay in design
   - Project risk and uncertainty
   - Poor contract duration estimation
   - Slow decision making by client
   - Complexity of projects
   - Contractor inexperience
   - Material shortages
   - Poor project scheduling and controlling

- Poor coordination between design and site team
- Other (Specify)

SECTION D: INFORMATION MANAGEMENT CHALLENGES IN 2D BASED CONSTRUCTION

7. How significant are the following challenges experienced in 2D modeling in causing cost and time overruns? **Tick the appropriate option (KEY; 1=Not Significant, 2=Less Significant, 3= Significant, 4= Very Significant)**

	1	**2**	**3**	**4**
2D drawings are not interlinked with cost and time schedules				
Inability to simulate the actual scenario on site				
Use of lines and symbols to represent 3D objects leads to ambiguity and misrepresentation				
Changes made on one document which relate to other documents are not interlinked				
Element clash detection can be a tedious and error prone process				
Lack of multidisciplinary interaction resulting in information loss and repetitive work				
It is difficult to confirm completeness of 2D documents without a reference model				

SECTION E: ROLE OF BIM FOR REDUCTION OF COST AND TIME OVERRUNS EXPERIENCED IN 2D BASED CONSTRUCTION

8. In your experience or opinion, can BIM be used to reduce cost and time overruns in construction projects?
    - Yes
    - No
9. If yes, which of the following roles is played by BIM in reducing cost and time overruns experienced in 2D based construction? (Select all appropriate options)
    - Cost estimation and monitoring
    - Design change/ change order management
    - Detection and elimination of errors and omissions in design
    - Project risk Management

- Schedule estimation and monitoring
- Speedy stakeholder decision making through visualization and simulation
- Design management of complex buildings/projects
- Reduction of Requests for Information
- Material scheduling
- Collaboration and coordination among project team members

10. How effective is BIM in playing the roles identified above? **Tick the appropriate option (KEY; 1=Not Effective, 2=Less Effective, 3= Effective, 4= Very Effective)**

	1	**2**	**3**	**4**
Cost estimation and monitoring				
Design change/ change order management				
Detection and Elimination of errors and omissions in design				
Project risk management				
Schedule estimation and monitoring				
Speedy stakeholder decision making through visualization and simulation				
Design management of complex buildings/projects				
Reduction of Requests for Information				
Material scheduling				
Coordination and communication among project team members				

APPENDIX B

DATA ANALYSIS: THE ROLE OF BUILDING INFORMATION MODELING IN REDUCING COST AND TIME OVERRUNS EXPERIENCED IN 2D BASED CONSTRUCTION

I. DESCRIPTIVE STATISTICS

Role of BIM in reducing cost and time overruns in 2D based construction	N	Min	Max	Mean	Population mean	Std. Deviation	z-stat
Collaboration and coordination among project team members	90	2	4	3.84	2.5	.394	32.26
Detection and elimination of errors and omissions in design	90	2	4	3.73	2.5	.469	24.88
Design management of complex projects	90	2	4	3.71	2.5	.503	22.82
Design or order management change	90	1	4	3.39	2.5	.760	11.11
Speedy stakeholder decision making	89	1	4	3.39	2.5	.748	11.22
Reduction of requests for information	89	2	4	3.27	2.5	.687	10.57
Schedule estimation and monitoring	86	1	4	3.17	2.5	.739	8.41
Cost estimation and monitoring	89	1	4	3.07	2.5	.704	7.64
Material scheduling	86	1	4	2.99	2.5	.728	6.24
Project risk management	89	1	4	2.74	2.5	.716	3.16

II. REGRESSION ANALYSIS

Regression models between the dependent variable and each of the independent variables

1. Collaboration and coordination among project team members

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.627[a]	.393	.386	.566

a. Predictors: (Constant), collaboration and coordination among project team members

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.214	1	18.214	56.864	.000[b]
	Residual	28.186	88	.320		
	Total	46.400	89			

a. Dependent Variable: likelihood of completion within cost and time constraints

b. Predictors: (Constant), collaboration and coordination among project team members

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.280	.588		-3.875	.000
	collaboration and coordination among project team members	1.148	.152	.627	7.541	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

2. Detection and elimination of errors and omissions in design

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.703[a]	.494	.488	.516

a. Predictors: (Constant), detection and elimination of errors and omissions in design

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.931	1	22.931	85.980	.000[b]
	Residual	23.469	88	.267		
	Total	46.400	89			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), detection and elimination of errors and omissions in design

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.905	.439		-4.340	.000
	detection and elimination of errors and ommisions in design	1.082	.117	.703	9.273	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

3. Design management of complex projects

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.695[a]	.484	.478	.522

a. Predictors: (Constant), design management of complex projects

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.444	1	22.444	82.449	.000[b]
	Residual	23.956	88	.272		
	Total	46.400	89			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), design management of complex projects

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-1.574	.412		-3.821	.000
	design management of complex projects	.999	.110	.695	9.080	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

4. Design or order management change

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.744[a]	.554	.549	.485

a. Predictors: (Constant), design or order management change

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25.689	1	25.689	109.148	.000[b]
	Residual	20.711	88	.235		
	Total	46.400	89			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), design or order management change

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.263	.235		-1.118	.267
	design or order management change	.707	.068	.744	10.447	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

5. Speedy stakeholder decision making

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785[a]	.616	.612	.435

a. Predictors: (Constant), speedy stakeholder decision making

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	26.421	1	26.421	139.687	.000[b]
	Residual	16.455	87	.189		
	Total	42.876	88			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), speedy stakeholder desicion making

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.373	.215		-1.734	.086
	speedy stakeholder desicion making	.733	.062	.785	11.819	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

6. **Reduction of requests for information**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.860[a]	.740	.737	.358

a. Predictors: (Constant), reduction of requests for information

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	31.736	1	31.736	247.839	.000[b]
	Residual	11.140	87	.128		
	Total	42.876	88			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), reduction of requests for information

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.746	.185		-4.022	.000
	reduction of requests for information	.874	.056	.860	15.743	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

7. **Schedule estimation and monitoring**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.895[a]	.802	.800	.309

a. Predictors: (Constant), schedule estimation and monitoring

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32.421	1	32.421	340.039	.000[b]
	Residual	8.009	84	.095		
	Total	40.430	85			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), schedule estimation and monitoring

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.573	.148		-3.876	.000
	schedule estimation and monitoring	.836	.045	.895	18.440	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

8. **Cost estimation and monitoring**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.956[a]	.914	.913	.206

a. Predictors: (Constant), cost estimation and monitoring

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39.174	1	39.174	920.613	.000[b]
	Residual	3.702	87	.043		
	Total	42.876	88			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), cost estimation and monitoring

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.795	.098		-8.092	.000
	cost estimation and monitoring	.948	.031	.956	30.342	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

9. Material scheduling

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.916[a]	.840	.838	.278

a. Predictors: (Constant), material scheduling

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	33.950	1	33.950	440.077	.000[b]
	Residual	6.480	84	.077		
	Total	40.430	85			

a. Dependent Variable: likelihood of completion within cost and time constraints

b. Predictors: (Constant), material scheduling

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.515	.127		-4.042	.000
	material scheduling	.869	.041	.916	20.978	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

10. Project risk management

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.764[a]	.584	.579	.453

a. Predictors: (Constant), project risk management

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25.033	1	25.033	122.058	.000[b]
	Residual	17.843	87	.205		
	Total	42.876	88			

a. Dependent Variable: likelihood of completion within cost and time constraints
b. Predictors: (Constant), project risk management

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.069	.191		.360	.720
	project risk management	.745	.067	.764	11.048	.000

a. Dependent Variable: likelihood of completion within cost and time constraints

III. RELIABILITY OF TEST SCORES

Reliability (Causes of cost and time overruns in construction)

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.948	.945	11

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	.545	.178	.889	.711	5.000	.041	11

Reliability (significance of 2D modelling challenging in causing cost and time overruns)

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.946	.950	7

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.159	2.700	3.578	.878	1.325	.121	7

Reliability (Effectiveness of BIM model in reducing cost and time overruns in construction)

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.939	.949	10

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Means	3.290	2.711	3.844	1.133	1.418	.150	10