UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

AN INVESTIGATION INTO THE USE OF BUILDING INFORMATION MODELLING AND ITS IMPACT ON CONSTRUCTION PERFORMANCE WITHIN GHANAIAN CONSTRUCTION INDUSTRY

WIREKOH FREDERICK KWASI

JUNE, 2020

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A Thesis in the Department of CONSTRUCTION and WOOD TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfilment of the requirements for the award of Master of Philosophy (MPhil) degree in Construction Technology

JUNE, 2020

DECLARATION

STUDENT'S DECLARATION

I, WIREKOH FREDERICK KWASI, declare that this thesis with the exception of quotations and references contained in published works which have all been identified and duly acknowledge, is entirely my original work, and it has not been submitted, either in part or whole, for another degree at the University of Education, Winneba or elsewhere.

SIGNATURE:…………………… ……………

DATE:..…………………… ……………………

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work were supervised in accordance with the guidelines for supervision of Thesis as laid down by the University of Education, Winneba.

NAME: DR. HUMPHREY DANSO

SIGNATURE:…………………… ……………

DATE:..…………………… ……………………

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Lastly, my sincere thanks go to anyone who in innumerable ways have contributed to making this study completes more especially all respondent from the various construction firms.

May the Sovereign Lord graciously replenish you all.

DEDICATION

This thesis is dedicated to my Parents Mr. Paul K. Wirekoh and Ms. Agartha Nyameah, my precious brothers; sisters and my two sons; Lawrence Yaw Wirekoh Ntiful and Clifford Kwasi Nyarku Ntiful.

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ABREVIATIONS

2D	Two Dimensional- X, Y
3D	Three Dimensional- X, Y, Z
4D	4 D + Time
5D	5 D + Cost
ABCECG	Association of Building and Civil Engineering Contractors of Ghana
AEC	Architectural, Engineering and Construction
BIM	Building information Modelling
BIMM	Building Information Modelling Maturity
CAD	Computer-Aided Design
CPM	Critical Path Method
CICRP	Computer Integrated Construction Research Group
CKPI	Construction Key Performance Indicator
FIC	Facility Information Council
FM	Facility Management
GHCCI	Ghana Chamber of Construction Industry
GIS	Geographical Information Systems
GhIE	Ghana Institute of Engineers
GhIS	Ghana Institute of Surveyors
GIA	Ghana Institute of Architects
GSA	General Service Administration
HVAC	Heating, Ventilation, and Air Conditioning
IPD	Integrated Project Delivery
KPI’s	Key Performance Indicators
KMO	Kaiser-Meyer-Olkin

LEED	Leadership in Energy and Environmental Design
LOD	Level of Development
MEP	Mechanical / Electrical / Plumbing
NBIMS	The National Building Information Model Standard
NIBS	National Institute of Building Sciences
RII	Relative Importance Index
SPSS	Statistical Package for Social Science
TAM	Technology Acceptance Model

ABSTRACT

Building Information Modelling (BIM) is a key computer aided technology that can facilitate construction productivity enhancements through the removal of numerous construction inefficiencies. This study investigates the use of BIM and its impact on construction project performance in Ghanaian architecture, engineering and construction industry. A cross-sectional survey design was adopted for the study. Self-administered questionnaires were used for data collection from architects, structural and civil engineers, project managers, quantity surveyors, contractors and general foremen in Greater Accra, Ashanti and Western Regions. A purposive sampling technique was used to elicit information from 300 participants. Data were analyzed through the use of multiple response analysis, relative importance index (RII), principal component analysis and descriptively analysis. The results indicated that experts in the construction industry agreed that the use of BIM has a great impact on construction project performance. Increase productivity, improve product quality and create customer value, help in removing barriers and constraints, reduce the time of project design and shop drawings, improve communication effectiveness, provide accurate cost estimation and take off materials, reduce conflicts and number of claims, reduce defects in the construction phase, increase collaboration in project design were considered by the respondents as the most important factors for project performance improvement. It is recommended that experts and stakeholders should encourage the use of BIM technology in the Ghanaian construction industry to improve construction project performance to meet customer satisfaction and also boost our infrastructural development.

CHAPTER ONE

INTRODUCTION

1.1 Backrond to the Study

Information technology (IT) is one of the promising tools which have been constantly deemed as a solution to save construction projects. Among those, computer-aided design (CAD) software applications have been playing the leading role for more than three decades in the construction industry (CI). BIM-supported software applications are the new generation of those CAD software applications (Parvan, 2012).

BIM stands for Building Information Model. BIM is known as a shared digital representation of the physical and functional characteristics of the facility in the Architectural, Engineering and Construction (AEC) industry. The basic premise of BIM is to improve collaboration and interoperability among the stakeholders of the facility during its lifecycle. The 3D visualization is the basic essential feature of BIM. However, BIM is not just a 3D CAD. It is more than the elaborated 3D renderings. Also, it is more than delivering the project documentation in the electronic version. It is about information use, reuse, and exchange, of which the digital format is just one part (Parvan, 2012; p.1).

According to Parvan (2012), BIM has been practised by many companies and organizations. They have their definitions of BIM. The General Services Administration (GSA) is an independent agency of the United States government, established in 1949 to help manage and support the basic functioning of federal agencies. GSA, with almost 7,800 buildings and 261 million square feet of space under its management, is the nation's largest property manager. GSA ran nine pilot projects to examine the implications of BIM. GSA estimated that the cost savings on just one of the nine pilot projects offset the cost of conducting the two-year pilot program. That set the stage for the agency in November 2006 to mandate BIM on all its new projects (Parvan, 2012; p. 2).

General Services Administration (GSA, 2007) BIM guide defines BIM as "Building Information Modeling is the development and use of a multi-faceted computer software data model not to only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design."

The National Institute of Building Sciences (NIBS, 2007) is a non-profit, private organization dedicated to bringing together government, professionals, building products manufacturers, construction labour, and the end consumer to identify and resolve the current and potential problems that disrupt the ability to design and build safe and economical private, public, and institutional structures throughout the United States.

According to NIBS (2007), it is best to think of BIM as "a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward (defined as existing from earliest conception to demolition)" (Parvan, 2012; p. 2).

Also, the Facility Information Council (FIC, 2007) which is the council chartered under the NIBS defines BIM as "a computable representation of the physical and functional characteristics of a facility and its related project/life-cycle information using open industry standards to inform business decision making for realizing better value. BIM can integrate all the relevant aspects into a coherent organization of data that computer applications can access, modify and/or add to if authorized to do so" (Parvan, 2012; p. 3).

Building Information Modeling (BIM) is the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way (Vanlande, Nicolle & Cruz, 2008). BIM is a revolutionary technology and process that has quickly transformed the way buildings are conceived, designed, constructed and operated (Hardin, 2009). BIM can also be referred to as a computer-integrated project due to its process and technology application in project delivery (Harris, 2008, cited Azhar et al., 2012).

It requires the development and use of a computer-generated model to simulate the planning, design, construction and operational phases of a project (Azhar et al., 2008).

Building Information Model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and to improve the process of delivering the facility (Associated General Contractors of America, 2005).

BIM is the process of creating a digital parametric model which represents the physical and functional characterization of a building in full detail and further shared knowledge pool which can be used to form reliable decisions during the design, construction phases and throughout the life cycle of the facility (Eastman et al., 2011; Suranga and Weddikkara, 2012).

It is a methodology to integrate digital descriptions of all the building objects and their relationships to others in a precise manner so that stakeholders can query, simulate and estimate activities and their effects on the building process as a lifecycle entity

Augenbroe, 2009; Baldwin, et al., 2009; Boon and Prigg, 2012; RICS, 2015, cited in Amuda-Yusuf, 2018; p. 2).

BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is a collaboration by different stakeholders at different stages of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder (NBIMS, 2010)."

The Associated General Contractors of America (AGC) perceived BIM as: "Building Information Modeling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and examined to generate information that can be used to make decisions and improve the process of delivering the facility (AGC, 2005)."

Karen (2014) defined BIM as an integrated, structured digital database, informed by the architecture, engineering, and construction, operations industry that consist of 3D parametric objects and allow for interoperability. BIM is an improved process and tool, which contains a set of virtual aspects, concepts and systems of a facility within one environment (Azhar, et al., 2012).

Sacks (2010) described BIM as the utilization of a database infrastructure to summarize built facilities with specific viewpoints of stakeholders so that stakeholders can query, simulate and estimate activities and monitor the building process as a lifecycle entity.

Arayici and Aouad (2010) also defined BIM as the use of ICT technologies to streamline the building lifecycle processes to provide a safer and more productive environment for its occupants, to assert the least possible environmental impact from its existence, and to be more operationally efficient for its owners throughout the building lifecycle.

Arayici and Coates (2012) also viewed BIM in most simple terms as the utilization of a database infrastructure to encapsulate built facilities with specific viewpoints of stakeholders.

BIM means not only using three-dimensional intelligent models but also making significant changes in the workflow and project delivery processes (Hardin, 2009). BIM represents a new paradigm within AEC, one that encourages the integration of the roles of all stakeholders on a project. It has the potential to promote greater efficiency and harmony among players who, in the past, saw themselves as adversaries (Azhar et al., 2008).

BIM also supports the concept of Integrated Project Delivery (IPD) which is a novel project delivery approach to integrate people, systems, business structures and practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle (Glick & Guggemos, 2009).

For more effectiveness and productivity, BIM yields advantages for scheduling, design, implementation, and facility management. From a stakeholder perspective, BIM helps owners, designers, contractors, and management teams to collaborate, visualize and manage construction work better (Azhar et al., 2012).

Consequently, BIM technology receives significant attention from practitioners. In light of improvement, increasing the use of ICT could help to address some of the current experienced challenges. The implementation of BIM should be considered in a developing country Like Ghana.

1.2 Statement of the Problem

Building Information Modeling (BIM) has recently attained widespread attention in the Architectural, Engineering and Construction (AEC) industry (AbuHamra, 2015). The building industry is under great pressure to provide value for money, sustainable infrastructure, visual and analytical checks to enable better code compliance and this has boosted the implementation of Building Information Modelling (BIM) technology (Mihindu and Arayici, 2008).

Alshani and Inginge (2003) noted that the traditional construction tools for Architectural,

Engineering and Construction (AEC) practitioners continue to make construction activities increasingly complex and very cumbrous and therefore necessitate a positive change hence the need for BIM.

According to Ahadzie & Amoa-Mensah (2010) and Laryea (2010), the Ghanaian construction industry faces challenges that include inadequacy of finance and credit services for contractors, design constraints and variation of works, poor preparation and supervision as well as low computerization.

A further challenge of construction management is the poor estimation of project cost (Agele, 2012; cited in Akwaah, 2015).

The industry is changing and adopting new ways of working which include an increased digitalization and implementation of building information modelling (BIM) (Crotty, 2013, Bryde et al. 2013), supply chain integration (Briscoe and Dainty, 2005) and productivity enhancement (Dubois and Gadde, 2002).

In this change process, public clients have been promoted as change agents via their ability to make demands on the AEC industry actors' work practices in procurement

(Linderoth, 2010, Wong et al., 2011; Porwal & Hewage, 2013; Bosch-Sijtsema et al., 2017).

Stakeholders in the construction industry use variety of scheduling methods, study as well as its application; however, they are not sufficiently competent to fulfil the need of building parties. There exists a huge discrepancy among the implementation as well as plan (Allen & Smallwood, 2008).

Drawings are produced by a computer-generated device as 2D charts or plans from the extended period in the absence of three-dimensional structures of real building (Wanga, Zhanga, Chaub, & Anson, 2004). Tarar, and Dang (2012) founded the critical path method (CPM) which is more activity-based has become a more preferred method to plan work nowadays. From Akbas (1998) cited in Jongeling and Olofsson (2007), additional struggle in the adoption of critical path method planning for building schedule is connected to the spatial configuration of the project. Examining detailed CPM schedules with 2D drawing might end up being problematic, and limits the possibility to notice thought-provoking classifications, mistakes and projections. Contradictory clarifications of the plan can be established by diverse participants when observing the 2D data and CPM plan. Factor like these greatly affects the performance of Projects.

Egan (1998) in "Rethinking Construction" also states that within the construction industry almost 10% of materials are wasted and 30% of construction is reworked. This also confirms the need to adopt effective strategies to mitigate the problem.

According to Eastman et al. (2010), more decisions and great effort are needed in the development of a 3D model that supports fabrication and analysis than the existing 2D method of producing construction documents. It has been established most firms that followed these procedures have realized productivity benefits at the construction documentation level regardless of the initial migration cost. It is therefore prudent for the Architectural, Engineering and Construction industry in Ghana to acquire and apply knowledge in building information modelling to overcome the misconception that Ghanaian Engineering, Architectural and Construction industries are noted for shoddy works and non-performance.

In demand to avoid problems with a decrease in productivity, poor collaboration and fragmentation of construction activities associated with the AEC industry, there is the need for BIM use as this can provide a better information sharing system to improve collaboration with the result to increased productivity (Yusuf et al., 2012).

Studies conducted on Building information modelling in Ghana are as follows; Akwaah (2015) researched Guideline for Building the Capacity of Contractors for Adoption and Implementation of Building Information Modelling (BIM) in Ghana.

Nani (2015) on the other hand conducted a study on the Guidelines for Capacity Building of Construction Firms for Building Information Modelling (BIM) Adoption in Ghana.

Furthermore, Eyiah, and Oteng (2017) researched the Acceptance of Building Information Modelling: A Survey of Professionals in the Construction Industry in Ghana.

Also, Akwaah and Nani (2015) look at the fundamental requirements for the adoption and implementation BIM of by contractors, the state of BIM implementation in Ghana by construction firms; the relevance of BIM implementation to construction firms in Ghana; and the challenges of BIM implementation to construction firms in Ghana.

Moreover, Armah (2015) considered the areas of implementing BIM in the Construction Industry of Ghana; the benefits that come with the adoption of BIM in the

Ghanaian Building Industry; and the barriers to BIM implementation in the Construction Industry of Ghana.

Last but not the least, Eyia, and Oteng (2017) researched Technology Acceptance Model (TAM) of BIM which explains how users respond to the introduction of new technology.

All the above research on BIM in Ghana did not investigate the use of Building information modelling and its impact on construction project performance.

This gap created in the above researches necessitated the need to conduct a study on the use of building information modelling and its impact on construction performance within the Ghanaian Construction Industry since that aspect is lacking in the studies on BIM conducted in Ghana.

1.3 Purpose of the Study

The purpose of the study is to investigate the use of building information modelling and its impact on construction performance within the Ghanaian construction industry.

1.4 Research Objectives

To achieve the purpose of the study, these objectives are established:

1. To determine key drivers for acceptance and implementation of BIM in the Construction Industry in Ghana
2. To determine the relevance of BIM maturity in the Ghanaian construction industry.
3. To explore the level of improvement in performance on construction projects as a result of adopting and implementing Building Information Modelling (BIM) in the Construction Industry of Ghana.
4. To determine the various software available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

1.5 Research Questions

1. What are the key drivers for acceptance and implementation of Building Information Modelling (BIM) in Ghanaian Construction Companies/Industries?
2. What is the relevance of BIM maturity in the Ghanaian construction industry?
3. How has the implementation and adoption of BIM improved performance/productivity on Construction projects?
4. What is the software available for BIM in the construction industry?

1.6 Scope and Limitation of the Study

The scope of the study mainly focused on the Construction Industry in Ghana. The study will be conducted by interviewing and surveying Architectural, Engineering and Construction (AEC) / BIM practitioners, AEC / BIM educators and other stakeholders of the construction industry to gain the best possible perspective on the current utilization in the construction industry. The study considered professionals in Engineering, Construction and Architectural industries in Ashanti, Western and Greater Accra Region, due to restricted time frame and financial implications**.**

Numerous difficulties were encountered during the information-gathering stage of the research which posed serious limitations to the execution of the study. Most construction

firms are not prepared to give out information since they considered the researcher an outsider. Contacting authorities of the construction firm and professionals require following strict protocols.

Most professionals in the construction industries had limited knowledge and limited practical experience on BIM issues.

1.7 Significance of the Study

Building Information Modelling is being endorsed as the ultimate tool for teamwork in construction, and numerous studies investigate the need for increased understanding and efficiency of BIM in the practical and working logic. This study is significant because it recognizes the importance of practical and working worth in the construction industry through the utilization of BIM in the construction industry.

This study draws on data and information from a wider variety of stakeholders and project types allowing for a broader and more meaningful understanding of how BIM enhance work in the construction industry. The approach of this study is to provide valuable insight and findings that can be used by companies of varying size and scale for improvement of their own BIM implementation plans. A better understanding of BIM from the practitioner perspective will also allow for expansion and better utilization of BIM to improve construction performance.

Academics could use the findings to better prepare their education programmes and make students cognizant of how to drive construction performance on a construction project with the effective use of BIM.

1.8 Organisation of the Study

The study was organized into six chapters.

- **The first chapter** will focus on the introduction which will include the statement of the problem the research purpose and objectives and another preamble of the research.

- **The Second Chapter** will be the literature review which will involve an extensive review of existing literature on an investigation into the current use of building information modelling within the Ghanaian construction industry other intellectual articles on the subject.

- **The Third Chapter** will be dedicated to the description of the main methodology to be adopted for the study.
- **The Fourth Chapter** will be mainly concerned with Data Presentation and Analysis.
- **The Fifth Chapter** will deal with the discussion of data analyzed in the previous chapter.
- **The Sixth Chapter** which is the last chapter will be purposely designed to look at the findings, conclusion and recommendations on the study.

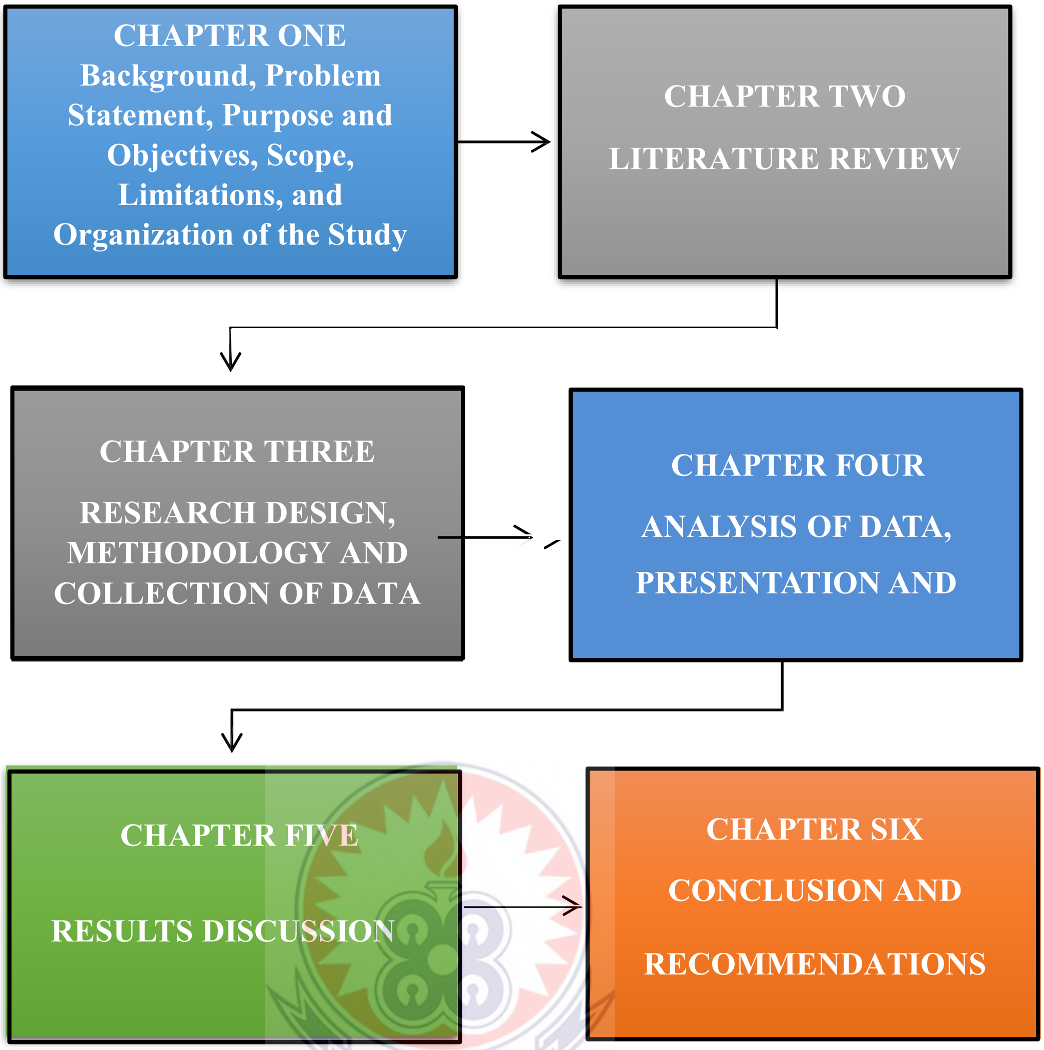

Figure 1. 1 Summary of workflow of the Thesis organization

CHAPTER TWO

LITERATURE REVIEW

This section presents BIM's definition, importance, benefits, uses, risks, barriers and challenges to the implementation of Building information modelling. The section also looked at the summary of existing BIM case studies, the impact of building information modelling (BIM) on construction projects performance and developing productivity/construction performance matrix.

2.1 Building Information Modelling (BIM)

Alvarez-Romero (2014), described Building Information Modelling (BIM) as one of the most promising technologies for the Architecture, Engineering, and Construction industries. Building information models encapsulate and represent the three-dimensional geometry of building objects and the corresponding attributes of a physical facility. By its very nature, it promotes collaboration from design and construction participants around the digital model of a facility. The core of BIM is the building geometry, but also is a structured information base of non-graphical data that provides detailed information about the identity of building components and their properties, for example a wall element in a model exists as a wall and is no longer represented by a set of drawn lines (Alvarez-Romero, 2014).

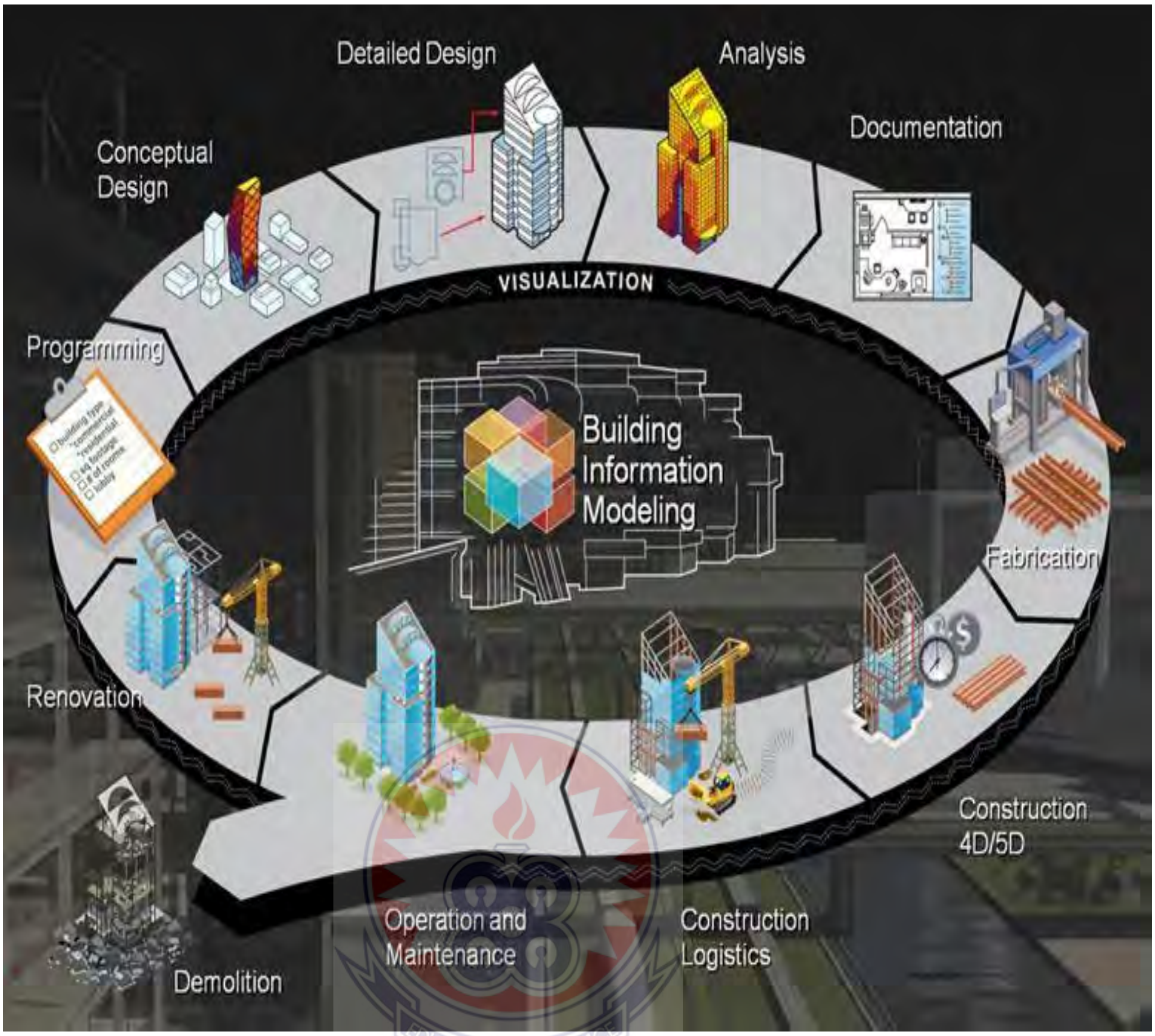

Figure 2.1: Collaborative and Integrated view of BIM through the project lifecycle, Image courtesy of Autodesk® **Source:** Alvarez-Romero (2014, P. 16).

The National Building Information Model Standards (NBIMS) vision for BIM is: "an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by throughout its lifecycle" (NIBS 2008). This definition implies a collaborative and integrated approach (see Figure 2.1).

Building Information Modelling (BIM) BIM is a tool used by designers, engineers, and contractors to present the graphics and database of a construction project to enhance the communication between all project stockholders (Krygiel & Nies, 2008).

Katez and Gerald (2010) define BIM as a "multi-faceted computer software data model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalized facility" (p. 26). Meanwhile, Krygiel and Nies (2008) define BIM as "the creation and use of coordinated, consistent, computable information about a building project in design-parametric information used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, and construction planning" (p. 27).

Furthermore, Azhar (2011) defines BIM as "a modelling technology and associated set of processes to produce, communicate, and analyse building models" (p. 215).

BIM presents the development processes of a project through computer-generated models to simulate the planning, design, construction, and operation process of a project. Although the software is a part of the BIM process, BIM is not just a piece of software or an application among the architectural, engineering, and construction industry (AEC). The discussion about BIM refers to the methodology and the process that BIM creates (Krygiel & Nies, 2008).

BIM can carry out all the project information and graphics in an integrated database. If there is any change in a project component, it will affect other views of the model. The BIM model presents the actual building construction and assemblies and two-dimensional drawings (Azhar, 2011). Figure 2.2 shows a 3D external model for a commercial building design in Iraq presenting the final design concept and the finishing materials of the building.

Figure 2.1: A 3D BIM model for a commercial building design in Babylon city-Iraq

Source: *Hussein and Zaid (2016).*

BIM has created a new development revolution in the design and construction industry. Recently, it has become a dynamic mobile methodology for design and Building Information Modelling (BIM) is causing a major paradigm shift in the Architectural, Engineering and construction industry while creating wider and newer opportunities for young professionals (Uddin & Atul, 2014). While this creates a positive drive and focuses on this industry, it is also important to fully understand what BIM encompasses. BIM is expansive (Turk, 2016). Turk's study discusses the structural, functional and behavioural attributes of BIM which indicate its complex nature. There are many definitions given for BIM, one definition represents it as the replacement of 2-dimensional (2D) drawings as an architectural design with a 3-dimensional (3D) model that is entangled with contextual, data-rich building components and elements (Latiffi, Brahim, Mohd, & Fathi, 2015). Hannele (2015), describes BIM as an emerging modelling technology that challenges the existing working procedures. Another definition describes BIM as the combination of technologies that are expected to increase inter-organizational and inter-disciplinary collaboration in the construction industry with the expectation of improving productivity and the quality of design, construction and maintenance of buildings (Reijo & Sami, 2014). Turk, also explains BIM as a tool of automation and integration that is evolving into a tool of further specialization (Turk, 2016). This view is further supported by the expanding career options in the AEC industry as a result of BIM (Uddin & Atul, 2014).

Roles such as BIM managers, BIM coordinators and BIM specialists are becoming increasingly popular and sought after for BIM assisted construction projects. While all these definitions are accurate, one of the most comprehensive definitions states that BIM is a verb or adjective phrase that describes tools, processes and technologies that are facilitated by digital machine-readable documentation about a building, its performance, it's planning, its construction and later its operation (Sacks, 2010). The complex nature of BIM can be seen in a study that identified the motivations for adopting BIM were multi-dimensional (Dongping, 2016). Therefore, a limited understanding of its capability and resultant impacts would mean that the industry would not be maximizing the benefits of BIM and in some instances could harm the progress and expansion of BIM.

The pursuit to better understand and define BIM has prompted studies to establish a standard for effectively measuring and understanding Building Information Modelling Maturity (BIMM). Chen (2013), explores BIMM and investigated the indicators and related factors that would capture a more comprehensive understanding of BIM as it relates to its maturity (Chen, Hazar Mark, & Mihaela, 2016). The study by Chen proposes that BIMM can be grouped under Technology, Information, Process and People. Succar identifies the factors proposed by Chen but also includes Policy as a factor of BIM (Succar, Sher, & Williams, 2012). Therefore, the literature review indicated that the comprehensiveness of BIMM can be measured through Information, Technology, Process, People and Policy Management. Chen (2013), presented a table listing the dimensions/factors and grouped indicators under the relevant dimensions as seen in Table 2.1.

Table 2. 1: BIMM Dimensions and Indicators

BIMM Dimension	BIMM Indicator
Technology (Chen 2013; Jung and Joo 2011; Succar 2010)	Software Applications Interoperability Hardware Equipment Hardware Upgrade
Information (Chen et al. 2014; Computer Integrate Construction (CIC) 2011; National Institute of Building Science (NIBS) 2007)	Information Delivery Method (IDM) Information Assurance Data Richness Real-Time Data Information Accuracy Graphics Geospatial Capability Work Flow Documentation and Modeling Standards (DMS)
Process (Giel and Issa 2013; Gu and London 2010; Mom et al.	Process & Tech Innovation (PTI) Strategic Planning Lifecycle Process

	Change Management
	Risk Management
	Standard Operating Process (SOP)
	Quality Control
People (Y. Chen, 2013); (Computer Integrated	Senior Leadership
Construction, 2013); (Gu & London, 2010); (Gu, Singh,	Role
& London, 2014)	Reward System
	Competency Profile
	Training Delivery Method (TDM)

Source: Chen (2013)

Collaboration among project participants is important for aspects of Productivity. However, it seems that software interoperability has been a significant issue in the application of BIM (Bynum, 2013). A critical success factor for the successful implementation of BIM is the willingness of participants to share information (Won, 2013). BIM can be used as an effective platform for collaboration by changing the way construction is performed and documented (James & Meadati, 2008). For collaboration in practice, a case study showed that there was an expectation for participants on BIM projects to drive collaboration, as opposed to having an expectation of a collaborative organizational structure (Dossick & Neff, 2010). These studies refer to BIM being a platform for collaboration and as a result a means of achieving productivity. However, the studies indicate a necessity to improve elements such as software interoperability of BIM, while also improving leadership from the participants to share information and collaborate.

The understanding of BIM should extend beyond just industry to the college education framework. There is a need for a more structured and organized BIM education (Pikas, 2013). The collaborated industry studies on BIM and a well-structured BIM education will help with improving and maximizing the benefits of BIM.

2.2 Understanding BIM

From a technology perspective, a building information model is a project simulation consisting of the 3D models of the project components with links to all the required information connected with the project planning, design, construction or operation as depicted in Figure 2.3 (Kymmell, 2008). The BIM technology hailed from the object-oriented parametric modelling technique (Azhar et al., 2008). The term "parametric" describes a process by which an element is modified and an adjacent element or assembly (e.g. a door attached to a wall) is automatically adjusted to maintain a previously established relationship (Stine, 2011).

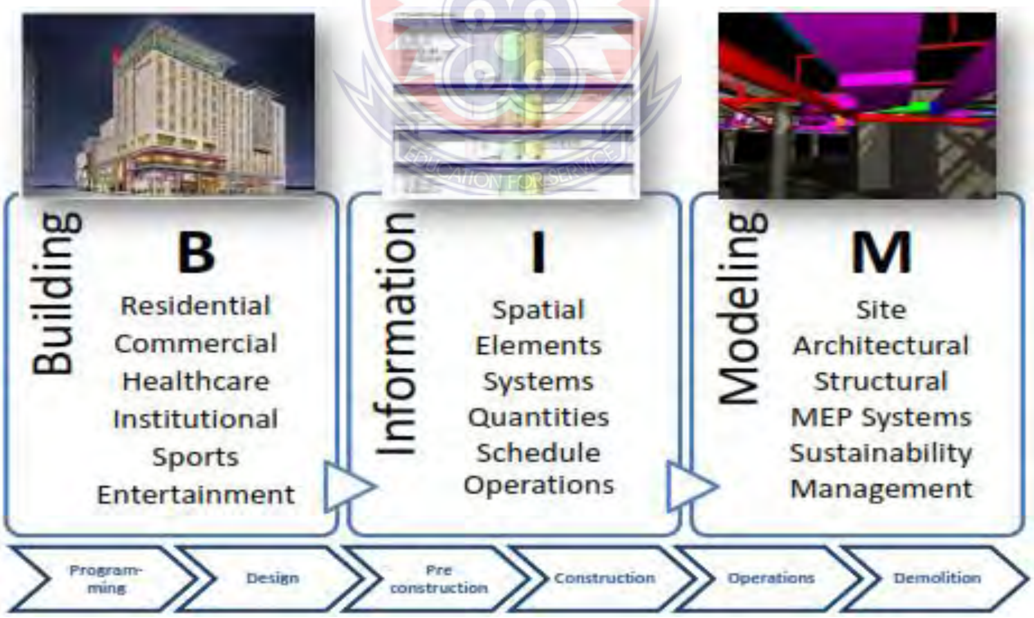

Figure 2.3: A Visual Representation of BIM Concept

Source: (Azhar et al., 2012)

The principal difference between BIM technology and conventional 3D CAD is that the latter describes a building by independent 3D views such as plans, sections and elevations.

Editing one of these views requires that all other views must be checked and updated, and an error-prone process is one of the major causes of poor documentation. In addition, data in these 3D drawings are graphical entities only, such as lines, arcs and circles, in contrast to the intelligent contextual semantic of BIM models, where objects are defined in terms of building elements and systems such as spaces, walls, beams and columns. A building information model carries all information related to the building, including its physical and functional characteristics and project life cycle information, in a series of "smart objects". For example, an air conditioning unit within a BIM would also contain data about its supplier, operation and maintenance procedures, flow rates and clearance requirements (Azhar & Richter, 2009; CRC Construction Innovation, 2007).

Eastman et al. (2011) indicated that the following types of digital models do not fall under the category of BIM:

(1) Models that contain three-dimensional (3D) data only and no object attributes (i.e. missing "i" of BIM);

(2) Models with no support of behaviour;

(3) Models that are composed of multiple two-dimensional (2D) CAD reference files that must be combined to define the building; and

(4) Models that allow changes to dimensions in one view that are not automatically reflected in other views.

2.3 BIM as Technology

From a technology perspective, a building information model is a project simulation consisting of the 3D models of the project components with links to all the required information connected with the project planning, design, construction or operation as depicted (Kymmell, 2008). The BIM technology hailed from the object-oriented parametric modelling technique (Azhar et al., 2008). The term "parametric" describes a process by which an element is modified and an adjacent element or assembly (e.g. a door attached to a wall) is automatically adjusted to maintain a previously established relationship (Stine, 2011).

2.4 BIM as a Process

BIM can be viewed as a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all team members (Owners, architects, engineers, contractors, subcontractors and suppliers) to collaborate more accurately and efficiently than traditional processes. As the model is being created, team members are constantly refining and adjusting their portions according to project specifications and design changes to ensure the model is as accurate as possible before the project physically breaks ground (Carmona & Irwin, 2007). The foundations of BIM are laid on two pillars, communication and collaboration. The successful implementation of BIM requires the early involvement of all project stakeholders. It means that the traditional project delivery systems (e.g. design-bid-build) have a very limited role in BIM-based projects.

Recently the Integrated Project Delivery (IPD) concept emerges as a natural companion to BIM. IPD brings key construction management, trades, fabrication, supplier and product manufacturer expertise together with design professionals and the owner earlier in the process to produce a design that is optimized for quality, aesthetics, constructability, affordability, timeliness and seamless flow into lifecycle management. In the United States, the IPD has become a preferred project delivery system for all major projects involving BIM (McGraw-Hill Construction, 2008). Figure 2.4 illustrates the difference between the "traditional" and "BIM" process.

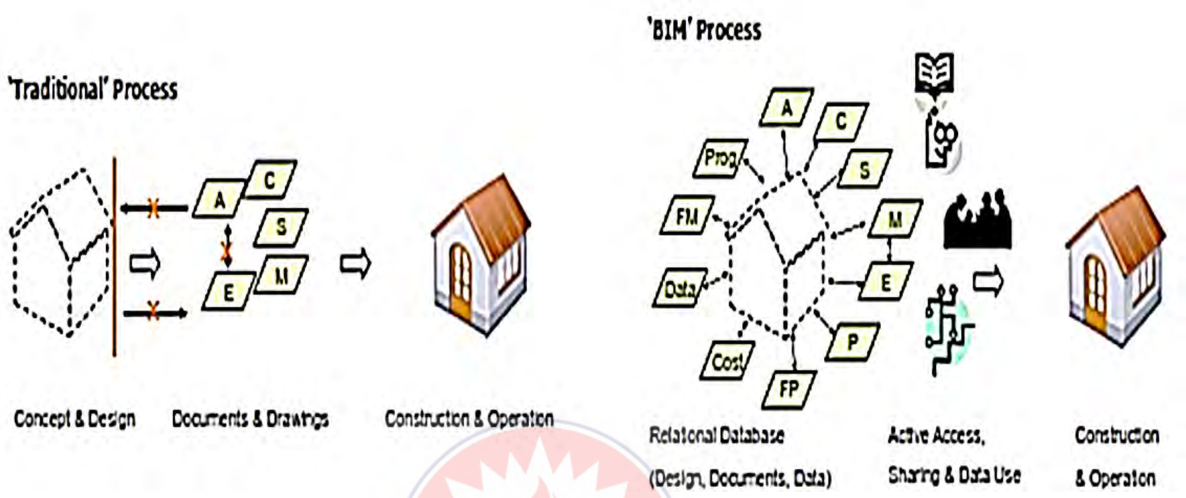

Figure 2.4: A Comparison between "Traditional" and "BIM" Process

Source: (Azhar, et.al 2012)

2.5 Uses of BIM

BIM adoption was expected to expand within firms and across the AEC industry. Kunz and Gilligan (2007) conducted a questionnaire survey to determine the value of BIM use and factors that contribute to success. The main findings of their study are as follows:

- The use of BIM had significantly increased across all phases of design and construction during the past year.
- The major application areas of BIM were construction document development, conceptual design support, and pre-project planning services.
- The use of BIM lowered overall risk distributed with a similar contract structure.

- At the time of the survey, most companies used BIM for 3D and 4D clash detections and planning and visualization services.
- The use of BIM led to increased productivity, better engagement of project staff, and reduced contingencies.
- A shortage was noted of competent building information modellers in the construction industry, and demand was expected to grow exponentially with time.

The results of these surveys indicate that the AEC industry still relies very much on traditional drawings and practices for conducting its business. At the same time, AEC professionals are realizing the power of BIM for more efficient and intelligent modelling. Most of the companies using BIM reported in strong favour of this technology. The survey findings indicate that users want a BIM application that not only leverages the powerful documentation and visualization capabilities of a CAD platform but also supports multiple design and management operations. BIM as a technology is still in its formative stage, and solutions in the market are continuing to evolve as they respond to users' specific needs.

BIM use Classification System and Structure

A BIM Use can be defined as "a method of applying Building Information Modelling during a facility's lifecycle to achieve one or more specific objectives" (Kreider, & Messner, 2013).

National Institute of Building Sciences (2007) disclosed that BIM uses can be classified primarily based on the purpose of implementing BIM throughout the life of a facility. In addition to the purpose alone, several other characteristics can be defined to properly identify and communicate a BIM use. These purposes and characteristics (see Figure 2.5) can be defined at varying levels depending upon the level of specificity required for different applications of the Uses.

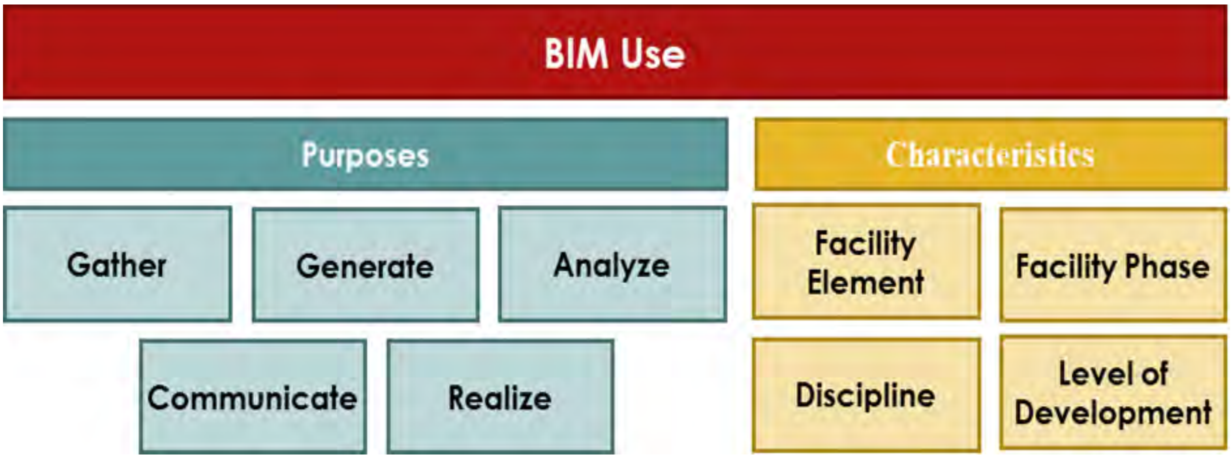

Figure 2.5: The Components of a BIM Use

Source: (Kreider and Messner, 2013, pg. 6).

A BIM Use Purposes communicates the primary objective of implementing the BIM Use. The BIM Use Purposes, shown in Figure 2.6, fall into five primary categories: gather, generate, analyze, communicate, and realize. Within primary BIM Use Purpose categories, numerous subcategories further specify the BIM Use Purposes. 2013).

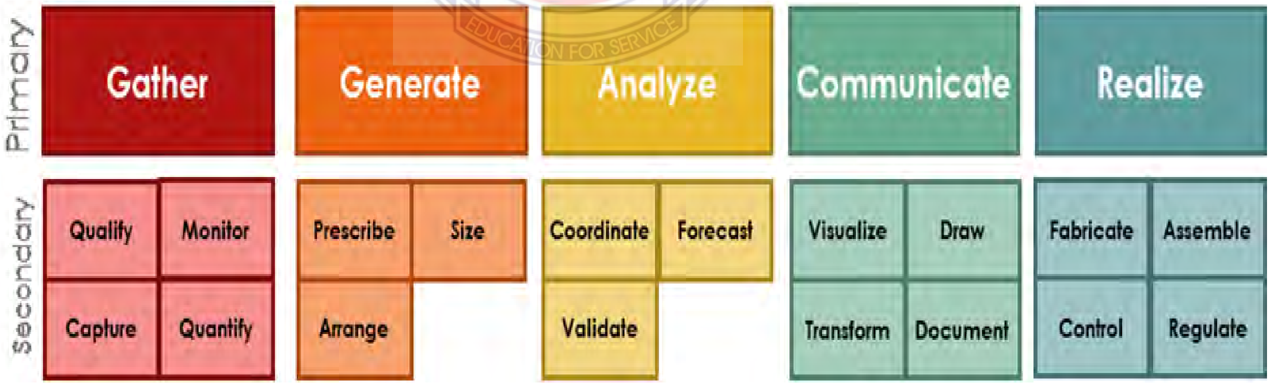

Figure 2.6: BIM use Purposes

Source: (Kreider et al., 2013, p. 6).

2.6 The description of BIM use under the five primary categories and their subcategories

The National Institute of Building Sciences (2007), described BIM use under five primary categories and subcategories as cited in (Kreider et al. 2013, Bamfo-Agyei & Nani, 2017). The five primary categories and their subcategories are detailed below:

2. 6.1 Gather

The objective is to collect or cull facility information. BIM is often used to gather information about a facility at various phases during a facility's life. Whether that is to count the specific amount of an element or determine the current status of a facility element to properly manage that asset, the use of BIM can greatly assist in this effort. This sub purpose of BIM Uses include Capturing, Quantify, Monitoring, and Qualifying. In this primary purpose of BIM Uses, the author is collecting, gathering and organizing information about the facility. This purpose of BIM Uses does not determine the meaning or make inferences about the meaning of the information gathered, rather it is solely focused on the collection and organization of the information. This is often the first step of a comprehensive series of BIM processes (NBIMS, 2007).

- **Capture:**

  BIM is often used to capture geometric and attribute data about a facility. This can be done using several methods and at a number of points during the life of a facility: the elements of the site prior to the development of a new facility or the conditions of an existing facility before renovation. Data could be captured using a laser scanner or recorded manually by inputting model and serial numbers into a spreadsheet. The common factor within this purpose of BIM Uses is that data is captured where no data existed prior. However, it is not newly generated information, rather creating a record of the facility elements that exists (Kreider et al., 2013; p. 9).

- **Quantify**

In this purpose of BIM Uses, BIM is used for counting or collecting the number of specific facility elements. This purpose is often used as part of the estimating and cost forecasting process.

During the design phase of a facility, quantities maybe are defined broadly, represented by a range and subject to change. In the construction phase, quantities become more certain and, in the operations phase, quantities of elements can be readily calculated, say for instance. For example, the area of carpet to be replaced or the vacant space which is available and rentable, the exact area and dimensions should be known (Kreider et al., 2013; p. 10).

- **Monitor**

BIM can be used to monitor real-time performance data of facility elements and facility activities. This purpose of BIM Uses includes those domain uses in which BIM is implemented to understand the performance of particular facility elements or processes. For example, during the operations phase of a facility, BIM can be used to monitor the temperature of a space. It is in this purpose of BIM Uses where Building Automation System data is integrated with the BIM data. Or in construction, BIM could be used to monitor the productivity of a construction process. It is for this purpose of BIM Uses that dynamic real-time data is collected to support decision making (Kreider et al., 2013; p. 10).

- **Qualify**

For this BIM Use Purpose, the status of a facility element is tracked. This includes information such as: does this element exist within the facility? How is it working?

This BIM Use Purpose tracks facility elements over time. For example, in design, what is the element's level of development? In construction, has the element been fabricated? Is it installed? Is it damaged? During operations, this BIM Use Purpose can collect warranty information on the element and whether or not the element is reaching the end of its useful life (Kreider et al., 2013; p. 10).

2.6.2 Generate

The National Building Information Model Standard (NBIMS, 2007) holds the view that the Objective is to create or author information about the facility. Within the lifecycle of a facility, almost every discipline that interacts with the facility will generate information about the facility. This purpose of BIM Uses includes those where BIM is used to create or author information about the facility. It includes prescribing, arranging, and sizing facility elements to various levels of development. Within the design phase, the design team will be the primary generators of information, while in the construction phase, the subcontractors will generate most of the information. Additionally, in the operations phase, that information could be generated by those maintaining the facility when they update or change that facility. Anytime new information is authored, modelled, or created, it is generated.

- **Prescribe**

  The prescribing purpose of BIM Uses is used when a generator determines there is a need for a specific facility element. The programmer or architect of the facility may prescribe the need for certain rooms or spaces in the facility. While the mechanical engineer may prescribe the need for a specific HVAC system. The contractor could determine the need for a temporary construction elements such as a tower crane, and the operator of the facility may prescribe a specific replacement part for the facility. The element prescribed depends on several factors such as phase, discipline, and level of development (Kreider et al., 2013; p. 11).

- **Arrange:** The arranging purpose of BIM Uses includes those Uses in which a location or configuration of a facility element is determined. During the planning phase of a facility's life, this could be the arrangement or adjacency of specific spaces within a proposed facility. During the design phase, it could be the general location of fire protection piping. While in the construction phase, it could include the placement of the hangers that support that piping. This could also be used during the operations phase to determine the placement of furniture systems. In general terms, any time a geometric location of the element is determined, it is being arranged (Kreider et al., 2013; p. 11).
- **Size:** The sizing purpose of BIM Uses is in use when the magnitude of a facility element is determined. Some of those elements during design could include the dimensions of spaces, the shape of a steel beam, or the size of ductwork. During construction, it could include the size of a crane or the thickness of duct insulation. Additionally, during operations, facility managers record the size of replacement parts or modifications to the facility (Kreider et al., 2013; p. 11).

2. 6.3 Analyse: NBIMS (2007) recognises the importance to analyse and this is to examine elements of the facility to gain a better understanding of it. Elements of the facility often require further analysis to determine their viability for the facility. This includes those uses in which a methodical examination of the facility elements is needed. It involves coordinating, forecasting, and validating. It is in these BIM Uses that data is often taken from what was gathered or generated and put into the format into which it can be used for decision making.

- **Coordinate:** The coordinating purpose of BIM Uses include those uses where facility elements are analysed to ensure their relationship to other elements is effective and in harmony. This purpose of BIM Uses is often called clash detection, collision avoidance, design coordination, and interference management, among others. Ultimately, all of the facility elements should work in conjunction with one another. This can include coordinating the design intent of various systems during design, coordinating fabrication and installation during construction or coordinating existing operations while renovations are underway. Overall this purpose of BIM uses ensures that the facility will fit together as it is planned and that all the various systems have been considered (Kreider et al., 2013; p. 12).
- **Forecast**: This purpose of BIM Uses is one of the largest and has the most variance in its application from element to element. Within this purpose of BIM Uses, a detailed analysis is conducted to predict the future performance of the facility and facility elements. Some of the primary performance factors that should be considered include financial, energy, flow, scenario, and temporal. Financial forecasting includes cost estimation of the first cost of construction as well as the life cycle cost of a facility. Energy forecasting predicts how future energy consumption and flow forecasting predicts performance such as airflow or occupant/crowd circulation. Scenario forecasting predicts the performance of the facility during emergencies, such as fire, flood, evacuation, and others. Temporal forecasting predicts the performance of the facility over time to include building degradation and the timing for element replacement. Together this purpose of BIM Uses examines multiple facility variables predicts facility performance. (Kreider et al., 2013; P. 12)

- **Validate:** This purpose of BIM Uses is implemented to validate facility information. This includes purpose checking facility information for accuracy to ensure that it is logical and reasonable. The validating BIM Uses fall into three primary areas: prescription, functionality, and compliance validation.

  Prescription validation ensures that the facility has the elements that were specified and programmed within the facility including the primary element of facility spaces or rooms. The purpose of functionality validation is to ensure that the facility is constructible, maintainable, and usable. Will the facility perform the purpose for which it has been designed? Compliance validation confirms a facility's compliance with codes and standards to include building codes, sustainability standards and others. Anytime facility information that was developed in another process is checked for accuracy, it falls into the category of validating (Kreider et al., 2013; p. 12)

2. 6.4 Communicate: NBIMS (2007) captured the essence of communication as to present information about a facility in a method in which it can be shared or exchanged. One of the primaries uses of BIM is to communicate facility information. The communication purpose of BIM is intended to present information about a facility in a method that can be shared or exchanged. This is often the last step of many other processes when a visualization, transformation, drawing, or document is developed to communicate information from that process to the next user of that information. This is one of the most valuable uses of BIM. It promotes and enhances communication and often reduces the time it takes to communicate. Additionally, communication of the data is often a by-product of the processes to accomplish other BIM uses.

- **Visualize:** As part of the communication purpose of BIM Uses, using BIM to better visualize a facility is very powerful. It is especially powerful for those who have not been trained within the design and construction industry but are critical stakeholders and decision-makers. The visualization purpose of BIM Uses include those BIM Uses which are implemented to form a representation of the facility or facility elements. Often this visualization can be very realistic and detailed. Visualization is often used to support decision making about the facility's design or construction as well as support marketing efforts. It can include walkthroughs, renderings, and schedule visualizations. The fact that the visualization is a by-product of other BIM processes improves the ability of individuals to share facility information more effectively with much additional effort (Kreider et al., 2013; p. 13).

- **Transform:** Often within the BIM process, facility information needs to be taken from one form to another so that it can be received and used by another process. This translation or transformation of data allows for interoperability between different systems. It also allows legacy data to be used by current infrastructure. Some examples include developing spooling information, developing layout data, and developing industry-standard formats. Often this translated data is in the manner in which it is not humanly interoperable, but readable by a machine (Kreider et al., 2013; p. 13).
- **Draw:** While it might be possible to one day rid the industry of drawings and paper, this is not the case today. With that said, BIM improves the ability to develop drawings including detailing and annotating them. These are developed in a parametric method rather static method. For example, when the BIM model is updated, the corresponding drawings and sheets are also updated. Anytime a symbolic representation is developed from an intelligent model, it is considered a

drawing. This includes isometric, one-line diagrams, figures and all other symbolic representations (Kreider et al., 2013; p. 13).

- **Document:** Often it is necessary to record facility data in a written narrative or tabular format. The documented purpose of BIM Uses includes uses in which a record of facility data is created. This includes those Uses necessary to precisely specify facility elements. The output of this BIM Use often includes specifications, submittals, design schedules, and other reporting of facility data (Kreider et al., 2013; p. 13).

2. 6.5 Realise: The Objective is to make or control a physical element using facility information BIM is beginning to allow the industry to remove the direct input of human interaction to develop specific elements of the facility. BIM Uses at this point includes those use in which facility data (BIM data) is used to make or control a physical element of the facility. This gives the industry the ability to fabricate, assemble, control, and regulate elements of the facility. It is this ability that could eventually lead to the improved productivity of both construction and operations of facilities. (NBIMS, 2007)

- **Fabricate:** BIM is allowing the industry to develop facility elements that were not possible before detail product modelling. The fabricate purpose of BIM Uses include those Uses in which facility information is directly used to manufacture elements of the facility. For example, facility information can be used to directly fabricate structural steel shapes from a CNC Machine or directly fabricate ductwork or cut piping. Within the design phase, BIM can be used to quickly generate prototypes of future facility elements, while in operations it could be used to quickly fabricate replacement parts (Kreider et al., 2013; p. 14).

- **Assemble:** The assembling purpose of BIM Uses include those uses where facility information is made available to bring together the separate elements of a facility. While still somewhat of a manual process, the precision that BIM allows, ensures that different systems can be prefabricated. It even gives the ability to fit together systems that were traditionally very separate. Some common example includes curtain wall systems, energy/MEP cores and restrooms (Kreider et al., 2013; p. 14).
- **Control:** BIM affords the ability to use facility information to control equipment operations. The controlling purpose of BIM Uses includes those Uses in which facility information is used to physically manipulate the operation of executing equipment. Some common examples include using facility information to lay-out future work within a facility such as the location of walls or the future placement of imbeds in composite decks. Another example is using facility information to control executing equipment: determining stakeout area using GPS systems which being tied to excavating equipment. It is the ability to control executing equipment that could one day lead to the automated construction site (Kreider et al., 2013; p. 15).
- **Regulate:** The use of BIM to regulate facility elements potentially allows facility operators to optimize their operations. The regulating purpose of BIM uses include those in which facility information is used to inform the operation of a facility element. A common example of this is when information gathered from a temperature monitor (or thermostat) is used to alter the output of the HVAC system. A critical component of the process is that the data is tied to intelligent monitoring systems and the building information model. This allows the systems to make informed decisions based on the entire system. It is this

purpose of BIM Uses which could eventually lead to fully automated operations of a facility (Kreider et al., 2013; p. 15).

2.7 The use of BIM on Site

Over the last years, different methods have been developed to bring BIMs to the workers on-site, enabling access to the model wherever they are. With BIMs on site, it is possible to find and solve problems early. This is a relatively new approach to on-site production control for contractors. Van Berlo and Natrop (2015) state that paper drawings typically dominate information in the workplace. Furthermore, they claim that BIMs on-site can realise a great potential during the construction phase and that construction workers get the benefit of visualising when communicating using a BIM on-site. The different tools that are being used can be divided into three categories.

1) Computer terminals on-site (hereafter called BIM stations),
2) Mobile devices such as tablets and
3) Specialised environments (e.g., BIM caves).

Hewage and Ruwanpura (2006) found that there was a need for a mobile, real-time information source on site. Workers wanted an opportunity to view 3D and 4D (3D with timeline) drawings, technical information, safety information, weather updates, and other information related to the project. Following this research, Ruwanpura et al. (2012) developed an information booth to give workers onsite access to material management, work demonstrations and updated drawings. This led to positive results in productivity, efficiency and worker satisfaction.

Davies and Harty (2013) found that there was only limited research on how BIM has been used on site. They studied the implementation process of “Site-BIM” in a case study of a large hospital project in the UK. Mobile tablets were used to access the project’s BIMs. Tablets onsite combined with in-house document management systems resulted in positive effects, like waste reduction and a lower than usual cost growth for service installations. Harstad et al. (2015) have also documented positive effects from their research on tablets on the construction site. Based on research carried out, we can maintain that tablets provide easy access to information, are easy to carry around, and can increase the understanding of the project while creating a new line of communication.

The contractor Skanska developed a prototype in 2014 of what they called a “BIM computer kiosk” (Bråthen and Moum, 2015). They placed a computer connected to a 50-inch TV-screen on each floor of the building site. These computer kiosks allowed workers to access the 3D-model on site. The equipment was placed inside a protective wooden cabinet with an internet connection (Bråthen and Moum, 2015). The BIM kiosks were widely used on the project and resulted in better productivity, especially for MEP (Mechanical, Electrical and Plumbing) workers.

Vestermo et al. (2016) showed that a device like a BIM-station could help reduce the volume of non–value-adding activities on a project and that the use of BIM-stations in a production phase could enhance lean outcomes.

Van Berlo and Natrop (2015) analysed a concept using BIMs to generate drawings adapted to the task of workers onsite. The idea behind this was to “provide site workers with all the information they need for the task, but nothing more”. They found that this approach created a very good communication tool between the site office management and construction workers. According to Chen and Kamara (2008), the most effective way for workers to acquire information onsite is to collect or capture information at the point where they are, when they need it.

Sacks et al. (2013) have developed a system for workflow control on-site, called KanBIM. The system visualises the workflow of both process- and product information on a 'live' BIM to the workers on site. A field test of the system revealed two desired results: a reduction of time spent 'looking for work and the system could potentially enable site superintendents to double the scope of work they could supervise.

BIMs can result in a leaner construction process with a greater degree of utilisation of prefabrication, improved workflow stability, reduced inventories and enhanced teamwork (Alarcon et al., 2013). When BIMs are implemented in the design phase, there could be some challenges to carry it forward to the construction phase.

Some of the most common barriers are software and hardware issues, cultural barriers, contractual and legal aspects, lack of commitment, lack of training and lack of a client request for it (Alarcon et al., 2013).

2.8 The BIM use Characteristics

Kreider and Messner (2013) noted that BIM use Characteristics are used to more precisely define the BIM Use beyond the purpose and objective alone. Depending on the facility's BIM utilization, it is possible to have multiple disciplines implement multiple BIM Use purposes during multiple phases on multiple facility elements to multiple levels of development.

- **Facility Element:** (Kreider & Messner, 2013) admitted that it is necessary to determine which facility elements the BIM Use(s) will be executed. Elements or other applicable element breakdown structures, the team can determine which facility elements are part of the BIM use.
- **Facility Phase:** After determining the discipline, the planning team should determine during which facility phase they will be implementing the BIM Use. Facility phase designation often results in multiple BIM uses and multiple disciplines. For example, the design team may be responsible for coordination analysis during the design phase and the construction team may be responsible

for the coordination analysis during the construction phase. (Kreider& Messner, 2013)

- **Discipline:** Kreider and Messner (2013) indicated that the disciplines include planning, design, investigation, project management, construction, facility use, and support. While the primary discipline may be identified, this does not preclude other disciplines from being responsible for part of the BIM Use. Additionally, it is possible to have multiple disciplines responsible for BIM Use. This would then make for separate BIM Uses.
- **Level of Development:** For each of the BIM Uses, the level of development should be identified to maximize the benefit from the BIM Use. The Level of Development describes the level of detail /granularity to which a Model Element is developed. AIA / BIM Forum has recently released a major revision to the level of development specification. This revision further specifies the level of development for specific elements of the facility. Table 2.2 shows a description of the Level of Development definitions (Kreider & Messner, 2013).

Table 2.1: Fundamental LOD Definitions

LEVEL OF DEVELOPMENT	DESCRIPTION
LOD 100	The Model Element may be graphically represented in the Model with a symbol or other generic representation but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, the tonnage of HVAC, etc.) can be derived from other Model Elements.
LOD 200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 300	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
LOD 400	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Source: (Kreider and Messner (2013; p. 17)

2.9 Applications of BIMS

BIM applications span the entire life cycle of a facility. This section presents a brief overview of BIM applications in the project programming, design, preconstruction, construction, and post-construction (operations and maintenance) phases.

BIM and Project Programming: The use of BIM in the project programming phase allows the project team to analyse space and understand the complexity of space standards and land regulations, which saves time and provide the team with the opportunity of doing more value-added activities (CICRP, 2009, Azhar et al., 2012).

Recently, some researchers have investigated the integration of BIM with GIS (Geographical Information Systems) which can aid project planners in selecting an appropriate site and conducting project feasibility and marketing studies (Berlo and Laat, 2011; Isikdag et al., 2008).

The following are some of the benefits of 'GIS-BIM' based site analysis (CICRP, 2009, Azhar et al., 2012):

- Aid in determining if potential sites meet the required criteria according to project requirements, technical and financial factors, etc.
- Decrease costs of utility demand and demolition.
- Minimize the risk of hazardous materials.

2.9.1 BIM and Project Design

The architects and engineers can take advantage of BIM applications at different stages of project design namely schematic design (SD), detailed design (DD) and construction detailing (CD) (Azhar et al., 2012).

Table 2.3 illustrates specific BIM applications in each stage of project design.

Schematic design	Detailed design	Construction Detailing
✓ Options Analysis (to compare multiple designs options) ✓ Photo Montage (to integrate photo-realistic images of the project with its existing conditions)	✓ 3D exterior and interior models ✓ Walk-through and fly-through animations ✓ Building performance analyses (e.g. energy modelling) ✓ Structural analysis and design	✓ 4D phasing and scheduling ✓ Building systems analysis (e.g. clash detections) ✓ Shop or fabrication drawings

Source: (Azhar et al., 2012)

2.9.2 BIM in the Preconstruction Phase

Azhar et al. (2012) summarized the applications of BIM in the preconstruction phase as follows:

- **Estimating:** From building information models, the contractors can perform fairly accurate quantity survey and prepare detailed estimates.
- **Site coordination:** Using 3D or 4D site coordination models, the contractors can plan for site logistics, develop traffic layouts, and identify potential hazards at the job site which can aid in preparing a more realistic site safety plan.
- **Constructability analysis:** Using BIM models, the project team can perform detailed constructability analysis to plan the sequence of operations at the job site.

2.9.3 BIM in the Construction Phase

Azhar et al. (2012) further stated that at the construction phase, the project team can use BIM for the following activities: Project progress monitoring using 4D phasing plans;

for trade coordination meetings

BIM in the Post-construction Phase: A building information model contains complete information about a facility as it evolves through planning, design and construction. This information can be leveraged for downstream use by facility managers thereby making operations and maintenance of a facility more efficient. Research suggests that 85% of the lifecycle cost of a facility occurs after construction is completed and approximately $10 billion are annually lost in the U.S. alone due to inadequate information access and interoperability issues during operations and maintenance phases (Newton, 2004, cited Azhar et al., 2012). The use of BIM for facility management (FM) can significantly help to prevent these loses.

Throughout the construction period, the project team must continuously update the BIM model so that it reflects the most up-to-date information which later on can be used by the facility managers for building operations and maintenance. This model can be used for operations and maintenance purposes.

The model can be used to demonstrate the entire building life cycle (Bazjanac, 2006, cited Azhar et al., 2012). As a result, quantities and shared properties of materials can be readily extracted. Scopes of work can be easily isolated and defined. Systems, assemblies, and sequences can be shown on a relative scale within the entire facility or group of facilities. Construction documents such as drawings, procurement details, submittal processes, and other specifications can be easily interrelated (Khemlani, Papamichael, & Harfmann, 2006, cited Azhar et al., 2012).

BIM can be viewed as a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all design team members (owners, architects, engineers, contractors, subcontractors, and suppliers) to collaborate more accurately and efficiently than using traditional processes. As the model is being created, team members are constantly refining and adjusting their portions according to project specifications and design changes to ensure the model is as accurate as possible before the project physically breaks ground (Carmona & Irwin, 2007, cited Azhar et al., 2012). It is important to note that BIM is not just software; it is a process and software. BIM means not only using three-dimensional intelligent models but also making significant changes in the workflow and project delivery processes (Hardin, 2009). BIM represents a new paradigm within AEC, one that encourages the integration of the roles of all stakeholders on a project. It has the potential to promote greater efficiency and harmony among players who, in the past, saw themselves as adversaries (Azhar, et al., 2008).

BIM also supports the concept of integrated project delivery, which is a novel project delivery approach to integrate people, systems, and business structures and practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle (Glick & Guggemos, 2009).

A building information model can be used for the following purposes:

- **Visualization:** 3D renderings can be easily generated in a house with little additional effort.
- **Fabrication/shop drawings:** It is easy to generate shop drawings for various building systems. For example, the sheet metal ductwork shop drawings can be quickly produced once the model is complete.
- **Code reviews:** Fire departments and other officials may use these models for their review of building projects.
- **Cost estimating**: BIM software has built-in cost estimating features. Material quantities are automatically extracted and updated when any changes are made in the model.
- **Construction sequencing:** A building information model can be effectively used to coordinate material ordering, fabrication, and delivery schedules for all building components.
- **Conflict, interference, and collision detection:** Because building information models are created to scale in 3D space, all major systems can be instantly and automatically checked for interferences. For example, this process can verify that piping does not intersect with steel beams, ducts, or walls.
- **Forensic analysis:** Abuilding information model can be easily adapted to graphically illustrate potential failures, leaks, evacuation plans, and so forth.

- **Facilities management:** Facilities management departments can use it for renovations, space planning, and maintenance operations.

Following are some additional applications of BIM for facility operations and management:

(1) Maintenance work order management;

(2) Emergency service request management;

(3) Space planning and management;

(4) Inventory management and inspections;

(5) Move management; and

(6) Real estate portfolio management.

2.10 Importance of BIM

BIM is a significant tool that is used by designers, architects, and contractors to manage increasing information and complexity in construction projects (Chelson, 2010; Krygiel and Nies, 2008).

During the last century, building design and construction has changed dramatically. Complex interrelated and integrated systems are now included in the building layers. For example, the modern office building became more complicated because of new systems such as data and telecom, air conditioning, security, underground parking, sustainability, etc. Figure 2.7 shows

some of these layers, which include structural design, architectural, and material quantities (Krygiel and Nies, 2008).

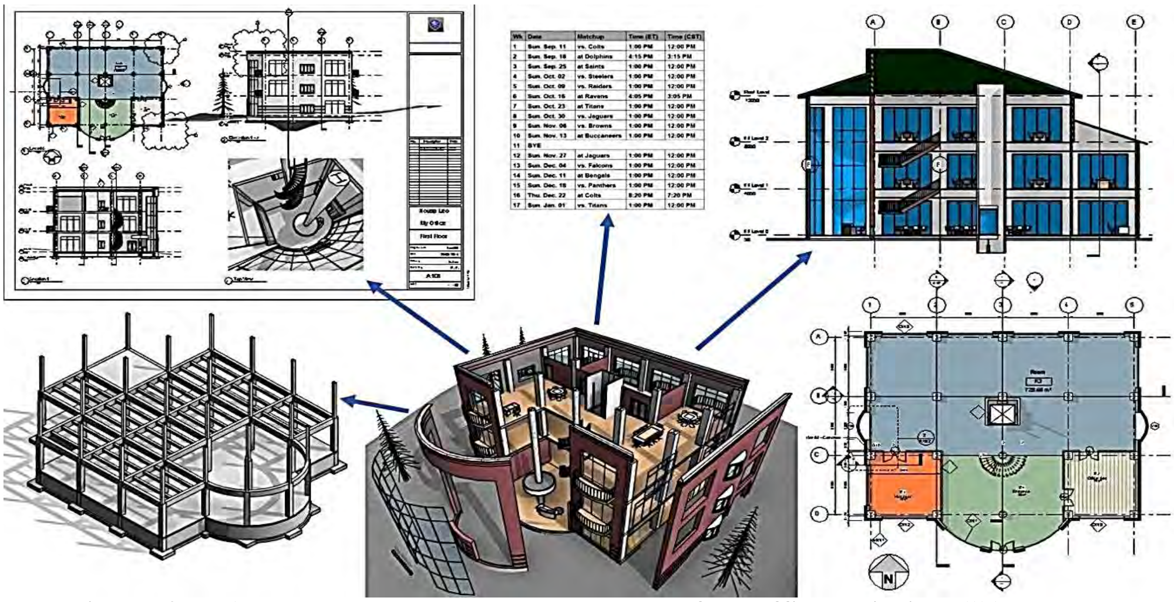

Figure 2.7: A BIM model shows some layers of an office building ("Autodesk Revit *Training," 2015) Source:* *Hussein and Zaid (2016*).

BIM concepts and workflows promise to deliver substantial benefits to "all participants in the process of designing, constructing, owning and refurbishing buildings" (BIS, 2011, p. 7).

The key benefit of a building information model is its accurate geometrical representation of the parts of a building in an integrated data environment (CRC Construction Innovation 2007).

It provides higher efficiency during construction and reduces variation in design and request for information (RFI) at all project delivery stages (Aranda-Mena et al., 2008). BIM is best for off-site prefabrication of structural elements because it easily co-ordinates and assimilates all structural element with the colour-coded format to enhance model development (Eastman et al., 2011). Commutatively, BIM provides ease of project documentation with better precision, up to a minute conception of models and quality management of work during the entire project life (Aranda-Mena et al., 2008; Eastman, 2008).

BIM saves a lot of time. This is because of the possible absence and reduction of repetitive work, drawing mistakes and oversights (Eastman, 2008). Also, it automatically updates any design variation in the building model; most arguments at the design stage are resolved easily with BIM to give way for effective project planning (McGraw-Hill, 2009; Popov et al., 2008). It also identifies clashes in programming before construction begins. More so, the likelihood of rework in conventional methods is curtailed with BIM implementation.

Furthermore, early cost estimation of the project is possible because BIM can enumerate quantities of materials. This helps in quantitatively and qualitatively checking design inputs early enough in the planning process (Eastman, 2008; Ahzar et al., 2012) and to alert project owners on the possible cost consequences of the design for informed decisions to be made (Bloomberg et al., 2012; Eastman, 2008). A lot of research recount financial benefits in the use of BIM (Jardim-Goncalves & Grilo, 2010; McGraw Hill, 2009) and has proven that it unifies all technical construction professional as well as perfecting bids and project pricing (Philip, 2012).

2.11 Importance of Building Information Modelling in the Current Environment

BIM in Construction Industry (2018) outline these as the importance of Building information Modelling in the current environment.

1) Helps improve coordination: BIM provides improved coordination among various disciplines involved in various project phases. For instance, through BIM, a model created by an architect can be studied by structural designer, MEP consultants or facade consultants for their respective domain-specific design and engineering tasks.
2) Expedites pace of the Construction Cycle: BIM helps improve the construction cycle by completely eradicating plagiarism and identifying standard and redundant components.

3) Enhanced visualizations: 3D visuals generated via BIM provide clarity on the product to various stakeholders, thus providing them sufficient visibility of the practical challenges.
4) Reduced wastage and Cost: BIM users can resolve coordination issues, produce a near 'zero-defect design and predict the material required more accurately, leading to reduced wastage on-site during the construction and maintenance processes.
5) Refined end product: BIM guarantees a better certainty of the end product over traditional CAD technology.
6) Improved project monitoring: BIM also assists a user in keeping a check on the progress of a project across all the phases of design development to construction to project operations and the maintenance phase.

2.12 General Benefits of BIM

The benefits attributed to BIM represent unique project deliverables and invariably reflect the industry's long-term expectations from this new CAD paradigm (Ibrahim et al., 2004).

Below is a non-exhaustive list of BIM benefits:

- BIM will reduce the industry's fragmentation (CWIC, 2004);
- BIM significantly reduces labour costs, production rework and installation conflicts (Khanzode et al., 2008);
- BIM creates a transparent project environment (Leicht and Messner, 2008);
- BIM enhances collaboration between construction professionals (Alshawi and Faraj, 2002);
- BIM is an "integration of product and process modelling" (Kimmance, 2002, p. 6);

- BIM allows rapid/accurate updating of changes; reduction of effort required for establishing spatial programmes; improved communication within the project team; and elevated confidence in scope completeness (Manning and Messner, 2008) as reported in (Linderoth, 2010);
- BIM results in a "clear improvement in engineering design quality, in terms of error-free drawings, and steadily increasing improvement in labour productivity" (Kaner, Sacks, Kassian, & Quitt, 2008, p. 303);
- A combined BIM/Lean approach is more efficient than a Design-Bid-Build or a Design-Build project delivery process (USAF, 2010);
- BIM can address the emerging challenges of sustainability within the construction industry (Watson, 2010);
- The adoption of BIM principles will allow all construction industry players to gain "substantial benefits in financial terms" (BIS, 2011, p. 7); and

BIM has many benefits including automated assembly, better design, controlled whole-life costs and environmental data, enhanced processes, higher production quality, and improved customer service (ACG, 2010).

- **Faster and more effective processes:** Information is more easily shared and can be value-added and reused.
- **Better design:** Building proposals can be rigorously analysed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions.
- **Controlled whole-life costs and environmental data:** Environmental performance is more predictable, and lifecycle costs are better understood.
- **Better production quality:** Documentation output is flexible and exploits automation.

- **Automated assembly:** Digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems.
- **Better customer service:** Proposals are better understood through accurate visualization.
- **Lifecycle data:** Requirements, design, construction, and operational information can be used in facilities management.

BIM is a methodology of continuous improvement and refinement (Krygiel and Nies, 2008). It has multiple benefits that can directly affect several important issues in a construction project such as quality, time, cost, and safety (Ningappa, 2011).

The basic benefits of a BIM-based methodology are:

- **3D simulation:** A 3D geometric model illustrates the exterior and interior building design, including all the components. This simulation illustrates different building assemblies that can be combined in the project and it can show environmental variables on building designs, calculate building materials, time, and quantities (Krygiel and Nies, 2008).
- **Increase design accuracy and reduce errors:** BIM simulates building construction and design on the computer before the real construction activities start on-site, which leads to increased accuracy and reduced errors for both building quantities and qualities. Furthermore, it enables the design team to calculate building materials and environmental variables on the job site in real-time rather than by manual estimation (Krygiel and Nies, 2008).
- **Increase drawing efficiency:** With BIM, the design teams can create the design drawing once instead of creating many separate drawings such as plans, elevations, sections, and perspectives. This can save time and enable

the team to focus on other design issues and details (Krygiel and Nies, 2008).

- **Reduce conflict*:*** The data in a BIM project can help a designer to investigate the compatibility of the components of a project and identify potential conflicts in a construction project (Madsen, 2008). Identifying conflicts on digital files before the construction activities start on-site can save time. Besides, identifying pre-construction conflicts can help to reduce bid amounts and decrease the difference between bids and actual costs (Krygiel & Nies, 2008).
- **Increase collaboration:** BIM increases the collaboration between design teams, engineers, and contractors and increases project efficiency by sharing BIM information, especially at the beginning of the design process in project development. For instance, contractors can review BIM models and report useful feedback to the design team and engineers regarding any deficiencies that might have occurred. That feedback could help the design team fix the issues early in the design process. This would save money and time by avoiding potential delays that might happen if the deficiencies were discovered late in the construction process. Moreover, increased collaboration can reduce the number of change orders and requests for information (RFIs) that could lengthen construction schedules (Katez and Gerald, 2010).
- **Reduce fabrication and estimation time:** Fabricators can get the detailed specifications directly from the BIM models. This saves time and avoids errors that might happen when these fabrication specifications are extracted manually. Moreover, prefabrication components are more likely to fit when

delivered because of the accuracy of the visualization design and to avoid conflicts. Similarly, suppliers, when they need to extract material quantities, can extract them directly from the BIM model, thus saving time and avoiding project delays (Katez and Gerald, 2010).

- **Life -cycle management:** A BIM model can be effective not just during construction time; it can be used during the whole life cycle of a project. The BIM model includes all maintenance information regarding building components. Facility owners can use this model to determine when they need to do maintenance and repair and how much it will cost. In addition, BIM models can be used to analyze the compatibility of any extension or development that might happen for a project in the future, and estimate the real cost for that expense (Katez & Gerald, 2010). The BIM model can also help in better understanding the environmental performance and life cycle cost of a project. Figure 2.8 shows the database infrastructure generated by BIM that stakeholders can use.
- **Increase the efficiency of processes:** BIM models can illustrate planned work between teams easily and quickly (Azhar, 2008). According to the survey conducted by McGraw- Hill constructions, more than 48% of the owners say that with BIM, the benefits are high due to the lower number of RFIs and site problems (Ningappa, 2011).

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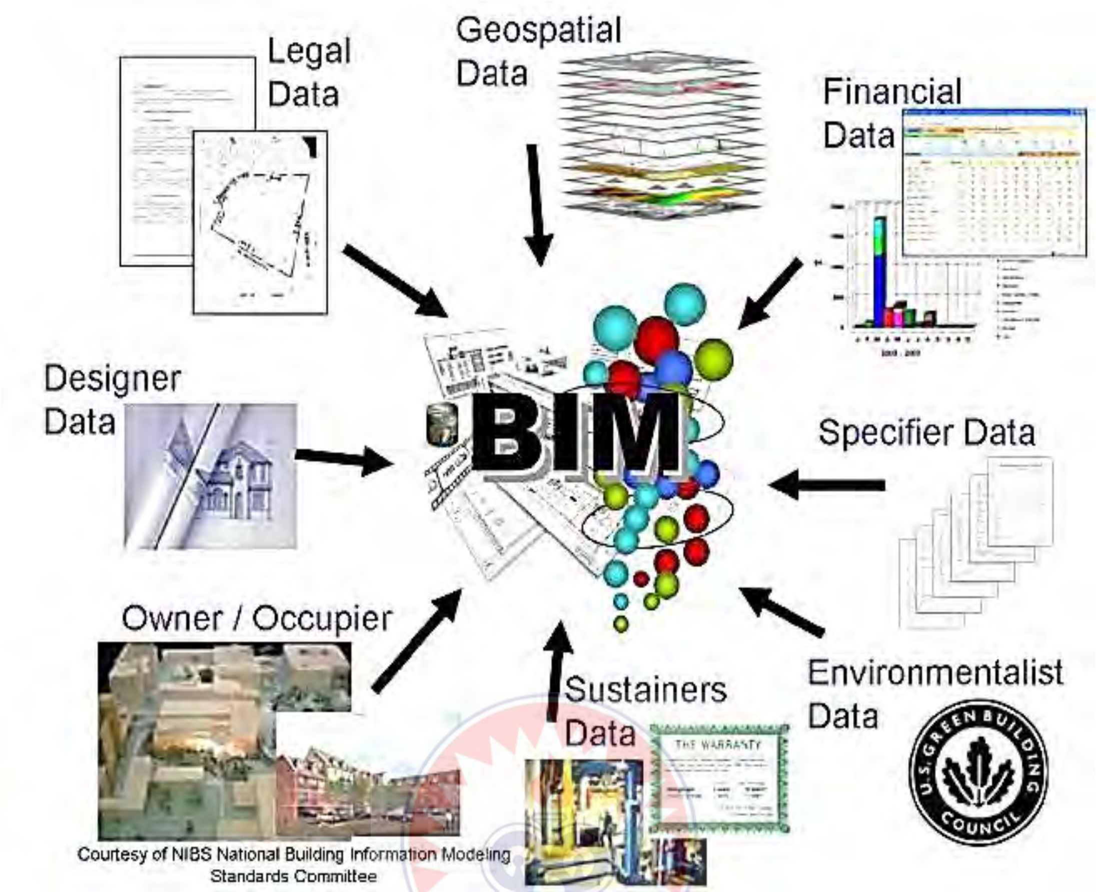

Figure 2.8: Communication, collaboration and Visualization with BIM model

Source: Arayici, Egbu & Coates (2012); cited in Hussein and Zaid (2016)

- **Data entry errors:** With BIM models, contractors can avoid many errors and mistakes that might happen during computation data entry. There is no need to extract the data manually from the design model and enter it back into another computer program to perform building code or LEED checks. BIM models can accomplish this task automatically by comparing building components to the relevant building codes and energy efficiency standards (Katez and Gerald, 2010).
- **4D capabilities make scheduling easier with BIM*:*** BIM models can visualize spaces in excellent 3D views. Another characteristic of BIM is that it can visualize the construction phases over time; this ability is called

4D (3D plus time). BIM is a helpful tool that can be used in visualizing the construction process and illustrating it to coordinate and communicate between the audience, teamwork, and stakeholders (Ho & Matta, 2009).

2.13 BIM Benefits for Project Stakeholders

Benefits of BIM for project owners, designers, constructors and facility managers

Project Owners can achieve significant benefits on projects where BIM technology and processes are applied. Eastman et al. (2011) and Reddy (2011) summarized the following benefits of BIM for project owners:

(1) Early design assessment to ensure project requirements are met;

(2) Operations simulation to evaluate building performance and maintainability;

(3) Low financial risk because of reliable cost estimates and reduced number of change orders;

(4) Better marketing of project by making effective use of 3D renderings and walk-through animations; and

(5) Complete information about building and its systems in a single file.

Project Designers The project architects and engineers can take advantage of BIM in schematic and detailed design; and construction detailing phases.

The following are some of the main benefits of BIM for project designers:

(1) Better design by rigorously analysing digital models and visual simulations and receiving more valuable input from project owners;

(2) Early incorporation of sustainability features in building design to predicts its environmental performance;

(3) Better code compliance via visual and analytical checks;

(4) Early forensic analysis to graphically assess potential failures, leaks, evacuation plans and so forth; and

(5) Quick production of shop or fabrication drawings (Kymel, 2008).

The early design and preconstruction stages of a building are the most critical phases to make decisions on its sustainability features (Azhar et al. 2009). Traditional Computer-Aided Design (CAD) planning environments cannot typically perform sustainability analyses in the early stages of design development. Building performance analyses are typically performed after the architectural design and construction documents have been produced. This failure to analyze sustainability continually during the design process results in an inefficient process of retroactive modification to the design to achieve a set of performance criteria (Schueter & Thessling, 2008). To assess building performance in the early design and preconstruction phases realistically, access to a comprehensive set of data regarding a building's form, materials, context and systems is required. Since BIM allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures to be incorporated throughout the design process (Autodesk, 2008). Azhar et al. (2011) found that information for up to 17 LEED (Leadership in Energy and Environmental Design, a green building rating system used in the USA) credits can be obtained in the design phase by performing BIM-based sustainability analyses. It means a building information model can be used as a by-product for LEED analysis thereby saving substantial time and resources.

Project Constructors in the United States general contractors are the early adopters of BIM among all stakeholders (Azhar et al. 2008). The contractors and subcontractors can use BIM for the following applications (Hardin, 2009):

(1) Quantity take-off and cost estimation;

(2) Early identification of design errors through clash detections;

(3) Construction planning and constructability analysis;

(4) Onsite verification, guidance and tracking of construction activities;

(5) Offsite prefabrication and modularization;

(6) Site safety planning;

(7) Value engineering and implementation of lean construction concepts; and

(8) Better communication with the project owner, designer, subcontractors and workers on site.

Through these applications constructors can achieve the following benefits:

(1) High profitability;

(2) Better customer service;

(3) Cost and schedule compression;

(4) Better production quality;

(5) More informed decision making; and

(6) Better safety planning and management.

2.14 Risks and Barriers to Implementing BIM

According to Azhar, et al. (2012), besides the numerous benefits of BIM for project stakeholders there are many risks and barriers to implementing BIM. In other words, BIM is not a panacea for every project and every firm. The BIM-related risks can be divided into two broad categories:

(1) Technology-related risks; and

(2) Process-related risks.

Technology-related Risks the first technology-related risk is the lack of BIM standards for model integration and management by multidisciplinary teams. Integrating multidisciplinary information in a single BIM model requires multiuser access to the BIM model. This requires the establishment of protocols in the project programming phase to ensure consistency in information context and formatting styles. At the moment, since there are no standard protocols available, each firm adopts its standards. This could create inconsistencies in the model, which if not properly detected, could lead to an inaccurate and inconsistent BIM model. The project team should perform frequent "model audits" to ensure avoidance of any such issues (Weygant, 2011).

The interoperability issues, though significantly reduced during the last 5 years, still pose considerable risk. Interoperability is the ability to exchange data between applications to facilitate automation and avoidance of data re-entry. The introduction of Foundation Classes (IFC) and XML Schemas has Industry significantly helped to solve interoperability issues (Smith & Tardif, 2009). However, both of these approaches have inherent limitations. The users must research interoperability while selecting BIM software applications.

When project team members other than the owner and architect/engineer contribute data that are integrated into the building information model, licensing issues can arise. For example, equipment and material vendors offer designs associated with their products for the convenience of the lead designer in hopes of inducing the designer to specify the vendor's equipment. While this practice might be good for business, licensing issues can arise if the designs were not produced by a designer licensed in the location of the project (Thompson and Miner, 2007).

Process-related Risks The process-related risks include legal, contractual and organizational risks. The first risk is the lack of determination of the ownership of the BIM data and the need to protect it through copyright laws and other legal channels. For example, if the owner is paying for the design, then the owner may feel entitled to own it, but if team members are providing proprietary information for use on the project, their proprietary information needs to be protected as well. Thus, there is no simple answer to the question of data ownership; it requires a unique response for every project depending on the participants' needs. The goal is to avoid inhibitions or disincentives that discourage participants from fully realizing the model's potential (Thompson, 2001). To prevent disagreement over copyright issues, the best solution is to outlined in the contract documents ownership rights and responsibilities (Rosenberg, 2007).

Another contractual issue to address is who will control the entry of data into the model and be responsible for any inaccuracies. Taking responsibility for updating building information model data and ensuring its accuracy entails a great deal of risk. Requests for complicated indemnities by BIM users and the offer of limited warranties and disclaimers of liability by designers are essential negotiation points that need to be resolved before BIM technology is used. It also requires more time spent inputting and reviewing BIM data, which is a new cost in the design and project administration process. Although these new costs may be dramatically offset by efficiency and schedule gains, they are still a cost that someone on the project team will incur. Thus, before BIM technology can be fully used, not only must the risks of its use be identified and allocated, but the cost of its implementation must be paid for as well (Thompson and Miner, 2007).

The integrated concept of BIM blurs the level of responsibility so much that risk and liability are likely to be enhanced. Consider the scenario in which the owner of the building files suits over a perceived design error. The architect, engineers, and other contributors to the BIM process look to each other to try to determine who responsibility for the matter had raised. If disagreement ensues, the lead professional not only will be responsible as a matter of law to the claimant but may have difficulty proving fault with others such as the engineers (Rosenberg, 2007).

One of the most effective ways to deal with such risks is to have collaborative, integrated project delivery contracts in which the risks of using BIM are shared among the project participants along with the rewards. Recently, the American Institute of Architects released an exhibit on BIM to help project participants define their BIM development plan for integrated project delivery (Building Design and Construction, 2008). This exhibit may assist project participants in defining model management arrangements, as well as authorship, ownership, and level-of-development requirements, at various project phases.

Based on a survey of 31 contracting firms in the United States.

Ku and Taiebat (2011) found the following barriers to BIM implementation:

(1) Learning curve and lack of skilled personnel

(2) High cost to implementation

(3) Reluctance of other stakeholders (e.g. architect, engineer, contractor)

(4) Lack of collaborative work processes and modelling standards

(5) Interoperability

(6) Lack of legal/contractual agreements

2.15 BIM Future Challenges

The productivity and economic benefits of BIM to the AEC industry are widely acknowledged and increasingly well understood. Further, the technology to implement BIM is readily available and rapidly maturing. Yet BIM adoption has been much slower than anticipated (Azhar et al. 2008). There are two main reasons, technical and managerial.

The technical reasons can be broadly classified into three categories (Bernstein & Pittman 2005):

The need for well-defined transactional construction process models to eliminate data interoperability issues, the requirement that digital design data be computable, and the need for well-developed practical strategies for the purposeful exchange and integration of meaningful information among the building information model components.

The management issues cluster around the implementation and use of BIM. Right now, there is no clear consensus on how to implement or use BIM. Unlike many other construction practices, there is no single BIM document providing instruction on its application and use (Associated General Contractors of America, 2005). Furthermore, little progress has been made in establishing model BIM contract documents (Post, 2009). Several software firms are cashing in on the "buzz" of BIM and have programs to address certain quantitative aspects of it, but they do not treat the process as a whole. There is a need to standardize the BIM process and to define guidelines for its implementation. Another contentious issue among the AEC industry stakeholders (i.e., owners, designers, and constructors) is who should develop and operate the building information models and how the developmental and operational costs should be distributed. To optimize BIM performance, either companies or vendors, or both, will have to find a way to lessen the learning curve of BIM trainees. Software vendors have a larger hurdle of producing a quality product that customers will find reliable and manageable and that will meet the expectations set by the advertisements. Additionally, the industry will have to develop acceptable processes and policies that promote BIM use and govern today's issues of ownership and risk management (Post, 2009).

The researchers and practitioners have to develop suitable solutions to overcome these challenges and other associated risks. As several researchers, practitioners, software vendors, and professional organizations are working hard to resolve these challenges, it is expected that the use of BIM will continue to increase in the AEC industry (Azhar et al., 2008).

In the past, facilities managers have been included in the building planning process in a very limited way, implementing maintenance strategies based on the as-built condition at the time the owner takes possession. In the future, BIM modelling may allow facilities managers to enter the picture at a much earlier stage, in which they can influence the design and construction. The visual nature of BIM allows all stakeholders to get important information, including tenants, service agents, and maintenance personnel before the building is completed. Finding the right time to include these people will undoubtedly be a challenge for owners (Azhar et al., 2008).

Industry's expectations of BIM are neither readily nor necessarily matched by reality. Numerous studies have shown that implementing BIM presents significant challenges in BIM education, multidisciplinary workflows and organizational transformation. A non-exhaustive list summarizing these is provided below: (Succar, 2013).

- BIM adoption and collaboration are negatively affected by the construction industry's confrontational culture (Watson, 2011);
- BIM is adversely influenced by "organizational and cultural divisions between designers and builders and between contractors and subcontractors" (Dossick & Neff, 2009, p. 466);
- BIM implementation across an organization has significantly different, and even competing requirements, to BIM implementation on projects (Kunz, 2012);
- There are only a few "procedures or tools to guide practical BIM implementation processes" (Mäkeläinen, 2012, p. 497);

- BIM adoption is affected by the lack of interoperability between different software platforms (Eastman, Teicholz, Sacks, & Liston, 2011);
- There are many business and legal barriers to collaborative BIM processes (Sebastian, 2010);
- BIM causes workflow disruptions and requires a reconsideration of construction business practices (Mihindu & Arayici, 2008);
- BIM implementation has resulted in the emergence of new knowledge and skill gaps within the industry (Mihindu & Arayici, 2008); and
- BIM technologies and processes represent a disruptive paradigm shift affecting established processes within the construction industry (Shelden, 2009; Younas, 2010; Watson, 2011) and "one of the most disruptive (positive or negative) episodes in the history of architectural education" (Denzer and Hedges, 2008, p. 9).

In addition to these domain-specific challenges, BIM reflects the complex and interdependent nature of design and construction projects (Austin, 2002; Froese, 2010) and its adoption by industry is challenged by the same factors affecting technology-adoption in general. In their research covering the construction industry, Peansupap and Walker (2005), identified several factors underlying the slow uptake of information and communication technology (ICT) by organizations. These factors include the complex nature of the construction industry; ICT immaturity levels; poor availability of tools for evaluating the benefits of using ICT; and lack of understanding of ICT implementation processes. These factors are likely to apply as well to BIM - as a technology-driven process within the construction industry - and need to be addressed if BIM is to be adopted and its benefits realized.

BIM also has some pertinent problems which need resolution (Xu et al., 2014) to promote its adoption and use to enhance performance in the construction industry.

Gu et al. (2008) identified challenges to BIM and classified them into various groups as product, process and people and a combination of several issues (Kivineimi, 2013). There is the significantly high cost associated with adopting BIM as against the conventional methods in major areas including hardware, software and the human factor.

The high investment cost of BIM know-how (start-up budget, software, personnel training and hardware budget), have continually remained a barricade to BIM acceptance. Also, most small-medium enterprises (SMEs) have challenges with funding and hence difficult for SME contractors to adopt the technology due to the massive capital investment needed. The construction industry doubts investing into it due to the high initial budget, inadequate evidence of financial benefits and the time to develop human expertise coupled with the absence of seeing BIM as a business point of view (Wix, 1997).

Researches have shown that there is little knowledge about BIM to stakeholders.

Again, Thurairajah and Goucher (2013) confirm that SME's had no basic knowledge about BIM and lack the required IT skill principally about BIM.

There are also legal issues with BIM technology. These issues are in relation to ownership, the responsibility to maintain and add on data to the set up (Boon, 2009).

Therefore, to achieve the collective purpose of BIM, stakeholders must work in a collaborative manner (Kelin, 2012). They must resolve all ownership issues by collectively seconding to a no requisition to guard BIM with patent law and other legislative matters (Thomson & Miner, 2006) for effective utilization. Legislative matters can also be managed by including the responsibilities of stakeholders during the development of the model in the contractual document for easy enforcement (Azhar et al., 2008). According to Porwal and Hewage (2013), these unsettled legal issues continue to put fear in most stakeholders on BIM while Eastman et al. (2008) consider it as a barrier to its implementation.

2.16 Disadvantages of BIM

BIM is a newer concept, so it is still developing. Most of the contractors, engineers, and architects still need to increase their experiences with BIM to understand it well. They have some concerns regarding the use of BIM because there are some risks associated with its practice (Katez & Gerald, 2010).

The main concern is that BIM will raise the level of liability for contractors towards owners by blurring the line between design and construction. According to the fundamental principles of construction law, a contractor who makes a project design and documents is not liable to the owner for defects that might look back in documents and/or specification. This protection is known as the "Spearing Doctrine." There is an implied warranty from the party who provides design documents regarding any defects. Contractors are becoming more concerned because BIM involves them in the design process and development. This will lead to undercuts in the implied warranty behind the design documents and weaken protection for contractors under the Spearin doctrine (Katz & Crandall, 2010).

Technology is also another concern. BIM has many different software programs and versions such as Autodesk Revit Architecture, Bentley Architecture, 3D Ultimate, Chief Architect, Realtime Landscaping Architect and Graphisoft ArchiCAD. Since there is no universal BIM file format, it is difficult to find any BIM software program that can import or edit file formats used by other software programs (Hussein and Zaid, 2016).

Recording and archiving the models are another concern. Many specialists can review and modify BIM models' multiple times during the design process. In this case, any defects that might happen on the original model such as the architectural model will make it hard to pinpoint the person who made those defects (Katez & Gerald, 2010).

2.17 Summary of existing BIM Case Studies.

Chelson (2010) studied the effects of BIM on construction site productivity and reported some significant benefits of BIM. The study examined eight BIM case studies (Table 2.4) and presented the benefits.

Table 2.1: summarizes these case studies

Case #	Company name	Participants	Tools		
			Model Generation Tools	BIM related Tools	Analysis Tools
1	Target (Owner)	General contractor, architects and engineers	PointCloud3D		Conceptual design, 4D and 6D in some projects
2	Layton Construction Company (GC)	Contractor, Subcontractors/ Fabricator, engineers, architects.	Revit	Auto Cad	Navisworks
3	Hunt Construction (GC)	Contractor, engineers, operators	Revit		NavisWorks , 4-D modeling
4	Deffenbaugh Construction (GC)	Contractor, Sub contractor	Revit		US cost NavisWorks
5	Helix Electric, Inc. with Turner Construction	Contractor, subcontractor, architects and engineers			NavisWorks
6	Southland Industries (Mechanical Subcontractor)	Owner, contractor and operator	AutoCAD MEP		NavisWorks
7	Kinetics Mechanical (Mechanical Subcontractor)	Contractor and owner		Total station	
8	Raymond (Framing/Drywall Subcontractor)	Contractor, Owner, engineer	Autodesk's Revit Architecture and AutoCAD 3-D		NavisWorks for clash detection

Source: Hussein and Zaid (2016)

These case studies indicated many BIM benefits; some of these benefits are:

Decrease the number of RFIs from 50% to 100% compared to non-BIM projects. This represents significant savings in time and cost.

- Reduce the amount of rework significantly, thus reducing the change order time and speeding up the construction process.

- Decrease the frequency of change orders and costs due to the use of plan conflicts. Chelson stated, "Owners claimed that change orders on BIM projects are reduced to virtually nothing for field coordination issues"

Involve all the contractors and owners in the design process earlier, as well as support the BIM expenditure as an integral part of the design process.

Enhance schedule compliance significantly. For example, Layton Company compared two similar hospital projects in California, one utilized BIM and the other, not. The one with BIM was 11% ahead of schedule, while the other was 8% behind schedule.

Layton case indicates that when using the model, the process of achieving shop drawings is 60% faster than using 2D clash detection.

2.18 The Impact of BIM on Construction Performance

Construction projects worldwide have been experiencing significant cost and time overruns, with low labour productivity making the poor performance of the construction industry a cause of great concern among practitioners and Academics, making productivity in construction critical (Thomas & Sudhakumar, 2014). In support of this concern, a study performed by (Odesola, 2015) suggests that the higher the construction labour productivity, the lesser the cost and time overruns. Hammad (2011), indicated that improving productivity in construction can lead to many benefits such as time-saving, cost savings, increased competitiveness and profitability for the contractor (Hammad, 2011).

The significance of understanding productivity in construction can also be observed in a Singaporean study (Hwang, 2013), where the researchers aimed to find the critical factors affecting schedule performance to respond to the decision by the Singaporean Government to increase and improve productivity to reduce wait time for finishing public housing projects. Literature review revealed that as a situational response, the

Australian Construction industry seemed to record an increase in labour productivity during tougher economic situations (Igor, 2014). A lab or productivity study of trends in the United States showed contradictory information on the different methods of assessing labour productivity and maybe indicative of a need to establish a standard measure for productivity (Nasir, 2014).

Productivity in construction is a hot topic for study around the world. A study done on construction productivity factors in Egypt stated that productivity for construction can be divided into three primary categories:

(1) Human/Labour,

(2) Industrial and

(3) Management and the findings indicated that management ranked first followed by labour and industrial (El-Gohary & Aziz, 2014).

Some of these studies approached productivity from a broader perspective, while others evaluate it solely from a labour productivity standpoint (Randolph, 2015).

Because of Construction Labour Productivity (CLP) importance to the profitability of most construction projects, a study in 2014 reviewed 129 CLP related papers (Yi & Chan, 2014). This is indicative of the interest and focus of the construction industry-related labour productivity. It is important to identify and understand the factors that influence productivity (Mojahed & Aghazadeh, 2008).

While the matrix by Kenley presents a framework for productivity systems assessment, it seemed to lack the level of details as highlighted by studies that discuss productivity factors.

A study from the UK discusses the extensive exchange of information required to track KPI's (Rigby, Dewick, Courtney, & Gee, 2014). The study discussed the importance of linking economic incentives to the process of benchmarking. The United Kingdom

KPI working group in 2000, proposed to the Minister of Construction the following indicators Time, Cost, Quality, Client Satisfaction, Change Orders, Business performance, Health and Safety (Group, 2000). In the following years, the Key Performance Indicators have been categorized into Economic, Respect for People and Environment (Excellence, 2007). Key Performance Indicators (KPI's) were often seen as the approach taken in order to measure and quantify construction productivity on a project.

The indicators identified and discussed in the literature seemed to fall under two main categories of performance indicators. Result Oriented KPI's and Process-oriented KPI's. Many studies also referred to these indicators and product attributes as Critical Success Factors (CSF's). A publication on Construction Jobsite Management (Mincks & Johnston, 2003) discusses many aspects of construction performance including Cost Goals, schedule goals, quality goals, customer satisfaction and also touches on process-related indicators such as resource management and sub-contractor management. Cox describes qualitative and quantitative performance indicators (Cox, 2003). The indicators described by Cox, also cover result-oriented indicators such as Cost Goals, schedule goals and quality goals. The process-oriented indicator of resource management was discussed by Cox while highlighting the attributes of material and labour management. Other authors who highlighted result-oriented performance indicators included (Gattorna & Walters, 1996) (Ng, Rose, Mak, & Chen, 2002), and (Wong & Cheung, 2005).

All these studies highlighted cost, schedule and quality goals as key performance indicators in construction.

A study on web-based Construction Project Management systems (Nitithamyong & Skibniewski, 2006), identified performance indicators that could be grouped under both result-oriented and process-oriented indicators. The study identified and discussed attributes related to cost, schedule and quality performance but also seemed to address risk improvement by reducing the number of injuries from a result-oriented lens. The aspect of safety and risk can also be viewed from the perspective of process-oriented performance as it relates to establishing safety and risk management procedures. A 2008 publication by the Project Management Institute highlights performance indicators: schedule goals, communication management, procurement, resource risk management, quality management, human resource management, stakeholder coordination and scope clarification (PMI, 2008). According to a study that evaluated the contractor perspective; customer satisfaction, communication and improved decision making (Ng et al., 2002) are important performance indicators.

Utilization and implementation of BIM may present an opportunity to better monitor and improve on both result-oriented and process-oriented performance in construction projects.

Suremann (2009), identified key performance indicators as Quality Control, on-time completion, cost, safety, cost per unit, and man-hours. The study by Suermann was identifying the impact of BIM on construction and therefore the identified performance indicators are very relevant to the approach of this study. A case study that evaluated how to measure the benefits of BIM established some return metrics which included: number of RFI's, percentage cost savings on Change Orders, and percentage of time saved on the duration of the project (Barlish & Sullivan, 2012). It is important to both identify the key factors that affect construction performance and accordingly develop metrics to monitor and continue improvement of construction performance through benchmarking results and process enhancement. Table 2.5 presents the Construction KPI (CKPI) dimension and indicators that were identified through the literature review.

Table 2.1: Construction Project Management Dimensions and Indicators

Construction KPI (CKPI) Dimension	Performance Indicator
KPI Result Oriented (Mincks & Johnston, 2003), (Cox et al., 2003), (P. S. P. Wong & Cheung, 2005), (Gattorna & Walters, 1996), (Ng et al., 2002), (PMI, 2008), (Nitithamyong & Skibniewski, 2006),	Cost Goal Schedule Goal Quality Goal Safety Goal Customer Satisfaction
KPI Process oriented (PMI, 2008), (Ng et al., 2002), (Cox et al., 2003), (Mincks & Johnston, 2003), (P. S. P. Wong & Cheung, 2005), (Nitithamyong & Skibniewski, 2006), (Naoum, 2003)	Communication Management Resource Management Cost Management Effective Schedule Control Effective Quality Management Effective Safety Management/ Coordination of H

Relationship between BIM and Productivity/ Construction Performance
Source: John, D. D. (2018)

Aziz, states that waste of time in construction is nearly 57% when compared to manufacturing which has a 12% waste in time (Aziz & Hafez, 2013). Additionally, the study also draws attention to the fact that productivity in the construction industry worldwide has been on the declining trend for the past 40 years, also stating that productivity in the USA construction industry has been on the decline since 1964. A whitepaper highlights a list of 33 labour factors that affect the productivity of which a few included are; over time, morale and attitude, stacking of trades, concurrent operations, Errors and omissions, Reassignment of manpower, site access, logistics, ripple effect, dilution of supervision, weather and season changes, over-manning and area practices (Intergraph, 2012). While all these factors may not be resolved through the direct application and usage of BIM, many of these factors can be addressed through improved planning and Construction Project Management (CPM).

Literature review revealed that many studies support that there is added value in BIM implementation and adoption (Boktor, Hanna, & Menassa, 2014). BIM enables and facilitates productivity enhancement on construction projects through the identifying of inefficiencies, finding their source and potential remedies by offering a platform for re-engineering the process (Nath, 2015). While improvements in productivity, quality of design, construction and the maintenance of buildings is highlighted as an objective of BIM (Reijo & Sami, 2014), the study draws attention to the importance of maintaining a realistic conception in the implementation of BIM while pursuing the future-oriented vision of BIM implementation. Many factors can affect and contribute to productivity. A study conducted specifically on labour productivity (Rojas & Aramvareekul, 2003) seemed to indicate that practitioners held the belief that construction labour productivity is under their control, and that management needs to be complemented by new technique and technologies to improve productivity. In a separate study, 82 per cent of BIM users indicated that BIM had a positive impact on productivity and 79 percent of the users indicated that project outcomes were improved with fewer RFI's and significant improvements in field coordination (Azhar, 2011). A South-Korean study focused on evaluating the Return on Investment (ROI) on the BIM-assisted D3 City project (Lee, Park, & Won, 2012) which showed that the use of BIM prevented 709 errors which would have otherwise caused a negative financial impact on the project. The ROI of avoiding a week's delay was estimated to be between 172% - 247%, while avoiding a month's delay was estimated to be between 624%-699%, showing a significant economic impact with the use of BIM. While some studies indicate a significant and relatively quicker ROI, a study in the United Kingdom, seemed to indicate that it may take a little longer, with factors such as long-run productivity and access to BIM mandated projects in the UK being the causes for a good ROI (Bryde, 2013). These differences may be due to a variety of causes such as the country of implementation, the nature and scale of the projects and method of calculation.

Improvement and monitoring of safety, quality and carbon emissions with the use of 4D applications in BIM are discussed by (Ding, 2014) given increased information available for decision making, while 4D applications of BIM are also discussed in the virtualization of the process for integration of codes and quality management (Chen & Luo, 2014) which highlights the use and potential positive impacts of BIM on the productivity of a construction project. Studies have also compared construction practices such as Lean construction that focuses on productivity and show a significant synergy between BIM and Lean construction (Rafael, Lauri, Bhargav, & Robert, 2010). In using BIM as a solution to productivity; according to a study by (Jensen & Johanneson, 2013), BIM is perceived as a tool that can diminish the troubling lack of productivity in the Nordic countries. Effectively tracking productivity is critical to assess progress on a project (Yelda, 2013). He highlights the use of 3D imaging tools such as BIM to track earned value on a project. Another study in South-Korea indicated that the time reduction enabled by 3D based quantity take-off and estimation has resulted in higher productivity (Kim et al., 2009). Extending beyond the realm of pre-construction and the construction process, some studies show that the use of BIM in facility management has also proved to be faster and more productive (Burcin, Farrokh, Nan, & Gulben, 2012) while another study in the United Kingdom indicates that all stakeholders benefit through a construction projects lifecycle with the adoption and implementation of BIM. But, Clients followed by facility managers tend to benefit the most through the implementation of BIM (Eadie, 2013).

A study on BIM uses and frequency of use highlighted 25 uses of BIM and assessed the frequency and perception of the uses, which revealed a positive benefit on all the highlighted uses; showing an industry perception that supports the notion of a positive impact of BIM on productivity (Kreider, Messner, & Dubler, 2010). Another study that studied the perceived value of BIM in the U.S construction industry, highlighted that U.S practitioner perceptions indicated savings in cost and time, with increased profitability for companies that were using BIM (Burcin & Rice, 2010). A significant benefit of BIM, which is not discussed as much as its impact on Risk Management. Tomek suggests, BIM should have a positive impact on risk management, by mitigating threats and raising opportunity as companies progress from BIM implementation to post BIM implementation (Tomek & Matejka, 2014).

There are many approaches discussed through Academic studies on how to improve the impact of BIM, (Deutsch, 2011) a book titled "BIM and integrated design" highlights the importance of leveraging people as an important means of enabling the best and most productive use of BIM. BIM is also seen as a remedy for improvement in labour productivity of the construction industry (Teicholz, 2013). He, indicated that it may be too early to measure the quantified impact of BIM on the element of labour productivity. A study on the perceived impact of BIM indicated that respondents felt that BIM is most likely to have a positive impact on the quality and on-time completion of construction projects (Suermann & Issa, 2009). While many studies highlight how improving BIM's impact on productivity should be approached, Barlish suggests a comparison of case studies approach that compare similar projects as a means of how to identify metrics and measure the benefits of BIM (Barlish & Sullivan, 2012). The return metrics as established in the study were an assessment of the number of RFI's, percentage cost savings on Change Orders and percentage of time saved on the duration of the project. A different study that proposes a practical framework for implementation describes the current objectives of computer integrated construction (CIC) and BIM to be improvement of effectiveness in construction through the use of information systems and integration (Youngsoo Jung & Mihee Joo, 2011).

Clearly defining that the mission of using computer technologies and processes such as BIM is for the broader purpose of improving efficiency, which in turn leads to productivity improvements.

A study by (Kihong & Taiebat, 2011) states that companies expect that construction graduates bring knowledge in areas of constructability and visualization in the short term, with expectations for facility management and energy analysis in the long term. This is indicative of the expectations that companies have from Academic institutions, for the growth of BIM implementation in curricula and the hope to increase productive outputs concerning BIM. A more comprehensive environment that trains and prepares young graduates will be beneficial to reducing the importance of leveraging people as an important means of enabling the best and most productive use of BIM. BIM is also seen as a remedy for improvement in labour productivity of the construction industry (Teicholz, 2013). He, indicated that it may be too early to measure the quantified impact of BIM on the element of labour productivity. A study on the perceived impact of BIM indicated that respondents felt that BIM is most likely to have a positive impact on the quality and on-time completion of construction projects (Suermann & Issa, 2009). While many studies highlight how improving BIM's impact on productivity should be approached, Barlish suggests a comparison of case studies approach that compare similar projects as a means of how to identify metrics and measure the benefits of BIM (Barlish & Sullivan, 2012).

In a McKinsey report, one study found that 75% of companies that have adopted BIM reported positive returns on their investment with shorter project life cycles and savings on paperwork and material costs. Because of these benefits, various governments like Britain, Finland, and Singapore, mandate the use of BIM for public infrastructure projects (Agarwal, Chandrasekaran & Sridhar, 2016).

In small speciality studies, BIM appears to be increasing productivity in labour. In a study involving a small contracting enterprise, the impact of BIM on labour productivity was quantified and findings demonstrated a 75% to 240% increase in labour productivity for modelled and prefabricated areas (Poirier, 2015).

For the professionals (architects, surveyors, engineers) involved in an infrastructure project, BIM allows for a virtual information model to be communicated from the design team to the main contractor and subcontractors and then to the owner/operator with each specific professional adding specific data to the single shared model. The whole system is designed to reduce information losses that traditionally occur especially when a new team takes over a project. It also provides an extensive information on complex structures (Eastman, 2009).

Utilizing building information modelling solutions in the construction sector resulted in higher quality work, greater speed and productivity, and lower costs for building professionals in terms of design, construction, and operation of buildings (Laiserin, 2002).

These results have been explained by Cherkaoui, H. (2016) in What is BIM? What are its benefits to the construction industry? lets build. as follows.

Higher Quality: BIM allows for flexibility in the exploration and changes to the project design or documentation process at any time without any hassle to the design team. This results in minimized coordination time and manual checking that enables the design team to have more time solving real architectural problems. Common modelling tools provide close control over technical and detailed decisions regarding design execution. The digital record of building renovations improves planning and management.

Greater Speed: BIM enables design and documentation to be done concurrently instead of serially. Schedules, diagrams, drawings, estimating, value engineering, planning, and other forms of workplace communication are created dynamically while work is progressing. BIM allows for the adaptation of the original model to changes like site conditions, etc.

Lower Cost: Using BIM allows for more work to be done by a smaller team. This means lower costs and lesser miscommunications. Less time and money are spent in process and administration because of higher document quality and better construction planning.

BIM is the process spanning the generation and management of the physical and functional information of a project. The output of the process is what we refer to as BIMs or building information models which are ultimately digital files that describe every aspect of the project and support decision-making throughout a project cycle. It has been thought that BIM is nothing more than 3D modelling but it involves more than that. BIM and the subsets of BIM systems and similar technologies feature more than just 3D (width, height, and depth) but may include further dimensions such as 4D (time), 5D (cost), and even 6D (as-built operation) (Smith, 2014).

Building Information Modelling (BIM) is a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition (NBIMS-US, 2016).

BIM covers more than just geometry — it covers "spatial relationships, light analysis, geographic information, and quantities and properties of building components" (Eastman, 2009).

Parvan (2012) studied the impact of BIM utilization on project performance and indicated some numerical benefits. Parvan reviewed a sample consisting of 33 gathered projects, which represent the industry projects. This sample was divided into two categories: non-BIM and BIM utilized models. Performance indexes were used as an indicator to measure the BIM impact on the projects' outcomes. Table 2.6 represents the schedule performance index and the cost performance index.

Table 2. 1: represents the schedule performance index and the cost performance index Quantitative Benefits

Activity	Schedule Performance Index (PI) Impact Rate	Cost Performance Index (PI) Impact Rate
Design	30%	8%
construction	10%	3%
Project	16%	4%

Source: Hussein & Zaid, (2016)

As deduced from the table, BIM has the highest impact rate on the design schedule (PI), Which is a 30% improvement. It has less impact on the construction schedule (PI) and project 2schedule (PI), which are 10% and 16% respectively. The cost (PI) indicates that the design cost is improved by about 8% by BIM, while the construction cost and project cost are improved by only 3% and 4% respectively.

2.19 Developing Productivity/ Construction Performance Matrix

Suermann evaluated the impact of BIM on construction by identifying six KPI's listed as Quality Control, On-time completion, Cost, Safety, Cost per unit and Man-hours (Suermann, 2009). A study on measuring the benefits of BIM identified the KPI's as: Number of RFI's, Change Orders = Cost / Total Cost, and Schedule = Actual / Standard (Barlish & Sullivan, 2012). Similar to that of Barlish and Sullivan (2012), an analysis of the UK construction project lifecycle listed KPI's: Number of RFI's, Change Orders, Overall cost, Cost of changes, Program duration and Man-hours (Eadie et al., 2013). A more detailed report on construction productivity grouped its 31 KPI's into Economic KPI's, Respect for People KPI's and Environment KPI's (Excellence, 2007). This would suggest that the factors for productivity are Economic, Environment and Respect for People; this is consistent with many of the other studies as the KPI's can be grouped under one of these three factors.

A study for construction projects in Hong Kong identifies productivity as performance in relation to safety, cost, time, quality, environment, communication, functionality and client satisfaction (Yeung, 2013).

Similarly, another study identified many of the popular performance indicators relating to cost, time, safety and satisfaction but also presented the factor of predictability of cost and time as a factor for performance (Skibniewski & Ghosh, 2009).

A report to the ministry of construction identified the KPI's for construction to be: Time, Cost, Quality, Client satisfaction, Change Orders, Business performance, Health and safety (Group, 2000). The study also highlighted the purposes of identifying KPI's to be the client's demand for construction projects to be on time, on budget, free from defects, efficient, right the first time, safe and built by profitable companies. The study also indicated the client's year-on-year expectation for the reduction in project costs and delivery times. Another study in 2002, approached construction productivity with a contrasting list of productivity factors which included: Risk, Project status, Decision effectiveness, Production, Cost-effectiveness, Customer commitment, Stakeholders and Project management (Pillai, Joshi, & Rao, 2002). Although the indicators were in contrast to many of the indicators called out by other studies, they still could be grouped with indicators that are similar and therefore did not indicate any additional productivity indicators for consideration. A web-based approach to monitoring the performance of construction projects listed 8 performance categories which included: People, Cost, Time, Quality, Safety & Health, Environment, Client Satisfaction and Communication (Cheung, 2004). This web-based performance monitoring tool also highlights many of the same performance indicators as identified in the literature.

A study by Wong in 2004 also highlighted staff experience as a factor of productivity along with the additional inclusions of contractor experience and site management (Wong, 2004). The final matrix for construction performance factors, indicators and attributes are provided in Table 2.7. This table provides the full Construction Key Performance Indicator (CKPI) matrix as identified through this study and presented as a key contribution of this research.

Table 2.1: Construction Performance Factors, Indicators and Attributes

Factors	Indicators	Attributes	References
KPI (Result oriented)	Cost Goal	Meet the target budget	(Mincks & Johnston, 2003), (Cox et al., 2003), (Wong & Cheung,2005), (Gattorna & Walters, 1996), (Ng et al., 2002)
	Schedule Goal	Meet schedule goal	(Mincks & Johnston, 2003), (Cox et al., 2003), (Wong & Cheung, 2005), (Gattorna & Walters, 1996), (Ng et al., 2002), (PMI, 2008), (Cox,
	Quality Goal	Meet quality specification	(Mincks & Johnston, 2003), (Nitithamyong & Skibniewski, 2006), (Gattorna & Walters, 1996), (Ng et al., 2002)
		Total number of Change Orders	
		Total cost of Change Orders	
		Total cost of rework	
		Total cost of punch list items	(Cox et al., 2003)
	Safety Goal	Meet safety goal	
		Total number of site accidents	(Nitithamyong & Skibniewski,
		Total number of near misses	
	Customer Satisfaction	Improve customers' satisfaction	(Mincks & Johnston, 2003)
		Decrease total number of legal claims and litigations	(Ng et al., 2002)
		Decrease total cost of legal claims and litigations	(Ng et al., 2002)
		Increase number of repeat customers	
KPI (Process-oriented)	Communication Management		(PMI, 2008)
		Information Management (Definition: Timely and appropriate generation, collection, distribution, storage, retrieval	(PMI, 2008)
		Communication Frequency	
		Communication Effectiveness	
		Communication Method	
		Coordination tools	(Ng et al., 2002), (Naoum, 2003)
		Open information sharing	(Ng et al., 2002)
	Resource Management		(Cox et al., 2003), (Mincks & Johnston, 2003)
		Material Management (e.g. waste reduction)	(Cox et al., 2003)
		Labour Management (e.g. Lost time/Idle time)	(Cox et al., 2003)
		Subcontractor Management	(Mincks & Johnston, 2003)
		Effective Procurement Management	(PMI, 2008)
		Risk (uncertainty) Management	(PMI, 2008)
	Cost Management	Effective Cost Management (Definition: Planning, estimating, budgeting, and controlling costs)	(PMI, 2008), (Wong & Cheung, 2005), (Naoum, 2003)
	Effective Schedule Control	Effective Schedule Control (e.g. plan, scheduling, monitor, and control of schedule)	

	Smooth work process	(Naoum, 2003), (Nitithamyong & Skibniewski, 2006)
Effective Quality Management	Effective quality management (Definition: Quality planning, quality assurance, and Quality Control)	(Wong & Cheung, 2005), (PMI, 2008)
	Earlier detection of problems	(P. S. P. Wong & Cheung, 2005)
	Total number of design errors	(Nitithamyong & Skibniewski,
	Total number of RFI during	(Nitithamyong & Skibniewski,
	Total number of RFI during	(Nitithamyong & Skibniewski,
Effective Safety Mgmt.	Effective Safety Management (e.g. Plan, implementation, evaluation, and management of safety)	(Wong & Cheung, 2005)
Management and		(PMI, 2008)
	Joint Solutions	(Cox, 2009)
	Effective Leadership	(Cox, 2009), (Wong & Cheung,
	Effective coordination of stakeholders	(PMI, 2008), (Nitithamyong & Skibniewski, 2006)
	Improve decision-making process	(Ng et al., 2002), (Naoum, 2003)
	Scope Clarification	(PMI, 2008)

Source: John, D. D. (2018)

This table above provides the full Construction Key Performance Indicator (CKPI) matrix as identified through the thesis on Building Information Modeling (BIM) Impact on Construction Performance.

2.20 The State of BIM in Ghanaian Construction Industry

Akwaah (2015) in his abstract indicated that the BIM adoption level in Ghanaian contractors (Construction industry) was very low, but can be implemented to achieve a high level and therefore recommended that the guideline factors for full BIM adoption should be implemented by Ghanaian contractors backed by government regulations. Akwaah further give Some of the benefits of BIM adoption by Ghanaian contractors which include the elimination of variation in design, saves a lot of time, and controls quality.

Nani's work (2015, p. 49) on BIM usage rates from 29 respondents on the adoption of BIM within Ghanaian Building organizations affirms that the utilization of BIM in the

Ghanaian Construction industry was low. Only a marginal (13.79%, n = 4) of the companies were presently by means of some level of BIM. On the contrary, the widely held, 25 (86.20%) testified as not expending on BIM. Given the low described practice of any form of BIM know-how, the percentage responses reported here characterize marginal outlooks. The data collected also displays a connection between the use of BIM and the size of the industry.

Asiedu (2016) indicated that the result of his study showed that notwithstanding the high level of knowledge and awareness of BIM among construction consultants, the level of adoption is still low (7.0%), and lags behind the level of adoption of the technology in the construction sectors in the developed world. He further stated that the low level of adoption can principally be attributed to the limited capacity of the construction consultants' ability to produce an Information Technology environment that is adaptable to BIM, produce capable system integration, and the absence of a capable human resource. The absence of government pressure and consultant's limited experience in BIM usage is also the possible reasons for the low adoption of BIM by the construction consultants in Ghana.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter looks at an in-depth overview of how the entire study was undertaken primarily describing in details the research design, study population, study areas, sample and sampling techniques, data collection method and instrument used with its corresponding validity, reliability, collection procedure and finally the analysis techniques enacted. The analogy of this chapter thus focuses on how information gathered from reviewed literature could be translated into questions for field survey and the eventual realization of the study's objectives.

3.2 Research Design

According to (Punch, 2000), the research design is the basic plan for a piece of empirical research and includes main ideas such as strategy, sample, and the tools and procedures to be used for collecting and analysing empirical data. In this section, this design and the approach adopted for the study were discussed. Comprehensively, a cross-sectional survey was employed for the research design as it permitted the researcher to study the participants once and therefore not necessitating him to make follow-ups (Shuttleworth, 2010). In turn, this design was used to determine the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, explore the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, measure the relevance of BIM maturity in the Ghanaian construction industry and determine the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Pertinently, this design stood appropriate as its key premise was dependent on comparing many different traits and characteristics and gathering an avalanche of perceptions and practices at the same time which in turn allowed the researcher to obtain a detailed perspective into the use of building information modelling and its impact on construction performance within the Ghanaian construction industry. Owning to the nature of the study, the qualitative approach was embraced, more specifically, to obtain data in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, measuring the relevance of BIM maturity in the Ghanaian construction industry and determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. To Bryman, (2001), the quantitative research approach is a type that emphasizes numbers and figures in the collection and analysis of data. Again (cool 1) emphasized that the use of this approach in statistical data for research descriptions and analysis reduces the time and effort which the researcher would have invested in describing his result. Likewise, Gorard, (2001); Connolly, (2007), argued that data (numbers, percentages and measurable figures) obtained with this approach can be calculated and conducted by a computer through the use of a statistical package for social science (SPSS) which save a lot of energy and resources. Conforming to these assertions, this approach was esteemed appropriate hence used for the study subsequently. In this regard, structured questionnaires were used to obtain data as directed by the study particularly in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, measuring the relevance of BIM maturity in the Ghanaian construction industry and determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

3.3 Population of the Study

A population is a group of individuals, persons, objects, or items from which samples are taken for measurement (Saunders et al., 2009). Creswell and Plano (2011) defined the research population as a large well-defined collection of individuals having similar features. They further differentiated between two types of the population into the target population and accessible population. Target population described the entire group of individuals or objects which researcher is interested in generalizing his conclusions whiles the accessible population defined the population researchers apply their conclusions, they added. Taking a cue from this submission and particularly interested in the former, the target population for this study constituted well informed and experienced professionals from the Architectural Consultancy Firms, Quantity Surveying Firms, and Structural Engineering Firms operating within the Ghanaian AEC industry.

3.4 Study Areas

The study took into consideration three key topographical towns which are Kumasi, Accra and Sekondi-Takoradi. Most of our Architectures, Engineering, and construction firms are located in these towns. Reliable institutions such as the Architecture and Engineering Service Limited, Ghana Highway Authority, Ghana Institute of Surveyors and Consultancy firms are located in these towns. Most of our multi-storey and high-rise infrastructures are located in these areas and are designed by architects, constructed by highly-experienced contractors with their respective civil and structural engineers. With the huge number of consultants, contractors, architects and engineers located in these areas of study; findings and conclusions drawn from the study can be generalised and rely on and assist in improving our infrastructure performance to meet the expectations of all clients in Ghana.

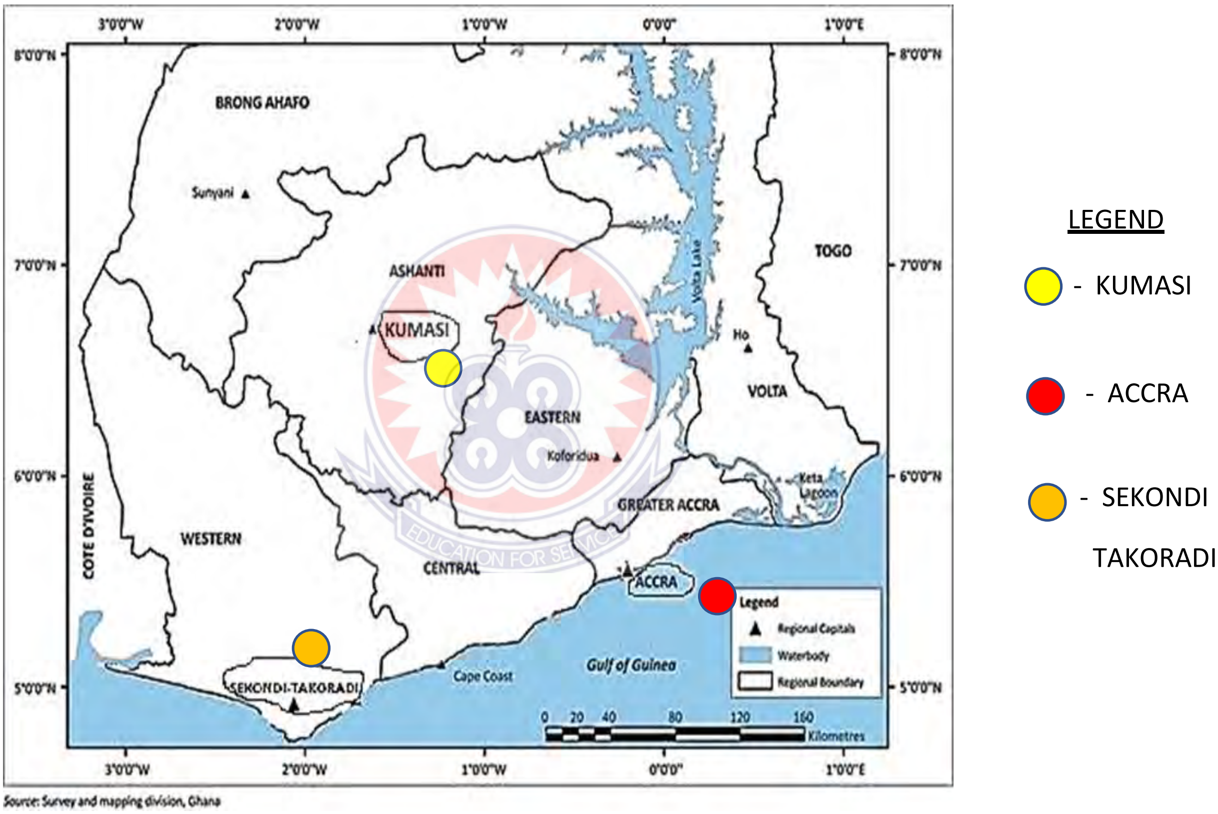

Figure 3.1: Map showing the location of the study areas

Source: *Ernest, Ankomah, Tengan, & Asamoh, (2016)*

3.5 Sampling Technique and Sample Size

The sampling frame used for the study included well-established firms registered by the Architectural Registration Council-Ghana, Ghana Institute of Surveyors and Ghana Chamber of Construction. Bryman (2004) opined that; sampling techniques tell us how part of the population used in data collected is carefully chosen. The study, therefore, employed purposive sampling, a non-probability sampling technique to select the firms from the sampling frame as well as the respondents engaged in the study. Purposive sampling techniques engage the researcher's judgment to spotlight the exact characteristics of the population and sub-populations under investigation. The latitude provided by this technique allows for the comparison of outcomes between groups that may not otherwise be attainable with common probability sampling (Leedy & Ormrod, 2010) (Kelly, 2015). This technique was chosen specifically because the number of construction projects who had adopted BIM technology greatly overshadowed the number of projects not into this technology so it facilitated the ease in reaching such firms. Again, this technique ensured participants selection was based on the participant's organization's knowledge on Building Information Modelling (BIM) (Saunders et al, 2012). In effect, the survey sample consisted of professionals such as architects, engineers, Quantity Surveyors, Contractors and General Foremen from the three towns; Accra, Kumasi and Sekondi-Takoradi.

In determining the sample size, data from the sampling frame consisting of Architect Registration Council-Ghana, Ghana Institute of Surveyor and Ghana Chamber of Construction Industry obtained through field survey backed by literature from these firms was interpreted and used consequently. According to the Architect Registration Council-Ghana as of December 2016, there were **977** registered architects. 150 others were registered on probation. he Ghana Institute of Surveyor (GHIS, 2019), provided 80 registered firms engaging in quantity surveying of which researcher considered one professional quantity surveyor from each firm and as stipulated by Nduro, (2010), only **209** registered quantity surveyors nationwide were in good standing. The Ghana Chamber of Construction Industry (GHCCI, 2019), it affirmed that the Association of Building and Civil Engineering Contractors of Ghana (ABCECG) had a membership strength of approximately **1285** companies, including 21 foreign contractors with the numbers still subjected to increment. This thus brought the total population to 2471 (i.e., Building contractors (1285) + Quantity surveyors (209) + Architects (977) participants. However, through the field survey and literature, it was noted that not all of these firms contributed to the use of BIM technology. For this study, a population of 1000 members were used within which the sample size was extracted subsequently. In reaching the sample size, the Yamane Formula (1967) was used.

The following denotes the Yamane Formula;

$$n = \frac{N}{1+N(e)^2}$$

Where n = the required sample size

N = Total Number (Building Contractors+Quantity Surveyors+Architects)

If N = 1000 since not all of them engaged in BIM.

e = The standard of Sample Distribution = 0.05

Total error = 0.1 at confidence level of 95%

Therefore $$n = \frac{N}{1+N(e)^2} = \frac{1000}{1+1000\ (0.05^2)} = 286 \approx 300 \text{ participants.}$$

Therefore, the sample size for this study was 300 participants sampled out from a population of 1000 members.

3.6 Data Collection Instrument

Predominantly hinged on quantitative data, a close-ended questionnaire became the pivotal method used for collecting data. This method was essential because it had the track record of the most reliable technique that helped collect important and valid data (Easterby-Smith et al., 2002). Fundamentally, this instrument was used to amass data from respondents in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, measuring the relevance of BIM maturity in the Ghanaian construction industry and determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. In the design, the questionnaire was supported by literature and thereafter categorized into four main broad headings. The process equally permitted respondents to either rate responses on a seven-point Likert scale and also make multiple choices when it was necessitated. The first part constituted the demographic characteristics of the respondents. The second part was composed of determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. Exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana made the third part as the fourth part highlighted on measuring the relevance of BIM maturity in the Ghanaian construction industry. The fifth and final part focused on determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Bent on soliciting the requisite information appropriate for analysis (Bobbie, 1990), this instrument was adopted. Again, it is an esteemed instrument for gathering data on the opinions and attitudes of respondents (Patton, 2002). In determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, participants were obliged to make multiple choices from a set of independent variables. Similarly, in exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, respondents were directed to rate the responses from strongly important (7), very important (6), important (5), moderately important, unimportant (3), very unimportant (2) and strongly unimportant (1). Further, in measuring the relevance of BIM maturity in the Ghanaian construction industry, respondents were asked to rate the responses from strongly agree (7), agree (6), agree somewhat (5), neither agree nor disagree (4), disagree somewhat (3), disagree (2) and strongly disagree (1). Also, participants were made to rank responses from Most Highly usage (7), Very Highly usage (6), highly usage (5), High usage (4), Average Usage (3), No Usage (2), Not Heard of it (1) in determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

3.7. Validation of an instrument

Conca et al. (2004) contended that validity explains the extent to which a test item or an instrument measures what it is purposed to measure. The question of validity typically applies to the conclusion or inference we make from what we observe. This is sometimes called face validity. Issues such as the length of the questionnaire, order of questionnaires and general state of the cluster are some of the factors that may affect the face validity of the questionnaire. To ensure that the instrument captured all the relevant areas of using BIM technology and the whole proposed survey instrument was well worded and understood; thus, content validity, the questionnaire was sent to two lecturers well versed in BIM technology to check the comprehensiveness of the items under each construct. This helped to improve the content, thereby eliminating ambiguity and ensuring its ease of understanding.

3.8. Reliability of the Test

To maximize the reliability of the questionnaire, the items generated were pretested on a sample of 20 professionals sharing similar characteristics as the study sample and also in the construction industry at Obuasi Municipal were encountered. Reliability refers to the extent to which an instrument measures the same way each time it is used under the same conditions with the same subjects (Naoum, 2007). This sample is consistent with a study by Patton (2002) that suggests that the sample size for a pilot study should be at least 20 respondents. This pre-test aimed to ensure that quantitative measurements corresponded with expected results from interaction with construction consultants. Cronbach's Coefficient alpha was calculated to determine the internal consistency reliability of the Likert scale (see Table 4.2). Cronbach's alpha is widely used in social science research to estimate the internal consistency of reliability of a measurement scale. All the Cronbach's alpha values of the measurement used met the threshold of 0.7 (Hair et al., 2003; Pallant, 2007).

3.9. Data collection procedure

Upon formal introduction and familiarization with the selected areas of study through a visit. The questionnaire was self-administered to the targeted respondents to seek the necessary information in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, measuring the relevance of BIM maturity in the Ghanaian construction industry and determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. This was preceded by previewing respondents on the necessary arrangements regarding the date, time and place where applicable. Respondents were also informed about the confidentiality of the responses. Most importantly, an introductory letter was obtained from the Head of Department (HOD) of Construction and Wood Technology Education, University of Education, Winneba-Kumasi campus to profess my identity and my intentions in the process. The sample of questions used for the survey can be found in Appendix A.

3.10. Data Analysis Procedure

The quantitative data collected from the field survey through the use of closed-ended questionnaire items were analysed on the Statistical Package for Social Sciences (SPSS) version 25 and Microsoft excel softwares. The reliability of the questionnaire that was used in the survey was also determined using Cronbach's Coefficient Alpha.

3.10.1 Research Objective One: To Determine the key drivers for acceptance and implementation of BIM in the construction industries in Ghana.

The questionnaire was used to obtain data for this objective. The items on the questionnaire were rated on a seven-point Likert scale from strongly Agree, Agree, Agree Somewhat, Neither Agree nor Disagree, Disagree Somewhat, Disagree and Strongly Disagree. This was further subjected to a multiple response analysis and the required conclusions drawn.

3.10.2 Research Objective Two: To Explore the most important factors of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana.

Equally, a questionnaire with items rated with the Likert scale structure was employed to acquire data for this objective. The ratings on the items will be from strongly important, very important, important, moderately important, unimportant, very unimportant and strongly unimportant. Relative Important Index construction (RII) was then be applied to rank variables and derive the appropriate conclusions.

3.10.3 Research Objective Three: To measure the relevance of BIM maturity in the Ghanaian construction industry.

To come out with the main indicators for measuring the relevance of BIM maturity in the Ghanaian construction industry, a questionnaire with the same degree of rating with the Likert scale from strongly Agree, Agree, Agree Somewhat, Neither Agree nor Disagree, Disagree Somewhat, Disagree and Strongly Disagree was used. Factor analysis was used to analyse the variables and concluded subsequently.

3.10.4 Research objective four: To determine the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

In deducing the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies, questionnaire with the same degree of rating with the Likert scale from Most Highly usage, Very Highly usage, high usage, High usage, Average Usage, No Usage, Not Heard of it was used. Descriptive statistics were then used to analyse the data and concluded subsequently.

CHAPTER FOUR

RESULTS

4.1 Introduction

In tandem with the objectives of the survey, this chapter presents a comprehensive analysis of data obtained in pursuance of this study. The layout of this report which also is consistent with the objectives of the study places the demographic characteristics of the respondents as the part. The second part was directed at determining key drivers for acceptance and implementation of BIM in the Construction Industries in Ghana. Constituting the third part highlighted the need to explore the level of improvement in performance on construction projects as a result of acceptance and implementation of Building Information Modelling (BIM) in the Construction Industry in Ghana. The fourth and final part focused on deducing the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

Descriptive statistics were used to analyze the data subsequently. 214 well-answered questionnaire items were received from a total of 300 items self-administered over about six months in the towns of Kumasi, Accra and Sekondi-Takoradi respectively. This thus approximates the response rate to about 71%. The deficit in the number of items resulted from reasons extending from; items answered halfway, items not answered at all, items wrongly answered and questionnaire missing upon retrieval. These items in turn were classified invalid and were discarded in the analysis process for this study.

4.2 Demographic characteristics

A summary of respondents' characteristics, a very key component partly involved in obtaining the requisite data is illustrated in Table 4.1. This comprised the consulting firm they belonged to, professional background, academic qualification, professional bodies associated, nature of projects engaged, number of years in the construction industry and expertise in using BIM.

Table 4. 1: Demographic characteristics of respondents

Characteristics	Category/Option	Frequency	Percentage (%)s
Consulting Firm	Architectural Firm	31	14.5
	Quantity Surveying Firm	99	46.3
	Structural Engineering Firm	84	39.3
	Total	214	100.0
Professional background	Quantity Surveyor	98	45.8
	Architect	26	12.1
	Structural Engineer	50	23.4
	Civil Engineer	32	15.0
	Project Manager	5	2.3
	Contractor	1	0.5
	General Foreman	2	0.9
	Total	214	100.0
Academic qualification	Post Graduate	10	4.7
	First Degree	174	81.3
	Higher National Diploma	29	13.6
	Technical	1	0.5
	Total	214	100.0
Professional Body	Ghana Institute of Architects	28	13.1
	Ghana Institution of Surveyors	66	30.8
	Ghana Institute of Engineers	96	44.9
	Ghana Institution of Construction	24	11.2
	Total	214	100.0
Nature of Project	Office buildings	2	0.9
	Residential buildings	20	9.3
	Industrial buildings	11	5.1

	Civil Engineering projects	71	33.2
	Combination of above	110	51.4
	Total	214	100.0
Work Experience	0 – 5 years	129	60.3
	6 – 10 years	68	31.8
	11 – 15 years	14	6.5
	16 – 20 years	2	0.9
	Over 20 years	1	0.5
	Total	214	100.0
Expertise in BIM usage	None	43	20.1
	Low	23	10.7
	Somewhat low	9	4.2
	Medium	98	45.8
	Somewhat high	17	7.9
	Expert	24	11.2
	Total	214	100.0

Source: Arthurs Field Study (2019)

As per table 4.1, the results display an analysis of the respondent's characteristics. Ahead on the table was the consulting firm the respondents represented. Consequently, it was revealed that the highest percentage of them belonged to the Quantity Surveying Firm (46.3%). Structural Engineering Firm (39.3%) came next as Architectural Firm recorded the least with 14.5%. Appearing closely after consulting the firm of the respondents was their professional background. Here, the majority of the respondents worked as Quantity Surveyors (45.8%). This was followed by Structural Engineers (23.4%), Civil Engineer (15.0%), Architects (12.1%), Project Managers (2.3%), General Foremen (0.9%) and Contractors (0.5%) accordingly. Then came the academic qualification of respondents. Interestingly, more than half of the respondents were first degree holders (81.3%). Higher National Diploma (13.6%) occupied the second spot with Post Graduate (4.7%) securing the third place as Technical (0.5%) recorded the lowest qualification academically. Regarding the professional bodies' respondents were enlisted, Ghana Institute of Engineers (44.9%) had the highest membership with

Ghana Institution of Surveyors (30.8%), Ghana Institute of Architects (13.1%) and Ghana Institution of Construction (11.2%) following sequentially. The nature of projects respondents engaged in was equally examined. Office buildings (0.9%) was the lowest attended to, this was followed directly by Industrial buildings (5.1%), Residential buildings (9.3%) and Civil Engineering projects (33.2%). Surprisingly, most of the respondents were engaged in a combination of one or more (51.4%) of the aforementioned projects placing it as the highest. Similarly, on the issue of work experience or better yet the number of years in their respective professions, more than half of the respondents were within the year bracket of 0 – 5 years representing the highest percentage of (60.3%). Per this attribute, 6 – 10 years (31.8%) of experience came next as 11 – 15 years (6.5%), 16 – 20 years (0.9%) and Over 20 years (0.5%) experiences followed orderly. On respondent's expertise in using BIM, it was observed that the greater number were average/ medium (45.8%) experts in using BIM. Securing the second position where those with no expertise in using BIM with a percentage of 20.1%. Low expertise in using BIM (10.7%) was next and was directly followed by experts (11.2%), somewhat high (7.9%) and somewhat low (4.2%) experts in using BIM.

4.3 Reliability Analysis

The results of the Cronbach's coefficient alpha value were used to determine the reliability of a Likert scales thus ensuring the statistical reliability of this scale. The variables were tested for their reliability hence the Cronbach alpha values are shown in Table 4.2 were determined. The total value of Cronbach's alpha in determining the key drivers for the acceptance and implementation of BIM in the construction industries in Ghana was 0.878. Again, the overall value of Cronbach's alpha obtained in exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana was 0.821. Also, the total value of Cronbach's alpha in measuring the relevance of BIM maturity in the Ghanaian construction industry was 0.871. In determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies, the value of the Cronbach's alpha secured was 0.846. This means that all the Cronbach's alpha values of the measurement used exceeded the threshold of 0.7 (Hair et al., 2003). In effect, all the measurement produced the desired representation of their internal consistency.

Table 4.2 Reliability Analysis

Objective	Cronbach's Alpha	No. of variables
Determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana.	0.878	36
Exploring the most important factors of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana.	0.821	13
Measuring the relevance of BIM maturity in the Ghanaian construction industry.	0.871	28
Determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.	0.846	23

Source: Arthur's Field Study (2019)

4.4 Determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana.

Aimed at determining the key drivers for acceptance and implementation of BIM in the construction industry, the respondent's views were subjected to multiple response analysis and ranked subsequently. This was established based on the fact that respondents were presented with items that demanded more than a single response and had the option to select any that they deemed appropriate. The items then again were tabulated as a dichotomy group at a value of 1 (Yes), a threshold set as the selected item of preference with value 2 (No) as otherwise. The number of "Yes" responses were only tabulated and ranked consequently against the "No" responses from the participants. Again, the key drivers as stated earlier in the objective explained the need and urge as well as the benefits accrued in the use of BIM in the construction industry. They were classified in terms of their advantages, stakeholder's involvement, capabilities and functions and types of buildings affected. These were the projected variables intended to push for the acceptance and implementation of BIM in the construction industries in Ghana. Table 4.3 illustrates the most selected items by respondents deemed to be the main booster for the acceptance and implementation of BIM in the construction industries in Ghana.

Table 4.3: Key drivers for the acceptance and implementation of BIM in the construction industries in Ghana.

Drivers	Responses		Ranking by category	Overall ranking
	N	Percent		
A. Advantages				
Enhance productivity	167	30.5%	1	3
Competitive Advantage	140	25.6%	2	8
Exploring and adopting new trends	91	16.6%	3	14
Required by owners or contracts	75	13.7%	4	19
Success stories of others using BIM	74	13.5%	5	20
Total	547	100.0%		
B. Stakeholders				
Architect/Engineers	183	35.9%	1	2
Construction Managers	155	30.4%	2	5
General Contractors	77	15.1%	3	17
Owner/Developers	43	8.4%	4	25
Consultants	31	6.1%	5	28
Subcontractors	18	3.5%	6	33
Software Vendors	3	0.6%	7	36
Total	510	100.0%		
C. Capabilities and Functions				
Create drawings	191	15.9%	1	1
Quantity Takeoff	159	13.2%	2	4
Site Planning	120	10.0%	3	9
Clash Detection	119	9.9%	4	10
Scheduling and sequencing	83	6.9%	5	15
Costing and Budgeting	80	6.7%	6	16
Improve project controls	74	6.2%	7	20
Communication	69	5.7%	8	21
Facility management	55	4.6%	9	22
Facilitate decision making	48	4.0%	10	23
Equipment management	46	3.8%	11	24
Waste management	41	3.4%	12	26
Labour resource allocations	35	2.9%	13	27
Collaboration with stakeholders	30	2.5%	14	30
Energy analysis	21	1.7%	15	31
Code compliance	19	1.6%	16	32
Virtual meeting capabilities	11	0.9%	17	34
Total	1201	100.0%		
D. Types of Building Projects				
Commercial	153	22.3%	1	6

Industrial	148	21.6%	2	7
Residential	118	17.2%	3	11
Educational	93	13.6%	4	12
Institutional	93	13.6%	5	12
Healthcare	77	11.2%	6	17
Transportation	4	0.6%	7	35
Total	686	100.0%		

Dichotomy group tabulated at value 1. **Source:** Arthur's Field Study (2019)

As reported by Table 4.3, under the criteria for the advantages gained for acceptance and implementation of BIM in the construction industries in Ghana, enhancing productivity (30.5%) with 167 responses came tops as the main advantage gained in this regard. This was followed by competitive advantage (25.6%), exploring and adopting new trends (16.6%), required by owners or contracts (13.7%) and Success stories of others using BIM (13.5%) accordingly.

Relatively, the influence of some activities by stakeholders in the construction industry in the use of BIM makes them inevitable as key drivers for acceptance and implementation of BIM in Ghana. Respondents opinions in this stand are presented were Architects/Engineers (35.9%) recorded the highest number of responses as the main stakeholder fostering as a driver for the acceptance and implementation of BIM in the construction industry of Ghana. Coming next to them were, Construction Managers (30.4%), General Contractors (15.1%), Owner/Developers (8.4%), Consultants (6.1%), Subcontractors (3.5%) and Software Vendors (0.6%) in order.

Again, the top five views of respondents on the main capacities and functions influencing this variable as a driver for acceptance and implementation of BIM in the construction industry came up as Create drawings (15.9%), Quantity Takeoff (13.2%), Site Planning (10.0%), Clash Detection (9.9%) and Scheduling and Sequencing (6.9%). On the other hand, Code compliance (1.6%) and Virtual Meeting Capabilities (0.9%)

were the least ranked as drivers for the acceptance and implementation of BIM in the Ghanaian construction industry.

Further, the outcome established after the opinions of respondents were drawn from the types of building projects affected by the use of BIM in the construction industry. Commercial buildings (22.3%) recorded the highest building project affected by the use of BIM. This was followed by Industrial (21.6%), Residential (17.2%), Educational (13.6%), Institutional (13.6%), Healthcare (11.2%) and Transportation (0.6%) respectively.

Six main drivers emerged eventually with at least one from each criterion and at a threshold set at a number of responses (≥ 150) to be the key driver. Any driver below this value however was deemed not a key driver. These divers systematically were; Create drawings under (191) under capabilities and functions, Architect/Engineers (183) under stakeholders, Enhance productivity (167) also under advantages, Quality Takeoff (159) again under capabilities and functions, Construction Managers (155) again under stakeholders and Commercial (153) under types of building projects.

4.5 Exploring the most important factors of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana.

In exploring the level of improvement in performance on construction projects as a result of adoption and implementation of BIM in the Ghanaian construction industry, opinions of respondents were analyzed using the Relative Importance Index (RII) and subsequently ranked according to their relative importance. This was based on a seven-point Likert scale from strongly important (=7) to strongly unimportant (=1). According to Akadiri (2011), the criticality of RII is defined as follows; strongly unimportant (≥ 0.14), very unimportant (0.15 – 0.29), unimportant (0.30 – 0.44), moderately important (0.45 – 0.59), important (0.60 – 0.74), very important (0.75 – 0.89) and strongly important (≥ 0.90). Data obtained from respondents therefore were used to calculate the importance of each level of improvement in performance as the basis of the ranking (Table 4.4). This may be calculated using the formula;

$$RII = \sum \frac{W}{AN}$$

Where *RII* (Relative index) is used for ranking indicators (degree of importance), *W* is the weight given to each item by respondents on a scale of one to seven with one implying the least and seven the highest, *A* is the highest weight (7 in our case) and *N* is the number of respondents (Akadiri 2011).

Table 4.4: Level of improvement in performance on construction projects as a result of adopting and implementation of BIM in the construction industries in Ghana.

Level of improvement in performance	RESPONSES (RANKING)							TOTAL	∑W	MEAN	RII	DESCRIPTION
	1	2	3	4	5	6	7					
Increases productivity	2	0	12	15	50	79	56	214	1214	5.67	0.81	Very important
Improves product quality and creates customer value	0	1	1	20	80	61	51	214	1208	5.64	0.81	Very important
Helps in removing barriers and constraints	1	2	1	24	67	80	39	214	1192	5.57	0.80	Very important
Reduces the time of project design and shop drawings	2	1	0	23	69	73	44	214	1187	5.55	0.79	Very important
Reduces the time of project design and shop drawings	0	1	0	19	87	76	31	214	1186	5.54	0.79	Very important
Improves communication effectiveness	0	1	14	31	56	54	58	214	1178	5.50	0.79	Very important
Provides accurate cost estimation and take off materials	0	0	1	33	87	67	26	214	1154	5.39	0.77	Very important

Reduces conflicts and number of claims	1	1	1	16	112	61	22	214	1150	5.37	0.77	Very important
Reduces defects in the construction phase	2	3	1	52	38	100	18	214	1135	5.30	0.76	Very important
Increases collaboration in project design	3	1	0	62	41	77	30	214	1130	5.28	0.75	Very important
Reduces uncertainty inherent in the construction phase	1	15	2	27	84	78	7	214	1082	5.06	0.72	Important
Generates and evaluates alternative construction plans	1	1	26	43	69	44	30	214	1072	5.01	0.72	Important
Aids in just in time delivery of materials and parts	0	1	8	57	96	41	11	214	1057	4.94	0.71	Important

Source: Arthur's Field Study (2019)

Not at all important (≥ 0.14); not important (0.15-0.29); neutral (0.30-0.44); moderately important (0.45-0.59); important (0.60-0.74); very important (0.75-0.89); most important (≥ 0.09)

Table 4.4 displays the Relative Importance Index (RII) of the level of improvement in performance on construction projects as a result of adoption and implementation of BIM in the Ghanaian construction industry with their associate rankings concerning their mean values. The threshold for the key levels of performance improvement was set at a range of 0.75 – 0.89 and any level below this range was not deemed prime. It was evident per the criticality of the Relative Importance Index (RII) that ten levels of performance improvement (falling within the range 0.75 – 0.89) were identified as "very important" which are interpreted as key levels regarding the level of improvement in performance on construction projects as a result of adoption and implementation of BIM in the Ghanaian construction industry. These levels with their corresponding RII accordingly were; Increases productivity (0.81), Improves product quality and creates customer value (0.81), Helps in removing barriers and constraints (0.80), Reduces conflicts and number of claims (0.79), Reduces the time of project design and shop drawings (0.79), Improves communication effectiveness (0.79), Provides accurate cost estimation and take off materials (0.77), Reduces conflicts and number of claims (0.77), Reduces defects in the construction phase (0.76) and Increases collaboration in project design (0.75).

4.6 Measuring the relevance of BIM maturity in the Ghanaian construction industry.

Table 4. 5: KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.856
Bartlett's Test of Sphericity	Approx. Chi-Square	6434.809
	df	231
	Sig.	0.000

Source: Arthur's Field Study (2019)

To ascertain the suitability of the data for factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and a Bartlett's Test of Sphericity were performed. As a rule of thumb, a KMO value of 0.5 or higher necessitates the need to proceed with factor analysis. Therefore, obtaining (Chi-square = 6434.809, df = 231, p < 0.000) signifies that it is worth continuing with factor analysis as there is a relationship to investigate.

To better appreciate the opinions of respondents in measuring the relevance of BIM maturity in the Ghanaian construction industry, their views were subjected to factor analysis (Table 4.6). In effect, five main factors came up regarding the precepts underlying the use of this statistical tool. First, the scree plot (Fig. 4.1) upon thorough observation pointed out six factors although the eigenvalue with its associate thumb rule of one or greater pointed out to five factors. Again, an accumulated value of about 80% emanating from five factors met the criteria of explaining variance of 5%. Further, these five had considerable theoretical backing thus making them interpretable. However, two factors fell outside the scope of this bracket and were eliminated eventually. Concerning their variance explained, their percentages were 53. 625%, 15.409%, 6.281% and 5.266% and subsequently ascribed to component 1, component 2, component 3 and component 4 respectively (Table 4.6).

Table 4. 6: Total Variance explained

Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11.797	53.625	53.625	6.262	28.466	28.466
2	3.390	15.409	69.033	5.266	23.937	52.403
3	1.382	6.281	75.315	3.555	16.160	68.563
4	1.163	5.285	80.600	2.648	12.036	80.600

Extraction Method: Principal Component Analysis

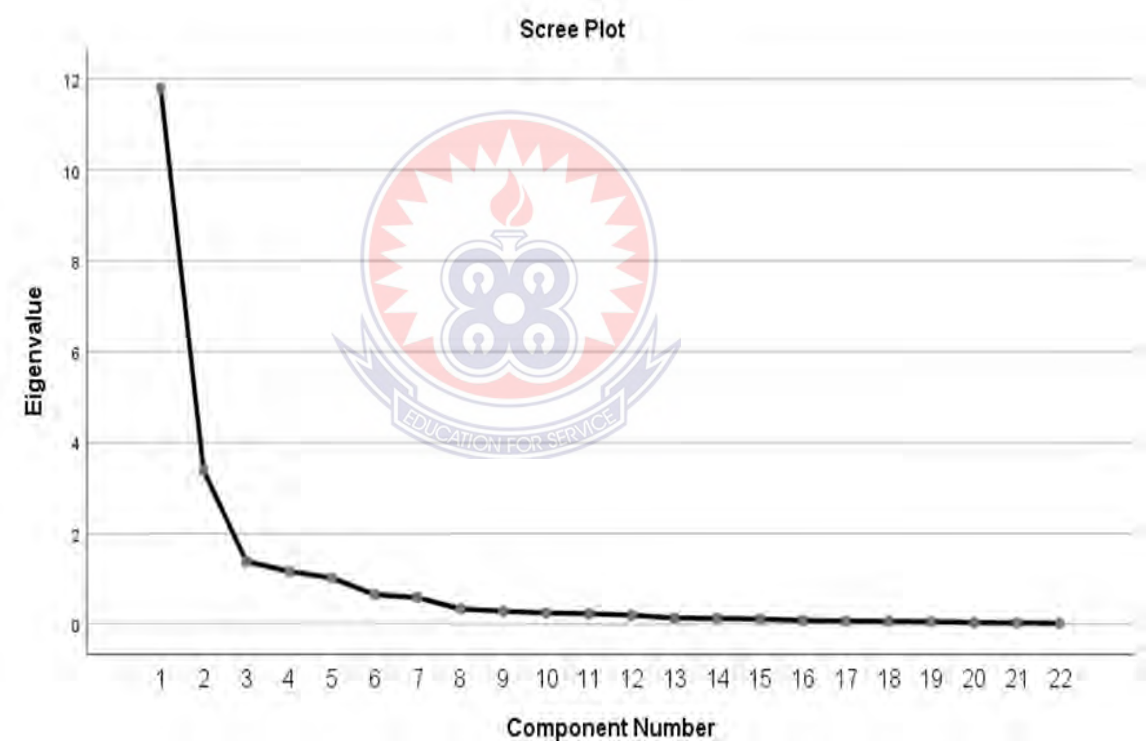

Figure 4.1: Scree Plot **Source:** Arthur's Field Study (2019)

Varimax rotation method was used to obtain the factor loadings with their corresponding components in measuring the relevance of BIM maturity in the Ghanaian construction industry (Table 4.7).

Table 4. 7: The relevance of BIM maturity in the Ghanaian construction industry

Relevance	Component			
	1	2	3	4
Interoperability			**0.847**	
Software Applications			**0.697**	
Hardware Equipment			**0.693**	
Information delivery method			**0.578**	
Information Accuracy	**0.874**			
Graphics	**0.865**			
Real-time Data	**0.834**			
Senior Leadership	**0.790**			
Process and Technology Innovation	**0.780**			
Data Richness	**0.700**			
Information Assurance	**0.689**			
Strategic Planning	**0.688**			
Geo-spatial Capability	**0.660**			
Specification		**0.904**		
Quality Control		**0.889**		
Documentation and Modeling Standards		**0.811**		
Standard Operating Process		**0.801**		
Work Flow		**0.765**		
Life Cycle Process		**0.737**		
Training Program				**0.844**
Competency Profile				**0.777**
Training Delivery Method				**0.771**

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser

Source: Arthur's Field Study (2019)

As presented in Table 4.7, nine factors loaded onto component one, with component two recording six-factor loadings as component three had four-factor loadings and component four loading three factors accordingly. Loaded onto component one were the factors; Information Accuracy (0.874), Graphics (0.865), Real-time Data (0.834), Senior Leadership (0.790), Process and Technology Innovation (0.780), Data Richness (0.700), Information Assurance (0.689), Strategic Planning (0.688) and Geo-Spatial Capability (0.660). Following was component two having factors as Specification (0.904), Quality Control (0.889), Documentation and Modeling Standards (0.811), Standard Operating Process (0.801), Work Flow (0.765) and Life Cycle Process (0.737) loaded onto it. Next was component three with loaded factors such as Interoperability (0.847), Software Applications (0.697), Hardware Equipment (0.693) and Information delivery method (0.578). Similarly, the factors loaded under component four were Training Program (0.844), Competency Profile (0.777) and Training Delivery Method (0.771).

4.7 Determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

Pursuance to determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies, respondent's views were descriptively examined. The outcome of the analysis was based on the precept that mean values of (≥ 3.5) were tagged as " Most available", those within the range (3 – 3.49) as "Available", so as those within (2.5 – 2.99) as " Somewhat available" and those falling under (≤2.0) also classified as "Rarely available (Table 4.7).

Table 4.8: Software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

Software's	Mean	SD	Description
Revit Architectural	4.02	1.138	Most available
AutoCAD Architectural	3.88	1.293	Most available
SketchUp	3.81	1.028	Most available
ArchiCAD	3.72	1.153	Most available
AutoCAD Civil 3D	3.52	1.244	Most available
AutoCAD	3.52	1.244	Most available
AutoCAD Design Suite Premium	3.36	1.146	Available
Bentley Systems	3.23	1.127	Available
Revit Structure	3.21	0.722	Available

ARCHline	3.18	0.988	Available
Revit MEP	3.18	1.099	Available
Chief Architect	3.11	1.445	Available
Edificius 3D Architectural	3.04	0.978	Available
3D Ultimate	3.00	1.179	Available
Tekla	2.92	1.221	Somewhat available
Autodesk Navisworks	2.91	1.600	Somewhat available
AutoCAD MEP	2.91	1.436	Somewhat available
Vector Works	2.78	1.246	Somewhat available
Autodesk Navisworks	2.64	1.149	Somewhat available
Twinmotion	2.53	1.741	Somewhat available
Lumion	2.12	1.252	Rarely available

Source: Arthur's Field Study (2019)

With over twenty variables opened to participant's opinion specifically on deducing the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies, six of these software's came up as the Most available software's, with seven following next as the Available software's as six recorded Somewhat available software's with one emerging as the Rarely available software for BIM relative to the threshold of the mean values established earlier. Accordingly, the six Most available software's were; Revit Architectural (4.02), AutoCAD Architectural (3.88), SketchUp (3.81), ArchiCAD (3.72), AutoCAD Civil 3D (3.52) and AutoCAD (3.52). Under the bracket of Available software's were AutoCAD Design Suite Premium (3.36), Bentley Systems (3.32), Revit Structure (3.21), ARCHline (3.18), Revit MEP (3.18), Chief Architect (3.11), Edificius 3D Architectural (3.04) and 3D Ultimate (3.00). somewhat available software's were Tekla (2.92), Autodesk Navisworks (2.91), AutoCAD MEP (2.91), Vector Works (2.78), Autodesk Navisworks (2.64) and Twinmotion (2.53). Consequently, Lumion (2.12) received Rarely available software.

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Introduction

A thorough discussion is presented in this chapter relative to the objectives driving the study as analyzed in the chapter before. The emphasis here is placed on providing explanations, appropriate evidence of the views and opinions of issues heightened in the survey. Clear and more comprehensive detail backed by literature on theories, ideas and thought on these issues were further examined.

5.2 Determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana.

In dealing with a data set that offers respondents the liberty to select more than a response at the same time, multiple response analyses stand significant (Simon, 2013). In this respect, the technique was used in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. Six main drivers were identified in this effect. These were; capability and function to create drawings, the involvement of Architect/Engineers as stakeholders, Advantage gained as a result of enhanced productivity, capability and function in providing quality takeoff, the involvement of construction managers as stakeholders and its usage in commercial building projects.

5.2.1 capability and function to create drawings

The capability and function to create drawings came up as a key driver in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. According to Azhar (2011), building proposals can be rigorously analyzed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions to generate a better design. Also, Smith et al, (2009) hint that the initial change was from hand drafting to 2D CAD (Computer-aided drafting/design) process, thus by introducing BIM recently, this process has been further improved. With these developments, it could be said that building proposals can be rigorously analysed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions for better designs.

5.2.2. Involvement of Architect/Engineers as stakeholders

Inevitably, stakeholders like Architects as well as Engineers form a core component in determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana. This assessment was clarified by Zhar et al, (2012), who claimed that the project architects and engineers can take advantage of BIM in schematic and detailed design; and construction detailing phases. They outlined some benefits accrued by these professions which placed them at a position imperative in influencing the acceptance and implementation of BIM in the construction industries in Ghana. These included; better design by rigorously analyzing digital models and visual simulations and receiving more valuable input from project owners, early incorporation of sustainability features in building design to predicts its environmental performance, better code compliance via visual and analytical checks and early forensic analysis to graphically assess potential failures, leaks, evacuation plans and so forth. Adding to Kymel (2008) BIM facilitates quick production of shop or fabrication drawings. In this regard, feedback could help the design team fix the issues early in the design process.

5.2.3 Advantage gained as a result of enhanced productivity

The advantages gained through enhanced productivity informed and induced participants outcome particularly, regarding the need for construction industries in Ghana to accept and implement BIM. The construction industry in developed countries is experiencing a major move from the traditional methods of intensive manual Laboure towards the utilization of automation that has been made possible through the use of information technology. This trend results in enhanced construction efficiency leading to improved productivity in terms of reduction in wastage, errors, and rework Nath et al. (2015). Expanding further, they noted that in Singapore, for sustained economic growth to be achieved, the Building and Construction Authority (BCA) of Singapore has set up a productivity improvement target of at least 20–30% by the year 2020. To improve the situation, BCA has identified and mandated Building Information Modelling (BIM) as a key technological tool to improve productivity. This, therefore, suggests the need to embrace this technology into our construction industry thus labelling it a paramount driver to boost the acceptance and implementation of BIM in the construction industries in Ghana.

5.2.4 Capability and function in providing quantity takeoff

Provision of quality takeoff as a function and capability of BIM greatly impacts the essence for the acceptance and implementation of BIM in the construction industries in Ghana. Efficient and accurate quantity take-off and cost estimation are pivotal to a project's success (Staub-French, 2003). Forgues et al. (2012) accentuated that, BIM serves as prerequisites to many other activities in a project from budgeting, bidding and contracting to value-based design, production planning and budget control; they require extracting information based on the knowledge of domain experts about the rules and processes throughout the products and projects lifecycle. There are commercial software products available that attempt to semi-automate these tasks through augmenting the quantitative information elicited from design models, creating pre-structured yet customizable cost databases and reducing repetitive aspects of these tasks. Aram et al. (2014) emphasized the conditions for successful BIM use in ensuring quality takeoff. Included were; architectural and structural design models to be readily suitable for quantity takeoff and cost estimation, all the needed information to be quantitative in nature and designers' models to contain complete information needed for these tasks. In effect, streamline costs and process, to help effective coordination and collaboration of different disciplines and to minimise the confusion on job sites.

5.2.5 involvement of construction managers as stakeholders

The involvement of construction managers as stakeholders forms a major element as a key driver for the acceptance and implementation of BIM in the construction industries in Ghana. Construction managers or general contractors can use BIM to extract quantities of work to prepare cost estimates (Hergunsel, 2011). Continuing further he stated that, BIM can provide powerful 3D renderings as well as schedule integrated BIM known as 4D BIM which can be used for animations, safety analysis, and to prepare site logistic plans. In concluding, he added that construction managers can use BIM to coordinate work with subcontractors, update schedule and costs with BIM and can turn over an as-built building information model to the owner's maintenance team. Invariably, this assertion reinforces the varied significance of the acceptance and implementation of BIM in the construction industries in Ghana.

5.2.6 usage in commercial building projects

Increasing predominantly for the acceptance and implementation of BIM in the construction industries in Ghana is its usage in commercial building projects. Complex construction projects require inter-organizational associations (Maurer, 2010). To ensure success in inter-organizational project ventures, trust between the different project partners is acknowledged as a key success factor (Kadefors, 2004; Maurer, 2010). Because of the nature of work in these inter-organizational ventures, there is a well-recognized need for better integration, cooperation, and coordination of construction project teams (Cicmil & Marshall, 2005, cited in Maunula, 2008). BIM could be the key approach to adopt to ensure this integration and shift from the document paradigm to the Integrated Database paradigm happens. Allison (2010) cited in Bryde et al. (2013), addressed the BIM potential as a project management tool more directly. Allison describes ten reasons why the project manager should champion 5D BIM. Aouad et al. (2006) defined this multidimensional capacity of BIM as "nD" modelling, for it allows adding an almost infinite number of dimensions to the Building Model. BIM takes the traditional paper-based tools of construction projects, puts them in a virtual environment and allows a level of efficiency, communication and collaboration that exceeds those of traditional construction processes (Lee, 2008). Hence "the coordination of complex project systems is perhaps the most popular application of BIM at this time. It is an ideal process to develop collaboration techniques and a commitment protocol among the team members…" (Grilo & Jardim-Goncalves, 2010). BIM has also been linked to the development of lean approaches to the management of projects, as the enhanced collaboration and information sharing can contribute to the lean management's goal of reducing non-value-adding waste (Olatunji, 2011).

BIM has a potential use at all stages of the project life-cycle: it can be used by the owner to understand project needs, by the design team to analyze, design and develop the project, by the contractor to manage the construction of the project and by the facility manager during operation and decommissioning phases (Grilo & Jardim-Goncalves, 2010). Looking to the future leads to speculation that BIM will eventually lead to a virtual project design and construction approach, with a project being completely simulated before being undertaken for real (Froese, 2010). As such BIM will provide potential beneficial project outcomes by enabling the rapid analysis of different scenarios related to the performance of a building through its life cycle (Schade et al., 2011).

5.3 Exploring the most important factor of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana.

In the quest to explore the most important factor of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, the Relative Importance Index (RII) was sought. In the process, nine factors were identified as the most important factors of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. These included, increases productivity, improves product quality and creates customer value, helps in removing barriers and constraints, reduces the time of project design and shop drawings, improves communication effectiveness, provides accurate cost estimation and take off materials, reduces conflicts and number of claims, reduces defects in the construction phase and increases collaboration in project design.

5.3.1 Increase productivity

An increase in productivity came up as an important factor in the improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. The Architecture, Engineering and Construction (AEC) industry are constantly in pursuit of techniques to improve quality, increase productivity, decrease the cost of construction projects. It is perceived to have the potential to significantly change and improve performance and documentation in the AEC industry by reducing inefficiencies, enhancing productivity, and increasing collaboration and communication (Campbell 2007; Goedert & Meadati 2008).

5.3.2 Improve product quality and creates customer value

Improvement of product quality and creation of customer value emerged also as one of the important factors in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. This is advocated by Jylhä and Junnila (2012) who claim that customers are the nursing companies and their nursing staff; special focus is given to the value potentials that building information modelling (BIM), as well as improved environmental performance, might offer to the customers. From this perspective, it could be said that, to improve product quality and customer value by using processes and systems which aim to fulfil the customer's requirements, enhance customer satisfaction, monitor against applicable quality standards have a great impact on the performance on a construction project. The rapid preparation and exchange of visual information mitigate the time needed for communicating complex ideas and allows more time to be creative for clients, which should result in repeat business and excellent references.

5.3.3 Help in removing barriers and constraints

Another most important factor in exploring the most important factors of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana is the improvement in product quality and creating of customer value. Czmoch and Pękala (2014) attested that the construction process enforces the final and accurate decision to be taken. They emphasized further that the BIM model requires accuracy in modelling from the very beginning and that strict standards and rules have to be set within the team to work according to BIM standards as this affects the whole designing teamwork and its efficiency. BIM technology requires the members of the design team to abandon the individual working schemes, so characteristic for each person and specific for discipline or design office. BIM 3D model - exactly following the architect idea and coordination provisions - is the key for the project to be done correctly. They reiterated. Azhar (2011) reckoned that because building information models are created to scale in 3D space, all major systems can be instantly and automatically checked for interferences. For example, this process can verify that piping does not intersect with steel beams, ducts, or walls. In this regard, BIM helps reduce errors and omissions which should in turn reduce claims and professional liability. A reduction in insurance costs, bonding fees and a positive impact on firm reputation should increase the number, scale and variety of opportunities available to design and integration firms.

5.3.4 Reduce the time of project design and shop drawings

Interestingly, reduction of time of project design and shop drawings found itself among the most important factors geared towards improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. In line with this, Azhar (2011) postulates that BIM can do faster drafting without compromising quality. Linderoth (2010) maintains that the result of using BIM is improved project coordination, minimised errors, as well as reduced delays and conflicts, which could lead to a potential saving in construction cost alone ranging from 15% to 40% (given the full integration of entire design and construction team at all stages of project development in place). Respecting these views, it is therefore imperative to stick to the use of BIM technology to meet help manage time schedules for all projects for there is the saying that time is money.

Wasting time on the projects can greatly affect its cost and schedule of delivery which may result in customer dissatisfaction.

5.3.5 Improve communication effectiveness

An essential feature directed at the improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana is its merit of improving communication effectiveness. Affirming this fact is Linderoth (2010) who indicated that one benefit realized when utilizing BIM during the conception phase of a project is increased communication across the entire project development team. Suggestively, BIM enables proper communication management through timely and appropriate generation, collection, distribution, storage, retrieval, and disposition of project information. The 3 dimensional (3D} models generated from building information modelling enhanced visual communication between the stakeholders involved in the project delivery. It assists to overcome any language barrier that might have to hinder better communication delivery between parties involved in project delivery and impede the construction performance and efficiency of work.

5.3.6 Provide accurate cost estimation and take off materials

Providing accurate cost estimation and take off materials, a very unique property that directly influences the improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. Corroborating this perspective is Azhar (2011) who opines that BIM software has built-in cost estimating features. Material quantities are automatically extracted and updated when any changes are made in the model, he added. Similarly, Krygiel and Nies (2008) maintain that the use of BIM enables the design team to calculate building materials and environmental variables on the job site in real-time rather than by manual estimation. Here, it could be said that for precision budgeting and costing of materials as well as quantity of materials required for a given project BIM usage will be the best alternative to achieve this result and by so doing the will be a reduction of material waste; cost-effectiveness and efficiency in construction performance.

5.3.7 Reduce conflicts and the number of claims

Reduction of conflicts and several claims equally surfaced as an important factor that contributes to the improvement in the performance of construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. Koc and Skaik (2014) in (Chenung and Pang, (2013) contend that contracts are often ambiguous to parties; the scope is not properly defined, specifications are unclear or cost rate evaluations are not provided i.e. in the evaluation of prime costs. In the event of a time or cost overrun or quality dissatisfaction, a claim arises to mitigate the undesired effects. The disturbance caused by disputes to projects is invariably significant. The stakeholders require their projects to run smoothly with no risk of investment failure (AAA, 2007). Shourangiz et al. (2011) in Greenwald (2013) established that BIM not only enables cost-saving and effective time management but also reduces disputes significantly. This is done through a solution of incidents, clash analysis and early detection of issues. Khoshnava et al. (2013) also stated that BIM models significantly reduce the number of events that might become conflicts, as it involves all core elements of data. Similarly, Azhar (2011) maintains that integrating all the parties within the project is an important approach for dispute avoidance. With this, all stakeholders are thus encouraged to do so via BIM. In consonance to these, with BIM technology usage adoption in carrying out construction projects the issue of conflicts and claims which normally results in a delay of the delivery of projects which equally affects construction performance will be thing of the past and since all stakeholders are involved if conflict does result in resolution become easily and timely as there are available document backing the project delivery and any changes made is taking care of automatically with the BIM software.

5.3.8 Reduce defects in the construction phase

Pertinent in the construction industry is the appropriate method, technique and technology in reducing defects in the construction phase of any project. Relative to this assessment presents an important factor aimed at reducing these defects in the construction phase to ensure improvement in the performance of construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. According to Hussein et al, (2016), BIM simulates building construction and design on the computer before the real construction activities start on-site, which leads to increased accuracy and reduced errors for both building quantities and qualities. Evenly, the simulation capability of BIM helps reduce unnecessary reworks at the site. However, better teamwork is necessary (Eastman et al., 2011). It is thus envisaged that; the introduction of BIM helps in addressing unforeseen occurrences such as clash detection which might have impeded the progress of work. Detection of errors, clash, energy analysis of building and proper coordination and collaboration of all stakeholders by the BIM system enhance the constructional ability of the project and continuous workflow for better construction project performance.

5.3.9 Increase collaboration in project design

An increase in collaboration of project design also appeared as an important factor for improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. Arguing this assertion is Hussein et al, (2016) who indicated that BIM increases the collaboration between design teams, engineers, and contractors and increases project efficiency by sharing BIM information, especially at the beginning of the design process in project development. For instance, contractors can review BIM models and report useful feedback to the design team and engineers regarding any deficiencies that might have occurred. That feedback could help the design team fix the issues early in the design process, they concluded. Moreover, Bhatla and Leite (2012) were of the view that BIM is focused more on the application of information technology to increase collaboration among the project participants in the entire project lifecycle. This we can say bringing on board all stakeholders right from the design stage through the life cycle of the project has a great influence on the construction project performance.

5.4 Measuring the relevance of BIM maturity in the Ghanaian construction industry.

In measuring the relevance of BIM maturity in the Ghanaian construction industry, factor analysis was used to dimension the variables under this objective into appropriate components. Four components were obtained following the conditions underlying the use of this statistical tool. These were named subsequently as information related factors for component one, process-related factors as component two, technology-related factors going for component three and people-related factors same for component four.

5.4.1 Component one: Information Related Factors

The principal component explained 53.625 % of the total variance with nine factors loading unto it. These factors were; Information Accuracy, Graphics, Real-time Data, Senior Leadership, Process and Technology Innovation, Data Richness, Information

Assurance, Strategic Planning and Geo-Spatial Capability. According to Eastman et al. 2008, BIM provides information on the ability to evaluate the impact of design changes on construction in a visual manner that is not possible with traditional 2D drawings. Regarding information accuracy, they reiterated further that automated quantity takeoff which is linked to the BIM model is more accurate as there are fewer chances of human error; hence, it improves flow by reducing variability. Buttressing this assessment is the Associated General Contractors of America (2005) who maintained that Building Information Model (BIM), is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and to improve the process of delivering the facility. Making information from the BIM especially with the increasing complexity of projects denotes such an improvement beneficial to better control its related complexity issues (Hamdi et al., 2012). Upon the submissions churned out, information related factors are very essential as it prevents doubts, clients and other parties in the Architecture, Construction, Engineering industry rely on requisite information in decision making on projects.

5.4.2 Component two: Process-Related Factors

Process related factors had their principal component explaining 15.409 % of the total variance with six factors loading unto it. These included, Specification, Quality Control, Documentation and Modeling Standards, Standard Operating Process, Work Flow and Life Cycle Process. Pas (2013) hints that and BIM defines how the information modelling aspects of a project will be carried out and clarifies roles and their responsibilities, standards to be applied and procedures to be followed. Giel et al. (2013) in Succar (2010) attested that, in terms of the BIM specification process, it has specific metrics well defined and serve industry-specific assessment purposes. Quality control, an inevitable process in BIM was clearly explained by Aranda- Mena et al. (2009) who advocates that with building information modelling implementation, quality control ensures that the activities conducted, the mechanisms or techniques used for a project meet the requirements for the product or service are used. This thus extends to suggest that, BIM use would require a change in the existing work practice. A unified model development needs greater collaboration and communication across disciplines. A standard process and agreed protocols are required to assign responsibilities and conduct design appraisals and endorsement.

5.4.3 Component three: Technology-Related Factors

The principal component defined 6.281 % of the total variance as four factors loaded unto it. The factors were Interoperability, Software Applications, Hardware Equipment and Information delivery method. The National Institute of Building Science (NIBS) (2007), advanced that BIM serves as an eminent technology with its interoperability properties. Expanding further, they explained that software interoperability is seamless data exchange among diverse applications which each may have its internal data structure. They added interoperability is achieved by mapping parts of each participating application's internal data structure to a universal data model and vice versa. Again, they noted that, if the employed universal data model is open (i.e. not proprietary), any application can participate in the mapping process and thus become interoperable with any other application that participated in the mapping. 3D Models are relied upon to generate 2D as well as 3D deliverables. Data usage, storage and exchange are well defined within organisations and project teams therefore signifying that interoperable data exchanges are defined and prioritized (Succar, 2010). This in effect affirms that Technology field BIM representing the availability, accessibility and affordability of hardware, software and network systems; also, the availability, usability, connectivity and openness of information systems have an impact on the construction project performance.

5.4.4 Component four: People Related Factors

People related factors under this principle component explained 5.285 % of the total variance. Three main factors were loaded unto it which were, Training Program, Competency Profile and Training Delivery Method. Gu and London (2010) suggested that, in reaching the level of BIM maturity to better understand and facilitate its adoption in the AEC industry, training should be organized for its users' overtime. They directed that this training should be dedicated to the use of BIM software tools and the workflows associated with them to be competent in its usage in project delivery. In defining this competency involved through training of the people concerned, Dakhil et al. (2019) suggested that two different meanings of the term competency have been established. Competencies may be expressed as "behaviours that an individual need to demonstrate", or they may be expressed as "minimum standards of performance". Consolidating this claim, they argued that BIM competency represents the ability of users to fulfil all the important areas of an effective BIM implementation to deliver value and achieve the expected BIM product/service. This indicates that new roles and relationships within the project teams are emerging. Keen roles such as BIM manager will be inevitable for large scale projects, as already seen in some real-world scenarios. Team members need appropriate training and information to be able to contribute and participate in the changing work environment.

5.5 Determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

Descriptive statistics were used to deduce the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Six software's came up as the most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. These included; Revit Architecture, AutoCAD Architecture, SketchUp, ArchiCAD, AutoCAD Civil 3D and AutoCAD.

5.5.1 Revit Architecture

Interesting, Revit architecture emerged as the most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Revit architecture software is used used for 3D Architectural Modelling and Parametric Design (Reinhardt, 2009). Guan-pei, (2010) accentuated that, Revit architecture assumes this enormous patronage because it contains a set of tools, techniques and concepts that allow realizing the BIM approach toward general construction design. Revit Architecture software, a subsidiary of Autodesk's brand of BIM software is designed to work the way you think, so you can create naturally, design freely, and deliver efficiently. And because it is purpose-built for BIM, any change you make any time, anywhere is automatically coordinated throughout your project. Designs and documentation stay coordinated, consistent, and complete (KIA, 2013). This thus demonstrates that for the architectural design purpose Revit Architecture was quickly adopted by most architecture, Engineering and Construction firms who were using BIM technology.

5.5.2 AutoCAD Architecture

AutoCAD architecture similarly surfaced as one of the most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Confirming this assertion is AutoCAD, (2009), which reckoned that AutoCAD Architecture is the version of AutoCAD software for architects. Drafting and documentation are much more efficient with the software's intuitive environment and purpose-built tools for architects. Experienced immediate productivity is gained while learning new features at your own pace. This software helps to share and communicate designs easily with DWG file format. Autodesk Architecture solutions help to increase design and documentation productivity, improve coordination and collaboration, and manage complex designs. Explaining further, AutoCAD presents a practical, affordable, and easy to deploy Autodesk's portfolio for architects and designers with the potential of bringing your design ideas to life. In this way, one can say that the utilization of AutoCAD Architecture enhances the design process and brings all stakeholders on board to prevent disputes and misunderstanding among parties involved.

5.5.3 Sketchup

Another significant software that fell within the bracket of the most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies was SketchUp. According to Ying et al. (2011), SketchUp is used to automatically construct 3D models with attributes and thematic information from 2D survey plans. They stressed that spatial topologic relationships and operations are analyzed with the programming and development of the Ruby language. The resulting system can manage 3D cadastral objects and manipulate them with spatial operations to support spatial analysis, they added. Toptas et al. (2012) in Fleron, (2009) postulated that, as one of the dynamic geometry software, Google SketchUp is a powerful, sophisticated, user-friendly Computer-Aided Design (CAD) program. This premise indicates that Sketchup pro with collaborations with other plugins like Lumion can be used for Building Information Modelling and come out with realistic designs without going through any tedious training. One does not need supplicated computers to work with Sketchup and it has uncountable sets of open library catalogues which can be fussed in the design to improve its aesthetic value.

5.5.4 ArchiCAD

ArchiCAD similarly remained as another most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. ArchiCAD allows its users to create 3-D structures with “smart objects” such as walls, slabs, roofs, doors, windows and furniture. 2-D drawings (plan and elevation views) can be created from 3-D creations (K. I. A 2013). Jiang, (2011) indicated that ArchiCAD is the Virtual Building Explorer, a real-time 3D navigation that is enhanced with gravity, layer control, fly-mode, egress recognition and pre-saved walkthroughs. ArchiCAD also includes a built-in analysis tool to conduct the energy analysis function on its BIM model. ArchiCAD supports a range of direct interfaces. In this respect, it can be said that ArchiCAD has modelling capability, bidirectional database associability, MEP modelling, clash detection, ready to use geometry libraries, cost and material tracking, rendering capability, and digital terrain modelling for Building Information Modelling resulting ineffective design and project delivery.

5.5.5 AutoCAD Civil 3D

AutoCAD Civil 3D equally emerged as one of the most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Varela-González (2013) suggests that AutoCAD Civil 3D software is a

Building Information Modeling solution for design and documentation in the civil engineering field from Autodesk. AutoCAD Civil 3D supports Building Information Modeling (BIM) and helps reduce the time it takes to design, analyze, and implement changes (Autodesk, 2017). They elaborate further that AutoCAD Civil 3D performs faster design iterations with an intelligent, 3D model-based application that dynamically updates related civil design elements when changes are made. It streamlines time-consuming tasks for corridor design, parcel design, and pressure and gravity network design. They continue that AutoCAD Civil 3D helps the designer to improve project delivery and make more informed decisions using visualization, simulation, and water analysis integrated with the design process for stormwater management, geospatial analysis, and model analysis. From this perspective, it could be said that the use of AutoCAD Civil 3D assists civil infrastructure professionals to improve project delivery, maintain more consistent data, processes, and respond faster to project changes.

5.5.6 AutoCAD

Convincingly, AutoCAD was selected as one of the most available software for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Autodesk (2017) hints that AutoCAD software provides the power and flexibility to help drive your projects from concept through creation quickly and efficiently; visualize design concepts within a 3D environment, quickly and accurately document designs, and collaborate with clients and contractors to save time and money. In this direction, one could say that AutoCAD is not 2D CAD we use to know but have gone on several transformations and have other components like AutoCAD MEP which provide workflows that support BIM processes such as data-rich intelligent objects. The study conducted by Danso (2012) found that the most known general CAD software program in the Universities in Ghana offering civil engineering and related programs is AutoCAD.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Summary of Findings

This chapter presents a summary of the key findings, conclusions drawn and the required recommendations obtained respectively, regarding the use of building information modelling (BIM) and its impact on construction performance within the Ghanaian construction industry. Fundamentally, the entirety of the study was defined on specific set objectives. In order of deliberation, they included; determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, exploring the most important factor of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana, measuring the relevance of BIM maturity in the Ghanaian construction industry and deducing the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. Quantitative in nature, data was gathered through field study from 214 participants emanating from about 300 questionnaires self – administered. These were selected from a population of Quantity Surveyors, Architects, Structural Engineers, Civil Engineers, Project Managers, Contractors and General Foremen. Outlined below, thus, are the key findings derived from the study.

6.1.1 Determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana.

In determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana, the study made out six main drivers geared towards the acceptance and implementation of BIM in the Ghanaian construction industry.

Achieving this feat using multiple response analysis, these drivers included; capability and function to create drawings, the involvement of Architect/Engineers as stakeholders, Advantage gained as a result of enhanced productivity, capability and function in providing quality take off, the involvement of construction managers as stakeholders and its usage in commercial building projects.

6.1.2 Exploring the most important factor of improvement in performance on construction projects as a result of the adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana.

The findings revealed nine factors through the use of the Relative Importance Index (RII) as the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana. These were; increases productivity, improves product quality and creates customer value, helps in removing barriers and constraints, reduces the time of project design and shop drawings, improves communication effectiveness, provides accurate cost estimation and take off materials, reduces conflicts and number of claims, reduces defects in the construction phase and increases collaboration in project design.

6.1.3 Measuring the relevance of BIM maturity in the Ghanaian construction industry.

The study with regards to measuring the relevance of BIM maturity in the Ghanaian construction industry identified four main principal components as relevant in measuring the BIM maturity in the Ghanaian construction industry. Factors analysis was used in this process to dimension the variables into the underlying components. These were virtually named as information related factors for component one, process-related factors as component two, technology-related factors going for component three and people-related factors same for component four.

6.1.4 Determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

In deducing the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies, the study conceived six main software as the most available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies. In realizing this, descriptive statistics were used in the analysis process. The six that came up eventually included; Revit Architecture, AutoCAD Architecture, SketchUp, ArchiCAD, AutoCAD Civil 3D and AutoCAD.

6.2 Conclusion

Building Information Modelling (BIM) is particularly focusing on people's minds as it involves ever-growing volumes of information exchange, especially as it no longer just focuses on working in three-dimensional (3D) drawing, but also adding time (4D) and cost (5D) dimensions to the equation. Digitisation is enabling new and better ways of working, but it introduces possible susceptibilities, which need to be protected from any lapses being subjugated.

Construction productivity has been and remains a concern of organizations, governments as well as individual projects. For construction productivity improvement, the use of BIM for the Architectural, Engineering and Construction Industry stands a key to sustaining general economic activity in most countries. The call to improve construction industry productivity drives government strategies and targets to reduce the construction costs because often governments are major clients for infrastructure construction.

The study in this direction sought to investigate the use of Building Information Modelling (BIM) and its impact on construction performance within the Ghanaian construction industry. The motive behind the study was to find out the usage of BIM in our Architecture, Engineering and Construction (AEC) industry and identify how best it has improved productivity and construction performance. Reliant on the analysis of the data collected, it was disclosed that most stakeholders in Architecture, Engineering and Construction (AEC) industry were aware of the benefits of utilising Building Information Modelling (BIM) in their projects in terms of their level of understanding. This was revealed through their rejoinders as they acknowledged that the key drivers of utilising BIM in the AEC industry in Ghana included; enhance productivity, competitive advantage, pave way for exploring and adopting new trends and Success stories of others using BIM.

Moreover, the top five views regarding their response on the main capacities and functions/benefits influencing the acceptance and implementation of BIM in their respective field of practice emerged as; Creating drawings, Quantity Take-off, Site Planning, Clash Detection and Scheduling and sequencing.

With regards to the levels of importance of improvement in performance on construction projects as a result of adopting and implementation of BIM in the construction industries in Ghana, nine of the levels considered to be very important were: increases productivity, improves product quality and creates customer value, helps in removing barriers and constraints, Reduces the time of project design and shop drawings, improves communication effectiveness, provides accurate cost estimation and take off materials, reduces conflicts and number of claims, reduces defects in the construction phase, and increases collaboration in project design.

The study, therefore, concludes that stakeholders in the Architect, Engineering and Construction in the Ghanaian construction (AEC) industry have a competitive advantage over other non-BIM users as the BIM application in construction projects reduces waste and safety problems in construction, leading to the completion of quality projects. Several BIM tools (software) have been used in the construction industry for improving construction processes. BIM benefits construction projects by improving project schedule, detecting any clash during the design stage, decreasing construction cost and improving communication between the construction team.

Implementing BIM in the construction industry can increase the overall quality of projects and improve the image of the industry. BIM is useful in supporting construction teams to construct small or high-risk projects successfully. BIM tools can be used to address problems such as project delay, increase in construction cost, accidents on construction sites and disputes between construction stakeholders.

6.3 Recommendations

With regards to the findings and discussions of this study, these recommendations were set out:

- All construction companies in the Ghanaian Construction industry must be encouraged to use BIM to improve profitability, reduce cost, enhance better time management and improve customer/client relationships as well as their satisfaction.
- Government's should make efforts to enforce the use of BIM technology more widely in construction projects in Ghana.
- The government should introduce better structure BIM courses for student offering Architecture, Engineering and Construction programmes to assist in improve the designs of our Architects, produce Engineers with Technical no

how in their field of study and skills workforce for improving our Construction sector.

- To deal with the problem of slow workflow and inefficiencies of the output of work executed by Architectural, Engineering and Construction (AEC) firms in Ghana, the government should award contracts to local contractors based on their experience and expertise in building information modelling process and Technology.

6.4 Limitations and Recommendations for future research studies

The entire structure concerning the methodology and research design of this study was without restrictions. Architectural, Engineering and Construction (AEC) firms are not easily accessible as most of the firms do not have offices and more often you can only locate most of them in their workplaces. With the nature of their work, most are very reluctant to accept you and even help you acquire the requisite data.

Suggestively, these areas of study are recommended for further research:

- Government's role in helping to improve the use of Building Information Modelling (BIM) or management.
- Addressing the legal issues concerning the use of building information modelling in Ghana and their impact on project procurement.
- Facilitating BIM in the AEC industry for management of waste, budgeting and costing of projects.

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APPENDIX A

QUESTIONNAIRE

UNIVERSITY OF EDUCATION – WINNEBA (KUMASI CAMPUS)

DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY

QUESTIONNAIRE FOR CONSTRUCTION STAKEHOLDERS (QUANTITY SURVEYORS, ENGINEERS, ARCHITECTS, PROJECT MANAGERS) ON THE USE OF BUILDING INFORMATION MODELLING AND ITS IMPACT ON CONSTRUCTION PERFORMANCE WITHIN GHANAIAN CONSTRUCTION INDUSTRY.

PREAMBLE

Dear Respondent, I am Wirekoh Frederick Kwasi, a Post-Graduate Construction Student of University of Education (Kumasi Campus) undertaking a research on the topic "An Investigation into the Use of Building Information Modelling and Its Impact on Construction Performance Within Ghanaian Construction Industry". This study forms part of the requirement for the program of Master of Philosophy (MPhil) in the Department Construction and Wood Technology, UEW-K.

KEY OBJECTIVE OF THE STUDY

To investigate into the use of building information modelling and its impact on construction performance within Ghanaian construction industry.

RELEVANCE OF THE STUDY

- ❖ It recognizes the importance of practical and working worth in the construction industry through the utilization of BIMs in the construction industry.
- ❖ This study draws on data and information from a wider variety of stakeholders and project types allowing for a broader and more meaningful understanding of how Building Information Modelling (BIM) enhance work in the construction industry.
- ❖ The approach of this study is with the intention of providing valuable insight and findings that can be used by companies of varying size and scale for improvement of their own BIM implementation plans. A better understanding of BIM from the practitioner perspective will also allow for expansion and better utilization of BIM to improve construction performance.
- ❖ Academics could use the findings to better prepare their education programmes and make students cognizant of how to drive construction performance on a construction project with the effective use of BIM.

I recognize that, these questionnaires would take part of your eventful plan however I would be very glad if you could spare me a little of your precious plan to read each question carefully before responding, and then circle or tick the appropriate answer in the designated space. Please response to the best of your capability.

You are assured that the study is for only academic purposes; all and every information provided will therefore be treated with the extreme clandestineness. Thank you for your assistance. For further enquiries, recommendations and contributions to this research, please contact the researcher below.

Thank you.

Wirekoh Frederick Kwasi.
Department of Construction and Wood Technology
UEW- Kumasi
Email: profred9@hotmail.com or fwirekoh21@gmail.com
Mobile: 0247113002

Section A: Demographic Background of Respondents

Please answer this section to help in the analysis of the data provided. (Please tick (√) as appropriate.

1. Which construction firm do you belong?

Architectural Firm [ ] Quantity surveying Firms [ ] Structural Engineering Firms [ ] Other (Please specify) ……………………………..

2. What is your professional background?

[ ] Quantity surveyor [ ] Architect [ ] Structural Engineer [ ] Civil Engineer [ ] Project Manager [ ] Other (Please specify) ……………………………

3. What is your highest academic qualification?

[ ] Post Graduate [ ] First Degree [ ] Higher National Diploma [ ] Construction Technician Certificate [ ] Advance in Construction Certificate [ ] Technical

Other (Please specify) ……………………………

4. Which professional body do you belong to?

[ ] Ghana Institute of Architect [ ] Ghana Institution of Surveyors [ ] Ghana Institute of Engineers [ ] Ghana Institution of Construction

Other (Please specify) ………………………………

5. what is the nature of projects you undertake?

Office Buildings [ ] Residential Buildings [ ] Industrial Buildings [ ] Civil Engineering Projects [ ] Combination of above [ ]

Others (Please specify) ………………………………

6. Number of years in the profession (work experience)?

0-5 years [ ] 6-10 years [ ] 11-15 years [ ] 16-20 years [ ] Over 20 years [ ]

7. What is level of expertise in using BIM?

Please indicate your confidence in your expertise in BIM

[ ] None [ ] Low [ ] Somewhat Low [ ] Medium [ ] Somewhat High

[ ] High [ ] Expert

Section B: Determining the key drivers for acceptance and implementation of BIM in the construction industries in Ghana.

8. What are the key drivers for acceptance and implementation of BIM in the construction industries in Ghana?

Please tick (√) any that may apply.

A) Identify the main drivers for choosing to adopt BIM on your projects.

[ ] It is required by owners or contracts

[ ] Competitive Advantage

[ ] To be a leader in industry by exploring and adopting new trends in industry

[ ] To enhance productivity

[ ] Success stories of others using BIM

[ ] Other (please specify) ______________________________________

B) Indicate all stakeholders who used BIM in the majority of your BIM-assisted projects.

[ ] Owner/Developer

[ ] Architect/Engineer

[ ] General Contractor

[ ] Construction Manager

[ ] Subcontractor (please specify)

____

[ ] Consultant (please specify)

____

[ ] Software Vendor (please specify)

____

[ ] Other (please specify)

____

C) What capabilities and functions of BIM have been used in most of those BIM-assisted projects?

[ ] Create drawings

[ ] Clash Detection

[ ] Quantity Take-off

[ ] Scheduling and sequencing

[ ] Site Planning

[ ] Labour resource allocations

[ ] Equipment management

[ ] Communication

[ ] Collaboration with stakeholders

[ ] Energy analysis

[ ] Code compliance

[ ] Facility management

[ ] Virtual meeting capabilities

[ ] Costing and Budgeting

[ ] Waste management

[ ] Improve project controls

[ ] Facilitate decision making

[ ] Other (please specify)

____

D) Please indicate the building types for the majority of those BIM-assisted projects.

[ ] Commercial

[ ] Healthcare

[ ] Residential

[ ] Educational

[ ] Industrial

[ ] Institutional

[ ] Transportation

[ ] Other (please specify)

____

Section C: Exploring the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana.

9. What are the most important factors of improvement in performance on construction projects as a result of adoption and implementation of Building Information Modelling (BIM) in the Construction Industry of Ghana?

Rank on Likert scale from 1 to 7.

Please tick (√) your level of importance by ranking each option.

1 = Strongly unimportant **2** =Very unimportant **3** = unimportant **4** = Moderately important **5** = Important 6 = Very important **7** = Strongly important

S/n	**FACTORS**	***Please Tick [√]***						
		1	**2**	**3**	**4**	**5**	**6**	**7**
1	Implementing BIM increases collaboration in project design and construction							
2	Implementing BIM reduces defects in the construction phase and design and prevents rework							
3	Adopting BIM improves communication effectiveness among the project's participants							
4	Adopting BIM reduces conflicts and number of claims among project's stakeholders							
5	Adopting BIM stabilizes workflow and reduces construction process variability							
6	Adopting BIM help in removing barriers and constraints from work assignments							
7	Adopting BIM reduces uncertainty inherent in the construction phase and design							
8	Adopting BIM reduces the time of project design and shop drawings							
9	Adopting BIM aids in just in time delivery of materials and parts							
10	Adopting BIM provides accurate cost estimation and take off material quantities							
11	Adopting BIM generates and evaluates alternative construction plans rapidly							
12	Adopting BIM improve product quality and creates customer value							
13	Adopting BIM increases productivity							

Section D: Measuring the relevance of BIM maturity in the Ghanaian construction industry.

10. How do we measure the relevance of BIM maturity in the Ghanaian construction industry?

Rank on Likert scale from 1 to 7.

Please tick (√) your level of agreement by ranking each option.

Strongly Disagree = **1** Disagree = **2** Disagree Somewhat = **3** Neither Agree nor Disagree = **4** Agree Somewhat = **5** Agree = **6** Strongly Agree = **7**

S/n	BIM Maturity (BIMM)	*Please Tick [√]*						
		1	**2**	**3**	**4**	**5**	**6**	**7**
1	Software Applications							
2	Interoperability							
3	Hardware Equipment							
4	Hardware Upgrade							
5	Information Delivery Method							
6	Information Assurance							
7	Process and Technology Innovation							
8	Strategic Planning							
9	Senior Leadership							
10	Data Richness							
11	Real-time Data							
12	Information Accuracy							
13	Graphics							
14	Geo-spatial Capability							
15	Life Cycle Process							
16	Work Flow							
17	Change Management							
18	Role and Responsibility							
19	Reward System							
20	Risk Management							
21	Standard Operating Process							
22	Documentation and Modelling Standards							
23	Quality Control							
24	Specification							
25	Competency Profile							
26	Training Program							
27	Training Delivery Method							
28	Information Security							

Section E: Determining the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies.

11. What are the various software's available for BIM essential for the Ghanaian Architectural, Engineering and Construction (AEC) companies?
Rank on Likert scale from 1 to 7.

Please tick (√) your level of usage by ranking each option.

Not heard of it = **1** No usage = **2** Average usage = **3** High usage = **4** Highly usage = **5** Very highly usage = **6** Most highly usage = **7**

S/n	Building Information Modelling (BIM) Software	*Please Tick [√]*						
		1	**2**	**3**	**4**	**5**	**6**	**7**
1	AutoCAD							
2	AutoCAD Architectural							
3	AutoCAD Design Suite Premium							
4	AutoCAD Civil 3D							
5	AutoCAD MEP							
6	Autodesk Navisworks							
7	ArchiCAD							
8	ARCHline							
9	Bentley Systems							
10	Chief Architect							
11	Edificius 3D Architectural							
12	3D Ultimate							
13	Revit Architecture							
14	Revit Structure							
15	Revit MEP							
16	Graphisoft							
17	Lumion							
19	Sketch up							
20	Tekla							
21	Twinmotion							
22	Vector Works							
23	Tekla Structures							

APPENDIX B

INTRODUCTORY LETTER FROM INSTITUTION

UNIVERSITY OF EDUCATION, WINNEBA
COLLEGE OF TECHNOLOGY EDUCATION, KUMASI
FACULTY OF TECHNICAL EDUCATION
DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION
P. O. Box 1277, Kumasi, Ghana
constwoodtech.coltek@uew.edu.gh
+233 (020) 5111914

UEW/KC/CW/

July 23 , 2019

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Dear Sir/Madam,

LETTER OF INTRODUCTION

I write to introduce **Mr. Wirekoh Frederick Kwasi,** a final year student with Index No. 8171760004 pursuing M.Phil (Construction) Programme at the College of Technology Education, Kumasi(UEW).

Mr. Wirekoh is undertaking a research project and wishes to collect some data in your Organisation. His research project is titled **'The use of Building Information Modeling and its Impact on Construction Performance within the Ghanaian Construction industry'.**

Please kindly offer him the needed assistance.

Thank you.

Yours sincerely,

MICHAEL K. TSORGALI
AG. HEAD, DEPARTMENT OF CONSTRUCTION AND WOOD TECH.