BIM INTEGRATION FOR CONSTRUCTION HEALTH AND SAFETY

Master thesis

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin

Submitted on 20.01.2020 from

Tolulope Ajibade

Metropolia UAS Student number: 1707880

HTW-Berlin Student number: S0562600

First Supervisor: Prof. Dr.-Ing. Nicole, Riediger

Second Supervisor: Arc. Eric Pollock

Acknowledgment

Quite a number of individuals have contributed to the successful completion of this dissertation. As this work represents the end of an inspiring two-year master program, the author uses this opportunity to show appreciation and acknowledge the effort of these individuals.

My foremost gratitude to Prof. Dr.-Ing. Nicole, Riediger for valued supervisory contribution through the course of this research as well as all the ConREM lecturers and administrative staff of the HTW Berlin and Metropolia University of applied sciences Helsinki.

Special thanks to my amazing parents for their love and care during the process of this program. I will also like to equally thank my siblings for cheering me on this journey.

My sincere gratitude to Folashade and Gbolahan for their words of encouragement and support; you guys are the best!

To end with, I will also like to thank all the researchers whose work has helped me during the cause of this study.

Conceptual formulation

Metropolia

htw. Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia Helsinki and HTW Berlin

date 19.08.2019

Conceptual Formulation
Master Thesis for Mr./Ms. Tolulope Ajibade
Student number s0562600

Topic:
BIM INTEGRATION FOR CONSTRUCTION HEALTH AND SAFETY

1.0 Introduction

In recent developments, the construction industry has seen appreciable growth in the use of Building information modeling (BIM) and modern-day information technology. Up till now, construction companies have made a remarkable effort of 20% reduction in accident rates according to (A. Ganah & A. John, 2014). This, however, is due to achieved progress in increased Health and Safety awareness in the industry in addition to improved Health and Safety regulations and sanctioned code of conducts (A. Ganah & A. John, 2014). They further argued that construction projects require complex processes. Design, construction planning, and management are quite complex and difficult because each project is uniquely complex and dynamic. (A. Ganah & A. John, 2014).

Research questions

1. What are the challenges in conventional safety planning in construction?
2. How can BIM be used to solves these challenges?
3. What potentials does BIM-based platform have for construction safety planning procedures?
4. What digital methods can be implemented in Health and safety through BIM?
5. What are the barriers on entry and implementing these methods?
6. What are the roles of various stakeholders in the implementation of a BIM based Health and safety platform?

30.08.2019
Signature of the supervisor

Abstract

In recent years, the influence of Building Information Modeling (BIM) has continued to soar in the construction industry, especially in the aspects of design, scheduling and most recently costing. However, one begins to question whether BIM can also influence construction safety. By laying emphasis on conventional health and safety practices, the aim of this academic dissertation is to explore ways in which BIM technology and digitalization can be used to improve safety outcomes within the construction environment.

The study begins with a detailed review and analysis of available literature on the study topics. The main topics were, however, further discussed together, before narrowing down to propose a BIM-based theoretical model to be implemented throughout the entire project lifecycle. In order to validate the content and concept proposed in the model, a survey was administered to some key stakeholders in the industry. The analysis of the outcome of the survey showed that the framework was valid and that BIM technology has barriers as well as the potential to enhance health and safety outcomes in the construction industry. This research further concludes with discussions on the entire work as well as provide answers to pending research questions from the thesis proposal along with recommendations for future research.

Keywords:

BIM, Health, Safety, Construction, Simulation, Communication, Design, Automation

Table of Contents

Table of Figures

List of Tabulations

List of Abbreviations

BIM	Building Information Modeling
AEC	Architecture Engineering and Construction
ICT	Information and Communication Technology
GIS	Geography Information System
VR	Virtual Reality
IFC	Industry Foundation Classes
GPS	Global Positioning System
3D	Three-Dimensional
CAD	Computer-aided Designs
CIM	Computer Integrated Manufacturing
CIC	Computer Integrated Construction
BDP	Building Product Models
IT	Information Technology
OHS	Occupation Health and Safety
2D	Two-Dimensional
4D	Four-Dimensional
RII	Relative Importance Index
JHA	Job Hazard Analysis

1.0 Introduction

This dissertation begins with an overview that draws attention to selected and identified problems in the study domain with the intention to explore probable solutions to the problems. The structure of this dissertation, however, is written with a conscious and detailed structure to enable the reader to fully grasp the full length of the topic as well as achieved results. First, the author explores a broader spectrum of the research theme in the preliminary part of this study, highlighting several implications of the study, as well as, considerations and recommendations for future research. Subsequent sections of this study discuss in detail, the selected topics.

The approach deployed by the author to tackle these issues is by first analyzing and investigating the current state of things, the position of industry practitioners and stakeholders as regards the integration of Building Information Modeling (BIM) for Health and Safety in construction. This chapter also offers the reader a decent knowledge of the contextual information on the problems relating to the topic as well as a summary of the entire work, discussions on the research questions and methodological approach.

1.1 Overview

While various studies and global indicators continue to highlight the problem of occupational safety, of which situations associated with fall from heights, collision, electrocution are major causes of job site fatalities in the industry. In other industries, workspace safety planning has occupied a significant position, but often time in the construction industry, safety planning, and management is done separately from the entire work[1]. One of the most important factors to consider for when planning the construction process is the health and safety of workers and in spite of the existence of safety laws and regulations as well as the effort of safety professionals, the construction industry is yet to experience a significant reduction in reports of injuries and accidental. However, some researchers attributed inappropriate work planning and supervision, poor communication with project participants, poor safety awareness and practice as the major influences contributing to construction injuries and mortalities.[2]

In as much as the idea is still in the novel phase, the influence and implementation of BIM have started to gain access to the construction industry's health and safety practices.[3] A safe place to begin is to put emphasis on safety from the early phases of a project, i.e. design and engineering phase.[4] Thus far, Architecture Engineering and Construction (AEC) professionals have been applying BIM technology in processes of planning, site management, and supervision. Furthermore, the majority of BIM technological applications have been tailored towards maximizing efficiency and cost savings. On the other hand, consideration of its application for health and safety is quite limited.[5]

Although safety implementations, practices and regulations exist in the construction industry, many reported cases of construction accidents are still prevalent. As such, there is a need for improving safety practices in the industry. The idea is to leverage BIM technology to achieve a proactive approach to safety practice in other to achieve a reduction in accidental figures. Just as BIM is being used to change the dynamics of design and construction supervision, the author seeks to explore the possibilities of a BIM-based application for construction health and safety.

[1] (Sulankivi K. et al, 2013)
[2] (Carter G. and Smith S., 2006)
[3] (Zhang S. et al, 2013)
[4] (Zhou W. et al, 2011)
[5] (Stefan Mordue, 2019)

1.1.1 Problem

The construction industry is renowned for life-threating injuries and job site fatality rate, even with the best practices and efforts of construction stakeholders, sundry people lose their lives or encounter serious injured through a direct or indirect influence of construction activities each year. While there was heavy rainfall in September 2015, a crawler crane collapse in Saudi Arabia. This single event led to the injury of 394 people and over 100 deaths.[6] Accounting for occupational fatalities cases being reported annually, the construction industry is renowned for the danger and high-risk potential it poses to construction workers.[7]

According to Wei Zhou et al, the global construction industry recognizes safety as one of the key issues facing it. Likewise, figures associated with accidents in the construction industry is twice when compared with the accidental figures in the manufacturing industry. Wei Zhou et al, in their research, underlined that 10 and 11 fatal accidents were reported for every 100,000 construction personnel between 2006 and 2007 in Europe and the United States (US) respectively.[8] Similarly, another research by Shafique M. & Rafiq M. pointed out the existence of global concern for project policymakers regarding the mortality rates among construction workers. They argue that the highest work-related risk ranging from injuries and illnesses are experienced by construction workers globally.[9]

Stefan Mordue, in his book on BIM for construction health and safety, argued that construction industry is one of the most important industry to economies globally, even in cases of economic recession, the sector is still considered as one world-leading industry. As much as it is almost impossible to undermine the importance of the industry, it also remains one of the most dangerous and hazardous. Over the past 20 years, appreciable efforts have been put in place to reduce the rate of construction-related accidents and injury, nevertheless, construction still remains a high-risk industry.[10]

[6] (Al Jabri, S., 2017)
[7] (Godfaurd J. & Ganah A., 2015)
[8] (Zhou W. et al, 2011)
[9] (Shafique M. & Rafiq M., 2019)
[10] (Stefan Mordue, 2019)

Similarly, this argument was supported by Khoshnava S. et al, stating that the safety of construction workers still is a foremost concern for the industry despite the fact that it has improved since the last decade. According to their research, statistics by the Bureau of Labour statistics in 2010 indicated that the construction industry suffered more life-threatening injuries than any other industry-leading into additional cost to the tune of billions annually.[11] In this light, the author will further exploit more literature research on available statistics related to construction accidents globally.

1.1.2 Background

The use of physical models in construction has been an old practice, many iconic buildings would have not been realized without the use of these models. While they are symbols showing design insights they can only be used for construction as they contain very limited information on a building, most especially, as-built data. And as much as they symbolize the design of the building, they do not usually correspond with the completed work; as such, their post-construction use is limited.[12]

These forms of inadequacies, however, are being addressed through the involvement of BIM in the construction industry. Buildings are as old as human existence, and the world has seen historic buildings being built overtime with no records of any injuries or fatality rate during the construction of a good number of these buildings. According to Stefan Mordue, the design team of the empire state building estimated a one death per floor during the construction phase of the building. However, at the end of the construction, death figures were pegged at seven. This figure, however, was seen as a positive achievement at that time. Since then, the technological advancement in the global construction market has resulted in the construction of much complex building.

Contributing enormously to economies across the globe, the construction industry occupies a key position amongst different industries in developed countries. As such, any national efforts towards the enhancement of the industry as well as providing a solution to problems relating to any part of the industry will have a positive influence on such a country's economy[13]. Often time, the performance criteria of the construction industry are based on time, cost and quality and safety. Safety, on the other hand, is important

[11] (Khoshnava S. et al, 2012)
[12] (Stefan Mordue, 2019)
[13] (Alomari K. et al, 2017)

as it has influence as much as it is influenced by the three other factors. Any bid targeted at improving the health and safety of construction workers will yield benefits for the project and for the industry at large. However, there is a need for supplementary research on a more enhanced approach to safety methods because accidents work safety hazards still constitute major problems in the construction industry.

According to Sulankivi K. and colleagues, the idea of a model-based digital approach for safety improvement hinges on 1. Proactive planning of work task structure along with safety provisions and services for the said task in a virtual environment, 2. Making certain that every construction works can be carried out without any safety threat and 3. Adequate and detailed documentation of already planned, easy to understand safety guidelines and to make every key player privy to this information. BIM thus far has been seen as an enabling tool, as such this study continues to explore BIM for construction health and safety, most importantly to tackle the problems associated with safety. [14]

[14] (Sulankivi K. et al, 2013)

1.2 Aim and objectives of the research

The aim of this dissertation is to determine and analyze the potential of BIM technology for improving safety outcomes in the construction industry. This process is aided by an extensive search of previously written and relevant literature on BIM as well as its implementation on construction health and safety. Too many accidents leading to death continue to occur on construction sites across the world, while some others suffer serious musculoskeletal injuries that could have been avoided through a sound safety planning system. BIM has continued to represent a platform for one of the most sophisticated techniques in the global construction market. By exploring the use of BIM technology as a modern tool for health and safety practices, this thesis seeks to help the reader to understand the method, benefits, limitations and perhaps the future of opportunities for a BIM-based safety model.

In order to fulfill the goal of this research which is to address the topic of health and safety with BIM. The research analyses separately the topic of BIM and construction safety before further combining them. From this combination, however, a theoretic concept is formed. This theoretical concept is used as a base for which validations can be made by key participants in the AEC industry based on their experience through a questionnaire. The construction industry has not been excluded from the constant change in technological advancement sweeping across global economic sectors.

This, of course, has been a driving force behind the change of approach to global industries. There is now a need for matters of precision and error-free processes as a result of digital and visual construction tools. However, the bulk of the application of these trending technological tools has been limited to the upstream and project delivery sector of construction. The author believes these digital trends ought not to be limited to the project delivery alone, especially since the topic of health and safety has remained challenged for construction stakeholders for a long time. It is not only enough to improve planning and management procedures of design, construction, and operations of buildings, but it’s a collective responsibility for the AEC industry to protect the lives and state of well-being of construction workers.

To get a better safety outcome in construction, there is a need to utilize digital means to design an automated, easily accessible, self-explanatory safety information system.

BIM technology is best suited for this description as it has the potential to support visualization and simulation of safety planning processes just has it has supported visualization for design, scheduling, and planning of construction processes. Besides the advantage of visualization, BIM equally fosters communication between stakeholders at all project levels and phases. With BIM, automatic safety checks are possible; as such, more precision can be applied to health and safety planning as safety professionals will be more informed and proactive such that they can focus their energy on solution giving rather than problem finding.

As previously mentioned, it is clearly evident that convention safety practices cannot provide adequate solutions to the health and safety problems the construction industry is facing. Although this does not mean that BIM will automatically eradicate and alleviate safety concerns immediately. Nevertheless, the idea is to support human efforts and approach towards safety with digitalization. Subsequent chapters of this research focus on a piece by piece guide form the beginning of the discussions for topic one to the thesis to the BIM-based theoretical concept which is further validated with a survey.

1.3 Research methodology

The methodology used for this dissertation is built and will follow a traditional literature review approach of the two main topics, in order to comprehend their development up to its present-day state. The work commences with the outline of research objectives followed by the literature review on BIM followed by construction health and safety. Through a combination of an extensive thematic analysis process on the two main themes (BIM and Construction health and safety), the author develops a suitable BIM-based theoretical concept for BIM integration throughout the lifecycle of a project. With detailed explanations and discussion, the model will discuss possibilities at every project phase.

In addition, the action point for key participants and stakeholders is explored as well as the benefits and limitations of the BIM-based model. In the following chapter, quantitative research was carried out to validate and authenticate the content in the model form key construction stakeholders. Because health and safety is a collective issue, the survey participants will include all key stakeholders and project participants represented across all phases of the project lifecycle from planning to operation and maintenance. The methodological process of achieving result follows thus:

- Problem determination
- Identification of research questions
- Analytical review of literature
- Formulation of a theoretical concept
- Preparation of questioners for survey
- Preparation of primary data form surveyed questioners
- Evaluation and analysis of data
- Discussion of results.

1.4 Structure Report

The structure for which this academic dissertation is framed follows thus:

Chapter 2: Discusses on BIM technology as it relates to this study through an overview of introduction, detailed definitions as well as the development of the technology. The chapter includes a peek into previous work done on utilizing BIM to increase safety performance which aids the formulation of answers for the research questions and development of the theoretical model.

Chapter 3: Discusses extensively the topic of construction health with a bid to determine the current state as well as conventional practice and approach to safety by construction stakeholders.

Chapter 4: Discusses the combination of chapters 2 and 3 with a review of how the discussions of chapter 2 can be implemented to solve the problems of chapter 3.

Chapter 5: Describes the total work done to administer questioners to key stakeholders in the construction industry as well as analysis of the work.

Chapter 6: Comprises of the discussions of inferences drawing for the outcome of the survey. This is done by studying the pattern of responses from the survey participants

Chapter 7 & 8: contains discussions on the conclusion made from the research as well as the answers to previously determined questions. Recommendations were also given to facilitate future research in the area of the study domain.

2.0 Building Information Modeling

BIM as one of the most encouraging developments of the 21st century AEC industry. The technology BIM provision makes it possible to accurately produce precise virtual models of any structure that contains precise geometry and all relevant data necessary for design, construction, fabrication, and procurement of the building.[15] BIM does not only offers a new approach to design, but construction also to building operation and maintenance; as a result, BIM can be implemented throughout the lifecycle of a building. However, it is hereby imperative also to grasp the BIM definition being used in the context of this dissertation. The technological concept of BIM over the last decade has gained ground in the AEC industry, offsetting the managerial and technological balance of scale within the industry from traditional methods towards an information-based technology.

[15] (Eastman et al., 2011)

2.1 Overview

Over the years, BIM has developed in construction industry and according to Zhou et al, BIM implementation in construction has been integrated with technological features such as sensor-based technology, information communication technology (ICT), Global positioning system (GPS), Virtual reality (VR) and Geographic Information system (GIS) particularly in the aspect of construction safety.[16] According to the EUBIM Task group, the implementation or growth in the use of computer technology by an organization, the industrial sector or country is often considered as digitalization. EU-BIM task group argue that in the current age, the construction industry identifies the BIM as her moment of digitalization. Generally, across all sectors, digitalization processes have been perceived to enormously contributed positively to the economic, social and environmental fabric. BIM technology is able to accommodate sundry tasks required to model the lifecycle of any building or infrastructural project, providing systemized coordination capable of support all processes various professionals and stakeholders on a project. [17]

As a result of this, many researchers establish that a major form of digitalization that the AEC industries wield is BIM in the 21st century. BIM is defined by Autodesk, is "an intelligent 3D model-based process that gives the AEC professionals the insight and tools to more efficiently plan, design, construct and manage buildings and infrastructure"[18]. The pivotal feature, in general, is the 3D model is the feature on which all other workflows (insights and tools) hinges upon. Crucial aspects of a 3D representation like dimensions, family name, position all contribute to the descriptive and numerical information used in BIM implementation.

Thus far, there have been quite a number of various BIM definitions available in written literature. Nevertheless, the author in this dissertation seeks to offer broad and operational definitions to enable the reader to undoubtedly comprehend the actual agenda behind BIM. Furthermore, these definitions enable one to comprehend every level and aspects of BIM technology as previous researchers on the topic also do not only con-

[16] (Zhou et al, 2013)
[17] (EUBIM Taskgroup, 2018)
[18] (Autodesk, 2019)

sider detailed explanations through their various definitions but corresponding comprehensive literature that similarly enables one to understand the benefits and potentials available for BIM users.

2.2 BIM definitions

Since early 2000, BIM influence has increased among stakeholders and professionals within the building industry; First, the term BIM was oblivious, then it emerged as a buzzword for most professionals.[19] BIM technology has affected significantly the modern-day AEC industry and has altered significantly, the process of building project delivery [20]. However, it is not only enough to acknowledge the progressive impact and focus BIM has triggered in the industry, but it is also imperative to fully comprehend what the technology encompasses. BIM technology permits further specialization and as such, it is extensive in nature[21].

The complex nature of BIM was further discussed by Turk in his research, highlighting the structural, functional and behavioral attributes of BIM. Frankly, BIM has many definitions, according to Levy F., the developments of design and analysis software combined with improvement in digital devices such as desktops, laptops, and solid computational power have been the driving force behind BIM. Stating that digital improvement is responsible for effective simulation of virtual buildings and infrastructures. Arayici & Aouad describes 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"[22].

Another definition according to Eastman et al's BIM handbook describe BIM "as a modeling technology and associated set of processes to produce, communicate, and analyze building models"[23] The handbook further highlighted that the representation of building components with smart digital images that are associated with data attributes,

[19] (Levy F., 2012)
[20] (Uddin & Khanzode, 2014)
[21] (Žiga Turk, 2016)
[22] (Arayici & Aouad, 2010)
[23] (Eastman et al., 2011)

components data with behavioral attributes as needed for analysis and work processes, component data changes are replicated automatically in all views to avoid redundant consistent and non-redundant data, and leveraging on coordinated data to produce coordinated views for 3D models are four main aspects that BIM models are characterized with.

Additionally, Turk explained his view on BIM, highlighting it as a tool of automation in the building industry while it facilitates integration and expansion for professionals in the industry.[24] Uddin & Khanzode further endorses this view by highlighting that BIM has become a catalyst for expanding career options in the AEC industry. BIM managers, coordinators, and experts are roles that have become progressively been a requirement for BIM assisted projects. Irrespective of the seemingly various extensively overlapping terms used to explain what BIM really is, quite a substantial amount of BIM researchers have in the past decided on distinguishing between the several available terms.[25]

B. Succar in his research highlighted a few studies available in industry and research literature to differentiate between various used terms (figure 1). According to him, these studies were implemented by industrial organizations and software developers; arguing that the overlapping margins of these terms leave a begging question on its exclusivity.

Sample terms	Organisation or Researcher
Asset Lifecycle Information System	Fully Integrated & Automated Technology
Building Information Modelling	Autodesk, Bentley Systems and others
Building Product Models	Charles Eastman
BuildingSMART™	International Alliance for Interoperability
Integrated Design Systems	International Council for Research and Innovation in Building and Construction (CIB)
Integrated Project Delivery	American Institute of Architects
nD Modelling	University of Salford – School of the Built Environment
Virtual Building™	Graphisoft
Virtual Design and Construction & 4D Product Models	Stanford University– Centre for Integrated Facility Engineering

Figure 1: Widely used terms related o BIM[26]

[24] (Žiga Turk, 2016)
[25] (B. Succar, 2008)
[26] (B. Succar, 2008)

Nevertheless, BIM definition can be diverse depending on its use and context, especially according to the profession, perception or aim of the user. The use of the BIM term is often associated with conventional connotations as described in figure 2

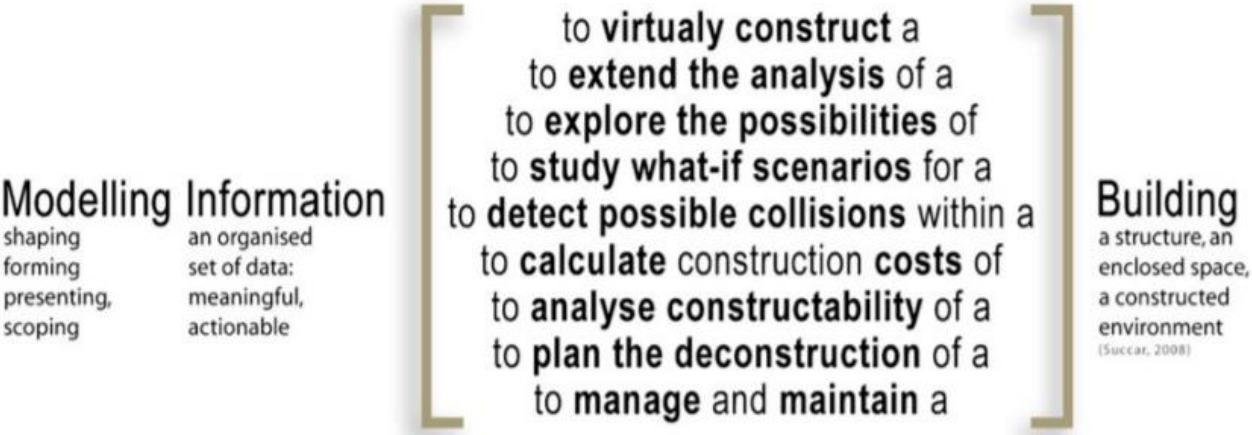

Figure 2: Common connotations of multiple BIM terms[27]

BIM potential is obviously extensive than researchers initially anticipated and it is safe to mention that the use of BIM technology has progressed over the course of time, hence the reseason for its discovery has lead to various acronyms and terms. Regardless of an individual's participation or profession, perspective or aim within the building industry, BIM is a tool developed to integrate and harmonize all disciplines working in the industry. Although BIM has its origins in CAD research from decades past, one of the main objectives of the development of BIM is to improve project efficiency through the utilization of data and collaborative project delivery process.

This, however, is made possible because BIM expresses architectural designs and model, cost, scheduling, and project health and safety features as well as building life cycle operations in a single digital model. While there has been a sluggish adoption of modern technologies in the AEC industry when compared to other industries, the change driven by digitalization is inevitable for the industry.[28] However, a high percentage of BIM implementation in the industry has been on 3D design. Nevertheless, BIM still remains a hub for all forms of digitalized tools. If entirely

[27] (B. Succar, 2008)
[28] (BCG, 2019)

embraced, this technology has adequate potentials not only in the design phase of a building or structure but the entire lifecycle of any project.

2.3 Background and development

According to research, the manufacturing industry and construction industry often is realized to have many similarities with the construction industry. These similarities impelled construction research to mirror successful models that had been applied in the manufacturing industry in the construction industry. Arayici. Y., in his BIM research, further argue that construction research highlighted Computer Integrated Manufacturing (CIM) as the strategic means to facilitate integration within the manufacturing industry, and therefore a similar model of Computer Integrated Construction (CIC) emerged; highlighting that the inspiration behind the CIC model for the construction industry was the CIM model. CIC model enables various project stakeholders to exchange project data through the use of a central database. According to Arayici. Y., the CIC model targeted the coherence and collaboration of fragmented project stakeholders across the industry's supply chain. At that time the concept of the CIM was also referred to as Building Product Models (BDP), after which it was referred to as BIM in the mid-2000s.[29]

Similarly, Dr. Smith's research on BIM development attributes BIM to the 1960s; although more sophisticated modeling programs emerged between the 1970s and 1980s. His research, however, highlighted that many consider the introduction of ArchiCAD software in 1982 as the actual commencement of BIM. Nevertheless, he attributed the major shift towards BIM implementation to the year 2000 when Revit was developed.[30] BIM has become increasingly sort-after since then, as contemporary market and political influences on the building industry have been emerging, demanding an increase in sustainability, efficiency, productivity, infrastructural value and, quality as well as the reduction in the lifecycle cost of building and infrastructure. The focus is to generate and reuse reliable digital information by stakeholders throughout the project lifecycle which is achieved by facilitating active collaboration

[29] (Arayici. Y., 2015)
[30] (Dr. Smith P., 2014)

and communication amongst all project participants. Largely, construction activities require a compound set of interactions between various construction professionals irrespective of their backgrounds and skillset to achieve a complex objective. As such, the presence of multiple stakeholders responsible for different individual tasks results in numerous construction documents and drawings.[31]

Traditional techniques for project delivery have been seen to be inadequate for complex projects and often time resulted in miscommunications between project participants. Figure 3 below, shows the difference between BIM and traditional based design and construction.

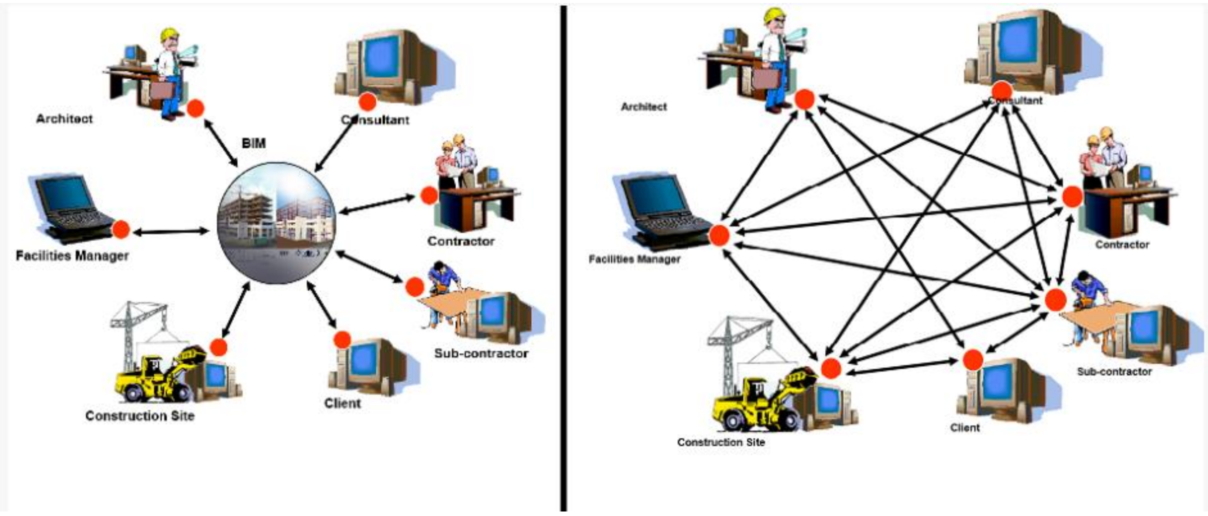

Figure 3: BIM-based Design and Construction vs Traditional Design and construction[32]

In any construction project, the quantity of data available for use from the period a project is set in motion to when it is finalized as well as during operation should not be underestimated. Similarly, Eastman et al. argue that, before the inception of BIM, a reasonable amount of project and facility delivery process was reliant on paper-based methods of communication within the building industry. This paper-based practice often time resulted in miscommunication between stakeholders and as such, resulted in additional costs, delays, unnecessary claims between project stakeholders because of errors and omissions. Although there have been alternative measures to tackle such problems in the past, and to a large extent, these alternative measures like design and

[31] (Aryani A. et al, 2014)
[32] (Prof. Dr. Y. ARAYICI, 2017)

build, use of 3D CAD tools have improved the timely exchange of information between project participants, they still have shortcomings to tackle conflicts and clash detections.[33]

According to Arayici. Y., contextual research has indicated that issues regarding integration between project stakeholders have been tackled from multiple angles. Recent BIM applications are designed to foster communication and integrations using a 3D geometry and information-based interface. These applications can as well connect to multiple applications and also databases that hold all the data relating to any project. Data exchange platforms such as Industry Foundation Classes (IFC), BuildingSmart, CORBA are products of earlier effort aimed at fostering integration in construction with the use of Information technology (IT) and digitalization.

Distinctively it is lucid that BIM technology offers a new and efficient path better create, store and reuse information for construction projects in the modern-day AEC industry. Figure 3 shows BIM's technological approach facilitates better communication and implements information exchange seamlessly. Exchange and storage of information are possible for all users and project stakeholders with BIM. Unlike the traditional paper-based approach, BIM methodology integrates digital images and descriptions of a building geometry along with their connections with another in an accurate method, to enable various stakeholders to query, simulate and estimate all undertakings and their resulting consequence of the building process as a lifecycle unit.[34]

Furthermore, BIM implementation also offers better satisfaction to clients and building users as the technology enables project stakeholders to make value judgments and assessments required to create more sustainable infrastructures. The technology behind BIM has been invented for over two decades, the adoption in the construction industry in comparison to other industries like manufacturing and engineering has relatively been at a slow rate. As such, the author considers that an important subject to consider its level of BIM implementation across the globe. Actively, there have been a series of research tailored towards communicating the many benefits of BIM implementation and addressing implementation concerns for the industry in recent years[35]

[33] (Eastman et al., 2011)
[34] (Arayici. Y., 2015)
[35] (Dr. Smith P., 2014)

As much as the dynamic force for digitalization in the AEC industry and BIM are sweeping across the globe, the level of standards and policy ingenuities on national levels differ from country to country. For example, BIM policy regulations and adoptions are prevalent in countries such as the US, Finland, Singapore, and the UK, while on the other hand BIM policy and adoption has remained slow countries like Germany and Australia. The USA, for instance, launched a Nation-wide 3D-4D BIM initiative in 2003 and since 2007 the country has mandated BIM in the approval of all major projects. Similarly, from the 1st of October 2007, Finland made directives for the use of IFC standards for models in her construction industry, likewise the UK government-mandated and set in motion in 2016, a BIM (level 2) model-based for all public sector projects.[36]

Obviously, BIM development varies around the world, the US currently leads the UK on BIM implementation and Germany perhaps is not currently at par with the UK. In 2015, the Federal Ministry of Germany (BMVI) announced through its federal minister its plan to mandate BIM for all public transport projects by the end of 2020, stating that the German construction industry must consider construction digitization as a standard.[37] Often time, major changes are usually accompanied by feelings of uncertainty and hesitation, particularly among small and medium-sized organizations.

In the case of Germany, small and medium-sized companies dominate the construction industry and just like any other BIM leading country has experienced, issues resulting from adaptability additional cost result from purchasing software and sophisticated hardware, user training and interoperability questions between various available software platforms. However, it is important that the government leads from the front and break the ice by implementing BIM for all public works and project, this will serve as a motivation for the private sector. BIM use has been limited in the sense that architects have been the biggest users as it has mostly been engaged in architectural design; nevertheless, the technology maintains huge potential. While the majority of BIM application is focused on increasing efficiency, cost and time savings and improving profit margins, fewer are considering the utilization of BIM to improve health and safety measures.

---

[36] (Edirisinghe R. & London K., 2015)
[37] (Lewis S., 2017)

2.4 Utilizing BIM for increasing safety performance

BIM for safety is still a novel concept and deliberations on BIM for safety are yet to be a collective and widespread topic in the construction industry. To achieve a reduction in the figures for a construction accident, injuries, and fatalities as well as success in safer designs and workplace safety, the industry needs to leverage on new safety enabling tools.[38] Even in a culturally diverse and dynamic setting BIM technology can aid support of exclusive construction safety planning and management. BIM offers a broad spectrum of use at every phase of a project.[39] With BIM, the possibility of reducing uncertainty and potential risk can be achieved; thereby increasing the general safety outcome and quality of project delivery of the construction project.

Construction is dynamic and characterized by workspace changes and changes in work practices, as such; there is a need for project teams to be safety conscious at all times. BIM helps to recognize potential conflict or risk even before they happen. Furthermore, BIM supports the principle of design for safety through visualization, with the aim of considering safety as early in the project (design stage).[40] Teo et al, further stated that essential health and safety data involving design changes, building materials, tools, and workers can be monitored with the help of BIM databases. Investigations relating to near misses and accidents can be done easily with the BIM model thereby reducing the time and cost spent on the investigation.

According to research done by Zhang S. et al, safety practices on site is less proactive and formalized which results in overall safety performance. While many contractors still utilize 2D drawings in their safety planning preparation, Zhang S. and colleagues in their work further pointed out that a feeble connection exists between safety and work-task execution. Such an approach to safety is clearly inadequate to guarantee workers' welfare on the construction site. There is a need to leverage on a geometric and parametric approach of the proposed construction task to be done as well as a visual representation of the intending workspace. With BIM, participants can visualize the workspace and detect potential conflicts.[41]

[38] (Seokho C. et al, 2012)
[39] (Markku Kiviniemi et al., 2011)
[40] (Teo et al, 2016)
[41] (Zhang S. et al, 2015)

There has also been quite some research in the AEC industry on the potential of BIM for health and safety, for instance (Benjaoran V. & Bhokha S., 2010) designed means to initial automatic safety checks to analyze building models, such that hazards can be prevented before the actual task is carried out. Similarly, (Seokho C. et al, 2012), developed a BIM-based platform to aid the planning of evacuation processes from highrise and complex buildings. By using algorithm rules to produce safety information (Wetzel & Thabet, 2015) also explored BIM for safety in the operation project phase. While these previously fragmented research exist the author seeks to explore health and safety in construction from a holistic lense. Such considerations are implemented for safety by every project participant and not just those in the construction phase of the project alone.

3.0 Construction Health and Safety

Prior to this chapter, the author establishes the concept of BIM technology, its development thus far, its integration with other technological means that help to further facilitate the efficiency of BIM models as well as a glance at how BIM can improve health and safety. Having given the reader a clear view of BIM, the author will further establish the topic of Health and safety in relation to the construction industry.

Firstly, the author's aim to further expound on the context in the topic of research by establishing a detailed understanding of the topic. Through detailed definitions and safety problem descriptions and accidental statistics, the author establishes global safety regulations to limit accidents on construction sites. Furthermore, the author establishes the current state of construction Health and safety in the global construction business as well as challenges faced by construction stakeholders to effectively implement pre-established safety regulations.

3.1 Overview

While the intended goal of this academic research still remains on the transformation and improvement associated with digitalization for the construction industry – and in particular BIM integration for construction health and safety. In this chapter, the author's aim is to introduce construction health and safety from a professional viewpoint. This is established by exploring previously written in-depth literature research on Construction Health and Safety.

The topic of Occupational Health and Safety (OHS) significantly concerns all sectors such as industrial, commercial, National Health service and most importantly to the construction industry. Construction Health and safety is a worldwide subject. The concept of modeling is not new and therefore, it safe to argue that the topic of health and safety date back much further. As mentioned earlier, this chapter is to introduce Construction health and safety by considering the scope and nature of it as well as the terms associated with it.

3.2 Background

Humanity relies upon the provision of the construction industry as it provides homes for a living, buildings for work as well as infrastructure for transportation. The construction industry does not only accounts for the development of physical infrastructure but is characterized correspondingly with its influence on investments. Other research concludes that construction products are linked with the creation of other commodities and as such, are considered as investment goods.[42] The industry, however, offers both economic and social benefits. Furthermore, construction is also considered a key part of economies globally, this industry plays a substantial role in the GDP contribution for most developed and developing nations as well as a significant impact on the health and safety of a country's workforce.[43]

According to Huges P. & Ferrett E., the United Kingdom (UK) construction industry is one of the largest industries nationally, contributing 8% of her GDP annually. The industry accounts for a yearly turnover of over £250 billion pounds and employs up to

[42] (Patricia M. Hillebrandt, 2000)
[43] (Lingard H. & Rowlinson S., 2005)

10% of the UK's working population. Similarly, Lingard H. & Rowlinson S. argue that the Australian construction industry contributes up to 7% of Australias GDP and employed over 600,000 people from 1995 to 1996.[44]

However, for all occupation types, health and safety are crucial, as it affects all aspects of the work done and quality of product delivery. In sectors characterized by minimal work hazards, health and safety perhaps can be managed by single experienced personnel. Although the product of the building industry contributes largely towards the development and improvement of our quality of life, many individuals, friends, and families across the world experience incredible pain and suffering due to severe injuries or accidental death as a result of their activity and work in the construction industry.

The knowledge and implementation of health and safety transcend beyond an individual or worker to wear protective coverings, safety boots, and helmet on a construction site. Health and safety values seek upholds the complete eradication of occupational hazards as well as hinder job practices that pose all forms of job-related risk not only be considered during the project realization phase but throughout the entire project lifecycle. To give a further detailed understanding of health and safety to the reader, this study will continue by considering some definitions relating to the subject.

3.3 Health and Safety definitions

Similarly, it is also important to consider some basic definitions as regards to OHS to provide the reader with a clearer understanding and oversite of this research. As a result of this, the author decided to use the definitions provided by Huges P. & Ferrett E., [45] in their book on Introduction to Health and Safety in construction:

Health – Safeguarding the life, bodies, and mind of individuals from sickness and diseases caused by the materials, processes or procedures used in the working environment.

Safety – Safeguarding individuals form physical harm or damage. Often time, the marginal difference in meaning between "Health and Safety" is downplayed. Nevertheless,

[44] (Huges P. & Ferrett E., 2011)
[45] (Huges P. & Ferrett E., 2011)

both terms are jointly used to indicate regard for both the physical and mental health of persons at the place of work.

Welfare – The provision of facilities and equipment to protect and maintain the health and welfare of individuals at the workplace. Welfare facilities may include sanitation arrangements, heating, lighting, first-aid equipment, protective and safety clothing.

Accident – Huges P. & Ferrett E., highlighted Health and Safety Executive definition of an accident as; "Any unplanned event that results in injury or ill health of people, or damage or loss to property, plant, materials or the environment or a loss of a business opportunity."[46]

Near miss – This is any occurrence or event with a possibility of leading to an accident. Research on near misses predicts the happenstance of a minor accident in places or locations where individuals have previously experienced up 10 near misses.

Dangerous occurrence – This term refers to a near-miss that could have a terminal serious injury or terminal consequences. Examples may include scaffold or crane collapse.

Hazard and Risk – "A hazard is the potential of a substance, person, activity or process to cause harm"[47]. Examples of hazards may include electrical and chemical hazards and can be ranked based on their threat level. Additionally, Huges P. & Ferrett E. in their book argue that with adequate management, the risk of potential hazards can be reduced. They further proceeded to define A risk as "the likelihood of a substance, activity or process to cause harm". [48]

[46] (Huges P. & Ferrett E., 2011)
[47] (Huges P. & Ferrett E., 2011)
[48] (Huges P. & Ferrett E., 2011)

3.4 International statistics of construction-related accidents

Historically, accidental numbers and work-related injuries have been high in the construction industry, despite being a key industry to a booming economy, the industry has resulted in one of the high risk and most hazardous sector to work.[49] According to the annually published statistics of the UK's Health Saftey Executive (HSE), the year 2012 to 2013 experienced 148 work-related terminal injuries, for which the UK's construction industry accounted for 39 of them and similarly, construction employees in Britain is estimated at 5%, the industry is responsible for nearly one-third of life-threatening injuries of all UK industrial sectors.[50] In addition, HSE statistics in figure 4, highlight a large number of construction workers falling from heights and it accounts for the highest numbers as the major cause of construction-related accidents.

The claim for prevalent health and safety hazard through falls is supported by Shafique M. and Rafiq M.'s research. According to them, the increasing need to accommodate the immense growing global population over the past few decades has resulted in the increasing demand for high-rise buildings. Construction of high-rise buildings poses an acute threat to construction workers globally as construction workers encounter enormous difficulties ranging from harsh weather conditions as well as safety issues such as falls from height and object struck. Similarly, current studies for health and safety for the Korean construction industry between 2011 and 2015 indicated that the majority of construction-related accidents were also attributed to falls from height.[51] In addition to this fact, J. Teizer and J. Melzner highlighted research done by Huang and Hinze in 2003, where they stated that poor use of fall safety gear is linked with 30% of all fall-related accidents.[52]

---

[49] (J. Teizer & J. Melzner, 2018)
[50] (Stefan Mordue, 2019)
[51] (Shafique M. & Rafiq M., 2019)
[52] (J. Teizer & J. Melzner, 2018)

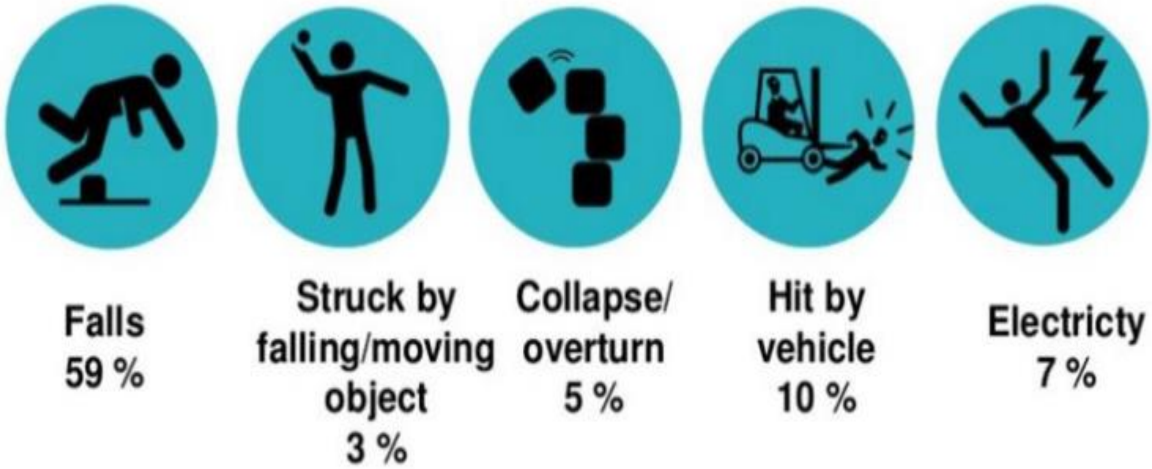

Figure 4**:** Major grounds of construction workers fatalities [53]

In the same vein, previous research indicated that the highest worker's compensation for construction accidents was fall-related; ranging from medical treatment and hospitalization cost and an average of 44-day leave.[54] However, another research by Hinze and Teizer in 2011 argue that the major causes for disappointing accidental statistics are due to the complex changing nature of construction environment, the physically challenging tasks of the industry, unavailability of pre-eminent operating practices, imperfect state of a company's commitment to health and safety as well as their internal organizational structure that often time results in human error.[55]

As much as it is important to build lasting, cost-efficient and sustainable structures, it is important also for stakeholders in the industry to protect the lives of those who work in it especially on construction sites. However, Godfaurd J. & Abdulkadir G's argument was that the lack of effective integration among construction workers was a major reason for construction accidents. Their argument centers on the absence of safety training and application; highlighting that construction companies should focus more on health and safety implementation and training in other to reduce the regularity and severity of construction accidents.[56]

[53] (Stefan Mordue, 2019)
[54] (J. Teizer & J. Melzner, 2018)
[55] (J. Teizer & J. Melzner, 2018)
[56] (Godfaurd J. & Ganah A., 2015)

Another research indicated that German construction workers tend to retire early as a result of musculoskeletal injuries acquired at their workplace. The resultant effect of these is a significant reduction in the number of qualified labour, reduced national productivity rate as well as limitation in the living quality of affected persons and perhaps of their families. Since the last 20 years, the German construction industry has also accounted for more work-related accidents than any other industry. According to J. Teizer & J. Melzner research, about 55 accidental incidences were accounted for out of every 1000 full-time construction employees within the German construction industry. Stating that reported cases usually include accidents that occur in commuting or onsite duty.

They further argue that this reported cases often time resulted in fatal or render a construction employee unhealthy for work for more than three days; every year, 100,000 construction-related work accidents are reported in Germany and in spite of these unencouraging numbers, figures for construction work-related accidents have declined since the last 20 years.[57] Similarly, the construction industry in the US is categorized as one of the most hazardous, accounting for the highest work-related injuries annually according to Shafique M. & Rafiq M.'s study. In their research, mortality figures for US construction workers were over 700 in the year 2010 alone. Furthermore, the stated that 2011 statistics from the U.S Department of Labour indicated that for every 100,000 full-time employees in the US construction industry, there are 9.5 fatal work injuries recorded.[58]

Furthermore, J. Teizer and J. Melzner's argument was supported by 2015 accidental statistics by Alomari K. et al. According to Alomari K. et al's 2015 report, the US construction industry recorded 985 terminal injury cases. While the sum of all other terminal injuries in the US industries for the same year was 4836, the comparison of both 2015 statistics meant that the US construction industry alone accounted for about 20% of all fatal injuries nationally.[59] Shafique M. and Rafiq M. maintained that 20% of all lethal work-related casualty in 2017 for major economies such as Hong Kong, US, UK, and Japan was associated with the construction events. Similarly, Shafique M. & Rafiq M. argue that in 2017, 76% of fatality occurrences in Hong Kong industries

[57] (J. Teizer & J. Melzner, 2018)
[58] (J. Teizer & J. Melzner, 2018)
[59] (Alomari K. et al, 2017)

occurred in the construction industry alone. They further cited similar studies by Fabiano et al. and Macedo's claim that the Italian and Portuguese construction industry is one of the most fatal sectors to work.[60] This research will also consider Figure 5 below, a graphical representation of the number of reported fatalities and fall accidents in the US, UK, Germany and Australia construction industry from 2006 to 2013.

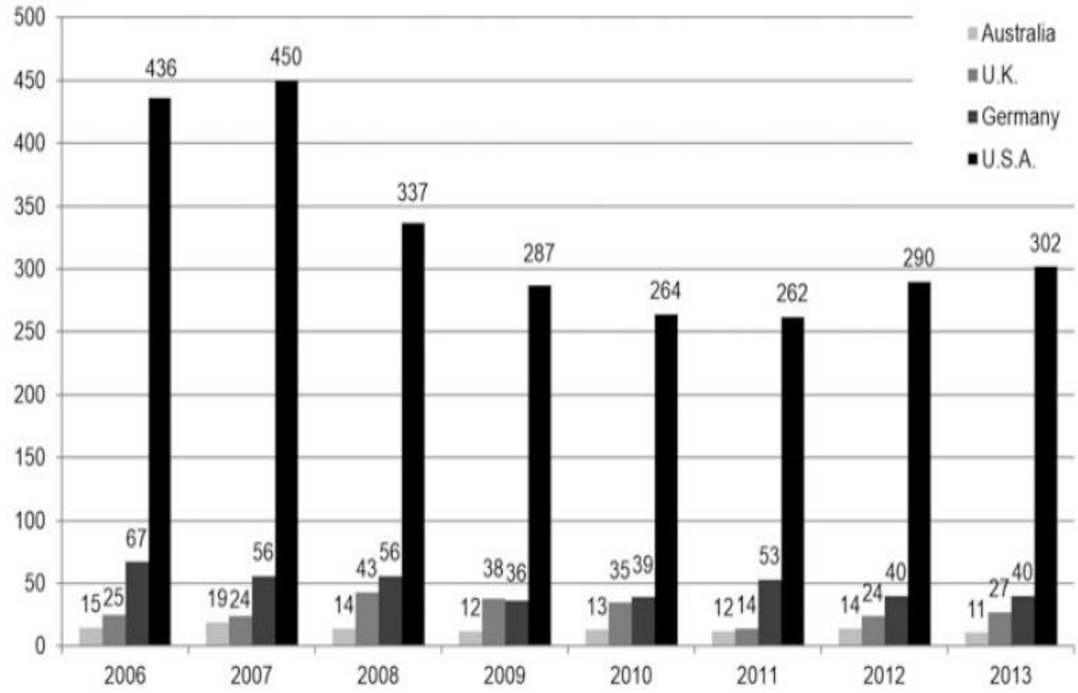

Figure 5: Reported fatality fall-related numbers in form 2006 to 2013 (US, UK, Germany, and Australia construction industry)[61]

Construction sites are dynamic as operative constantly change over time as a result of various work specifications and requirements. In addition, a particular hazard posed by construction is usually varied and cannot be generalized. Often time, new workers typically are enlisted for new tasks without having enough preceding information or awareness about potential hazards they may encounter while working[62]. More than ever before, various safety professionals and construction stakeholders are becoming more aware of the significance of work-related fatal injuries in the industry and they

[60] (Shafique M. & Rafiq M., 2019)
[61] (J. Teizer & J. Melzner, 2018)
[62] (Godfaurd J. & Ganah A., 2015)

continue to make improvements to provide more safe working environments for construction workers. These safety goals are achievable through better safety planning and design[63].

Although improvements in construction health and safety have been made since previous years, J. Teizer & J. Melzner. pointed out that researchers still retain the idea that awareness at the early stages of a project; that is, design and planning phases is a key factor in the implementation of better safety standards not only for construction but also for the entire project lifecycle. Similarly, Qi Jia et al. supports this argument; in their research, they stated that designers usually are not equipped with the prerequisite knowledge for construction safety and this leads to the manifestation of various hazards during the construction phase of a project.[64]

Thus far, BIM technology has been beneficial and leveraged as a technological tool in the design and management of construction processes especially at the early stages of a project, the impact of BIM is still in a stage of infancy in reference to health and safety.[65] Up until now, the dissertation has established health and safety-related issues in the global construction industry through an extensive literature review and while there is an obvious problem to tackle. Just as implementation was previously considered to a reasonable extent in the previous chapter, this research likewise considers it important to consider research on legal obligations on construction health and safety across the globe as they defer in the level of implementation, awareness, and regulations.

3.5 Legal requirements across the globe

Safety history can be traced back to the International Labour OYce (ILO) intervention in 1985. From this period, the body acknowledged that design professionals in the construction industry ought to consider the issue of safety in their designs. According to Khoshnava S. et al’s report, the ILO recommended that designers should shoulder the responsibility of safety for their design. Their research further highlighted the efforts of construction authorities around the world to implement this approach. For instance,

[63] (J. Teizer & J. Melzner, 2018)
[64] (Qi Jia et al, 2011)
[65] (Zhou et al, 2013)

The European Union issued a 1992 directive for the consideration of safety at the design stage. Likewise, the UK's construction design and management body, the American Society of Civil engineers (ASCE) and some regions in Australia aligned their policies on construction safety to fit with the same ideology.[66]

Moreover, the minimum guiding principle was put in place by the Occupational Safety and Health Administration (OSHA) in the US to protect the health and safety of construction workers and other occupational fields in 1962. These guiding principles outline that the general contractor is responsible for the safety of all workers on site and that each subcontractor is likewise responsible for keeping their workers safe. Germany likewise has a matching regulation in place (§4 BaustellV)[67]. In J. Teizer and J. Melzner's argument, health and safety responsibilities associated with each stakeholder may sometimes lead to problems, for instance, if a general contractor responsible for site coordination and provision of general safety gears may not be conscious of a subcontractor carries out an unsafe work at dangerous height on the site.

Their research also underlined that communication of necessary information and needed safety on potential hazards often time may lead to issues on a project. Stipulations in the German law provides that a health and safety coordinator should be hired in situations when the contractor is not competent to perform necessary health and safety duties. Figure 6 further illustrates the correlation between the client, contractor and health and safety coordinator under the German guideline. The "Employers' Liability Insurance Association for Construction" controls and maintains safety-related issues in the German construction industry as well as make legally binding publications safety protection regulations.[68]

[66] (Khoshnava S. et al, 2012)
[67] (J. Teizer & J. Melzner, 2018)
[68] (J. Teizer & J. Melzner, 2018)

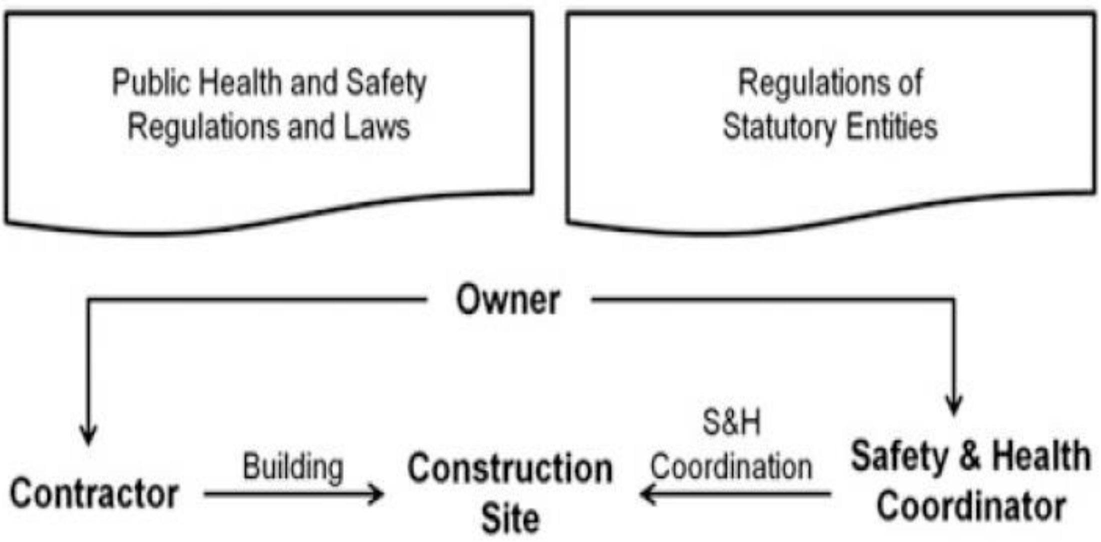

Figure 6**:** Relationship between Client, Contractors and the German regulative entities[69]

As much as the implementation health and safety on a project often time leads to a budget increase between 0.3 to 1% of total construction finance, the construction cost saving can likewise be achieved through the reduction of construction accidents, rate of loss, interferences, implementation of better coordination as well as other positive means. Furthermore, the involvement of a health and safety professional in any project should not excuse the contractor from performing health and safety duties. For maximum outcomes, health and safety professionals should actively partake early in design and construction processes.

As shown in figure 7, the German safety regulations stipulate that the health and safety professional shall be responsible for detailing out health and safety plans form the project, give details on necessary protective measures and also be available to address all health and safety matters throughout construction. This plan should also be communicated effectively to the constructors, planners and all affected parties. In light of this, the author seeks to further deliberate on general health and safety practices within the construction through extensive literature research. Giving focus to communication models as reported by construction scholars, as well as the considerations for health and safety in design decisions as stipulated by construction health and safety regulations

[69] Taylor and Francis adopted by (J. Teizer & J. Melzner, 2018)

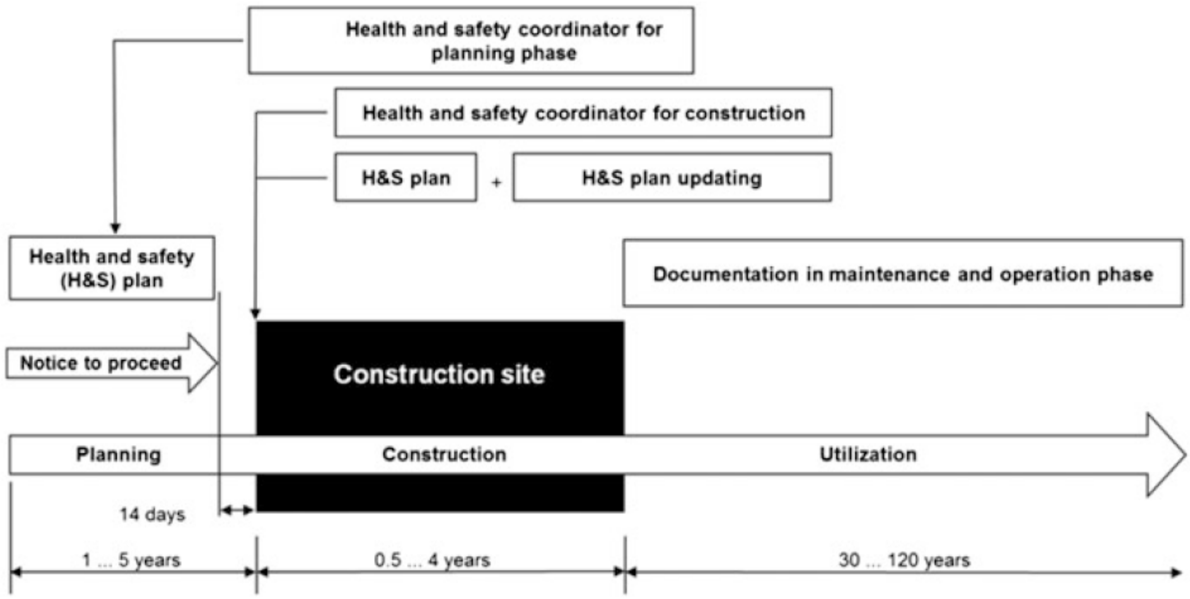

Figure 7**:** Health and safety coordinator duty in project development under the German system.[70]

3.6 Conventional Health and Safety practice in construction

While this study has considered and analyzed global Statistics of Construction related accidents, as well as the intricacies of legal obligations for safety, the author corresponding, seeks to consider what is the conventional practice in the construction business as regards to health and safety. As mentioned earlier, practice, safety laws differ from nation to nation, construction industry practice is quite similar, especially for developed nations. Based on an extensive literature search, this study however considers commonly studied planning and management of health and safety. As such, the summary on construction safety process according to [71] conventional practice is given thus:

- Laws, Regulations, Standards, Rules, and Procedures of construction safety.
- Client involves and designate construction and design management coordinator.
- Initiation of Health and safety considerations at the upstream level, creation of objects related to hazard and risk outcomes.

[70] Taylor and Francis adopted by (J. Teizer & J. Melzner, 2018)
[71] (Howarth T. & Watson P., 2008)

- Risk management for pre-established risk during construction which includes a method statement for work activities.
- Formation of a Health and safety plan and management throughout the project life cycle.

In a construction project, health and safety preparation thus constitute a share of the broader planning and management procedure. As inferred earlier, current accidental figures call for a more effective health and safety approach. As much as safety regulations exist on paper, the industry can improve health and safety through strict implementation of outlined regulations when planning a project. The author argues that although there are specific safety rules and guidelines to follow, the level of implementation of set rules is lacking. For instance, these rules can only be fully implemented through an effective communication process between project stakeholders. Safety is a collective topic and it requires not just the safety coordinator but every project stakeholder to take responsibility.

During of project realization phase, the construction site often time undergo dynamic changes. Unlike industrial or manufacturing facilities that are fixed, the construction environment experiences constant changes over time in terms of work teams, space change, physical structure as well as weather variation and climatic changes. More often than not, construction teams that may or may not be related frequently expose other teams to danger, risk and work hazard. Similarly, the constant change associated with construction site conditions would make carrying out a prior risk analysis before every task is very demanding and may be difficult to sustain; even in situations of a repeated task.

These complications demand more effort which most contractors are reluctant to devote; as such, leads to inefficient safety management practices as the implementation of an effective risk analysis is carried out rarely.[72] Sacks et al further argued that in situations where there is a lack of efficiency in envisaging peak risk outcomes, the effort devoted to performing safety risk management on construction sites turns out to below. As a result of this, construction participants tend to fulfill regulatory safety requirements by centering on reactive investigations of an accident

[72] (R. Sacks et al, 2009)

or near-miss situations, provision and use of personal safety equipment and organization of safety training.[73]

3.6.1 Conventional safety consideration at the design phase

While studies have shown that the design team has a distinctive position in the initiation and planning of a construction process as the designer often time serves as a professional adviser for the client. Major considerations should be given to construction safety from the commencement of a project, that is at the preliminary and design phases.[74] Szymberski illustrates this concept using a curve to show the influence of safety decisions with respect to different project phases in figure 8. From his concept, the ability to influence safety decisions is high at a project conceptual phase and it continuously reduces as the project tends towards the construction phase.

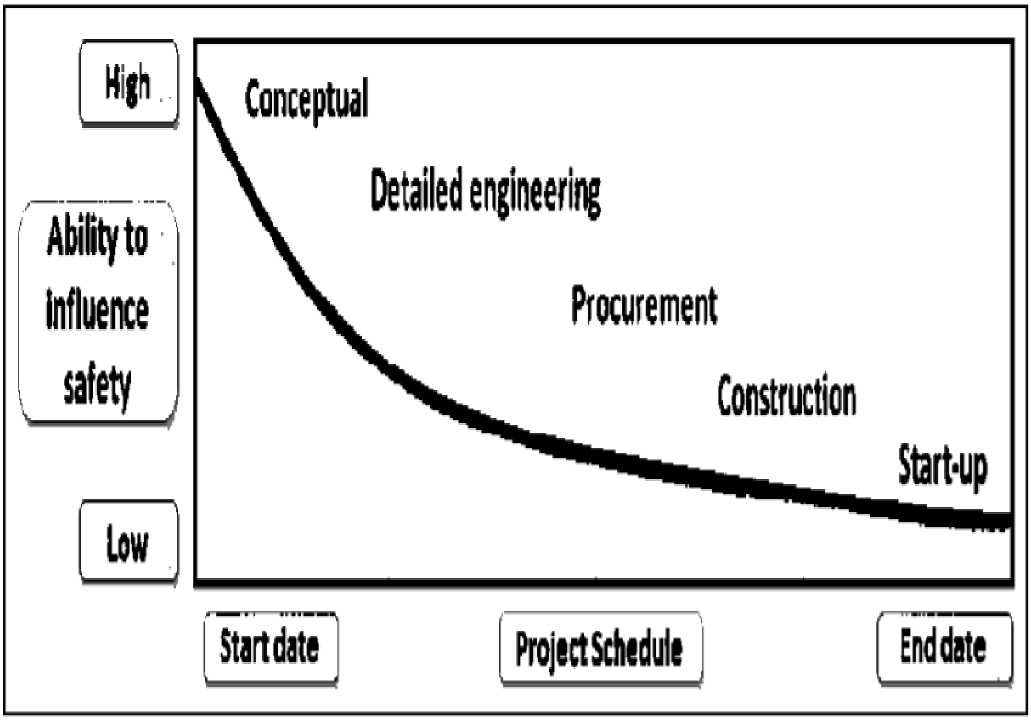

Figure 8: Influence curve for time and safety[75]

Research suggests that although legislations in most develop countries considerations for construction safety at the design stage, for the most part of it, the practice has been

[73] (R. Sacks et al, 2009)
[74] (R. Szymberski, 1997)
[75] (R. Szymberski, 1997)

voluntary. In the US for instance, contract arrangements according to their occupational safety body evidently place safety responsibility for construction workers on the constructor. This safety methodology, however, is common in many construction markets globally.[76] However, a recent study suggests that this approach is changing as a result of an increased lawsuit concerning workplace accidents.

Subsequently, the awareness of project owners as regards to the safety performance of their projects has increased. Similar to the previously mentioned German system for safety considerations, M.D. Martinez Aires et al. in their study highlighted that European directives on safety considerations at the design phase have steadily resulted in a statistical decrease in safety incidents. Many regulations such as the Germans BG Bau and the UK's Construction design management regulations have stipulated safety obligations for project stakeholders from the design of construction work. As such, the burden of safety is not left for the contractors alone. [77]

Other research by Baxendale T. and Jones O. in their study argued this viewpoint is key to developing competent teams capable of managing heat and safety risks associated with construction projects. Furthermore, regulations in 2007 as stated in research stipulates the early appointment of the Construction design management coordinator by the client. This will allow an adequate period to address health and safety-related issues during the planning and the design stage. These guidelines, however, highlight the need for a multi-stakeholder safety collaboration by allocating safety responsibilities to not just the client but other project stakeholders such as the project design and the general contractors.[78]

Although these regulations exist, the awareness level for safety rules for all project participants is crucial. While researchers have a focus on raising awareness levels by developing short courses to raise safety awareness in the construction industry. Research on Construction design management coordination indicates that there is a need for project designers to have prerequisite knowledge and understanding of their design can affect risk and hazard on construction sites and how their design can be used to avoid them.[79] This design-safety connection is, however, better implemented

[76] (Behm M., 2005)
[77] (T. Bazendale & O. Jones, 2000)
[78] (Zhou W. et al, 2011)
[79] (J. Gambatse & H. Hinze, 1999)

in design-build scenarios as designers are able to work closely with other stakeholders responsible for managing the construction process in the same firm.

On the other hand, contract circumstances that separate the designers and general contractor has indicated that there is a lack of training to properly hand worker safety-related issues. This, however, is a clear indication that there is a need for a knowledge hub for designers to tackle safety in their designs. Similarly, several studies have been implemented to establish the impact of design decisions on construction safety. Behm M., in his study, examined the connection concerning construction accident and design. His statistical hypothesis suggests that 42% of fatalities studied were related to design issues; which indicates that the concomitant risk that leads to the accident would have tackled if detailed safety considerations were given at the design phase.[80]

A similar study was conducted by, Gambatese et al., to validate the influence of design on construction safety. This study denoted that fall-related accidents were linked to the installation of thermal doors, fenestrations, and metal design building components.[81] Practical actions to improve construction safety may warrant the designer to ask the contractor for his method of constructing the work, this way, the designer can make sure the constructor has enough knowledge about the design. However, the dominance of the conventional design-bid-build contracting procedure creates a complex level of pecking order between the designer and the sub-contractor that gets to do the work. Alternatively, liability concerns may restrict designers from dictating the technique of constructions, as such, research highlights the reluctance of designers to take an active role in construction safety in order to avoid safety liability.[82]

Stuart D. Summerhayes[83] suggest that, Unfortunately, design failures usually result in poor implementation of other subsequent decisions. As it is often experienced in all projects, the client initiates a preconstruction information stream which serves as a medium for which all project participants contribute and from which they obtain and send applicable information on the project at different times. However, the designer

[80] (Behm M., 2005)
[81] (Gambatese et al., 2008)
[82] (J. Gambatse & H. Hinze, 1999)
[83] (Stuart D. Summerhayes, 2010)

expects that the contractors are competent and as such, he/she is inclined to communicate on such level. This implies that attention is not given to deliberations associated with contractor incompetence on the project.

It is clear that, for safety to be meaningful, the strategy deployed must have a need for co-operation between all project stakeholders. Hitherto, it will be incautious to submit that centering on safety at the design stage of a project will spontaneously eradicate accident construction accidents. Design considerations for safety are one piece of the puzzle to curtailing site risk improving workers' safety.[84] Rather than a single approach, the author likewise submits to the argument to support the need for multi-level risk evaluation and hazard forestalling methods throughout the lifecycle of a project. Obviously, there is a void to be filled to fully establish that design implications have the largest impact on the outcome of constructions safety, hitherto the previously highlighted arguments in this chapter indicates a level of relational impact between design and construction safety.

3.6.2 Modules of communication in the construction industry

The topic of communication has a broad spectrum and some studies have discussed what communication really is as well as several theories of communication. However, the author seeks to establish in this subsection is to analyze common communication types more suited for the construction industry. Furthermore, the author will also analyze the traditional medium of communication, its inadequacies, and possible improvement. One of the studies by Godfaurd J. & Abdulkadir G. identified communication theories more suitable for the construction industry as the following;

- Linear approach: Stresses that an individual is only a communication source or a receiver.
- Interactional model: Suggest the existence of a double way communication route between two people; that is communication is routed in two ways.
- Transactional approach: Accentuates an incidence with concurrent sending and receiving of messages between multiple parties.

[84] (Gambatese et al., 2008)

In cases when the transactional approach is used, the sender and receiver are equally liable for the outcome and efficiency of the communication. Similarly, the interactional model realizes meaning through a feedback mechanism. Not overlooking that the medium of communication, the level of knowledge and mutual understanding between all participants are as important as the communication module itself. [85]

Likewise, rudimentary characteristics of interaction between teams are classified into two groups according to Bennett J. in his project management study. The first group has to do with the intricacies of communicating any information between teams. As analyzed, the information being communicated should be carried out to the teams through an efficient communicative medium and the message itself could be expressed or translated into readable and understandable text or graphics. The second group of communication involves a clear and defined work organization where every team is responsible for coordinating and managing their actions; this will allow for effective cohesion between work teams.[86]

While teams on conventional construction site and other participants in the construction industry still rely on face-to-face meetings, printed drawings, construction schedules, and other traditional methods of communication on a construction project. The industry thus far has continued to gradually demonstrate acceptance of new technological means and foster change in the direction of innovative means of communication. Although communication in the construction industry has been improved with the use of digital communication systems like email and mobile phones, some researchers argue that with regard to health and safety of site workers, its impact is noticeable with respect to communication speed and not necessarily the efficiency of communication as well as the quality of information exchanged.[87]

Furthermore, development in the construction industry has seen technological advancement of onsite communication. Examples include the use and adoption of broadband internet, Personal digital assistance devices, internet protocol communications, Computer-aided designs (CAD) and most recently BIM and other associated digital innovative technologies. Although these technological means continue to gain ground in the construction industry, quite a good number of researchers suggest that their

[85] (Godfaurd J. & Ganah A., 2015)
[86] (Bennett J., 1983) & (Abdulkadir G. et al, 2000) & (Lin K. et al, 2014)
[87] (Davies R., 2013) & (Godfaurd J. & Ganah A., 2015)

implementation impact is most dominant at the upstream end of the AEC industry. While a large percentage of digital implementation focuses on design, consultancy, and educational institutions.

A prevalent argument that most research support is that there is a growing need for digital knowledge implementation also in the downstream sector of the industry, i.e. in the construction and maintenance phase. Though the downstream participants, e.g. sub-contractors are well conscious of the essential information to be communicated within diverse onsite participants, there is a need for a new effective and efficient means of communication. Commitment to safety can be expressed through the combination of formal and informal means as they are essential to promote effective communication. While some authors also submit that safety enhancement and keeping account of near misses, reporting of unsafe work environmental practices are critical, and can be achieved not only through effective management but also through an effective employee feedback system. Also, it remains that most existing health and safety communication practices in the construction working environment utilize a one-directional approach, and as such without an available feedback system.[88]

Principal construction documents such as the project risk register are routinely used to gather significant and important concerns associated with health and safety from the project team members. The collated data is however inputted into a central document and is likewise contains properties such as title, time of resolution and outcome of various safety concerns. By leveraging on review and management of the risk register, the project team is able to center on various action points. Although poor communication may raise safety concerns on-site, other factors such as ownership deficiencies, team fragmentation, resource constraint, incompetence, and low awareness levels, risk management let-downs, complacency, lack of proactive responses, infrastructural deficits and unrealistic schedule time may lead to the failure of the design management process and may raise safety concerns on a project.[89]

Also, the assumption based on the presumption that all contractors operate at a required level of competence is often a fallacy and as such may trigger health and safety concerns. In the project realization phase, the construction site often time undergoes dynamic changes. Unlike industrial or manufacturing facilities that are fixed,

---

[88] (Godfaurd J. & Ganah A., 2015)
[89] (Stuart D. Summerhayes, 2010)

the construction environment experiences constant changes over time in terms of work teams, space change, physical structure as well as weather variation and climatic changes. More often than not, construction teams that may or may not be related frequently expose other teams to danger, risk and work hazard. Similarly, the constant change associated with construction site conditions would make carrying out a prior risk analysis before every task is very demanding and may be difficult to sustain; even in situations of a repeated task.

These complications demand a lot of effort which most contractors are reluctant to devote; as such, leads to inefficient safety management practices as the implementation of an effective risk analysis is carried out rarely. Sacks et al further argued that in situations where there is a lack of efficiency in envisaging peak risk outcomes, the effort devoted to performing safety risk management on construction sites turns out to below. As a result of this, construction participants tend to fulfill regulatory safety requirements by centering on reactive investigations of an accident or near-miss situations, provision and use of personal safety equipment and organization of safety training.[90]

3.7 Challenges of convention Health and safety practice in construction

The construction industry is heterogeneous because it is typically dominated by several stakeholders; as such, the active participation of multiple stakeholders makes planning somewhat complicated. As mentioned earlier, every construction project differs from one another and in most cases “each project is built for the first time”, with repeated construction of the same building types happen in uncommon cases. Similarly, the complexity of the construction process demands fresh planning or additional activities that the inception of any project or phase.[91]

While quite a number of researchers have also indicated that the traditional approach to construction planning often time does not consider integration health and safety planning along with other planning processes. Other research also suggests that safety issues are bound to arise if the layout planning and design decisions are prepared without proper deliberations of its significance on safety factors as well as continuous

[90] (R. Sacks et al, 2009)
[91] (J. Teizer & J. Melzner, 2018)

modifications in the project layout during construction. The construction industry is famous for a large number of trades working together on a specific project. Research in the previous chapter establishes existing regulations and practices which suggest that contractors should shoulder an important part of the safety burden during construction. While the responsibility of preliminary design and construction documentation are in most cases attributed to the architect or engineer, the contractor still is required to assume responsibility for site safety in many countries.[92] This argument also was supported by Zhou W. et al, in a study, stating that the AEC industry in many countries still operates with this approach.

However, designing a detailed safety plan requires time, and while further research demonstrates that for many construction practices, the contractor's involvement comes at a somewhat tardy period or at best participate inadequately in design and construction planning stages. And since the construction process always seeks to make time savings, the consequence of this often time results in impromptu safety planning while construction is ongoing.[93] Furthermore, researchers argue that in some cases construction planning is confronted with the problem of insufficient human capital during the project realization phase. Safety cording on a project is maximized when the expertise of an external safety expert is leveraged, especially in the preliminary planning stage.

However, in minor projects the safety coordinators may not always be available; in this case, safety responsibilities are assigned to a staff that maybe not be competent enough to handle safety protocols. Similarly, research indicates that the methodology behind the common traditional safety planning process in the industry is somewhat inadequate. Usually, safety planning is essential to facilitate potential hazard detection in the working environment before work commencement. This potential risk analysis process however, for most safety implementations is still performed manually; while observations are done on marked-up two-dimensional drawings to construe health and safety hazards on site. In most cases, detailed analysis is only possible a few days before the actual task is being done; an example is the Job Hazard Analysis (JHA) highly dependent on extended personal experience of the safety coordinator, constant

---

[92] (Gambatese et al., 2008)
[93] (Zhou W. et al, 2011)

monitoring of the site progress, partially carrying out the task as well as, refereeing to the two dimensional printed drawings.[94]

Recently, the debate has circled around the need for improved methods for construction safety planning methods and processes[95]. Depending on the knowledge and experience of the planning personnel, the planning sequence and work preparation are done concurrently. As such, the planning personnel can support and increase the quality of his/her planning outcome with digital knowledge-based decision tools. Decision making can be improved by deploying digital hazard detecting tools, the outcome of this may tailor the planning activities towards problem-solving instead of problem finding. Although improvement can be made with smart digital means, humans decision is yet still required for making significant decisions especially in reference to safety. Thus, the proposed BIM-digital context does not seek to eliminate human factor but rather combine human input and expertise, preeminent practices and permissible obligations in a knowledge-based BIM digital platform.[96]

[94] (J. Teizer & J. Melzner, 2018)
[95] (Yusuf A. et al, 2012)
[96] (J. Teizer & J. Melzner, 2018)

3.8 Chapter summary

In reference to all previously outlined arguments, the author seeks to highlight that as much as the conventional safety approach has been depended upon, it remains limited and more can be achieved with the help of digitization. There is a need for a more beneficial and effective approach to solving construction health and safety difficulties. Including the construction industry, the use of digital technology has been instrumental in building a more efficient operational process across industries globally.

This study thus far has established the need for a more efficient and effective approach to mitigate the confronting safety issues in the construction industry. From research, there is no denying that the AEC sector, in general, has experienced progress in aspects of design and construction information through the increased use of digitalization. As much as the industry commends these existing progress, there is also a need for the AEC sector to similarly invest more in safety competences by leveraging both technology and digital skills to facilitate progress in health and safety on construction sites.

4.0 BIM integration for construction Health and safety

In the previous chapter, the author establishes the concept of construction safety as well as the implications of the design on safety as well as how communication between construction stakeholders can affect health and safety. Over the years, construction stakeholders and scholars have not only continued to seek for means to increase the quality of project delivery within a specific budget and duration but also to device fast and sustainable way of project delivery. While some studies argue that many BIM users, design consultants and key stakeholders in the industry are yet to even harness the complete potential, as such the quantity of technological savvy consultants is at an infancy stage as the industry currently falls short in terms of education and training.

As mentioned earlier, the safety coordinator is limited to carry out his/her duties within the confines of their ability to imagine the working environment. The aforementioned argument on health and safety indicates that a decent amount of health and safety planning for the safety coordinator or engineer hinges on many manual tasks that are prone to human errors and they are similar time consuming and tedious. Having discussed the concept of BIM and current state of construction safety, this chapter combines in detail both topics, in other to determine the potential benefits and barriers of digitalization on health and safety outcomes. Furthermore, this study proposes a theoretical framework for the implementation of a BIM-based health and safety method throughout the lifecycle of a project.

4.1 Overview

Each construction project is uniquely complex; design, construction planning, and site management is often time challenging. Jianoing Z. & L. Ding, argued that, although the present-day project delivery method for building and infrastructural construction has continued use digitalized means to communicate and distribute professional work; most of the construction activities still substantially depend on local physical labour. In any case, the key is to combine both standardized regulations and contemporary tools to implement efficient safety practices. Such new tools and practices may, of course, be criticized and evaluated based on how they resolve safety challenges through health and safety checks, provision of solutions as well as responses in emergency situations.

While studies examined in the previous chapter have indicated the inadequacy in executing safety analysis based on 2D drawings as a result of multiple changes that are inevitable on the site. Similarly, to tackle some of the inadequacies of onsite communication earlier mentioned, it is beneficial to leverage on the use of contemporary digital communication methods. The construction industry can benefit from digitalization means with the right implementation and initiatives. While the aforementioned problems with design for safety and onsite communication exist in the construction industry, BIM essentially is an enabling digital tool with the potentials capable assisting project stakeholders bring solutions to these problems.

4.2 BIM implementation of Health and safety planning procedure

Generally, BIM technology can be used as an enabling tool to enhance the dynamics of a lot of influencing factors that affect the outcome of a construction project. Project stakeholders can use BIM to boost the quality of information available during project resolution, enhance communication between stakeholders, facilitate the reduction of project duration and cost as well as a tool for quality control in a project lifecycle.[97]

Similarly, the knowledge of the link between Spatio-temporal workspace and time is crucial when dealing with safety hazard detection. Unlike 2D and 3D CAD enabling digital platforms, BIM offers a platform for both the design representation (graphics) aspect of a project as well as the informational attributes. BIM package for graphics and project data empowers all project stakeholders to make intelligent decisions as they are able to automatically generate drawings, project reports, analyze the project design, project schedules, etc. [98] Rather than focusing on monitoring hazards and guarding construction workers during tasks, the sensible argument to adequately tackle the occurrence of construction hazards at the design stage. Although the concept of BIM for safety is still novel, some have suggested the need for the safety engineer to use BIM when modeling various protective safety gear. [99]

Similarly, a graphical simulation of a project 3D can be linked with the scheduling to form a 4D which in turn is a key BIM feature that can enhance safety planning. BIM 4D simulation is a possibility, and simulation can be made to the smallest detail. For instance, movement characteristics of cranes and construction vehicles have been studied in some previous research; with a BIM platform, digital devices are capable of simulating real-time onsite construction activities even more accurately. A. Ganah & A. John study highlighted that most previous research on BIM for safety has not quite focused on the phase where the bulk of construction accidents take place.

The construction phase also has a large turnover rate of dominantly participating professionals ranging from subcontractors and small company representatives. The need for contemporary means is expedient to proactively manage factors that may eventually lead to health and safety problems. While studies have described 2D project

[97] (Godfaurd J. & Ganah A., 2015)
[98] (Zhang S. et al, 2013)
[99] (J. Teizer & J. Melzner, 2018)

drawings as ordinary abstract project illustrations in the form of plans, sections, and elevations, BIM offers much more. In place of the 2D image, the technology uses a 3D simulation of all the components of a project, gives better accuracy for project estimation as well as focus on efficiency over redundancy.[100]

Thus far, BIM-based platform has been used by construction stakeholders to estimate cost, manage project risk, plan project as well as other BIM aspects to manage the overall construction process. Just the way in which the use of 3D BIM models for design and construction has increased in the AEC industries, the idea is to have such an innovative investigation for implementing BIM for safety planning. As deduced from an extensive literature review[101], current conventional safety processes can leverage BIM capacity to:

- Automatically detect construction-related hazards through a BIM-based simulation of the real-time project progress.
- Support and improve human decisions in the choice of adequate safety equipment in pre-identified hazards as identified in the 3D or 4D model.
- Use 3D and 4D models to identify safety threats, work-space conflicts, clash detection, and prevention methods.
- Effectively communicate adequate operational and technical guidelines of the already determined prevention methods to all project participants and process level.

4.3 BIM Based-Digital applications for Construction health and safety

Thus far, a variety of digital tools has been developed by researchers to assist project stakeholders to succeed in project safety implementations. This research, however, will study some applied digital tools used for the prevention of hazards on construction sites such as VR, sensory warning technologies, 4D BIM, online databases, GIS, etc. Also taking into consideration that, a number of these technological tools are sometimes combined together to achieve the best possible safety outcomes. However, safety is a collective topic affecting all activities throughout the project lifecycle; as

[100] (A. Ganah & A. John, 2014)
[101] (J. Teizer & J. Melzner, 2018)

such, these technologies have been developed to implement safety at all levels of the project delivery process.

4.3.1 Online database

Assessing the competence level of potential stakeholders is commonly done through an online database system. Based on enormous data available, the client/owner at the pre-design phase uses such a digital platform to assess competence level as regards the safety of designers, general contractors as well as safety engineers and coordinators. Through this, the client is well informed on who to hire for his/her project. According to Zhou W. and colleagues, the UK's Construction Design and Management (CDM) regulations created a web-based tool that uses Artificial Intelligence (AI) to guide project owners when assessing the safety competence of duty-holders.[102]

Furthermore, researchers have also developed a web-based safety monitoring system called the Construction safety and health monitoring system (CSHM) to manage and give warning signals for corrective actions when potential safety threats and hazards are detected on construction sites. With the benefit of high-speed internet, this CSHM system allows for remote access and quick collection of information for project stakeholders. CSHM was not only developed to facilitate safety activities during the construction phase but to equally use an online knowledge database to monitor project performance, get vital project data in the form of charts, curves, and tables. The CSHM fast-track health and safety performance within organizations and also helps to make a safety comparison between projects.[103]

4.3.2 Virtual reality

Virtual reality (VR) is used to provide interactive, real-time, 3D digital technologies through a set of computer applications. With VR, construction professionals have access to risk-free and realistic training in a virtual construction environment.[104] According to research, a VR-based DFSP tool was created by some researchers to detect safety hazards in the design and conceptualization phase that may lead to accidents

[102] (Zhou W. et al, 2011)
[103] (Cheung S. et al., 2004)
[104] (Zhou W. et al, 2011)

during the construction phase. This DFSP database system functions with a database of local accident reports and safety regulations and integrated theory of accident causation. Part of the incorporated features of the DFSP are construction component/object types such as walls, columns, slab, staircases, etc. and accident deterrent database used to check the occurrence of an accident during the construction phase. VR provisions were also made for features to support user interactions to support functions such as clash detection, topography, and 3D measurement to enable a realistic walk-through virtual environment. [105]

According to (Zhou W. et research, other tools such as Virtual Construction Laboratory (VCL) and the Construction safety and digital design system (CIGJS) have been developed by health and safety researchers to improve safety on construction site. VR is an innovative way to carry out virtual safety experiments of construction processes. While construction workers have a comprehensive knowledge of the actual workspace, they are able to contribute to their own health and safety before and during tasks by defining accurately the parameters for the simulation. Also, VR has immense potentials in relation to educating and training construction workers to implement adequate and safe working conditions. As a result of this argument this study, therefore, recognizes VR as a tool for construction safety.

4.3.3 Geographic Information system (GIS)

GIS contains detailed data on environmental factors as such, the technology offers another approach to construction health and safety from a macro perspective.[106] Bansal in his work, utilized GIS for safety planning to solve environmental issues that ordinary BIM software was unable to model in insolation because of the absence of detailed geospatial information in the BIM software. With GIS technology, more details on factors such as site topography, thermal comfort, etc. In combination with 3D and 4D BIM, GIS was used to analyze geospatial features and its surrounding topography. With his work, Bansak established a link between GIS and BIM to carry out safety review processes prior to the task is done and make suitable corrections in cases where the planned work sequence result in a hazard situation.[107]

[105] (Hadikusumo BHW. & Rowlinson S., 2004)
[106] (Zhou et al, 2013)
[107] (Bansal V.K, 2011)

In the past, a BIM-based GIS system has also been utilized for the safety management of excavation activities. With this technology, safety engineers privy to enhanced data required to carry out foundation excavation that may lead to construction hazards. Information on soil threshold limit and forewarning/consequence of any negative effect of the construction. The potential of GIS and BIM within a single safety virtual environment assist safety planners to examine actual safety measures they are to implement, it's timing, position on the site and why such safety measure is being taken.

4.3.4 Sensory warning technologies

Workspace awareness of construction sites and environments is being maximized with the help of technological improvements in data, sensing, and visualization. Previous research suggested that sensory technology has positive potential in reducing near misses and health and safety risks; as such, leveraging on sensing equipment during the construction phase of a project as well as effective management practices is beneficial. With the aid of this technology, warning and cautionary systems can be created in the construction environment to safeguard workers from fall or collision risk while they perform their various tasks. Often time, conventional safety measures leverage on passive personal safety gears such as hard hats, safety shoes, etc. but on the other hand sensory warning systems are active and they are able to detect the hazard, produce warnings and reaction when risk is close. [108]

Zhou and colleagues in their work established the primary principle behind this safety concept. They stated that this technology functions by classifying vulnerable zones from active construction workspace. Such that, the detection, modeling, and tracking of 3D borders of hazardous areas on-site, the risk associated with safety can be improved. Another key approach is to automate the process of avoiding obstacles such that humans, moving construction machines and vehicles are able to circumnavigate and function safely.

Furthermore, technological tools such as Radiofrequency Identification (RFID), Ultra-Wideband (UWB) and Global positioning systems (GPS) have been applied to track and detect the constant movement of construction resources such as machines, workers and materials in the construction environment to maximize accuracy by

[108] (Teizer, J. et al, 2007)

determining the position, speed and direction of construction resources. Nevertheless, the use and application of sensory technology are not flawless because this technology involves the tagging of each individual resource in the construction environment. The tagging process, on the other hand, may have situations of mistakenly untagged resources. Also, problems associated with a reduction in signal strength as a result of obstruction may cause the reduced performance of the devices and as well as the high cost of the tags and other digital equipment. [109]

4.4 BIM-based theoretical concept for health and safety implementation for construction safety

Based on various aforementioned arguments and literature and as this dissertation culminates, a theoretical framework (figure 9) is formulated to establish an implementation idea for the integration of BIM for health and safety practices for the project lifecycle. Although the construction phase is where the bulk of the health and safety problems occur, safety remains a collective issue, and it affects every project stakeholder regardless of the project phase.

Therefore, to adequately combat safety risks and limit accidental figures on construction sites, the idea behind this BIM-based theoretical concept is an early bird approach to safety implementations, planning, and management. Delay in commencing needed safety processes and focus on safety considerations in the construction phase alone is insufficient. The window of opportunity to influence the project “safety-wise”, effect safety policies and achieve desired safety results reduces as the project tends to the construction phase. The sequence of construction activities is highly dynamic, and although digitalization has continued to gain grounds in the AEC industry, a large percentage of construction works require substantial physical labour. It is therefore also of a necessity to integrate BIM to better enhance and galvanize pre-existing safety regulations and human imputes for health and safety.

[109] (Zhou et al, 2013)

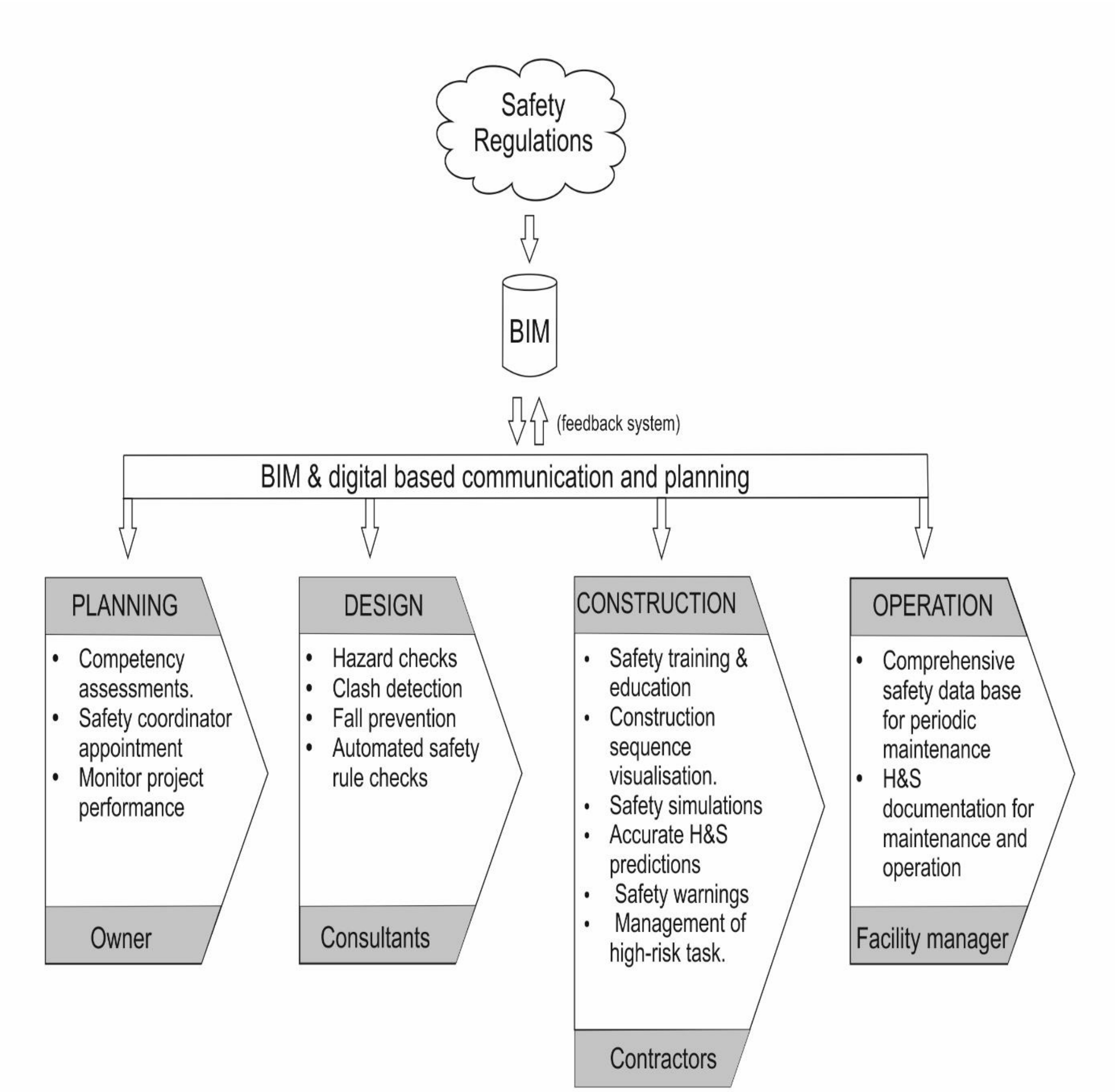

Figure 9**:** BIM-based theoretical model for construction health and safety[110]

In general, the concept of BIM implementation for health and safety is still a novel concept and the foundation on which the above BIM-based framework is built is that it combines already established safety regulations, implementations, recent safety data, statistics, rule compliance as well as local accident report of similarly building projects in a cloud database. This bulk of pre-existing data is synchronized through a BIM-based system. Utilizing one or more BIM software as well as BIM supported safety digital platforms available at various phases of the project process. Because every project is unique, the BIM-based platform acts as a filter for relevant safety information

[110] Author, 2019.

for each project, allows for clarity, easy interpretation of safety regulations and obligations. As such, seek to eliminate any form of ambiguity. Through this, communication and rules of objective for every project participant is improved. As mentioned in the previous chapters BIM has been successful in the early stage of the project lifecycle, especially in the improvement of communication between project stakeholders. Therefore, the author seeks to replicate this BIM success in the downstream end to manage the communication and management of safety processes.

Furthermore, the framework allows for early safety planning from project inception and since safety is a collective issue, every stakeholder has the following obligations:

- The owner/client: sets the tone and with the BIM-digital approach, he is able to maximize his influence as regards to safety on the project safety. An online database for safety competency will aid the selection of available potential project stakeholders based on good safety track records as well as their use of contemporary safety methods. The framework also allows for the early involvement of a safety coordinator and facility manager by the owner for the planning and coordination phase and also to work with the design team to implement design for safety ideas.
- Consultants (Architect or Civil engineer etc.): Implementing safety policies in the design phase of the project and working closely with the appointed safety coordinator to prepare a health and safety plan for their design. They exert their influence to drive the entire project towards safe execution. With BIM-based software, hazard identification checks, clash detection, fall prevention checks as well as safety rule compliance checks can be made. The BIM further carries out automatic safety checks, alerts the designer for necessary review and design adjustment.
- Contractors/Construction companies: Application of 3D & 4D BIM to communicate and train workers, leveraging on simulation on construction safety measures prior before the task is done to enable accurate Health and safety prediction, continuous safety monitoring using real-time data till project phase-out and working closely with the safety coordinator and strictly adhering to safety regulations. Continuous use of the feedback system to BIM database to

improve the process of construction safety in the future as well as for the operation and maintenance phase.

- Facility manager: Leverages his/her early involvement on the project and the BIM-based platform where the project documents and manuals have been synchronized into, to prepare for building operation, maintenance and renovation strategies, user guidance documentation that fulfill all necessary safety regulations as regards to remodeling and reconstruction.

4.5 Benefits of BIM-based model for Construction Health and Safety

BIM application for safety has the potential to benefit each stage of the construction process as stakeholders are able to make use of a bulk of information within the BIM environment. BIM allows for the connection between various project safety documentations and attributes thereby improving relationships between fragments of data and user guidance. With BIM, information on safety rules and obligations are fine-tuned such that value and potential is maximized. Databases, spreadsheets, 3D drawings, scheduling, and clash detection tools, etc. are sources of information required to fulfill the safety criteria of the construction industry dynamics. As indicated in the theoretical framework in the previous chapter, BIM functions as a hub and an enabling tool for combinations of various sources of information formats available at all stages of a project. The following are further benefits of BIM for construction safety:

- BIM aids the arrangement, coordination, and distribution of safety concerns around a particular subject. Hazards can be categorized based on location in risk order per-floor or building section and accompanied by a custom-made report which is circulated to each applicable subcontractor.
- Leveraging on BIM technology for construction safety also will support construction bodies to create better pro-active policies such as an emergency response plan for health and safety
- BIM allows project participants to have visualized safety educating and training before an actual task is carried out, for example, safety training for acceptable procedures of installation.

- BIM has the potential to support compliance checking, automatic safety & hazard checks of the design and workspace based on pre-established regulations which result in quick reporting and feedback.
- Risk and hazard can be reduced during construction through BIM by carrying out model-driven prefabrication in a safe environment as well as carrying out actual construction in a safe virtual environment before the project is built. Through this contractor is able to plan better and explore different safety outcomes.
- BIM allows for clash detection that may lead to accidents and dangerous occurrences during construction. With the support of previously mentioned digital tools such as remote sensing, GIS, etc. work accidents and dangerous occurrence can be reduced
- 4D BIM allows for visualization of constructions sequence which has potential enhance communication between stakeholders. Studies considered previously indicates that visualized safety training for workers is yield more beneficial than commonly used conventional methods like the safety toolbox.

4.6 Limitations for BIM-based model for Health and safety

Even though BIM has a great amount of potential for safety implementations and has been successful thus far in the upstream end of the industry, the adoption of the technology is confronted with limitations that cannot be overlooked. As explained previously in chapter 2, there is a level of reluctance towards embracing new technology in the construction industry. This argument is also supported by Gambatese & Hallowell's study where they established that fear of change, and varied market readiness, lack of BIM savvy professionals as key limitations to adopting BIM for safety.[111] Similarly, further research concluded that consultants and contractors are yet to fully embrace BIM because they struggle to comprehend the full benefit and business value of BIM.

BIM implementation for safety comes at a high cost; as such, small & some medium-scale construction companies face a daunting task to purchase BIM software, buy new hardware train staff. There is also a question of additional cost for enchasing BIM models, insufficient knowledge on the part of the individual handling the BIM software and often time hesitant to think through construction safety as they develop the BIM model. Other research has indicated that safety features and equipment are yet to be included in some BIM software library as well as collective awareness is lacking on BIM use for safety. [112]

[111] (Gambatese & Hallowell , 2011)
[112] (Azhar S. & Behringer A., 2013)

5.0 Survey

As mentioned earlier at the beginning of this study, the methodology and approach used for this study bases on a review of the literature to comprehend the development and current state of BIM technology and construction health and safety in the AEC industry. Concentrating these two major topics, investigations were carried out to highlight the integration and application of BIM for construction safety. Each individual research topic was first investigated through an analysis of the common and modern-day theory that reinforces them. The work commences with a literature review on BIM along and further orientated to its use for health and safety in construction.

Under the main topic topics, detailed literature investigation was done on BIM development and innovation, conventional health, and safety practices related to design for safety and communication modules in the construction industry. After which they were further investigated in a combined sense to formulate a workable BIM-based theoretical concept that highlights important factors on the combined topic as well as barriers to its implementation. The work in this chapter, further explored the use of primary data to validate the content of the BIM-based theoretical concept. As such, a description is made for the design made for the research, selection of the population sample size, methods and instrument adopted to collect the data, analysis procedure in addition to the validity and reliability of the research variables.

5.1 Research design approach

The author leveraged on the use of an academic questionnaire to facilitate the collection of information form key stakeholders in the construction industry. However, the questions in the questionnaire have been designed to mirror the content in the previously proposed framework alone, to collect information based on their experience from key stakeholders and decision-makers who occupy management positions in the industry. The process and build up to formulating the final questioner include the following:

- Extensive research was carried out by the author to understand and explore previously written and relevant literature on the study domain. The author's review of the literature is to distinguish previously accomplished feat on BIM and health and safety as well as the current state and convectional practice for safety programs on construction sites.
- A preliminary questionnaire was designed such that it presents the theoretical framework to the participants as well as the inclusion of important factors associated with BIM for safety as described in the framework.
- Survey questioned were designed such that it measured responses through a Likert-type arrangement. Properties and factors concerning the framework were used to form question statements to determine the potential success level of the framework.
- Decisions for the apportionment of these factors were carried out by the author in a pilot study under the guidance of Prof. Dr.-Ing. Nicole, Riediger who is the first supervisor for this work.
- The final questionnaire was drafted having considered the outcomes and adjustments made as a result of the pilot study.
- These questionnaires were distributed online to all participants and the collected responses were reviewed and analyzed with the aid of excel and Statistical Package for Social Sciences (SPSS) and Microsoft Excel software.

5.2 Population sampling

The population sampling of the questioners consists of key experienced stakeholders in all available project phase of construction. They include architects, civil engineers, project managers, contractors (including general contractors and sub-contractors) and safety engineers. Since it is not only enough to initiate the BIM-based health and safety program at the beginning of the project but also to be able to manage the implementation of the program as well.

As such, one of the key reasons for targeting these participants was because they occupy a crucial position both in the upstream end and downstream end of the project. In addition, respondents were also expected to be active in the industry with a level of work experience as it is important that respondents have formal training and sufficient experience in order for them to be able to contribute to the subject matter.

The target was to have a total number of expected respondents was 100 participants and questioners were sent and distributed to participants with an accompanying cover letter to various targeting participants through the Linkedln social media platform, experienced stakeholders within the authors' network as well as online groups and communicates from construction stakeholders as well as.

5.3 Content within the questioner

In order to achieve the aim of the study, the content of the questioners comprises three sections. The first section of the questioner was designed to categorize the background of characteristics of each respondent based on the listed field of specialization, size of organization and years’ work experience. The following section required the respondents to indicate based on their experience, their views of BIM use and integration for health and safety planning and management according to the theoretical framework.

The concluding section required the respondents to give a level of importance rating, based on their experience, *twelve* already identified factors relating to application of BIM for health and safety as discussed in the framework; and in addition, they were also required to rate based on levels of importance, seven key barriers for the implementation of the BIM-based theoretical framework for safety out of the previously discussed ones in the report. As previously mentioned, the respondents were required to represent their thoughts on a five-point Likert scale.

5.4 Data analysis

The intention of the author on the analysis is to ascertain the comparative importance between selected factors in the BIM-based framework as it relates to BIM implementation for health and safety as well as barriers for adoption of the framework. The author aims to achieve this by calculating the Relative Important Index (RII) of every single factor according to responses given by each respondent. The outcome will be further used to provide a ranking for all the factors based on their level of importance to the respondents. The coefficient of the RII is usually scaled between 0 and 1, as such, the closer the resulting figure calculated for each factor is to 1, the greater the level of importance for that factor. The formula for calculating the RII therefore is[113];

$$RII = \frac{\sum W}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N}$$

Where;

W – weighting assigned to the factors by each response based on a 1 to 5 scale for which 1n represents very low, 2n represent low, 3n represent moderate, 4n represent high and 5n represent very high.

A – represent 5 which is the highest weight on the scale

N – represent the over-all number of respondent

[113] (Raja R. et al, 2018) & (A., Hatkar K. & Hedaoo, 2016)

5.5 Questionnaire validity

The validity of a questionnaire indicates the extent to which it "measurement measures what it purports to measure"[114].The validity of the questionnaire was done using the expert opinion from the first supervisor of this thesis to explore the extent to which the theoretical construct is being represented in the questionnaire. As such, the content of the questionnaire was examined by the first supervisor to ensure that the questions in the questionnaire fully validate the content and properties for the BIM-based theoretical framework.

The validity procedure went through round two consultations, following the first meeting, a rational analysis of the questionnaire was completed under the expert guidance of the first supervisor after the author presented the initial draft. Corrections were carried out by the author based on the supervisors' analysis. The content validity process was concluded in the second meeting which involved the further review of all questionnaire pieces for readability, lucidity, and inclusiveness.

5.6 Questionnaire reliability

The degree to which the designed questionnaire produces similar results or outcomes when repeated on several trials is expressed in reliability. Pertaining to scores and not respondents, the reliability of this study was carried out by means of a pilot test on fifteen respondents (Table 1). Responses from these fifteen were further analyzed using the Cronbach's alpha coefficient contain in the SPSS software. Cronbach's alpha coefficient ranges from 0.0 to +1.0. According to Mohsen Tavakol & Reg Dennick, higher values ranging from 0.70 to 0.95 are acceptable as they reflect a higher degree of internal consistency[115].

The Cronbach's alpha coefficient was calculated to ascertain the reliability for the questions on the safety-related application of the BIM base framework as well as barriers to implementing them. As indicated in Table 2 below, the reliability coefficient equals

[114] (Olademeji B., 2015)
[115] (Mohsen Tavakol & Reg Dennick, 2011)

safety-related application of the BIM base framework and barriers connected to applying them are 0.820 and 0.749 respectively which indicates an acceptable limit for the coefficients.

		Frequency	Percentage
Cases	Valid	15	100.0
	Excluded	0	.0
	Total	15	100.0

Table 1: Pilot test Summary

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.820	.786	12

Table 2: Reliability Statistics for safety-related application of the BIM base framework

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.749	.757	7

Table 3: Reliability Statistics for barriers for application of BIM-based framework

6.0 Result and discussions

This chapter highlights and discusses the results of the analysis of this research in tables. The survey has been carried out to validate the concept of theory of the proposed BIM-based platform which supports the integration of BIM technology and construction health and safety. While existing literature on the research domain remains limited, the author narrows down on available relevant literature for the topics previously discussed to formulate the theoretical model. After introducing the survey as well as population sample, content, data analysis, validation and reliability of the survey. This research proceeds further by discussing the results of the survey

6.1 Questionnaire return rate

The target group for survey respondents consists of a number of experienced key stakeholders in the construction industry. As such, they are able to validate the model based on their experience in the industry. Accompanied with a cover letter, the survey was sent to 100 targeted experienced stakeholders, however, 87 responses were submitted and accepted within the time frame planned by the author as further delay will affect the timeline to complete this dissertation. This indicates an 87% response rate which is above the response rate limit of 60% for most research[116]

6.2 Questionnaire analysis

Section one: Respondents characteristics

The profile of the respondents is contained in the first section of the survey. The design of the survey provided for the respondent a comprehensive representation of major stakeholders and roles which include architects, civil engineers, project managers, contractors and safety engineers who actively participate across all project phases in the construction industry. Details of the description and distributions are however indicated in Table 4. To an appreciable extent, the targeted respondents have a decent and thoughtful knowledge of the conventional procedures within their companies as

[116] (Jack E. Fincham, 2008)

well as the construction industry as they all occupy important positions in their respective organizations.

I. Professional category in the AEC industry.

Type of service provided	Frequency	Percentage
Architect	33	37.9
Civil Engineer	25	28.7
Project Manager	11	12.6
Contractor	9	10.3
Safety Engineer	9	10.3
Total	**87**	**100.0**

Table 4: Demographic distribution of survey respondents

The first section of the survey includes questions on the category of profession you belong to in the AEC industry, size of organization and years of experience. As shown in table 4, the distribution across the table indicates that out of 87 responses, Architects (33.9%) form the majority of professionals that responded to the survey, followed by civil engineers (28.7%).

The remaining bulk of respondents which include project managers, contractors and safety engineers responded least to the survey with (12.6, 10.3 and 10.3) % respectively. This shows that consultants in the industry (architects and civil engineers) form the largest percentage of 66.6%. This is a good indication as the idea behind the framework supports the early implementation of the concept. In most cases, the consultants are usually the first point of contact for many clients, as such, they are in the best position to advise the client on the best possible safety practice.

II. Size of organization

Size of organization	Frequency	Percentage
1-50 employees	34	39.1
51-250 employees	37	42.5
250 or more employees	16	18.4
Total	**87**	**100.0**

Table 5: Size of the respondent’s organization

Accounting for the largest number in Table 5, over 40% (n= 37) of respondents work in organizations with a strength of 51 to 250 employees, closely followed by 39.1 ((n= 34) of the participants who are actively employed in organizations with a strength of 1-50 employees. It is safe to say respondents of the former and the latter work for small and medium-size organizations respectively. However, the overall results suggest that over 50% of the respondents both work for organizations with 51 to 250 employees (medium size) and 250 or more employees (large) at their disposal. This suggests that the majority of respondents work for either medium or large size organizations which is also good for the research.

III. Number of years of experience in responders' line of profession

Years of experience	**Frequency**	**Percentage**
1-3 years	25	28.7
3-5 years	39	44.8
5-10 years	18	20.7
More than 10 years	5	5.8
Total	**87**	**100.0**

Table 6: Demographic distribution of respondent's years of experience.

Similarly, the demographic distribution of all the respondents as highlighted in Table 6 indicates that 44.8% (n = 39) of all respondents have between 3 to 5 years working experience in their respective organization, followed by a percentage of 28.7% (n = 29) with working experiences between 1 to 3 years. However, the author observed that the total demography for respondents with at least 3 years of work experience is over 70% (n = 62) of the entire population sample which suggests that the majority of survey participants were with thorough and comprehensive work experience in the construction industry. As such they are able to adequately contribute to the research domain.

Section two: Observation and results for according to BIM-based theoretical model

IV. Impact of BIM implementation of construction safety

Impact of BIM implementation	**Frequency**	**Percentage**
Greatly improved	37	42.5
Improved	35	40.3
No effect	4	4.6
I don't know	11	12.6
Total	**87**	**100.0**

Table 7: Demographic distribution of responses on the impact of BIM implementation on construction safety.

As proposed in the theoretical model, Table 7 gives details on the degree to which BIM implementation can promote and enhance safety practices, outcomes, and performance. As shown in the table, over 80% of respondents subscribe to the idea that BIM has the potential to facilitate health and safety planning in the construction industry. This result strongly validates the entire idea behind the theoretical model. Although BIM for safety planning and management is still a novel idea, these respondents recognize the potential of BIM technology for enhancing planning and management procedures form their experience.

Similarly, about 12.6% (n=11) of respondents indicated that they had no idea if BIM could enhance health and safety planning. Although these respondents form the minority, the author, however, suggest that this may be due to the fact that majority of BIM implementation in the industry thus far has been on the upstream end of the industry; as such, more research and application of BIM on the downstream end project realization phase can help educate such respondents better.

V. What phase has BIM implementation for safety yielded maximum success so far?

According to the result of this study, Table 8 indicates that the majority of respondents supports the idea that the best phases to implement BIM are the pre-design and design phase. Totally up to 74.8% of the total responses, respondents similarly support the idea of early implementation for safety considerations in the BIM-based model. According to the model, the window of opportunity to affect safety policies and achieve desired safety results reduces as the project tends to the construction phase.

This suggests that from experience, the respondents realized that the majority of accidents can be prevented or avoided at the early stages of a project (pre-design and design stage) with BIM technology. This also further supports the concept of design for safety for architects and civil engineers which is encouraged through the implementation of BIM for automated rule-based safety checks, compliance checking and clash detection on the 3D designs and graphical representations prepared by them.

Best project Phase for BIM Implementation	**Frequency**	**Percentage**
Pre-design	34	39.1
Design	31	35.7
Pre-construction	11	12.6
Construction	11	12.6
Maintenance	0	0
Total	**87**	**100.0**

Table 8: Responses on what project phase yield maximum benefit for BIM implementation as regards to health and safety

VI. The most effective safety program commences at the pre-design and design development phase of a project.

Based on their experience in the industry, respondents were asked to validate the idea according to the model on a BIM-based implementation during the pre-design and design development project phase. According to Table 9, 25.3% (n=22) and 63.2% (n=55) of respondents validates this idea by their choice of strongly agree and agree respectively according to the BIM-based concept.

Commencement of safety program in pre-design an design development phase	**Frequency**	**Percentage**
Strongly agree	22	25.3
Agree	55	63.2
Neutral	10	11.5
Disagree	0	0
Strongly disagree	0	0
Total	**87**	**100.0**

Table 9: Responses on Commencement of safety program in pre-design and design development phase

Totally up to over 80%, this is a strong indication that the respondents understand the benefit of the early implementation of a BIM-based approach on a project. While none of the respondents opted to disagree or strongly disagree with the idea, however, 11.5% remained neutral on this idea. Nevertheless, the majority of respondents validates this part of the proposed theoretical model with numbers associated with Strongly Agree and Agree.

Section three: safety-related applications of BIM-based technology

VII. Relative important Index and ranking for utilization of BIM-based technology for health and safety

Table 10 shows the result of the distribution for selected safety-related applications contained in the previously proposed BIM-based model. As described, RII calculations show that respondents' first preference for BIM application is *Safety training and education* with a 0.90 RII mark and ranked as first amongst other safety applications. This result validates the theoretical model as the use of BIM for promoting sound education and training regarding all safety-related issues on construction projects. This emphasizes the significance of leveraging BIM technology to augment the awareness of construction workers through digital-based safety training and education system for improved safety results. Similarly, respondents rank *Hazard identification and recognition in second place* with an index of 0.89.

no	Safety-related application	Index	Rank
1	Fall prevention planning	0.87	3
2	Safety training and education	0.90	1
3	Communicate H&S mitigation plans to construction workers	0.86	4
4	Automatic safety checks for regulations	0.84	6
5	Safety monitoring using real-life site data	0.80	8
6	Hazard identification and recognition	0.89	2
7	Simulation of construction sequence	0.85	5
8	Construction sequence visualisation (4D)	0.83	7
9	Management & Planning of high-risk task	0.87	3
10	Provide safety warning for onsite workers	0.78	9
11	Clash detection	0.77	10
12	Visualization and simulation of construction procedures	0.80	8

Table 10: Relative important index for safety-related applications of BIM-based technology.

While this result also validates the content of the proposed model, it also highlights the pressing need for BIM tools and practices to investigate and identify project hazards as well as to support the enhancement of health and safety in the construction sites.

The factor of *fall prevention* was rank third with an RII score of 0.87. While most common accidents that occur on construction sites have been attributed to falling from heights, many construction practices still use traditional procedures to prevent accidents on construction sites, BIM offers a more developed process for the improvement of safety performances and results. As stated in the theoretical model, BIM aids the implementation of early detection on 3D models that may eventually lead to falling as well as a tool to support a fall protection plan.

In general, all the factors listed have been ranked highly by all 87 respondents with the least RII of 0.77 for Clash detection (rank 10). The distribution of the ranking, however, suggests that the respondents to an appreciable level understand and acknowledge the need for BIM implementation on the issue of health and safety in the construction environment; as such, these results further validate the theoretical model proposed through this study.

VIII. Ranking of barriers to BIM adoption for construction safety.

no	**Barriers to BIM implementation and adoption**	**Index**	**Rank**
1	Absence of generalized usage and awareness within construction industries	0.79	2
2	Lack of guidelines for BIM implementation on construction safety	0.76	4
3	High cost related to BIM implementation and training	0.75	5
4	Uncertainty of benefits from BIM-based safety implementation platform	0.75	5
5	Lack of knowledgeable workforce	0.71	6
6	Inadequate training available	0.83	1
7	Low demand from owners on a project	0.78	3

Table 11: Relative important index for safety-related applications of BIM-based technology

As shown in Table 11, out of the selected factors of barriers to the BIM-based implementations presented into the respondents, Inadequate training available was ranked first with an index of 0.83 as the most important barrier. This result indicates that respondents acknowledge the problem of inadequate training for stakeholders in the industry in relation to BIM use and implementation. There is a need global construction industry to develop more technologically savvy professionals as this problem threatens the realization of holistic change in the industry as well as the ability to adapt to new technologies. With this result it is clear than the significance of training cannot be overemphasized as the implementation of sound BIM training will deliver new technological knowledge.

Similarly, respondents ranked the absence of generalized usage and awareness in construction industries as the second most important barrier to BIM adoption for safety in the industry with an index of 0.79. This result suggests the need for all project stakeholders across all construction phases to have a sound knowledge of BIM and its application in order for the technology to flourish. While the topic of safety remains a collective issue affecting all project stakeholders, BIM is yet to be fully implemented in many national construction industries.

Furthermore, Low demand from clients and owners for BIM technology was ranked third with an important ant index of 0.78. This result suggests that clients and owners play an important role in BIM implementation for safety. The client's ability to influence his/her project is highest at the beginning of a project as such, it is necessary for clients to lead from the front and take needed initiative. The online database proposed in the model is a tool that clients can leverage on to guide them in this aspect as they may not have sufficient BIM knowledge or do not recognize the advantage and value of using BIM for safety planning and management. Generally, other factors were given an adequate ranking, which suggests that they are all been overserved as important barriers to the implementation of the study domain by the respondents. For instance, lack of knowledgeable workforce was ranked sixth in the group, this can also be traced closely with the problem of inadequate available training.

7.0 Conclusions

In spite of current safety codes of practice for safety in the construction, safety remains a weighty problem in the industry. With regard to the demands and problems associated with the occurrence of accidents on construction sites, this study has proposed a BIM-based solution with the intention of minimizing safety risk and limit hazards by reducing manual effort and error tendencies in the planning and management of health and safety process.

The idea behind this study is to propose for the industry a more proactive and informed approach towards safety planning through BIM. BIM technology can be used automatically detected safety problems at the project design stage as well as a tool for safety learning. As such, stakeholders can focus their effort on safety solutions and implementation when during construction. Although not too many people are thinking of using BIM to improve health and safety gains. The foundation for this approach is based on the hypothesis that conventional health and safety practices in the construction industry are not sufficient enough to reduce drastically the number of fatal accidents being experienced in the industry globally.

Previously proposed research questions, however, have helped in facilitating a thorough analysis and assessment of existing literature on the study domain. Similarly, the survey conducted in this study formed a basis for validation of the previously discussed theoretical model. While the proposed BIM-based framework was discussed in chapter 4, the previously discussed stages of this study discuss the concept and potential of BIM as well as an analysis of the current state of construction safety in the construction industry. This later resulted in the encapsulation of both topics with the view of integrating them to achieve health and safety gains, which was proposed in the model to be implemented throughout the project lifecycle.

An additional point to stress is the need for a collective effort from all project stakeholders in the implementation of the model. Thus far in the industry, BIM has been used to improve profit margins in project delivery. This has only been made possible as a result of collective implementation by key stakeholders in the industry, and although accidents do not occur until the construction phase, through BIM and digitization as proposed in the model, they can be proactively anticipated, prevented or avoided through the likes of automatic safety rule compliance checks, safety checks, hazard identification, fall prevention, etc. before construction starts. This is not an easy task to achieve for the safety coordinator or safety engineer alone, there has to be a collected effort right from the beginning of any project. This idea is mirrored in the theoretical model proposed by this study and has been further validated through a survey by eighty-seven diversely experienced construction stakeholders.

Furthermore, the outcome of this study clearly highlights the deficiency in communication using conventional methods. BIM, however, offers an innovative way of maximizing communication among project stakeholders as regards managing site safety information. Through BIM, information can be passed on forward and backward for an efficient understanding of rules of engagement on safety-related issues. Through detailed discussions in the previous chapters and in the course of this study, direct or indirect answers have been given to the previously proposed research questions. However, this study will conclude with summarized answers to address all questions proposed in the conceptual formulation. The answers given are as a result the outcome of the previously conducted survey, extensive research, as well as discussions, form the theoretical model.

1. *What are the challenges in conventional safety planning in construction?*

Several stakeholders from a typical construction environment and are exposed to risk and hazard due to the work being done. As such, planning for their safety is not an easy task. Similarly, construction projects are usually built for the first time and therefore require a new "tailor-made" safety planning based on the task at hand because one project differs from another. This can be somewhat challenging of a task and requires sophisticated innovative tools to ease the burden and increase the efficiency of safety planning as conventional safety planning has appeared to be insufficient in many cases.

Furthermore, assigning the burden of all safety implementation, planning, a procedure to the safety engineer or coordinator is a common practice in many countries. While there are many causes of delayed involvement or appointment of a safety professional on any construction project, this in most cases leads to weak planning as the coordinator has limited time to influence the project before the actual task is carried out.

Finally, the majority of conventional safety planning is hinged on manual communication and safety procedures like performing JHA on 2D drawings which is inadequate to critically analyze safety implications of the activities engaged by construction workers.

2. *How can BIM be used to solve these challenges?*

BIM is described as an enabling digital tool especially for enhancing communication among construction workers and project stakeholders. Just as BIM has been used to facilitate communication at the upstream level between project consultants, BIM can be similarly used as the technology offers enhanced visual and simulated communication models that are needed for adequate safety training, education and improved awareness. Furthermore, the principle of design for safety can be maximized with the use of BIM technology, as such there is an early practice for compliance checks on 3D models as well as an early recognition of potential risk and hazards.

Through the use of a BIM database, information can be stored as project progress which will facilitate the investigation of near misses. Challenges associated with limited workspace representation is dealt with the use of BIM as the technology offers construction participants the means to visualize clearly their task and the risks involved. As a final point, BIM technology helps to support the needed holistic approach to safety throughout the lifecycle of a project, even at the operation and maintenance phase, data can be stored up for future use and references.

3. *What potentials does a BIM-based platform have for construction safety planning procedures?*

Thus far, this study has proved that implementing a BIM-based platform has the potential to support and connect external digital and innovative technologies discussed in chapter 4. Through BIM the information produced from these external innovative sources can be put to good use and managed for the benefit of construction safety. As the outcome of this study has revealed, BIM has the potential to enhance the already existing communicative platform between all project stakeholders on safety. Through the use of a computational algorithm on a BIM-based platform, potentials hazards can be anticipated.

This will further assist the building team to plan early for corresponding safety equipment. The potential of BIM to reduce the occurrence of accidents on site will lead to a positive impact on the overall quality of the project delivered. Through a well-implemented BIM platform, construction companies can also potentially achieve a higher reputation in the industry, reduce recordable injuries, make financial gains as a result of a reduced claim and medical expenses for an employee as well as have a better return on investment on their project.

4. *What digital methods can be implemented in Health and safety through BIM?*

As discussed previously in the theoretical model, a full range of innovative methods can be implemented for safety practices through BIM. The first step is to equip a project with an adequate safety database in order to support methods for automation and safety checks against already established rules. By adopting this method, construction stakeholders can be sure they adhere and comply strictly with safety rules regardless of the project phase.

Another method that can be implemented through BIM is scenario and workspace planning; such that the BIM manager and safety coordinator are able to simulate the construction process in a virtual environment. Through this, the contractors can explore different scenarios of site logistics, hoisting options, etc. The innovative method of visual simulation like VR can be used as a tool in scenario planning. Furthermore, visual communication methods can be implemented to enhance health and safety practices as it facilitates visual-based training and education, especially for nontechnical stakeholders.

5. *What are the barriers to entry and implementing these methods?*

As validated in the concluding part of the survey analysis, BIM implementation and adoption is still generally perceived as a new development across the world, as such, construction stakeholders still struggle with the change it brings to the construction process. This by itself is a major barrier as humans naturally can be resistant to change. However, the industry has continued to realize the benefit of BIM in the industry, especially in the project and process level. In spite of the feat achieved in the industry BIM wise, quite a lot of construction stakeholders are yet to increase their awareness of the technology. As such, there still remains a bulk of the ill-informed workforce. This barrier further, reflects on the perceived uncertainty benefit of BIM for construction health and safety.

Furthermore, many countries are yet to mandate BIM for their national construction industry which is seen as a drawback to adoption for safety. Similarly, results from the survey conducted indicated the issue of low client demand for the utilization of BIM for safety planning. Another barrier revealed in this study is the high cost incurred to fully implement BIM. Training and acquiring software and sophisticated digital hardware can be quite expensive as implementation can somewhat be a struggle for small scale construction companies.

6. *What are the roles of various stakeholders in the implementation of a BIM-based Health and safety platform?*

The topic of BIM integration for health and safety is a collective issue and all stakeholders spread across the project lifecycle have a role to play. Based on the theoretical model, roles were assigned to key stakeholders in the construction industry. To have a sound BIM safety program, clients or owners have the responsibility of insisting on BIM utilization not just for profit gain but also for safety planning and education. The client also has the responsibility of appointing a safety coordinator for his/her project inception as his/her influence on safety outcomes can be maximized at the pre-design phase.

Furthermore, architects and civil engineers have the responsibility to work closely with the appointed safety coordinator in the design phase in order to maximize the idea of “design for safety” in their work. They are also able to exert their influence to propel the entire project towards safe execution. Under a BIM-based construction safety platform, consultants are able to carry out hazard identification checks, clash detection, fall prevention checks on their model. Furthermore, contractors also have the responsibility of encouraging the use of BIM for safety training and awareness through simulative means before the task is done. Contractors should also make sure that their workers adhere to established safety rules and regulations.

8.0 Recommendations

BIM for safety is still in a novel state and there is still a lot of work to be done to implement it full swing. However, this study will recommend and stress the need for government involvement in BIM implementation in countries across the world. Acting as an initiator, governments can help facilitate the use of BIM for safety on public projects. However legislative approaches may be introduced in this regard which will equally spur national construction industries into action. Recommendations are also made for the terminology of “BIM-safety certifications” for construction companies.

Effort and research should also be directed towards the commercializing of BIM for construction safety. Currently, there is a good number of BIM software in the global market focus on 3D generation, scheduling and cost calculation. Not so many people are currently thinking of leveraging or integrating BIM for health and safety processes. Recommendations are therefore suggested towards research that will support and enable commercialization of BIM technology for construction health and safety, just as it has been used for efficiency gains with design and scheduling processes.

Getting the best out of communication is a very important part of any business setting. The role of enhanced communication cannot be overemphasized when it comes to the aspect of construction safety. Similarly, the idea of “design for safety” at the design phase of a project by consultants can be further maximized by giving room to valuable and expert knowledge form experienced construction site operatives. Construction site operatives have the best knowledge of the construction environment. In this light this study will further recommend further research in the path of BIM, that will facilitate the implementation of construction site experience and expertise into design. Such that it will allow construction site workers to share their understanding and experience with project designers.

Declaration of Authorship

I hereby declare that the attached Master’s thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Location, Date

Signature of the student

References

A. Ganah & A. John, 2014. Integrating Building Information Modeling and Health and Safety for Onsite Construction. *Safety and Health at Work,* 6(1), pp. 39-45.

A., Hatkar K. & Hedaoo, 2016. DELAY ANALYSIS BY USING RELATIVE IMPORTANCE INDEX METHOD IN INFRASTRUCTURE PROJECTS. *International Jornal of Civil engineering and concrete structures,* 1(3).

Abdulkadir G. et al, 2000. *The Use of Visualisation to Communicate Design Information to Construction Sites.* Glasgow, UNIVERSITY OF CENTRAL LANCASHIRE.

Al Jabri, S., 2017. *How can BIM improve health and safety in construction?,* s.l.: BIMhub.

Alomari K. et al, 2017. Opportunities for Using Building Information Modeling to ImproveWorker Safety Performance. 8 02.

Arayici & Aouad, 2010. Building information modelling (BIM) for construction lifecycle management. In: S. G. Doyle, ed. *Construction and Building: Design, Materials, and Techniques.* Newyork: Nova Science Publishers, pp. 99-118.

Arayici. Y., 2015. *BUilding Information modeling.* 1st ed. s.l.:bookboon.

Aryani A. et al, 2014. The Development of Building Information Modeling (BIM) Definition. *Applied Mechanics and Materials ,* 06 06, Volume 567, pp. 625-630.

Autodesk, 2019. *DESIGNING AND BUILDING BETTER WITH BIM.* [Online] Available at: https://www.autodesk.com/solutions/bim#targetText=Building%20Information%20Modeling%20(BIM)%20is,and%20manage%20buildings%20and%20infrastructure. [Accessed 19 09 2019].

Azhar S. & Behringer A., 2013. *A BIM-based Approach for Communicating and Implementing a Construction Site Safety Plan.* s.l., Associated Schools of Construction.

B. Succar, 2008. Building information modelling framework: A research and delivery foundation for industry stakeholders.. *Automation in Construction,* 10, Volume 18, pp. 357-375.

Bansal V.K, 2011. Application of geographic information systems in construction safety planning. *International Jornal of Project management* , 29(1), pp. 66-77.

Baxendale T. and Jones O., 2000. Construction design and management safety regulations in practice-progress on implementation. *International Jornal for project management* , 18(1), pp. 33-40.

BCG, 2019. *Engineered Products & Infrastructure.* [Online] Available at: https://www.bcg.com/industries/engineered-products-infrastructure/digital-engineering-construction.aspx
[Accessed 26 09 2019].

Behm M., 2005. Linking construction fatalities to the design for construction safety concept. *Safety science,* 43(8), pp. 589-611.

Benjaoran V. & Bhokha S., 2010. An integrated safety management with construction management using 4D CAD model. *Safety Science* , 48(3), pp. 395-403.

Bennett J., 1983. Project management in construction. *Construction management and Economics* , 1(3), pp. 183-197.

Carter G. and Smith S., 2006. Safety Hazard Identification on Construction Projects. *COnstruction engineering and management,* 132(2).

Cheung S. et al., 2004. CSHM: web-based safety and health monitoring system for construction management. *Journal of Safety Research,* 35(2), pp. 159-170.

Davies R., 2013. Implementing ‘Site BIM’: A case study of ICT innovation on a large hospital project. *Automation in Construction,* Volume 30, pp. 15-24.

Dr. Smith P., 2014. *BIM implementation - Global strategies.* Sydney, Elsevier Ltd, pp. 482-492.

Eastman et al., 2011. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.* 2nd ed. New Jersey: John Wiley & Sons, Inc..

Edirisinghe R. & London K., 2015. *Comparative Analysis of International and National Level BIM Standardization Efforts and BIM adoption.* Eindhoven, Proc. of the 32nd CIB W78 Conference .

Egbu & Sidawi, 2019. BUILDING INFORMATION MODELLING (BIM) IMPLEMENTATION AND REMOTE CONSTRUCTION PROJECTS: ISSUES, CHALLENGES, AND CRITIQUES. *Journal of Information Technology in Construction - ISSN 1874-4753,* 05, Volume 17, pp. 75-92.

EUBIM Taskgroup, 2018. *Handbook for the introduction of Building Information Modelling by the European Public Sector,* s.l.: EUBIM Taskgroup.

Fred A. Manuele, 2003. *ON THE PRACTICE OF SAFETY.* THIRD EDITION ed. s.l.:A JOHN WILEY & SONS, INC.

Gambatese & Hallowell , 2011. Enabling and measuring innovation in the construction industry. *Construction Management and Economics,* 29(6), pp. 553-567.

Gambatese et al., 2008. Design's role in construction accident causality and prevention: Perspectives from an expert panel. *Safety Science*, 04, pp. 675-691.

Godfaurd J. & Ganah A., 2015. Integrating BIM and Planning Software for Health and Safety Site Induction. *Safety and Health at Work,* 6(1), pp. 39-45.

Goubau T., 2017. *A History of BIM,* s.l.: s.n.

Hadikusumo BHW. & Rowlinson S., 2004. Capturing safety knowledge using design-for-safety-process tool. *Construction Engineering and Management,* Issue 2, pp. 281-289.

Howarth T. & Watson P., 2008. *Construction Safety Management.* s.l.: Wiley-Blackwell.

Huges P. & Ferrett E., 2011. *Introduction to Health and Safety in Construction.* Fourth ed. s.l.:Routledge.

J. Gambatse & H. Hinze, 1999. Addressing construction worker safety in the design phase Designing for construction worker safety. *Automation in Construction,* Volume 8, p. 643–649.

J. Teizer & J. Melzner, 2018. BIM for Construction Safety and Health. *Building Information Modeling ,* 20 09.pp. 349-365.

Jack E. Fincham, 2008. Response Rates and Responsiveness for Surveys, Standards,and the Journal. *American Journal of Pharmaceutical Education,* 72(2).

Jianoing Z. & L. Ding, 2010. *Research on 4D virtual construction and dynamic management syetem based on BIM.* s.l., Nottingham university press.

Khoshnava S. et al, 2012. *Application of BIM in Construction Safety.* Malasia, Research gate, pp. 115-160.

Levy F., 2012. *BIM in small scale sustainable design.* New Jersey: John Wiley & Sons, Inc..

Lewis S., 2017. *BIM in Germany.* [Online]
Available at: https://www.lexology.com/library/detail.aspx?g=f1dcbcbd-4f8c-4989-80c2-29340b5627e8
[Accessed 09 2019].

Lin K. et al, 2014. A user-centered information and communication technology (ICT) tool to improve safety inspections. *Automation in Construction,* Volume 48, pp. 53-63.

Lingard H. & Rowlinson S., 2005. *Occupational Health and Safety in Construction Project Management.* London & Newyork: Taylor & Francis e-Library.

M.D. Martinez Aires et al, 2010. Prevention through design: The effect of European Directives on construction workplace accidents. *Safety science,* 48(2), pp. 248-258.

Markku Kiviniemi et al., 2011. *BIM-based Safety Management and Communication for Building Construction.* VTT Tiedotteita - Research Notes ed. Espoo.: VTT Technical Research Centre of Finland.

Melzner, J. Teizer & J., 2018. BIM for Construction Safety and Health.. *Building Information Modeling,* 09.pp. 349-365.

Mohsen Tavakol & Reg Dennick, 2011. Making sense of Cronbach's alpha. *International Journal of Medical Education,* Volume 2, pp. 53-55.

Olademeji B., 2015. Principles and methods of validity and reliability testing of questionnaires used in social and health science researches. *Nigerian postgradu medical jornal,* 22(4), pp. 195-201.

Patricia M. Hillebrandt, 2000. *Economic Theory and the Construction Industry.* London: Palgrave Macmillan.

Prof. Dr. Y. ARAYICI, 2017. *Construction IT and Management.* [Online] Available at: https://yacem.hku.edu.tr/department/consit/ [Accessed 09 2019].

Qi Jia et al, 2011. Integration Of Safety In Design Through The Use Of Building Information Modeling. *International Workshop on Computing in Civil Engineering 2011*, 06, pp. 19-22.

R. Sacks et al, 2009. *Journal of Construction Engineering and Management,* 135(8).

R. Shah & J. Edwards, 2016. *A study of 'Site BIM' impact on health and safety in construction sites.* Hong Kong, Research Gate.

R. Szymberski, 1997. Construction project safety planning. *Tappi Journal,* p. 69–74.

Raja R. et al, 2018. *Relative Importance Index of Sustainable Design and Construction Activities Criteria for Green Highway,* s.l.: AIDIC.

Seokho C. et al, 2012. *Using BIM for smarter and safer scaffolding and formwork construction: a preliminary methodology.* s.l., International council of research and innovation in building and construction.

Shafique M. & Rafiq M., 2019. *An Overview of Construction Occupational Accidents in Hong Kong: A Recent Trend and Future Perspectives,* Hong Kong: MDPI.

Stefan Mordue, 2019. *AUTODESK UNIVERSITY.* [Online] Available at: https://www.autodesk.com/autodesk-university/article/BIM-Health-and-Safety-Construction-2017
[Accessed 10 2019].

Stefan Mordue, 2019. *BIM for Health and Safety in Construction,* s.l.: Autodesk Univeristy.

Stuart D. Summerhayes, 2010. *Design Risk Management: Contribution to Health and Safety.* s.l.:Wiley-Blackwell.

Sulankivi K. et al, 2013. *Utilization of BIM-based Automated Safety Checking in Construction Planning.* Brisbane, Australia, Proceedings of the 19th CIB World Building Congress Queensland University of Technology, p. 11.

T. Bazendale & O. Jones, 2000. Construction design and management safety regulations in. *International Journal of ProjectManagement,* 18(1), pp. 33-40.

Teizer J., Melzner J., 2018. Building Information Modeling. In: *BIM for Construction Safety and Health.* Bochum: Springer, Cham, pp. pp 349-365.

Teizer, J. et al, 2007. Real-time three-dimensional occupancy grid modeling for the detection and tracking of construction resources. *Journal of Construction Engineering and Management,* 11(133), pp. 880-888.

Teo et al, 2016. Design for safety: theoretical framework of the safety aspect of BIM system to determine the safety index.. *Construction Economics and Building,* 4(16), pp. 1-18.

Uddin & Khanzode, 2014. *Examples of How BIM can Enhance Career Paths in Construction,* s.l.: ASCE library.

Wei Z. et al, 2012. Construction safety and digital design: A review. *Automation in Construction,* 8 September, Volume 22, pp. 102-111.

Wetzel & Thabet, 2015. The use of a BIM-based framework to support safe facility management processes. *Automation in Construction,* Volume 60, pp. 12-24.

Yusuf A. et al, 2012. BUILDING INFORMATION MODELLING (BIM) IMPLEMENTATION AND REMOTE CONSTRUCTION PROJECTS: ISSUES, CHALLENGES, AND CRITIQUES. *Journal of Information Technology in Construction,* 05, Volume 17, pp. 75-92.

Zhang S. et al, 2013. Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Automation in construction*, 01, Volume 29, pp. 183-195.

Zhang S. et al, 2015. Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA). *Automation in Construction,* Volume 52, pp. 29-41.

Zhou et al, 2013. *Applying advanced technology to improve safety management in the construction industry: a literature review,* s.l.: Taylor Francis online.

Zhou W. et al, 2011. Construction safety and digital design: A review. *Automation in Construction,* Volume 22, pp. 102-110.

Žiga Turk, 2016. Ten questions concerning building information modeling. *Building and Environment,* 08.

Appendix A

Questionnaires

Section one: *Respondents characteristics*

1. Kindly indicate the category of profession you belong to in the AEC industry.
    a. Architect
    b. Civil engineers
    c. Project managers
    d. Contractor
    e. Safety engineer
    f. Others

2. Please indicate the size of your organization.
    a. 1-50 employees
    b. 51-250 employees
    c. 250 or more employees

3. Kindly indicate your years of experience in your line of work
    a. 1-3 years
    b. 3-5years
    c. 5-10years
    d. More than 10years

Section two: Observation and results for according to BIM-based theoretical model

4. From your experience, what is the impact of BIM on construction safety
    a. Greatly improved
    b. Improved
    c. No effect
    d. Less effect
    e. I don’t know

5. Based on your experience, in what phase has BIM implementation maximum success so far?
    a. Planning
    b. Design
    c. Pre-construction
    d. Construction
    e. Operations & Maintenance

6. From your experience, most effective safety programs commence at pre-design, design development and pre-construction phase of a project
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree

Section three: safety-related applications of BIM-based technology

7. On a scale of 1 – 5, kindly rank the following safety-related applications of BIM-based technology (Taken 1 as Very low and 5 as very high)

- Fall prevention planning
- Hazard Identification and recognition
- Communicate H&S mitigation plans to construction workers
- Automatic safety checks for regulations
- Safety monitoring using real-life site data
- Safety training and education
- Simulation of the construction sequence
- Construction sequence visualization (4D)
- Management & Planning of high-risk tasks
- Provide safety warning for onsite workers
- Clash detection

- Visualization and simulation of construction procedures

8. From your experience, kindly rank the following barriers to BIM adoption for construction safety. (where 1 is very low and 5 being very high)

- Inadequate training available
- Lack of guidelines for BIM implementation on construction safety
- High cost related to BIM implementation and training
- Absence of generalized usage and awareness within construction industries
- Uncertainty of benefits from BIM-based safety implementation platform
- Lack of knowledgeable workforce
- Low demand from owners on a project