ADOPTION OF BUILDING INFORMATION MODELLING (BIM) IN CONSTRUCTION PROJECTS DELIVERY IN RWANDA. CASE STUDY OF CITY OF KIGALI

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Adoption of Building Information Modelling (BIM) in Construction Projects Delivery in Rwanda

Case Study: City of Kigali

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signed……..…………………………………… Date: ………………………………….

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This thesis has been submitted for examination with our approval as the university supervisors.

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DEDICATION

With Special appreciation to the Almighty God, my beloved mum Alexiane Pendage, Sylvere Nyabyenda (dad), Martha Nyiramacumbi (stepmother), Suzanne Nyirakazuba (Grandmother), the family of Fordouald Ncaha Rutwaza and Jacques Bishangi, brothers, and sisters.

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LIST OF ACRONYMS

AEC	Architecture, Engineering, & Construction
AR	Augmented Reality
AUGI	Autodesk User Group International
BIM	Building Information Modelling
BPMIS	Building Permits Management Information System
BS	British Standards
CAD	Computer Aided Design
CRC	Cooperative Research Centre
D	Dimension (al)
EN	European Norm
gbXML	Green Building Extensible Markup Language
GDP	Gross Domestic Product
ICT	Information Communication Technology
IER	Institution of Engineers Rwanda
IFC	Industry Foundation Classes

IPD	Integrated Project Delivery
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical Electrical Plumbing
MININFRA	Ministry of Infrastructure
NBS	National Building Specification
OSHA	Occupational Safety and Health Administration
PAS	Publicly Available Specification
RFI	Request for Information
ROI	Return on Investment
RIA	Rwanda Institute of Architects
ToR	Terms of Reference
UK	United Kingdom
US	United States
XML	Extensible Markup Language

ABSTRACT

Worldwide, the construction industry is experiencing fast and adaptive innovations; new construction technologies such as 3-Dimensional printed structures and different platforms are developed to help professionals involved in the planning, design, construction, and management of buildings and infrastructure. Building Information Modeling (BIM) is transforming the way that buildings and infrastructure are designed, constructed and operated, and it is also helping to improve decision making and performance across the buildings and infrastructure in general. Where BIM has not been fully applied in the design, construction, and operation of infrastructure like our case of Rwanda, the industry has to undergo these technologies in order to be in line with the others, in the performance improvement. BIM adoption in construction projects in Rwanda is the issue that is discussed in this study. The study focused on investigating the level of use of BIM and elaborating a process that could enhance its adoption in construction projects in Rwanda. The research enquired into the awareness of the respondents on BIM need in Rwanda, with the aim of exploring the level of use, addressing related benefits and barriers in the country, and elaborating the process of adoption which the industry can opt for to ensure full BIM usage in construction project life cycle and facilities management. In Rwanda, the term BIM does not sound as new to a number of design and construction professionals, and facility managers in the country, but the number remains low. Results revealed that only 29.1% of the total respondents were aware of BIM existence, 82.9% of those who were aware have been using it while 17.1% have not. Results also revealed that only 2D and 3D are the most frequently BIM dimensions used in the construction industry in Rwanda while the technology is continuously evolving. They have been using them in existing conditions modelling, civil works design, review of designs, quantity, cost estimation, structural modelling, analysis, and design, but none of them have used BIM tools in energy analysis, code validation, digital fabrication, maintenance scheduling, or in other engineering activities. The fact is that BIM is used in a vague manner with inappropriate practices and certification.

The level of awareness of BIM existence and the insufficient use of BIM in the construction industry in Rwanda which have been observed in this study validate the current shortage of building design professionals trained in collaborative design and construction practices. The study also addresses the need for the BIM full adoption in construction projects in Rwanda. A process for adopting BIM with focus of enhancing delivery of construction projects in Rwanda is formulated from the results of the data analysis and expert opinions of the respondents. The formulated processes process involves setting needs and goals of using BIM tools, organizing training and courses, availability of ICT infrastructure, authorizing software, advocacy to policy and decision makers, establishment of policy and legal framework, dissemination of the importance of BIM, enforcement, strategic implementation, sustainability, monitoring and evaluation, and scaling-up. The Ministry of Infrastructure would benefit from implementing the process for adoption discussed in this study. Additionally, recommendation is made for full uptake of BIM in the life-cycle of construction projects and facilities management in Rwanda.

CHAPTER ONE

INTRODUCTION

1. 1 Background of the Study

The construction industry in Rwanda is continuously booming and subsidized by the government in line with the provisions of the Constitution (1995) and the divesture policy, with the aim of achieving full and effective participation of the private sector for the sustainable development of the country's physical infrastructure. Amid 2010-2015, the industry comprising construction, manufacturing, mining, and others grew on average 9.3% annually, outperforming the overall economy at 7%. The building and infrastructure construction sectors accounted for majority of the industry growth, reporting 12.8% average annual growth in 2010-2015 sector (Ministry of Infrastructure, 2009). Thus, the construction industry plays a major role in the economic and social development of the country and substantially contributes to 51% of the total of industrial Gross Domestic Product (GDP) (The Swedish Trade & Invest Council, 2017) because it serves as the central delivery mechanism in generation and quality of all economic and social development activities in the country. Due to this role that the industry plays, the government of Rwanda developed supporting policies to encourage and facilitate the development of the sector (Ministry of Infrastructure, 2009).

Rwanda is a country with limited resources and to ensure its development, it is essential for the countrymen to invest in appropriate technologies. Communication and documentation within the industry need to be improved. In order to achieve this improvement, it is better to institute an appropriate process of adopting new technologies such as Building Information Modelling (BIM), an intelligent 3D model-based process that gives the Architecture Engineering & Construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes (Autodesk, 2018).

During construction activities, consultants and contractors set up together teams of professionals and technicians and who often work for quite a short period of time on site by using different platforms during the preparation of necessary documents needed for any construction project implementation with aim of designing and planning of what is to be constructed. CAD, the traditional technology used by AEC in past years, does not promote a true collaborative approach (Teicholz, 2004). Architects and engineers process CAD documents to hand on their designs to owners and contractors. The drawings produced are not integrated and usually pose conflicts of information which result in inefficiency in labor productivity hence estimators need to count and generate their own quantity take offs based on the produced CAD documents (Masood, Kharal, & Nasir, 2013). In addition, the 2D CAD approach does not promote the integration of the drawings with schedule and cost (Hergunsel, 2011). In order to get more insights about BIM adoption process and practices, it was crucial to explore and understand how other countries have implemented them through review of literatures as detailed in Chapter Two.

1. 2 Statement of the Problem

Hergunsel (2011) emphasized that construction firms do not have as much of an incentive or the resources to invest money in research and development of new technologies because of the high risks and costs of such investment. When the new methods and technologies are used, they are applied per project basis and are not adapted quickly in the construction industry as a whole. Globally, the construction industry must undergo a model shift from its old approach to the new project delivery approach, and this is the case for Rwanda particularly in the City of Kigali.

Due to the contemporary sophistication in construction contracts, building design and the resulting demand for the construction of quality infrastructure, the constructability challenges that many construction companies face are very sophisticated and cannot be addressed and solved easily without the help and application of technology (Sahil, 2016). According to GenieBelt (2017), one technology that has emerged over the last decade and a half is BIM. This technology has enabled designs to become more sophisticated as the technologies supporting BIM have evolved. Currently, the modeling industry in developed countries can support not only 3D models but the construction management areas of scheduling, cost control, estimating, safety training, and sustainability. As highlighted in Chapter One, the focus of this study is to identify what issues/problems one may face when adopting BIM in a developing country like the case of Rwanda. Prior knowledge of potential issues/problems could be the difference between successful adoption and a failure to adopt BIM in a timely and cost-effective manner.

Recent advances in technology have allowed the AEC industry to keep up with the multi-dimensional real world and the tool that has allowed them to do this is Building Information Modelling (Christoph & Bjørn, 2012). The future of the construction industry is BIM. As it is becoming more popular, it introduces many opportunities for the improvement of business information transfer through the construction process. Perceived and actual benefits have been investigated throughout many studies. However, a framework for adoption of BIM in the AEC industry in Rwanda has not yet been formulated. BIM can only be of full benefits to the AEC industry adopters once it has been more widely adopted through the industry. It is hard for a company to fully achieve the benefits of BIM while other partners are not using it. BIM provides a much better means of communication and distribution of information between clients, construction and architecture firms and legal authorities involved in project.

From the literature reviewed in this study no research conducted on the need and use of BIM or a process elaborated for its adoption in construction projects in Rwanda was found. As going hand in hand with new technologies is necessary for any construction project delivery, the study focused on investigating the current level of use of BIM in Rwanda and elaborating of a process of enabling the industry to adopt and implement the technology in the delivery of construction projects life-cycle and facility management is necessary as well.

1. 3 Research Objectives

1. 3. 1 General Objective

The main objective of the study was to develop a process for enhancing BIM adoption in construction projects delivery in Rwanda particularly in the City of Kigali.

1. 3. 2 Specific Objectives

The specific objectives included:

1. To explore the current level of BIM usage in the City of Kigali,
2. To examine of benefits due to use of BIM in the City of Kigali,
3. To survey barriers due to use of BIM in the City of Kigali,
4. formulate a process for enhancing BIM adoption in the delivery of construction projects in the in the City of Kigali.

1. 4 Research Questions

The study intended to answer the following questions:

1. To what extent is BIM used in City of Kigali?
2. What are the benefits due to use of BIM in the City of Kigali?
3. What are the barriers due to use of BIM in the City of Kigali?
4. Which process could be followed to ensure delivery of construction projects provided BIM is fully adopted in the City of Kigali?

1. 5 Justification of the Study

The National Construction Industry Policy (2009) of the government of Rwanda motivates the use of appropriate technology in construction and maintenance of infrastructure facilities with machines and labor as resource inputs, there is no official BIM practices recognized in Rwanda. BIM as a modern technology, might be considered as the best initiative within the construction industry and has been thrived for the industry with the aim of improving the cooperation and collaboration between involved parties during the realization and maintenance of construction projects (Musabyimana, 2017). Due to low BIM practices in Rwanda, this research aimed at sightseeing the extent to which BIM is used by professionals within the construction industry particularly in the City of Kigali, examining barriers and benefits, as well as formulating the process of adoption that would improve construction projects in the City of Kigali. Specifically, MININFRA, private and public institutions, investors, partners (non-government organizations, donors), contractors, consultants, higher learning and citizens of Rwanda in general would benefit from this research through being aware of BIM need, impacts and barriers, and a process of applying the model in construction projects life-cycle and facility management.

1. 6 Scope of the Study

In the construction industry, design and construction professionals are the most users of BIM, this study brought together ideas of key players comprising registered professionals comprising of construction project managers, engineers, architects, quantity surveyors, and urban planners in order to get their concern on how BIM can impact the industry and rate technological implementation related barriers in Rwanda particularly in the City of Kigali. The study also fostered to elaborate a process of adopting BIM in Rwanda as a strategy for its implementation in country’s infrastructure and facility management.

1. 7 Limitations of the Study

In order to get expert views on the current use of BIM in Rwanda, the study involved only the AEC and MEP practitioners whose projects were run in the City of Kigali. As Kigali is a booming city and capital of Rwanda. The case study has been selected because it is the biggest city in country and a good number of construction projects are implemented in the City of Kigali. For practical considerations, only the practitioners in the City of Kigali were reached for the study since most of construction professionals live in the Kigali

1. 8 Outline of the Study

The study is presented in five chapters. Chapter one (1) discusses the Rwanda's construction industry and identifies gaps related to BIM usage in the country. It also addresses the research problem in general, the objectives of the study, research questions, limitations and scope are stated, and the study is justified. Chapter two (2) presents related studies on adoption of BIM in the construction industry of other countries. It also discusses various concepts of BIM uptake, history, trends, benefits, tools, risks, opportunities, and policies globally and relates in the Rwandan context. Concepts and theories informing the study are identified. Chapter three (3) discusses the methodology used in conducting the study comprising the research design, population, data collection procedures and analysis. Chapter four (4) presents analysis of the data and the results observed. Chapter five (5) covers conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents review of literature related to BIM adoption globally and regionally. It highlights the fundamentals and history of BIM, related research findings, and perceptions on BIM adoption in different countries. It also highlights the knowledge gap in this field in the case of Rwanda, and outlines the theoretical framework for the study. Finally, the conceptual framework for the study is presented.

2.2 History of BIM

The concept of BIM has existed since the 1970s and the idea was conceptualized and initially called Building Description System (BDS) (Goubau, 2018). The term building model was first used in 1985 in architectural design paper on CAD and 7 years later, the term BIM first appeared in a 1992 paper by G.A. van Nederveen and F. P. Tolman. However, the term BIM was not popularly used until 10 years later when Autodesk released the white paper entitled Building Information Modeling, then Jerry Laiserin helped popularize and standardize the term as a common name for the digital representation of the building process as then offered under differing terminology — by Graphisoft as Virtual Building, by Bentley Systems as Integrated Project Models; and by Autodesk or Vectorworks as BIM — to facilitate exchange and interoperability of information in digital format (Bimpanzee, 2018). Graphisoft developed early system solutions longer than the competitors in the market and was responsible for ArchiCAD, which was then one of the most mature BIM solutions in the market; it was regarded as the first BIM implementation in 1987 and was the first CAD product on a personal computer able to create 2D and 3D geometry, and the first commercial BIM product for personal computers (Goubau, 2018). Autodesk became the first to the top of the BIM deal when it acquired Revit in 2002 and later in 2012 also developed FormIt, a mobile based application that enables the conception of BIM model on portable devices (Goubau, 2017).

Figure 0.1 BIM evolution: from hand drafting to BIM

Source: Goubau, 2018

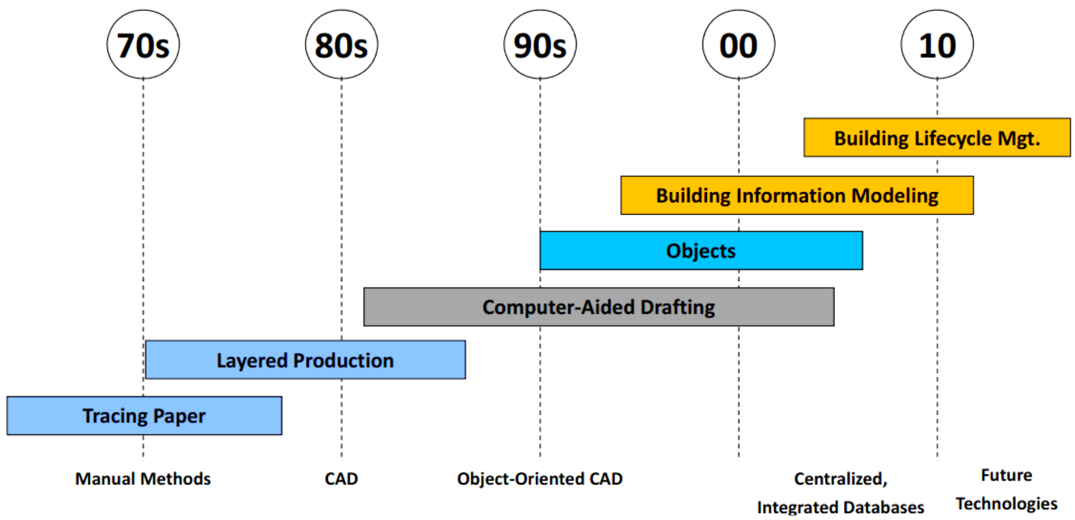

Figure 0.2 History of Methods of Production

Source: Karul et al., 2014

2.3 Global Trends in BIM Uptake

According to Karul et al. (2014), BIM is currently hailed as a solution that would eventually make collaborative working a reality. The UK Government has announced that BIM would be compulsory on all public sector projects from 2016. In addition, the Ministry of Justice in the UK announced in April 2011 that contractors on its framework should use it by the middle of 2013. Therefore, there has been a strong push for the industry to adopt BIM but very limited appreciation of the issues that need to be resolved, example: cultural, procedural, contractual, process-related, so that BIM becomes the vehicle for collaboration. Technological solutions to this problem existed but they needed to be creatively combined to facilitate true collaboration between disparate project stakeholders who were often reluctant to share innovative solutions due to contractual relationships and Intellectual Property. Therefore, in order to gain insights about BIM, it is important to understand how other countries have implemented them. The Scandinavian countries have been noted for being technologically advanced with highly educated populations and large public sectors; as an overview of BIM practices.

2.3.1 BIM Penetration: Scandinavia versus UK

A survey conducted by Kiviniemi in 2008 revealed that the usage of BIM and Industry Foundation Classes (IFC) compliant applications stood at 33%. In January 2007, Denmark launched an initiative called Det Digitale Byggeri which means Digital Construction for mandatory use of BIM in government projects (Karul et al., 2014). While these countries have already established BIM mandatory requirements, Morrel (2011) reported that the UK's first BIM mandatory requirements would come into force in 2016, nearly 9 years later; despite immense benefits of BIM already noted in these countries, and others, industry experts had often affirmed that BIM only became a vehicle to delivering better value if parties truly collaborate.

2.3.2 Current Approaches to Project Delivery

Standardization, off-site manufacturing, prefabrication and similar innovative approaches to delivering buildings is another area which provides opportunities to deliver better built facilities. The benefits of standardized construction are fast return on investment, health and safety savings, time savings, quality savings, efficiency savings, material savings, fewer defects and fewer mistakes (Ross 2005), from five (5) decades ago, the provision of standardized schools has an established track record in UK and most projects including standardized schools are often required to use construction lifecycles. These lifecycles often adopt a stage-gate approach to project delivery, where professionals are involved only during the stages when their expertise is deemed necessary. In addition, many project partners still pursue these lifecycles in a linear fashion contrary to the BIM approach which is non-linear and provides project partners opportunities to collaborate simultaneously in a project.

In this way the role of BIM can contribute to reducing industry fragmentation, improving efficiency/effectiveness and fostering interoperability thereby reducing cost and time, and it is considered that the use of BIM can greatly enhance the production of standardized buildings by providing integrated information solutions from the factory to the site. According to Lu and Korman (2010), the use of modular construction techniques may increase as BIM becomes more prevalent in the construction industry.

2.4 BIM Levels

According to GenieBelt (2017), on any construction project, there are commonly four (4) different levels of generating and exchanging data known as BIM maturity levels. They vary based on the increase of parties involved shared collaboration. The first is the BIM level zero or low collaboration, which is the simplest step of the information generating process because it does not practically involve any level of cooperation (CAD drawings are used during this level, but there is no sharing of the generated information models). The second is the BIM level one (partial collaboration), which focuses on the transition from CAD to 2D and 3D pieces of information where a large number of companies are at the moment conducting their work on the partial collaboration level using online shared tools. The third one is the BIM Level two (full collaboration), where the main focus of interest on this level is the way in which the information is shared across the various project members and collaborative working is at the core of BIM Level 2. And the fourth one is the BIM Level 3 (full integration) which is the ultimate goal for the construction industry, its main point is the attainment of full integration (iBIM) of the information in a cloud-based environment. This will be achieved by the use of a common shared model.

As discussed in Section 2.3, countries like the UK have been pushing hard towards the direction of maximizing the use of necessary levels where the government mandated for adopting the BIM Level 2 model by 2016 in public projects that makes clear that there is a strong focus on optimizing the construction process.

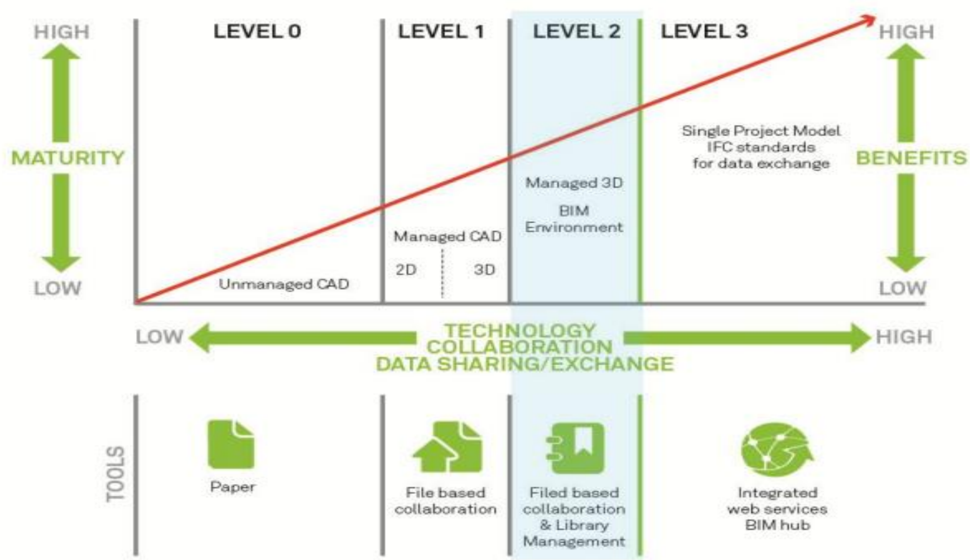

Figure 0.3 BIM levels

Source: Government Construction Client Group , 2011

2.5 BIM Dimensions

Goubau (2018) defined BIM dimension (nD) as the capacity or ability of a specific BIM product or platform to process attributed data (inputs) in order to achieve useful information (output); nDs are ultimately digital files that describe every aspect of the project and support decision-making throughout a project cycle as proclaimed by Arnal (2018). BIM has been thought of as being nothing more than 3D modelling but it actually involves more than that in the past 20 year.

BIM and the subsets of its systems and similar technologies feature more than just 3D (width, height, and depth [shape]) but include further dimensions such as 4D (time), 5D (cost), and even 6D (as-built operation or performance), 7D (sustainability), and even 8D (safety). The ninth dimension is about introducing Lean Management Philosophy into the building sector; it is all about integration of Emergency Reponses into the designs. The tenth dimension is to industrialize construction and transform the construction sector into a more productive sector by integrating the new technologies through its digitization (Goubau, 2018; Arnal, 2018 & Kamardeen, 2010). Figure 2.4 outlines the dimensions of BIM, from 3D to 7D.

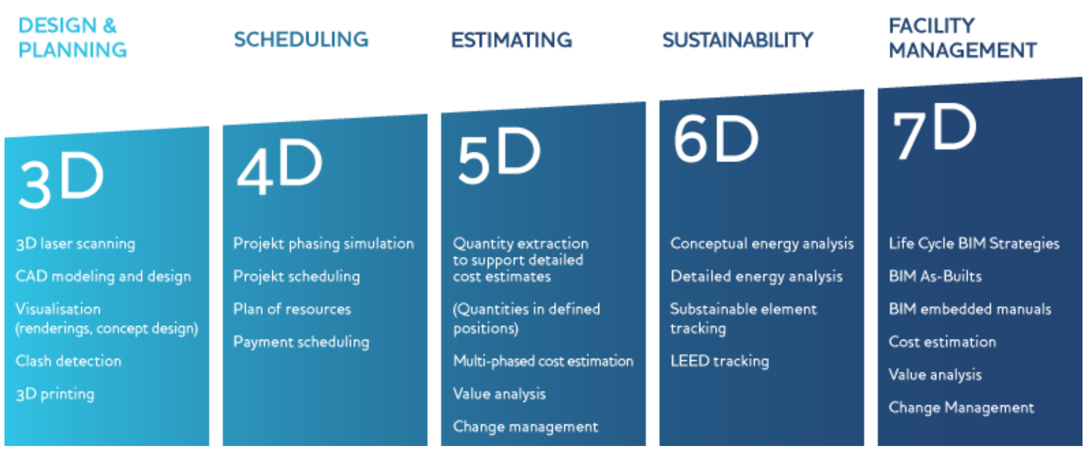

Figure 0.4 BIM dimensions

Source: CÉH, 2018

2.6 BIM Objects and Tools

GenieBelt (2018) highlighted that BIM is the future of construction. Using BIM, you can break down silos that hinder collaborative engagement, thus allowing information to flow seamlessly among different construction stakeholders. BIM aims to make information accessible, instantly, across the board to all stakeholders. Because of this social-media like nature of BIM, everyone can access information, provide inputs, and eradicate potential conflicts – which could possibly result in change orders and even, disputes and litigations.

Building an information-rich and construction-ready BIM model is far more difficult than building a pretty-looking design model for a client presentation. The old adage, “GIGO – Garbage in, Garbage out” espouses the BIM philosophy quite well. In order to build a useful model that simulates the actual site conditions, you need to feed in accurate information from different stakeholders. Building a BIM model is a painstaking and iterative process (GenieBelt, 2018).

According to Karul et al. (2014), it is imperative to understand the technological, practical and methodological challenges impeding the uptake of BIM so as to provide a way forward for its full-scale adoption. In the ensuing section, a review of the different BIM tools is undertaken; what makes BIM unique, is a representation of a design as an amalgamation of objects, meaning that any change of the object automatically affects the design. BIM tools allow the extraction of different views from a model for production of drawing among other things. There are plenty of BIM products; some of the products are identified as Revit, Microstation, Allplan, Bentley Building Suite, AutoCAD, Vectorworks, ArchiCAD, and Trimble SketchUp. Some of these them are integral and capable of scheduling, cost estimation, modelling, analysis, and design (Hergunsel, 2011). Table 2.1 illustrates the list that includes MEP and AEC software.

Table 0.1 BIM Tools

	Stage	Domain	Users
Revit Architecture	Planning and Design	Architecture	Architects and drafters
Revit Structure	Planning and Design Construction	Structure	Structural engineers
Revit MEP	Planning and Design	MEP	Mechanical, Electrical and Plumbing Engineers
ArchiCAD	Planning and Design Construction	Architecture	Architects
Allplan Architecture	Planning and Design	Architecture (3D design)	Architects and drafters
Allplan Engineering	Planning and Design Construction	Structures (3D design for structural design)	Structural engineers
Allplan Facility Management	Operations	Facility Management	Facility managers
MicroStation	Planning and Design Construction Operation	Architectural Design	Architects, engineers, contractors, planners, GIS professionals
Vectorworks	Planning and Design	Landscape design	Planners and Landscape Architects
Bentley suite	Planning and Design Construction	Architecture, Structures, MEP	Architects, MEP and Structural Engineers
Trimble SketchUp	Planning and Design	Architectural design	Architects

Source: Karul et al., 2014

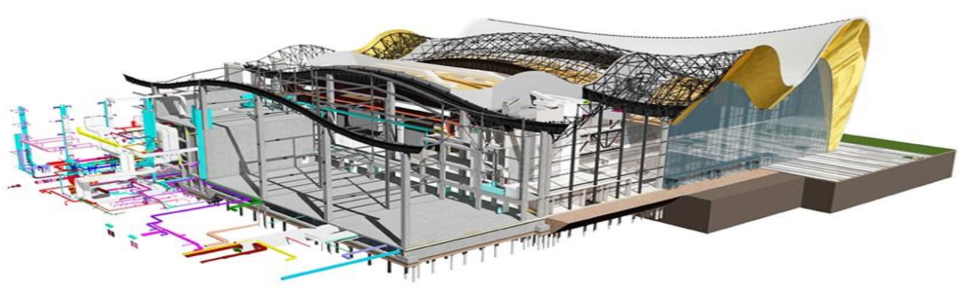

Figure 0.5 The complete BIM model: MEP and structural sections

Source: Graphisoft, 2018

Figure 0.6 BIM based infrastructure model

Source: Autodesk, 2018

2.7 The Uses of BIM

A BIM Use can be defined as a method of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives (Kreider & Messner, 2013). A survey was conducted in 2009 to help determine the frequency by which organizations make each BIM use and the benefit to the project of each use. While the BIM uses of 3D coordination and design reviews were both the most frequently used and most beneficial based on the survey results, all of the uses in the survey are being made to a degree on projects and are perceived beneficial (Ralph & John, 2011). Based on phases of project development as shown on Figure 2.10, 25 BIM uses were identified through a number of interviews with the industry experts (Kreider & Messner, 2013).

Kreider and Messner (2011) stated that the majority of the survey focused on one two-part question. First, how frequently does your organization use each BIM uses defined in the BIM Project Execution Planning Guide? Second, what is your organization's perceived level of benefit to the project for each use? The first portion of the question gave the response options of 0%, 5%, 25%, 50%, 75%, 95%, and 100%, while the second portion of the question gave the response options of very negative, negative, neutral, positive, and very positive. Below is a graph showing both the Frequency and Benefit of Each BIM uses and a table showing the ranking of the BIM uses.

Figure 2.7 below highlights the life-cycle of BIM in the construction industry.

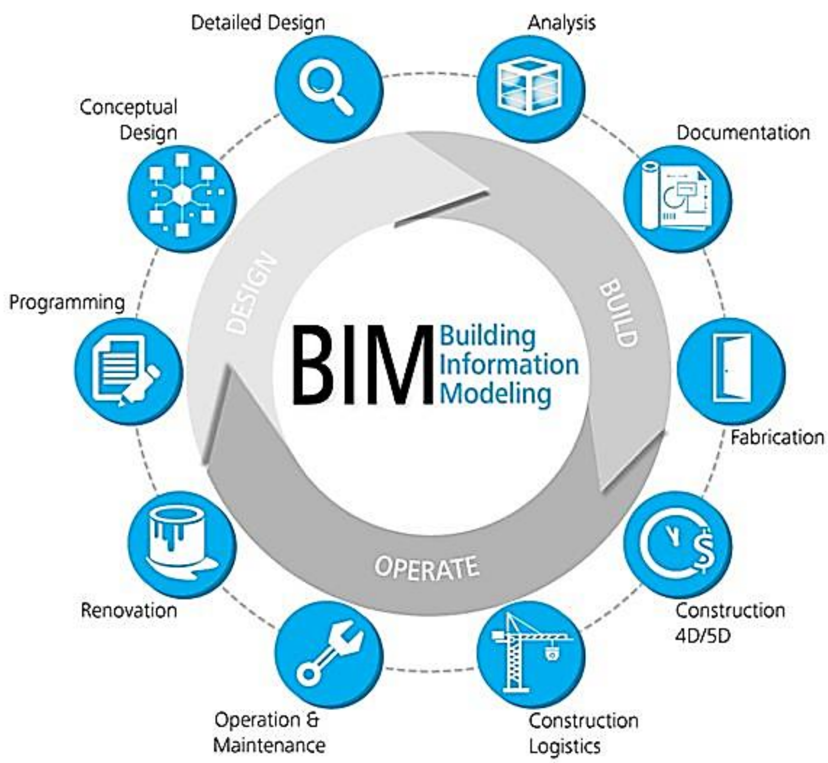

Figure 0.7 BIM Life-Cycle

Source: Autodesk, 2018

The figures below show the project life cycle in which BIM use is very important.

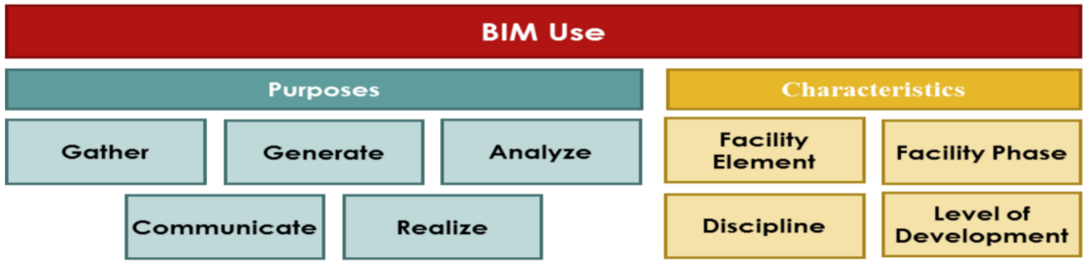

Figure 0.8 The Components of a BIM use

Source: Kreider and Messner, 2011

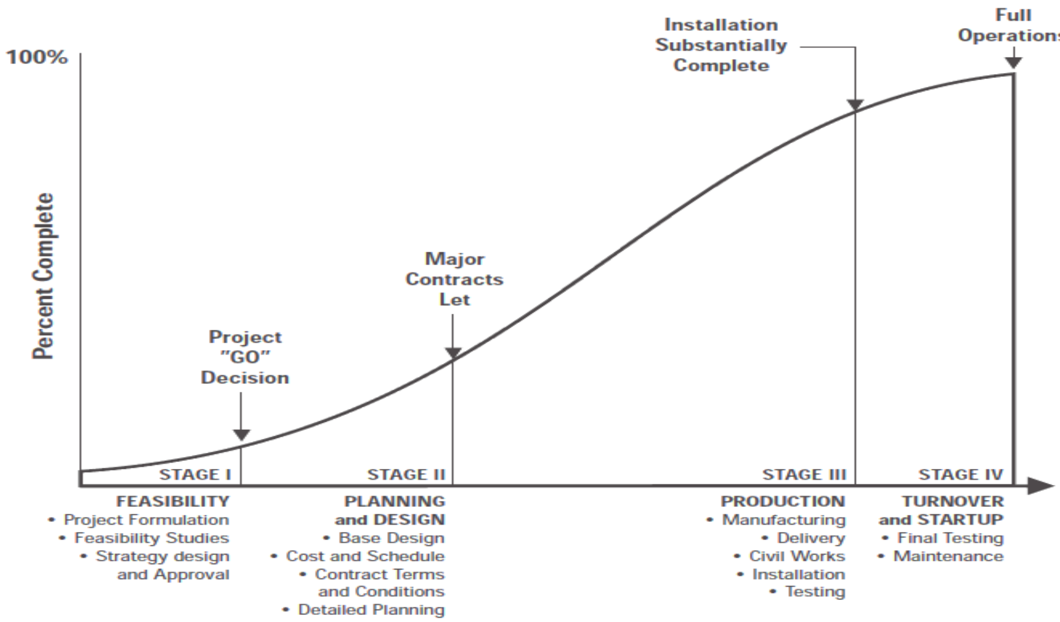

Figure 0.9 BIM Uses throughout a Building Lifecycle

Source: Kreider & Messner, 2011

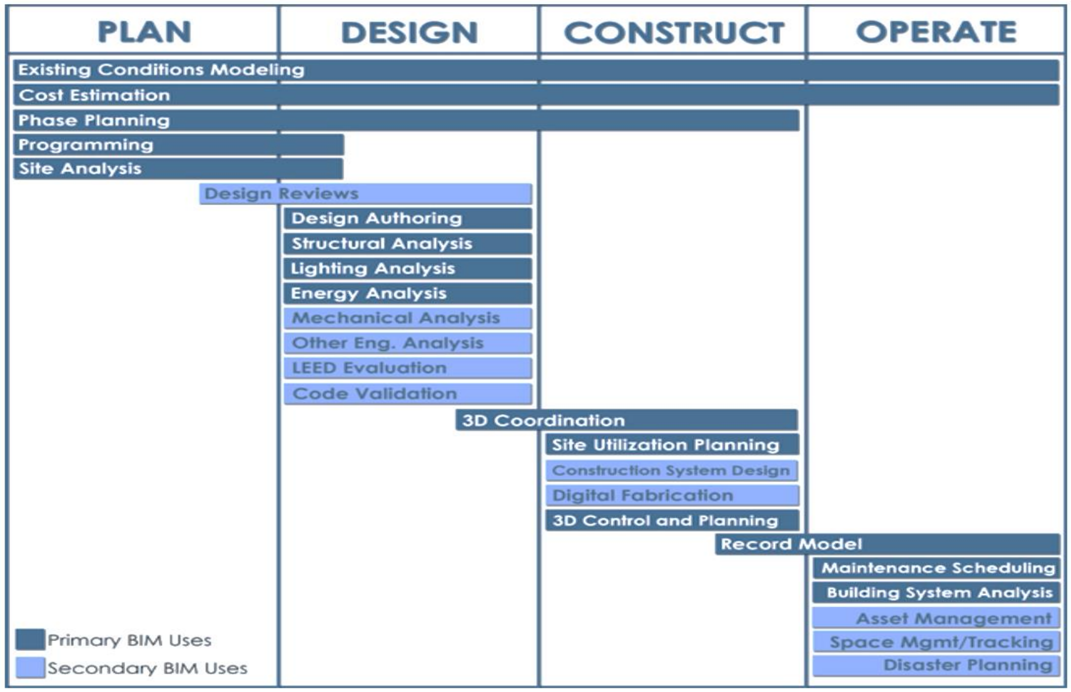

Figure 0.10 BIM uses within the BIM Project Execution Plan

Source: Kreider & Messner, 2011

Figure 0.11 Uses of BIM

Source: LOD Planner, 2019

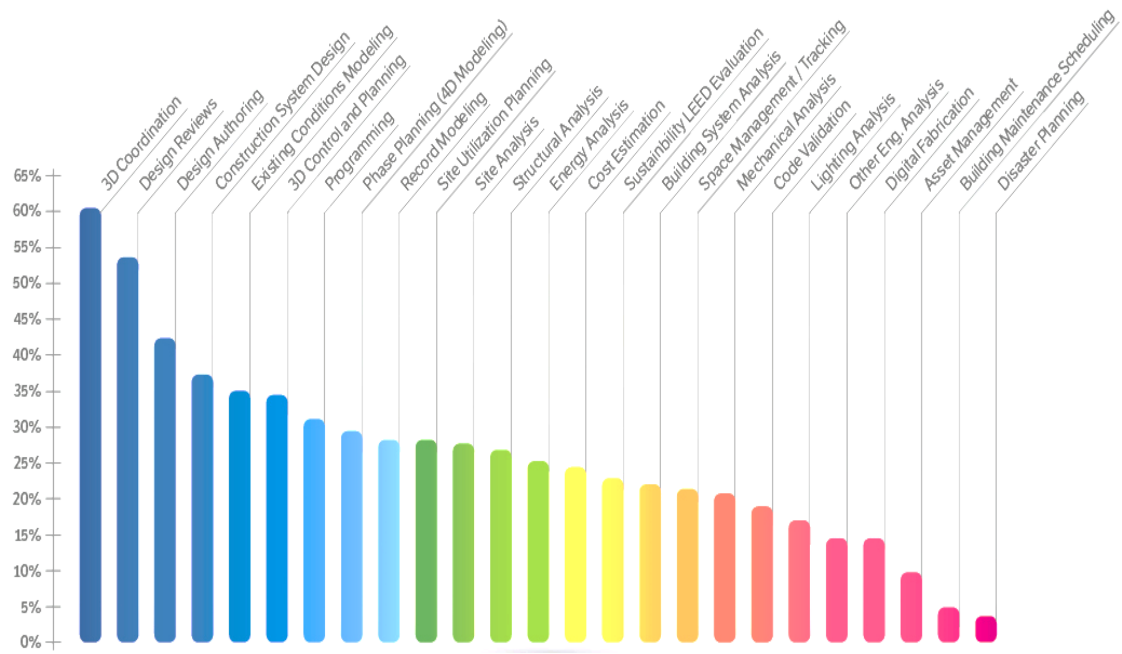

Figure 0.12 Distribution of the application of BIM

Source: Team System, 2018

As shown in Figure 2.12, Building Information Modelling has different applications in the-AEC sector. The figure aims at showing a distribution of the activities. It is possible to derive an average value of the frequency of the application for each use of BIM. The data shows that 3D coordination and the revision of the design are widely used while the majority of the remaining usages are lower than 30%. However, the most significant result is that the use of BIM is well consolidated and covers almost all the activities in the AEC sector (Team System, 2018).

2.8 BIM Enablers

Many companies have adopted BIM in the AEC, MEP and manufacturing sectors. They are trying to hire BIM-proficient professionals, able to perform the many new tasks this technology has introduced. The first step for companies to procure those specialists is to write their job descriptions, listing their specific tasks and higher education institutions will be interested in this same information, as they need to adapt their curricula to meet this demand, as soon as possible (Barison & Santos, 2010). Findings of Howard & Björk (2008) revealed that companies that are using BIM technology are finding difficulties like, for example, the lack of communication between those involved in the design and in the construction. The need for new professionals in the application of BIM context should be recognized by the industry. There must be a special role in the project team: the BIM Manager and the cost of hiring of that professional is a small investment compared to the potential benefits of using BIM (Salzar, et al., 2006). In addition to the BIM Manager, depending on his/her main functions, has also been named as Information Manager, Virtual Construction Manager, Virtual Architect/Engineer, Digital Contractor, Digital Project Coordinator, BIM Champion, IDS Champion Administrator, 4D Specialist, Building Modeler, Model Integrator, BIM Integrator, BIM Coordinator, BIM Leader, Modelling Manager, and among others.

2.9 BIM Companies

There is already a decent number of companies which play a significant role in this transition from partial collaboration to full integration. GenieBelt (4D) is a vital part both of BIM Level 1 and Level 2, as it is inextricably connected with the project task management. Same goes for Aconex (5D) whose main point of focus is on providing a CDE and the cost management of a project. Solibri, Revit and Tekla are mainly part of BIM Level 1 and Level 2. There is also Asite and Viewpoint which can contribute in BIM Level 2 as CDE. Finally, in the BIM Level 0 and Level 1, the industry come across Autodesk Autocad. To get a better overview of the companies that are at the moment an indispensable part of the BIM process, have a look on the Figure 2.13 below:

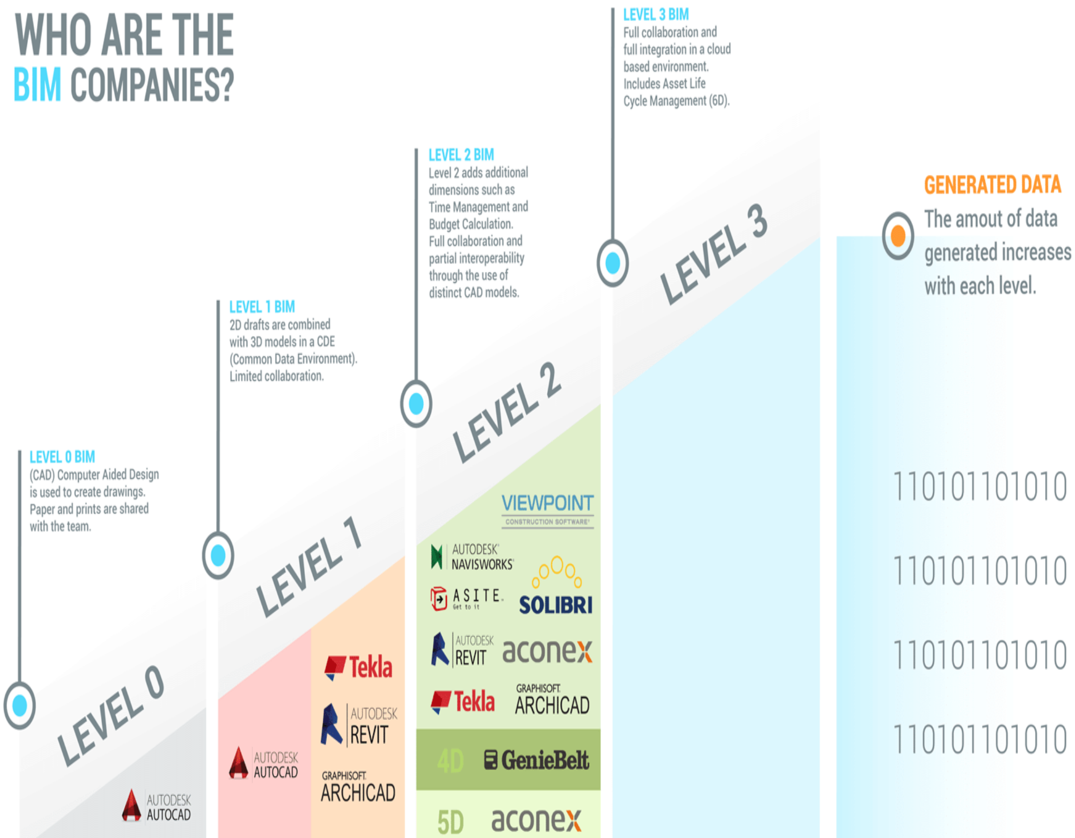

Figure 0.13 BIM companies

Source: GenieBelt, 2017

2.10 Adoption of BIM in the AEC Industry

Due to the contemporary sophistication in construction contracts, building design and the resulting demand for the construction of quality infrastructure, the constructability challenges many constructions companies face are very sophisticated and cannot be addressed and solved easily without the help and application of technology (Sahil, 2016). One technology that has emerged over the last decade and a half is Building Information Modeling (BIM). This technology has enabled designs to become more sophisticated as the technologies supporting BIM have evolved. Currently the modeling industry in developed countries can support not only 3D models but the construction management areas of scheduling, cost control, estimating, safety training, and sustainability. The focus of this study is to identify what issues/problems one may face when adopting BIM in a developing country. Prior knowledge of potential issues/problems could be the difference between successful adoption and a failure to adopt BIM in a timely and cost-effective manner.

No one would dispute that the world is living in 3-dimension (3D). If time or money is included one could even say that our world encompasses four or five dimensions. Extending this approach, it is literally to think of a world of up to n-dimensions. However, the building industry has been trapped in the 2D-3D realm for decades, first on paper, and more recently using Computer Aided Design (CAD). Recent advances in technology have allowed the Architecture, Engineering and Construction (AEC) industry to keep up with the multi-dimensional real world. The tool that has allowed them to do this is Building Information Modelling (Christoph & Bjørn, 2012).

The future of the construction industry is Building Information Modeling. As BIM is becoming more popular, it introduces many opportunities for the improvement of business information transfer through the construction process. Perceived and actual benefits have been investigated throughout many studies. However, a framework for adoption of BIM in the AEC industry in Rwanda has not yet elaborated. BIM can only be of full benefits to AEC industry adopters once it has been more widely adopted through the industry. It is hard for a company to fully achieve the benefits of BIM while other partners are not using it.

Actually, a BIM design is equivalent to virtually designing a structure which shows virtual elements of actual building parts and pieces used to build a building. These virtual elements are digital prototype of physical building elements that allows us to simulate the building and understand its behavior in a computer environment way before actual construction starts. BIM provides a much better means of communication and distribution of information between clients, construction and architecture firms and legal authorities involved in project.

Figure 2.14 and 2.15 show a distinction between information exchange in a traditional context and in BIM, and a comparison between the 2D scheme and a BIM executive project based on a shared. These figures also present different actors involved in the use of BIM in construction projects.

Figure 0.14 A distinction between information exchange in a traditional context and in BIM

Source: Team System, 2018

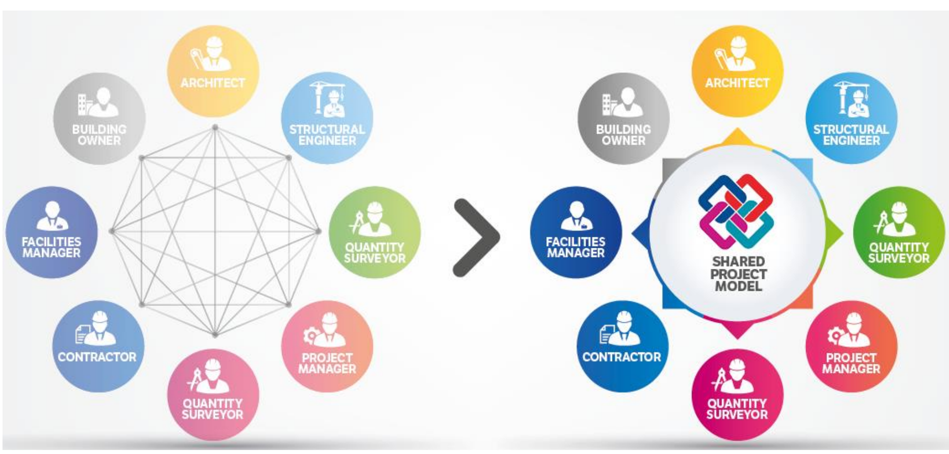

Figure 0.15 Comparison between the 2D scheme and a BIM executive project based on a shared

Source: Team System, 2018

2.11BIM Benefits

Building Information Modelling (BIM) plays a significant role in the construction industry and its benefits are not limited to the actual building and infrastructure, and their construction simulation or project management. the benefits also include:

i. sustainable attributes and processes such as faster and more effective processes (information is more easily shared and can be value-added and reused);
ii. better design (building proposals can be rigorously analyzed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions);
iii. controlled whole-life costs and environmental data: environmental performance is more predictable, and lifecycle costs are better understood;
iv. better production quality (documentation output is flexible and exploits automation);
v. automated assembly (digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems);
vi. better customer service (proposals are better understood through accurate visualization, lifecycle data (requirements, design, construction, and operational information can be used in facilities management), and so many others (Musabyimana, 2017).

According to Goubau (2018), in a case study of 32 major projects, Stanford University's Center for Integrated Facilities Engineering reported the following benefits in statistical data (CRC Construction Innovation, 2007): up to 40% elimination of unbudgeted change, cost estimation accuracy within 3% as compared to traditional estimates, up to 80% reduction in time taken to generate a cost estimate, a savings of up to 10% of the contract value through clash detections, up to 7% reduction in project time. Additionally, there are specific benefits to various project participants:

i. Clients; Better requirement capturing thanks to enhanced communication with design team;
ii. Designers; An increased clarity in design intent, easy testing of design options, and easy distribution of design documentation across the teams;
iii. Contractors; Access to better quality information for estimation and bidding, early involvement to contribute to constructability and effective scheduling, and clash-free construction due to ability to simulate before actual construction; and
iv. Facility managers; Enhanced quality of as-built and handing-over information, and easier integration into computer-aided facilities management systems for maintenance and post occupancy assessments.

Benefits of BIM process are outlined in the Figure 2.16 below:

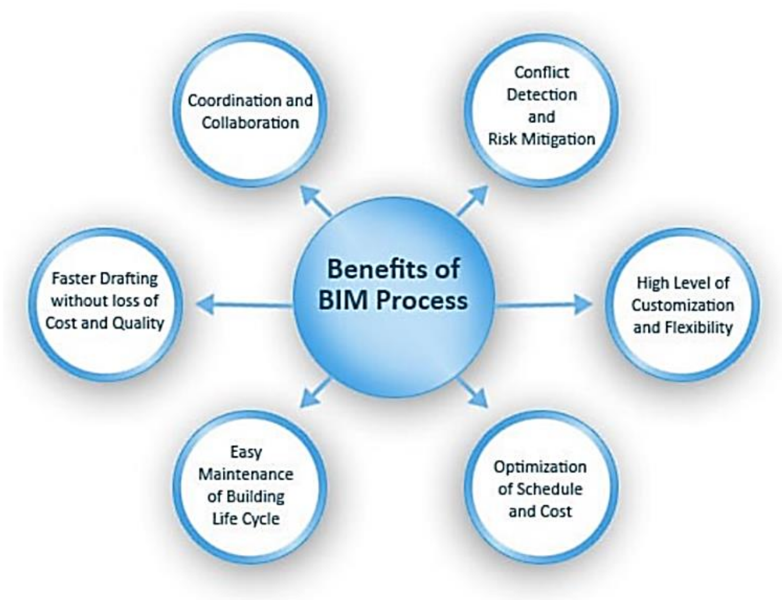

Figure 0.16 Benefits of BIM process

Source: Goubau, 2018

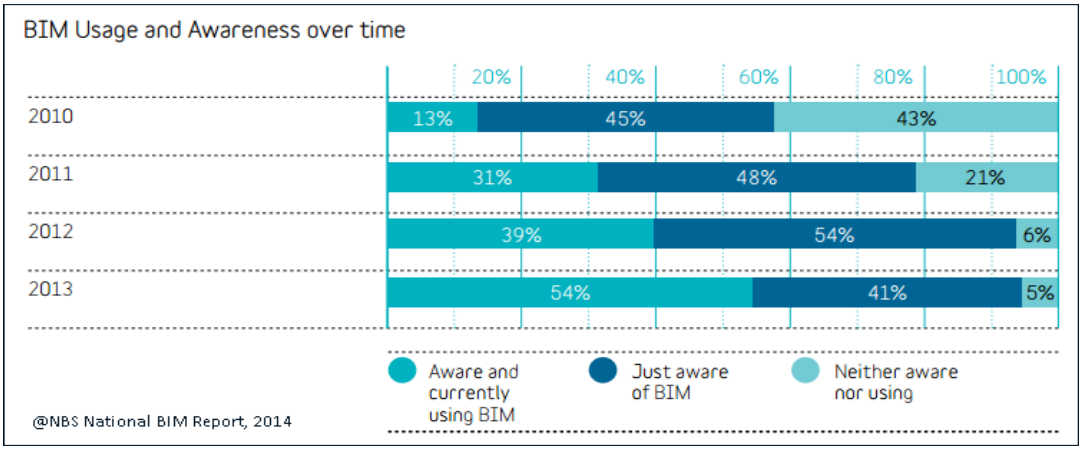

Figure 0.17 BIM usage and awareness over time

Source: NBS National BIM Report, 2014

2.12Prevalence of BIM objects

BIM objects, the building blocks of a BIM model — are data-rich, intelligent and have geometry. Apart from visual and product data, BIM objects store functional data too. This allows BIM Objects to simulate actual product performance. If any construction stakeholder makes any change to a BIM object, this change is instantly reflected across the board.

NBS (2018) describes a BIM object as a combination of many things, comprising of:

1. Information content that defines a product
2. Product properties, such as thermal performance
3. Geometry representing the product's physical characteristics
4. Visualization data giving the object a recognizable appearance
5. Functional data, such as detection zones, that enables the object to be positioned and behave in the same manner as the product itself.

According to GenieBelt (2019), there are different benefits of BIM and BIM objects in planning, construction and facility management. These include, but not limited to:

2.12.1 Coordination

Different software is used to create different objects-and so, they can be joined together to find out possible conflicts. Anyway, the perfect solution would be the usage of models connected together since the beginning, such as, technologies of cloud computing.

2.12.2 Extraction of 2D sketch

During every moment in the design process, it is possible to extract from 2D sketches from the model and the designer can make sure that they are always up to date.

2.12.3 Visual Communication

GenieBelt (2019) asseverated that the construction manager can share a BIM model not only with the stakeholders but also with the owners. Lifelike visualization or virtual mock-ups give stakeholders and clients better insights into the planned sequencing. The ease with which you can convey information makes BIM a far superior option to 2D plans and blueprints. Slopes and complicated construction that is challenging to visualize in 2D can be easily visualized and understood in a 3D BIM model.

Moreover, when nascent and powerful technologies like drone mapping are integrated with BIM, the end result is a lifelike and accurate model. BIM Objects allow the creation of a realistic model without actually building one.

The 3D model is particularly useful for a deeper understanding of the planning solution, not only for the designers but also for all the different parties involved that are not familiar with the work of the experts. It also possible to work through the model; moreover, the use of BIM can be useful to real estate agents thanks to a strong visualization and potential buyers can more easily personalize the house's design.

2.12.4 Decision making support

BIM can also be adopted to study the different alternatives, compare different parameters such as ranges of performances, scopes and costs. For instance, it can be helpful as support for different decisions on the investments.

2.12.5 Guarantee on costs

The control of the project is one of the most enriching values of BIM, because it allows us to spot and work out problems in the design phase instead of during the construction phase. Due to the control tools of the model, it is feasible to favor the building with rule-based software validation that relies on information that have been defined according to the BIM requirements. This method is advantageous to the client who can oversee and control if the requirements have been respected, but also for the security personnel of the building in order to do security checks.

2.12.6 Quantity Take-off (QTO)

BIM is convenient to extract quantity throughout the offer stage and for acquisition during the building phase.

2.12.7 Costs estimation

Linking costs to quantity, can allow you to accurately evaluate the costs. Moreover, the 5D model can allow the study for the development of the costs throughout the whole process.

2.12.8 Simulation and Optimization

BIM can help architects in the simulation of the performance and life of the building. A different analysis can be run such as structural analysis, energetic analysis, sound and lights analysis. By using BIM Objects, you can simulate real-life conditions in your model. Are you designing an energy efficient building? Is your building insulation performing according to your design requirements? Are there specific spots which could result in energy loss? When you are using readily available BIM Objects, it becomes easy to test different products to zero in on the best one (GenieBelt, 2019).

2.12.9 Construction

BIM can also be adopted for the design of the security system and to study the layout of the construction site with a focus on synergies within the surrounding areas. Additionally, 4D simulations can be powerful for example to master the sequence of installation of the different components, the planning of the production, the building inspections and to visualize the construction phase.

1.20.1 Clash Detection and Resolution

Clash detection and resolution become easy when sub-contractors can visualize details in a lifelike model. Precisely, at which locations are electrical fittings clashing with plumbing fittings? Will your planned foundation clash with existing underground utilities? Having such actionable insights beforehand will prevent design changes at a later date. And, when you use BIM Objects, the quality of your data increases greatly (GenieBelt, 2019).

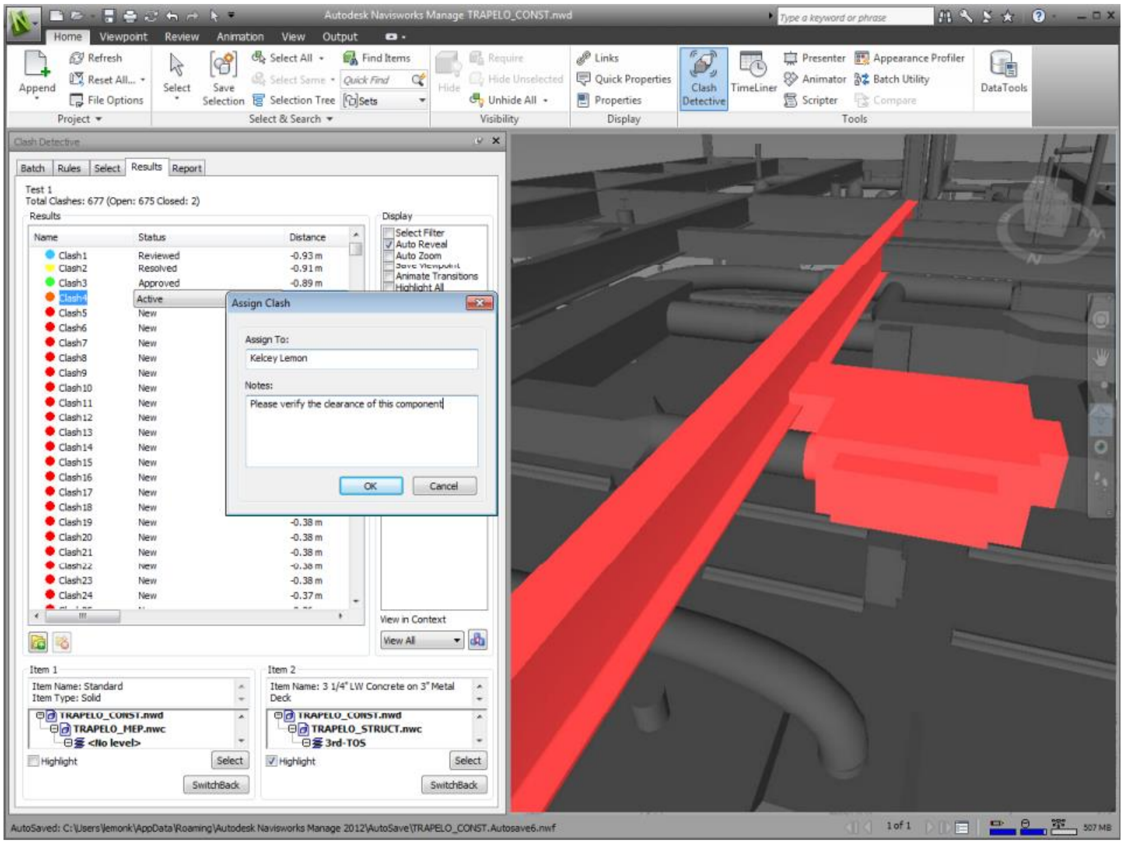

Figure 0.18 Example of clash detection in Navisworks

Source: Autodesk, 2018

2.12.10 Facility Management (FM)

BIM can be used as a support tool during the operation and maintenance of the structure, as well as for the restoration and design of the spaces.

2.13BIM objects in construction

2.13.1 BIM Incorporation

GenieBelt (2019) stated that implementing well-thought-out systems and processes is crucial for building an accurate BIM model. Without these systems, it is not possible to correctly simulate site conditions. For starters, bar codes need to be attached to equipment and construction components for cataloging and tracking. The site manager needs to scan equipment when it arrives on site, and even when it is installed. Once you have this tracking system in place, other information like operation manuals, date of shipping, and others, can also be entered into the database. Ideate BIMLink is a particularly useful Revit plugin that allows you to take elements from an Excel file and link it to elements within your BIM model. This information can then be uploaded to the cloud so that site personnel can access this information via iPads and/or other tablets.

Building an accurate BIM model also requires intensive and continuous subcontractor training. As a project manager, you need to establish uniform standards across the board. For instance, a common issue on the construction site is that different sub-contractors end up using different reference points. Using BIM, such discrepancies can be eliminated from the get-go.

2.13.2 Construction Design and Detailing

Let us presume that you are modeling the structural details of a building. After modeling these details, you might receive details of overlaying elements like gasket plates and connectors from the fabricator. Once you build these into your BIM model, your MEP contractor will have far greater insights about what gets where (GenieBelt, 2019). Now, by using manufacturer-specified BIM objects, the designers can get useful inputs from the manufacturer. This ensures a collaborative design process.

2.13.3 Quantity Take-offs

Construction managers can realize considerable time savings when they use BIM models for doing their quantity take-offs. Moreover, using BIM will result in a far more accurate estimate as well. For instance, let's consider a building with varying elevation. This would require hundreds of unique columns with varying dimensions. The normal (and inaccurate) practice would be to average out the areas of these columns. However, with BIM, it is possible to estimate the quantity of each column, and then do a sum total. This would result in a far more accurate quantity and cost estimate (GenieBelt, 2019).

There different effects of variations in the physical works can be capture in the BIM simulation, there remains many other non-physical sources/causes of variations (contractors' claims, fluctuations, and others.).

2.13.4 Construction Coordination

Tying your construction schedule to your model has multiple benefits. This allows you to create a 4D movie-like simulation. Seeing the sequencing visually helps the sub-contractors understand how their work fits into the larger construction schedule. For instance, let's presume that you need to explain the scope of work and construction sequencing to your glazing sub-contractor. Using BIM, you can easily create a movie-like simulation where different sub-phases of the glazing work are depicted by different colors (GenieBelt, 2019).

2.13.5 Prefabrication

Using BIM models also results in greater construction safety. Because construction managers can estimate quantities and dimensions accurately, they can resort to prefabrication to a much greater extent. As more and more work is done in the safe and controlled confines of a warehouse, fewer people need to be on the site – which results in safer operations. And, by using manufacturer-specific BIM Objects, you can ensure that the prefab structure fits perfectly (GenieBelt, 2019).

2.14BIM Objects in Facility Management

Apart from planning and the actual construction, GenieBelt (2019) asserted that BIM can drive efficiencies and cost savings in facilities management as well. The first end use of a BIM model can be in maintenance – both preventive and emergency. Using BIM, you can link resources like training videos, project images and operating manuals to each component. When the facilities manager is dealing with a breakdown – he can easily access data at the click of a finger. Greater control over Retrofits and Renovations is another strong reason for incorporating BIM into the workflow. For instance, assuming that a chemical plant needs to upgrade their boiler capacity from 5 tons to 25 tons. Now, in order to do so, they need to raise the elevation and strengthen the foundation. If the chemical plant was built using BIM, it would be simpler to execute this project. By using BIM Objects, it would be easier to estimate quantities, assign costs and a timeline to the entire project.

GenieBelt (2019) concluded that:

- Building an information-rich and construction-ready BIM model is a slow, painstaking and iterative process which requires inputs from multiple stakeholders.
- BIM Objects make it possible to simulate, test and optimize.
- Implementing BIM will require supporting hardware and software. Moreover, the construction manager also needs to implement rigid systems and processes to realize collaboration, and thus, maximize benefit from BIM.
- BIM has immense benefits across the entire construction lifecycle – planning, construction, and facility management.
- Some of the major benefits of BIM include easier visual communication, clash detection, streamlined construction coordination, and resource and cost optimization.

2.15BIM Return on Investment

To evaluate a proposed investment, the return on investment (ROI) is usually analyzed. It contrasts the gain anticipated from the investment against the cost of the investment (ROI = earnings/cost). For example, according to Goubau (2018) in a detailed cost study from 10 projects, the BIM ROI for various projects varied from 140% to 39,900%, the average was calculated to 1,633% for all projects and 634% for projects without a planning or value analysis phase. Due to the large data spread, it was difficult to conclude a specific range for BIM ROI. Other projects measure BIM savings through real construction phase direct collision detection cost avoidance or planning/value analysis, none of the mentioned cost figures accounted for indirect, design, construction, or administrative, or other forms of cost savings as a result of BIM implementation as reported by Goubau (2018). It was reportedly agreed in a McGraw Hill Construction BIM study (2013) that 75% of contractors globally reported a positive ROI, thus, the actual ROI from BIM can be far greater than reported.

2.16BIM Risks

Azhar (2014) outlined that the risks involved in BIM implementation can be divided into two categories comprising legal (or contractual) and technical. Legal risk is when there is a lack of determination of ownership of BIM data and the need to protect it through copyright laws and other legal channels. There is no simple answer to data ownership as team members provide proprietary information for use in a project design that is being paid for by the project owner. When project team members other than the owner and architect/engineer contribute data that are integrated into the BIM, licensing issues can arise. Therefore, the issue is who will control the entry of data into the model and be responsible for any inaccuracies, thus the concept of integration blurs the level of responsibility that risk and liability are likely to increase. The technical risk is when the cost and schedule are added as additional dimensions onto the building information model to ensure responsibility for proper technological interface among different programs that becomes an issue as well. Responsibility for accuracy and coordination of cost and scheduling data must be contractually addressed and the risks of using BIM are shared among the project participants along with the rewards.

2.17Impacts of BIM on the Industry

Implementing BIM solutions brings out quality, productivity and effective costs for construction industry professionals in the design, construction, and operation of buildings; thus, the technology helps architects and engineers to produce building designs based on specified constraints and objectives, such as daylight, thermal performance, and structural integrity (Autodesk, 2017). Apart from designing, BIM serves a wide variety of purpose in construction project management. What makes BIM unique is its collaborative effort to solve problems related to construction engineering. The collaborative feature it offers can be appreciated very well by its application in almost all construction related activities. BIM serves an essential purpose in all aspects of construction and project management including design, scheduling and estimating, resource allocation, supply chain management, account of deliverables during the course of construction, structural health monitoring, data management and structural Management. Looking at these aspects it can rightly be said that instead of implementing BIM as a technology it is rather implemented as a process which starts even before actual construction and is serves useful purpose throughout the service period of structure (Kushwaha, 2016).

Using a BIM model has a number of advantages over the traditional 2D approaches to design and construction, it can enable collaboration and manage changes between different professionals involved in the design and construction phase of the built asset, and it can also offer a wealth of information that is generated automatically as the model is created, such as cost estimating, project planning and control, and even for management of the operation and maintenance of the built asset (Construction Skills Queensland , 2014).

As highlighted by Agarwal et al. (2016), in a McKinsey & Company report, one study found that 75% of companies that have adopted BIM reported positive returns on their investment with shorter project life cycles and savings on paperwork and material costs, because of these benefits, various governments such as Britain, Finland, and Singapore mandated the use of BIM for public infrastructure projects. In small specialty studies, BIM appears to be increasing productivity in labor. In Goubau (2018), the impact of BIM on labor productivity was quantified and the findings demonstrated a 75% to 240% increase in labor productivity for modeled and prefabricated areas. Therefore, utilizing BIM solutions in the construction sector resulted in higher quality work, greater speed and productivity, and lower costs for building professionals in terms of design, construction, and operation of buildings.

2.18 Opportunities in BIM

BIM is certainly replacing CAD with preference as a tool for planning and modelling AEC and MEP projects. BIM is actually pretty phenomenal when you think about how it is getting us to where the industry is going and will soon take the architectural practice a step further. BIM and allied quantities technologies provide opportunities for the project but also challenges for the project manager. As automation is increasingly used in quantification in the construction industry, BIM models will need to adapt accordingly to allow for more sophisticated management components that incorporate 4D time and 5D cost modelling and sharing the information with the project team in an integrated project delivery approach. However, BIM is just not about new software and technology. It requires an alternative way of thinking and a different approach to project procurement and delivery. It is imperative to move from the traditional approach of project participation with separate information pools and incompatible software technologies to one that is totally integrated with a common platform where participants can share and work on the same information (Goubau, 2018).

BIM is a promising future wherein buildings, design and construction will be cheaper, safer, more efficient, and more responsive to end-users that presents several opportunities in its adoption such as automating design optimization; where computers will be able to automatically sort through thousands of possible design permutations and select the top designs that meet a project’s requirements. Thus, computers are going to be able to design things so much more efficiently than humans can. BIM can provide the industry with important opportunities to raise the quality of the industry to a much higher and sophisticated level (Goubau, 2018).

2.19BIM Policies

According to Coventry University (2017) professionals who want to embrace BIM-friendly processes cannot because of company policies where legal departments are a common obstacle and contracts in many instances fail to keep up with emerging technologies. Mostly, BIM works best when all parties working on a project can share information freely. Contracts, however, often forbid such information sharing due to liability and litigation concerns, for example, if a contractor acts on information an architect supplied and something goes wrong, the contractor or project owner could then sue the architect. It is therefore obvious that solutions must simultaneously protect companies while encouraging them to collaborate, all parties can agree upon definitions, processes, policies, and parameters at the start of every project; doing so will reduce risk while streamlining the workflows BIM relies on.

2.20BIM in Climate Change Mitigation and Adaptation

Climate Change and the resultant need to drastically reduce carbon emissions across the Globe (while adaptation measures are also vital), had long been acknowledged as key challenges to industries before the unprecedented global economic crisis started to overwhelm major economies in 2008. It was reportedly affirmed by Skanska and Statsbygg (2009); and Nyári (2015) that buildings contribute 40% of global carbon emissions, adequate processes are required to cut-off these emissions since it is used to calculate and evaluate the footprint of these emissions. Therefore, it cannot be hesitated to state that BIM is a vital mechanism through which targets to lessen emissions can be achieved up to 50% of reduction in greenhouse gas emissions in the built environment; every industry has been forced to re-think its processes and practices to deliver efficiently. The UK Construction Industry, the efficiency of which was identified as being critically important for the UK economy in the Government's Plan for Growth published in March 2011, is no exception (Kurul et al., 2017).

The UK Built Environment Sector faces a number of important challenges such as reducing carbon emissions and cost, whilst delivering better value to the client; BIM is a relatively new technology in an industry typically slow to adopt change, yet many early adopters are confident that BIM will grow to play an even more crucial role in building documentation (Bimpanzee, 2018). BIM has numerous uses that are effective to climate change, hence, adopting BIM could further contribute to climate resilience through optimized designs and green building development. The technology offers improved visualization & productivity due to easy retrieval of information, increased coordination of construction documents, embedding & linking of vital information such as vendors for specific materials, location of details and quantities required for estimation and tendering, increased speed of delivery and reduced costs.

As asserted by Bimpanzee (2018), BIM contains most of the data needed for building energy performance analysis, which means that the building properties in BIM can be used to automatically create the input file for building energy simulation and save a significant amount of time and effort. Moreover, automation of this process reduces errors and mismatches in the building energy simulation process, for example, Green Building Extensible Markup Language (XML) (gbXML) is an emerging schema, a subset of the Building Information Modeling efforts, focused on green building design and operation, and it is used as input in several energy simulation engines. With the development of modern computer technology, a large number of building energy simulation tools are available. When choosing which simulation tool to use, the user must consider the tool's accuracy and reliability. In Whitley Group (2017) there was developed an artificial intelligence approach towards assessing building performance simulation results and found that more detailed simulation tools have the best simulation performance in terms of heating and cooling electricity consumption within 3% of mean absolute error.

Figure 0.19 BIM outside the building: Infrastructure and landscape

Source: Environment Agency, 2019

2.21BIM Uptake Challenges

According to Goubau (2018), the adoption of BIM technology in construction has been slow but the industry is increasingly becoming aware of BIM's potential in the field. In addition to its benefits, BIM promises better decision making throughout the lifecycle of a project as well as addressing age-old problems in a more cost-effective manner with better problem solving, more effective communication and faster project building. However, few BIM challenges have been identified and need to be overcome before implementation can be the norm in an industry.

As reported by Lymath (2014) in the NBS national BIM report 2014, in 73% of smaller companies having five staff or less, it was observed that there is no client demand for BIM; while the UK government is enforcing the use of BIM for publicly-funded work, clients of smaller firms do not often make similar demands. Additionally, 71% of small firms believe that BIM is not always appropriate to their typical projects; they feel that their workload is not on a complex level to warrant the use of BIM. Shifting to BIM does involve spending on software, training, and time, considering the potential benefits outweigh the costs. As in most case studies, those who have adopted BIM tend to report that the results have been better than they anticipated, as it is falsely believed that BIM is only effective for big projects. Actually, BIM can work for both big and small projects and the benefits be realized. Regarding the inhouse skills, 62% of small contractors with five or less staff and 77% of firms with six or more staff expressed that they do not have the in-house current BIM skills. Therefore, smaller contractors can also invest in training which would incur lower aggregate costs (Lymath, 2014). As shown in Figure 2.20, the barriers to BIM adoption were observed in both large and small firms in UK.

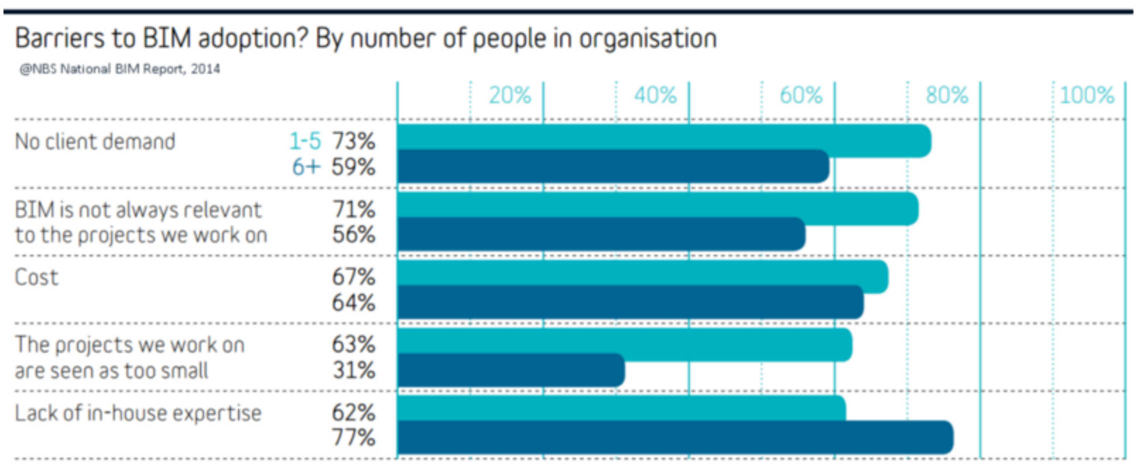

Figure 0.20 Barriers to BIM adoption by number of people in organization

Source: NBS National BIM Report, 2014

2.22Construction Technology Trends

According to GenieBelt (2018), it was expected in 2019 to be a breakthrough year for the construction industry. During the year of 2018, construction technology investment has grown by 30% and equal to $1.05 billion. The total value of the sector is expected to exceed $10 trillion by 2020. The following are construction technologies trends for 2019.

2.22.1 **Augmented Reality (AR)**

AR is something that is bound to open many new opportunities for the construction industry even though it shall come with cost. A $90 billion increase in global AR market is expected by 2020 (GenieBelt, 2017). Although virtual reality has been an emerging trend over the past few years, it is quickly growing outdated – especially when compared to augmented reality uses and benefits. This is the ability to visualize the real world through a camera lens. It is something that is bound to open many new opportunities for the construction industry even though it will come with a cost. For those companies who can afford to start using it now, it will revolutionize how they project and build things. This is a trend that will grow much bigger in the next few years. In fact, many people believe that instead of using safety goggles, construction professionals will start planning and plotting sites before they even break ground.

2.22.2 Construction Software and Data Ecosystem

Real-time collaboration software is expected to function as the digital backbone for the construction process from the start to finish. 95% of data is thrown away (GenieBelt, 2017). Real-time collaboration software is already regarded as an essential component of the entire building process. Nevertheless, its impact on the sector is expected to increase substantially in the near future. It goes without saying that data has played an integral role in this paradigm shift in construction. The emergence of a data ecosystem where all the innovative players of the industry will come together and share data, experience and project knowledge is closer than the industry might think. And it is no exaggeration to maintain that it is the only way forward for construction. The ability to integrate your existing processes and systems into a single fully-connected platform can empower the way people in the industry work. A plethora of software solutions for different functions and disciplines in the course of a construction project can now effortlessly be combined in one place (Agarwal, et. al, 2016).

The use of digital tools facilitates the accumulation of these valuable bits of information and by extension, the minimization of delays, rework rates, and communication hiccups between the site and the office. In that sense, a reliable real-time collaboration software is expected to function as the digital backbone for the construction process from start to finish.

2.22.3 Building Information Modeling

According to Autodesk (2017), BIM technology will be the catalyst for the fundamental change in construction actors manage, design and develop projects. 88% of construction stakeholders believe that BIM can enable better design insight. BIM is again one of the hottest construction technology trends. It comes as no surprise if it is taken into account that the emergence of an open and highly collaborative data ecosystem is on the way. From a general point of view, BIM will bring more accuracy to the building process and empower the exchange of important project information between the numerous stakeholders. Moreover, its further evolution is anticipated to make construction projects more productive and affordable by including revolutionary sustainability and safety measures.

It is evident, then, that BIM could function as a game changer for construction and offer a detailed depiction of the project development in an open and highly collaborative environment.

2.22.4 Increased Prefabrication, Modularization, and Eco-Friendliness

The use of standardized processes to assemble as much as possible off-site before they complete the construction project on site can cut down on costs and lead times. Construction projects can be completed 65 times faster through modular construction. There has been a growing trend towards multi-trade prefabrication. This is something the Multi Trade Prefabrication Conference is now addressing (Arnal, 2018). It was the first ever multi-trade conference that was held for the growing number of construction companies who are implementing prefabrication strategies. A great example of this occurred in Dubai where a 3D office building was printed in 17 days, followed by only two days spent on site assembling it

(Construct Connect, 2018) (Agarwal, et. al, 2016) (GenieBelt, 2017). Many construction industry experts believe that they will continue seeing this practice grow in the coming years, especially since cost and time are no longer as prohibitive. This does not mean that they are no longer issues, simply that they are being addressed in ways that will help propel this industry forward. Another growing trend is off-site construction (modularization). This trend is similar to prefabrication in that many people see it growing in popularity over the next several years. There are already some progressive construction companies who have started implementing these strategies in the way they run their operations – especially manufacturing companies. These companies use standardized processes to assemble as much as possible off-site before they complete the construction project on site. The benefit here lies in the fact that the standardization cuts down on costs and lead times. All these processes are very beneficial in the following three ways: -

Firstly, they are quite eco-friendly because when working in construction in a factory you can easily recycle any extra materials. This is much better than what was happening with traditional construction practices – many of which would often be forced to send large amounts of waste to landfills. Prefabrication saves a lot of money because construction companies can get bulk discounts on materials. Secondly, this also saves them time, which will, in turn, save them even more money. Since all the work occurs in a factory-controlled environment there is less risk for problems that are typically associated with things like moisture, environmental hazards, and dirt. Finally, construction workers and the project's eventual tenants are also less likely to be exposed to weather-related health risks.

2.22.5 Drones

In the construction industry, the use of drones has been opted to monitor construction sites and they are controlled using BIM tools. As drone technology continues rapidly developing in its accuracy and precision of its readings, even less human involvement will be necessary (Agarwal, et. al, 2016) (GenieBelt, 2017). Many construction sites are already heavily dependent on the use of drones. These drones are very beneficial in that they save a lot of time. For instance, surveyors can survey an entire site in just a few minutes, whereas in the past it would take them several weeks or months. Obviously, this will also save construction companies a lot of money. As drone technology continues rapidly developing in its accuracy and precision of its readings, even less human involvement will be necessary. In the past, many companies were hesitant to use drones because they still needed a controller, but today as the technology grows much more efficient, more construction companies are willingly and openly embracing this technology.

2.22.6 Robotics

They are continuously growing more precise and accurate, and they will soon become a commending force in the construction industry. The industrial robotics market is expected to grow by 175% over the next decade (GenieBelt, 2017). Industries like healthcare are already investing a lot of money in them. As these robots grow even more precise and accurate, they will become a commanding force in the construction industry. In the beginning, the cost of robotics will be high, but it will still be well worth it to at least pay attention to this technology (Construct Connect, 2018). Eventually, construction professionals may witness robots being able to do things like lay bricks and tie rebar, they may even see them complete most of the current man-operated construction projects (Agarwal, et. al, 2016).

2.22.7 Advanced uses for Global Positioning System (GPS)

Nowadays, GPS goes hand in hand with BIM. The GPS tracking solutions are now being used in more creative and resourceful ways facilitating the quick and accurate collection of data. 120 positioning satellites ready to be used in the next 10 years (GenieBelt, 2017).

GPS tracking solutions are not anything new, they are now being used in more creative and resourceful ways including:

- Surveying has been dramatically improved because crews no longer need to use traditional surveying equipment.
- Data for prospective project sites can be quickly and accurately collected.
- Project managers are also using GPS in fleet management. Today, each of their vehicles is equipped with a device that is trackable via both computer and smartphones. This lets everyone know where vehicles always are.
- It's easier to find lost or stolen equipment because managers can now generate maps that pinpoint the exact location of any of these items.

Many people within the construction industry feel that actors have not even come close to seeing the end of the growth of GPS technology today though. Not only are applications in autonomous vehicles and wearable technology are on the rise, but construction professionals are bound to see driverless vehicles as well and construction companies will also be using them too. In fact, the general public will probably have these vehicles available to them as soon as 2020 (GenieBelt, 2017). They will see it in the form of buses, trains, and trucks but construction fleets seriously aren't far behind. There are many construction actors who are currently working on autonomous vehicles that will make job sites even more efficient (Agarwal, et. al, 2016).

2.22.8 Wearable Technology

BIM-based wearable technology is expected to play a substantial role in boosting safety on site and monitor efficiently the project process. While many people may think this is only common sense, it should not go unmentioned that wearable technology (example: Fitbit's, 3D glasses, Google Glass, armbands that can communicate with coaches on the sidelines) will become an emerging trend that is useful in keeping workers safe (Agarwal, et. al, 2016) This will help keep workers from constantly looking down at their instructions because now they can talk to one another via this technology. Additionally, it can help track where workers are if there is an accident (GenieBelt, 2017). This is bound to become mandatory at some point in the future.

2.22.9 New Effective Scanning Solutions

Scanning using BIM tools is now creating many cost-effective solutions over the past few years. These have helped the construction industry fully understand in what stages certain projects are.

2.23The Future of BIM in construction

GenieBelt (2017) reportedly highlighted that BIM is the future of construction industry, as illustrated in Figure 2.21. Meaning that the future of the construction industry is digital, and BIM is the forthcoming of design and long-term facility management; it is government led and driven by technology and clear processes; and it is implementing change across all industries. As hardware, software and cloud applications herald greater capability to handle increasing amounts of raw data and information, use of BIM will become even more pronounced than it is in current projects.

In 2025, the Industrial Strategy for Construction is targeting lower costs, faster delivery, lower emissions and improvements in exports to position the UK at the forefront of international construction (NBS, 2018).

2.23.1 The Importance of Model Checking

Model checking is a fundamental element in computer science and by extension in BIM. Model checking could be described as the detailed process of examining a particular system model on whether or not is meeting certain criteria. It is understandable that model checking has tremendous importance for BIM.

There are various BIM viewer tools that could help a lot during this effort. Solibri and Navisworks are two reliable pieces of software that can offer a lot toward that direction. In a nutshell, they could be used for design coordinating and compliance checking purposes. Similarly, a tool like Revit can be part of this procedure.

2.23.2 What the future brings

The transition to BIM Level 2 and hopefully soon enough to Level 3 will have some important benefits for the construction industry. In short, boost in productivity is the sum up of what BIM brings in the future. This the ability of BIM to share information faster and easier can offer a significant productivity boost. Collaborative working can decrease the required time for incorporating and editing new information. Increased productivity means also lower cost and by extension higher efficiency in terms of project planning.

2.23.3 New Possibilities for Smaller Markets

BIM can play a great role in the optimization of the construction process. This element may very soon lead to the opening and development of new markets which until now did not have the right tools in order to expand. Thanks to a fully or partially integrated collaborative model, they will be able to tackle a big number of difficulties that they face on a daily basis at the moment.

2.23.4 Buildings of Higher Quality

The larger amount of data in conjunction with the ability to manage them with higher precision will eventually lead to a remarkable improvement of the quality of our buildings. To put it simply, more complex buildings that have much more to offer to their residents will be designed and built. Parameters such as the environment and the modernization of the designed structures will be easier to be taken into consideration during the building procedure.

2.23.5 Improved Clash Detection

Thanks to BIM, the clash detection process is drastically ameliorated. The term clash is referring to potential mistakes that emerge during the design and construction of a building. Building Information Modeling can help a lot in clash detection and as a result in increasing the project's efficiency. IFC files offer great assistance during this process. Figure 2.21 below shows how the future of BIM in construction looks like:

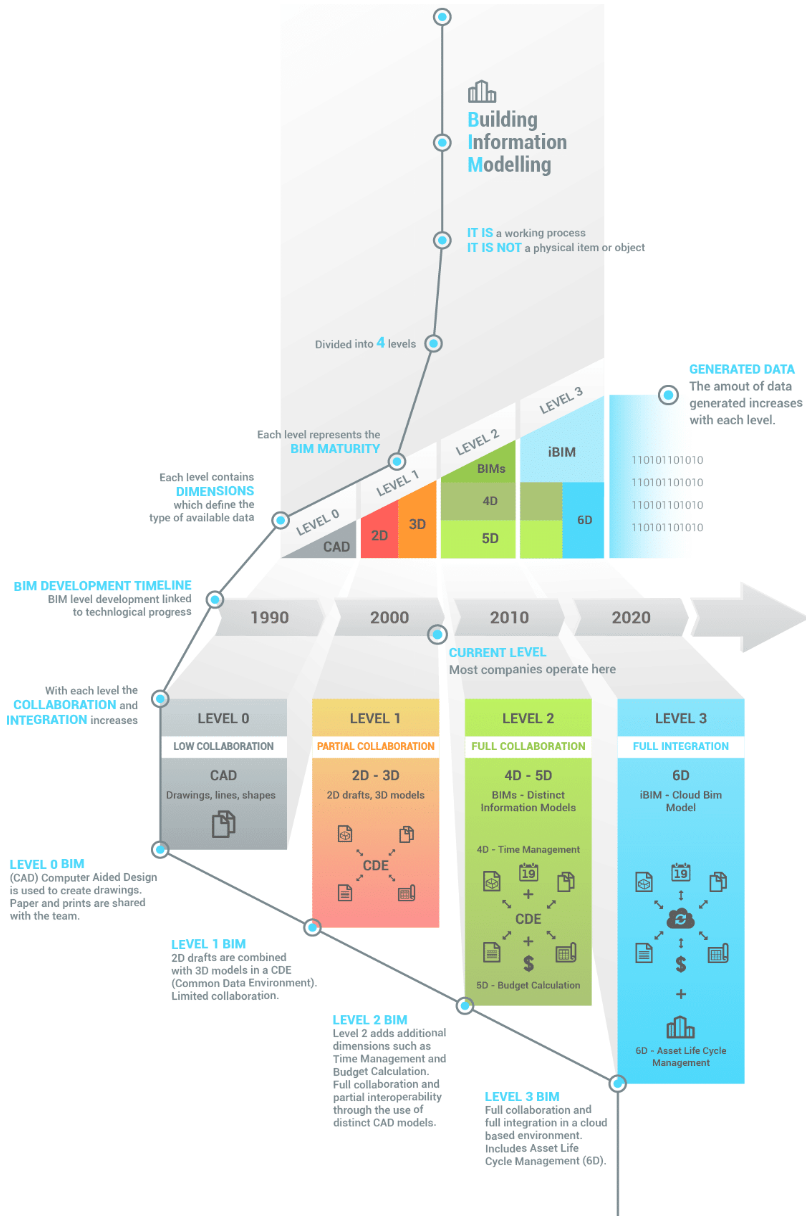

Figure 0.21 The future of BIM in construction

Source: GenieBelt, 2017

2.24 Impact of Information and Communication technology in the Construction Industry

According to Construct Connect (2018), technological advancements have always driven construction forward, so it is odd that so many companies are slow to adopt new tech. Construction professionals are able to build stronger, taller, and more energy efficient structures. Technology has made construction sites safer and workers more efficient. It has allowed us to increase productivity, improve collaboration, and tackle more complex projects. Construct Connect (2018) adds that new technologies in construction are being developed at a breakneck pace. What seemed like future tech 10 or 20 years ago like connected equipment and tools, telematics, mobile apps, autonomous heavy equipment, drones, robots, augmented and virtual reality, and 3D printed buildings are here and being deployed and used on jobsites across the world.

And, while construction firms continue to underinvest in technology, venture capitalists are betting big on the future of construction tech. A report from James Long LaSalle, Inc. released earlier this year shows that venture capital firms invested $1.05 billion in global construction technology startups during the first half of 2018. That is a nearly 30% increase over the amount invested for all of 2017. Since 2009, investors have closed 478 funding deals totaling $4.34 billion.

2.24.1 Productivity

Construction productivity has remained flat for decades. The traditional method of design-bid-build makes construction disjointed and siloed. Every construction site is different, presenting its own unique set of challenges and risks. This makes it difficult to streamline processes and increase productivity the way industries like manufacturing and retail have been able to do (Construct Connect, 2018).

2.24.2 Software & Mobile Applications

Construct Connect (2018) outlined that there are software and mobile solutions to help manage every aspect of a construction project. From preconstruction to scheduling, from project management and field reporting to managing your back office, there is a software solution out there to help streamline your processes and improve productivity. Most software solutions are cloud-based, allowing changes and updates to documents, schedules, and other management tools to be made in real time, facilitating better communication and collaboration. Mobile technology allows for real-time data collection and transmission between the jobsite and project managers in the back office. Cloud-based solutions enable on-site employees to submit timecards, expense reports, and requests for information (RFIs), work records, and other verified documentation. This can save hundreds of hours per year in data entry and automatically organizes critical files, no more shuffling through files looking for old reports. More and more software providers are forming strategic partnerships to allow you to seamlessly integrate your data with your other software solutions, making it easier than ever to run your business.

2.24.3 Offsite Construction

Construct Connect (2018) highlighted that offsite construction is typically used on projects with repetitive floorplans or layouts in their design such as apartment buildings, hotels, hospitals, dormitories, prisons, and schools. Offsite is performed in a controlled environment and it works similar to an auto manufacturing plant. At each station, workers have all the tools and materials to consistently perform their task, whether that be constructing a wall frame or installing electrical wiring. This assembly plant method of construction reduces waste and allows workers to be more productive.

Offsite construction typically comes in two forms: modular and prefabricated. With modular construction, entire rooms can be built complete with MEP, finishes, and fixtures already installed. They can be rooms as small as bathrooms or modules can be fitted together onsite to create larger spaces like apartment units. The modular units are transported to the construction site and then inserted and attached to the structural frame. With prefabricated construction, building components are built offsite and then assembled or installed once they have been transported to the construction site. Prefabricated building components cover everything from framing, internal and external wall panels, door and window assemblies, floor systems, and multi-trade racks, which are panels with all the ductwork, wiring and plumbing packaged together.

2.24.4 Artificial Intelligence (AI) & Machine Learning

Construct Connect (2018) emphasized that construction firms are now using data to make better decisions, increase productivity, improve jobsite safety and reduce risks. With artificial intelligence (AI) and machine learning systems, firms can turn the mountains of data they have collected over the years on projects to predict future outcomes on projects and gain a competitive advantage when estimating and bidding in construction projects. AI can improve worker productivity by reducing the amount of time wasted moving about the construction site to retrieve tools, materials, and equipment to perform certain tasks. Workers are tracked throughout the day using smartphones or wearables.

Sensors installed on materials and equipment track how everything else is moving about the construction site. Once enough data sets are collected, AI can analyze how workers move about and interact with the site to come up with solutions to reorganize the placement of tools and materials to make them more accessible to workers and reduce downtime. Robots and artificial intelligence (AI) are also being used to monitor jobsite progress with real-time, actionable data to improve jobsite productivity. Autonomous drones and rovers are equipped with high-definition cameras and LiDAR to photograph and scan the construction site each day with pinpoint accuracy. AI then uses those scans to compare against your BIM models, 3D drawings, construction schedule, and estimates to inspect the quality of the work performed and to determine how much progress has been made each day (Construct Connect, 2018).

Deep-learning algorithms are then used to identify and report errors in work performed. This can be anything from the excavation and site work to the mechanical, electrical and plumbing systems. The AI can recognize a building component based on its shape, size and location even if only a portion of the component is visible. By classifying and measuring quantities installed, these systems can tell you how much work was done each day, which it can then compare against your construction schedule and alerts you if your project is falling behind. The AI also detects deviations between installed components and onsite work with models so you can quickly identify errors and avoid costly rework (Construct Connect, 2018).

2.24.5 Safety & Training

As technology adoption continues to ramp up in the construction industry, one area getting a lot of attention is improving safety. Of the 4,963 worker deaths in 2016, 991 were in construction. Worker safety should be the number one priority of every construction company and technology solutions are making it easier to properly train and monitor workers to prevent accidents and reduce the rate of serious injuries and worker deaths (Construct Connect, 2018).

2.24.6 Augmented & Virtual Reality

Safety training and equipment operator training are two areas where virtual reality (VR) could have a strong impact on the construction industry. With VR, workers could get exposure to environments such as confined spaces or working at height in a safe, controlled environment. VR simulators have been used for years to train soldiers, pilots, and surgeons and could be used in the same way to train workers on everything from operating cranes and excavators to doing welding and masonry work. Augmented reality (AR) is another technology that can greatly improve safety on the construction site. Whether it is allowing for a more detailed safety plan to be developed or providing training on heavy equipment using actual equipment on real sites with augmented hazards, there are a number of ways that AR can be deployed on the jobsite. Workers could walk to a specific area of a jobsite and have a safety checklist, specific to the task at hand, pop up on a display integrated into a smart hard hat or safety goggles to make sure they have the proper personal protective equipment on and are performing their tasks safely. Safety managers and trainers could monitor exactly what the workers are seeing and walk them through tasks as they work (Construct Connect, 2018).

2.24.7 Wearables

Wearables are being used to monitor workers and their environment to make jobsite safer. Wearable tech in construction is being embedded into apparel and personal protective equipment (PPE) already common in construction sites like hard hats, gloves, safety vests and work boots. Construction wearables are being outfitted with biometrics and environmental sensors, GPS and location trackers, Wi-Fi, voltage detectors, and other sensors to monitor workers' movements, repetitive motions, posture, and slips and falls. Geofencing allows site or safety supervisors to establish restricted or hazardous areas that will alert workers with a combination of alarms and lights that they have entered an area that is off limits. Smart clothing, or e-textiles, that can monitor vital signs like respiration rate, skin temperature, and heart rate will also make their way to the construction site. These wearables will be able to monitor a worker's posture, track movements, determine if they are suffering from fatigue and whether they are intoxicated or under the influence of narcotics. Keeping a watchful eye on workers can help predict an accident before it occurs (Construct Connect, 2018).

2.24.8 Site Sensors

Site sensors that can be deployed across a construction site to monitor things like temperature, noise levels, dust particulates, and volatile organic compounds to help limit exposure to workers. The sensors are mounted throughout the construction site and can alert workers immediately when they are at risk from permissible exposure levels being reached. Data from the sensors are collected and can be analyzed to mitigate exposure levels and keep workers safe and stay compliant with OSHA regulations (Construct Connect, 2018).

2.24.9 Labor Shortages

As a result of the housing crash and the Great Recession, over 2.3 million workers left the construction industry through layoffs, early retirement, or to pursue careers in other industries. While job growth in the industry has been strong the past few years, there are still areas of the country feeling the pinch of a skilled labor shortage? Demand for workers in construction is expected to grow significantly through the next decade. The Bureau of Labor Statistics project construction employment growth to be 11% from 2016 through 2026. Younger workers, who lack the skills and experience of their veteran peers, can benefit from the technology being deployed on jobsites today (Construct Connect, 2018).

2.24.10 Drones

Drones are being used on jobsites in a number of ways. Drones can be used to quickly conduct jobsite inspections and identify potential hazards each day. They can also be used to monitor workers throughout the day to ensure everyone is working safely. Drones are being used to take photos of as work progresses to create as-built models of jobsites to keep everyone informed of the changing work conditions each day. Drones are also being used to tackle more dangerous jobs, like bridge and building inspections. This won't eliminate the need for workers, but it will mean that workers will need to be trained on how to use the technology to perform these tasks (Construct Connect, 2018).

2.24.11 Robots

Current robots are good at doing simple, repetitive tasks which is why construction professionals are seeing things like bricklaying robots or rebar tying robots. Once set up, these robots can work continuously to complete tasks faster than human workers without needing to take breaks or go home for a good night's sleep. Robots don't get tired from lifting bricks, applying mortar and setting them in place or constantly bending over to tie rebar. In both these examples, humans are still needed to perform some of the work. Both still require workers to set up the robots and get them started. For the bricklaying robot, a mason is needed to oversee the work, ensure bricks are correctly placed and clean up the mortar after they’ve been set. The rebar tying robot still needs humans to correctly place and space the rebar before it gets set in motion. Instead of replacing workers, most construction robots are there to aid and augment a worker’s performance, enabling them to be more productive (Construct Connect, 2018).

2.24.12 Autonomous Heavy Equipment

Autonomous heavy equipment, using similar technology for self-driving cars, is currently being used on jobsites to perform excavation, grading, and sitework. This type of technology allows operators to be completely removed from the machine, allowing companies to do the same amount of work with fewer workers. These machines use sensors, drones, and GPS to navigate the construction site and conduct sitework based on 3D models of the terrain to accurately excavate and grade the site. Augmented GPS, a combination of onsite base stations and satellites, can be used to geofence the site and allow autonomous equipment to move around the site with precision accuracy. The benefit of adopting technology like drones, robots, and autonomous or self-controlled equipment are twofold. First, within the next decade, workers entering the workforce that has grown up using tablets and smartphones their entire life, so operating these machines will be second nature to them. Second, younger workers, regardless of what field they go into, are going to expect to be using technology to perform their jobs (Construct Connect, 2018).

2.24.13 Collaboration

As it is mentioned earlier, a major issue in construction projects today is a highly fragmented industry. With workers, engineers, and equipment distributed around a jobsite, plus offsite stakeholders, including project managers and the customer, it can be hard to get everyone on the same page when a decision needs to be made (Construct Connect, 2018).

2.24.14 Mobile Technology

Smartphones and mobile apps have made communication and collaboration on projects easier. Instead of driving to the office for impromptu meetings, firms can use mobile technology to facilitate a meeting of the minds that lead to definitive conclusions without interrupting the day's work. Being able to communicate in real time ensures that any issues on the jobsite get resolved quickly and effectively and that every stakeholder can have a say. Integrated solutions that sync in real-time allow different stakeholders to add notes, change drawings and responds to RFIs instantly and then share that information with everyone involved with the project at the same time (Construct Connect, 2018).

2.24.15 BIM Implications in the Construction Industry

Changes to the BIM model occur in real time, so any changes or updates to the model are instantly communicated to all team members when they access the model. Everyone is working with the most up-to-date information at all times. Because the schedule can be simulated, a visual representation of the construction process allows team members to plan out each phase of construction. The type of immersive visualization made possible by VR paired with BIM will lead to better collaboration and communication. Virtual reality will also lead to greater acceptance and implementation of BIM. Most virtual reality applications being developed for the AEC industry are using BIM models as the basis to create virtual environments (Construct Connect, 2018).

With AR, a project manager or contractor could walk through a construction site and easily view an overlay of a BIM model on top of as-built construction and compare the two. At the same time, they could be accessing checklists completing a daily report using a heads-up display. The project manager could instantly take photos or record the augmented reality walkthrough and send it back to the design team for clarification as issues arise. Construction firms are starting to come around on tech adoption. Companies that are researching and implementing technology are reaping the rewards with increased productivity, better collaboration, and completing projects on time and under budget resulting in higher profit margins. It might be a tough pill to swallow, but it has been gotten to the point where firms that are not investing in new technologies and solutions are no longer staying competitive those that are strategically adopting and implementing tech solutions. Construction firms that continue to refuse to innovate are destined to die (Construct Connect, 2018).

2.25 Influence of BIM on Big Data

A higher demand for data will emerge within the construction industry and more effective managing of big data will change the way many of the professionals within construction (example: contractors, engineers and others) are working (GenieBelt, 2017). Therefore, BIM will offer remarkable help in handling vast amounts of data and shall be integral with blockchain or smart contracts systems.

BIM brings together all of the information about every component of a building, in one place. BIM makes it possible for anyone to access that information for any purpose, example: to integrate different aspects of the design more effectively. In this way, the risk of mistakes or discrepancies is reduced, and abortive costs minimized.

According to NBS (2018), BIM data can be used to illustrate the entire building life-cycle, from cradle to cradle, from inception and design to demolition and materials reuse. Spaces, systems, products and sequences can be shown in relative scale to each other and, in turn, relative to the entire project. And by signaling conflict detection BIM prevents errors creeping in at the various stages of development/ construction.

2.26 Literature Gap

There are several factors inhibiting the uptake of BIM. They may be classified in technical and non-technical barriers.

Information exchange and interoperability: Information exchange is crucial in fostering integrated process, it emerged that some of the common BIM tools can output information in at least one standard format, an example of IFC. However, a recent study revealed that most construction professionals have never used most of the exchange protocols (Redmond et al., 2012). Karul et al. (2014) stated that without the knowledge of exchange protocols, the tendencies of buying the most common software will most likely prevail.

BIM integration stage in projects: opinions on the applications of BIM processes and tools on various phases of a construction project vary (Karul et al., 2014). These variations are generally based on the level of information available with regard to each construction phase, and the current belief is that information about the operational phase of a building is widely abundant and well-researched. Cheung et al. (2012) emphasized that there is a shift in investigating the implementation of BIM at early design stages and various views from Redmond et al. (2012) show that some respondents adamantly postulated for BIM to be implemented in the whole life cycle while others recommended the early design stage.

Web-based or desk-top applications: despite an overwhelming support and acknowledgement of cloud-based BIM systems supported by the Web (Redmond et al., 2012). Many common BIM tools in the UK construction industry are still localized on desktops and most of them are desktop-based systems (Karul et al., 2014). Therefore, overcoming the technical barriers alone is not sufficient to trigger the uptake of BIM. Olatunji (2011), Gu and London (2010), Redmond et al. (2012), Yan and Damian (2008), and NBS (2013) presumed that other non-technical barriers such as cost, contractual issues, intellectual property, behavioral, cultural are known to hinder the uptake of BIM because:

i. Most of the BIM tools are not free, in both the UK and the US; cost and human resources are among the major barriers hindering the implementation of BIM by construction firms. This is particularly worrying given the huge number of SMEs in the construction industry;

ii. About contractual issues with BIM, the openness in sharing construction information in BIM is the fundamental underlying principle of BIM and key in overcoming fragmentation in the industry.

Additionally, Redmond et al. (2012) asserted that openness has been considered as a barrier. Current construction contracts do not cover information exchange, as emphasized by Ashcraft (2008) that the lack of Standard BIM contract documents is a barrier to the uptake of BIM and issues such as risk allocation, compensation, insurance and dispute resolution common in traditional contract documents cannot be easily dealt with in BIM projects unless being integral with blockchain. Furthermore, ownership and copyright attributions of construction BIM model and/or pieces of a particular aspect of a BIM model still constitute major concerns in BIM managed projects.

The lack of immediate benefits of BIM for designers is considered as a strong barrier to BIM implementation within an industry. Ashcraft (2008) & Yan and Damian (2008) point out that the benefits of the adoption of BIM have been acknowledged by academics and construction professionals, and that amongst them, a level of economic benefit in the supply chain exists. For the project owner, the benefits are obvious and include design optimization, fewer construction errors, fewer design coordination issues, increased quality, decrease in cost, shorter delivery times, less coordination and engineering effort and reduced fabrication costs. On the other hand, designers feel less enthusiastic about BIM as they believe that its economic benefits are less apparent to them (Ashcraft, 2008).

Ashcraft (2008) report shows that during the conceptual phase of a construction project, the ability to explore various design alternatives using BIM tools leading to greater efficiency and improvement in quality is a major benefit to designers. Sebastian (2010) stated that unless the designer shares in the economic benefits, the owner, not the designer, reaps the immediate rewards, yet, it is the designer, not the owner, who must adopt and invest in BIM more than owners.

A major use of BIM is the measurement of quantities. Whereas BIM measurement could potentially change current measurement practices, a classic example is the need to filter quantity measurement output so that it complies with Standard Methods of Measurements. The existence of many different standard methods of measurement further exacerbates this challenge. For example, in the UK building and civil engineering works are managed by the Standard Methods of Measurement (SMM7) or New Rules of Measurements (NRM) and Civil Engineering Standard Method of Measurement (CESMM3) respectively. The application of BIM to support cross disciplinary, knowledge-intensive and multi-faceted projects opens new dimensions in the roles and responsibilities of actors in the construction industry. The relationships between the various actors are likely to change while new roles with special responsibilities and skills (example: Model manager, BIM analyst, BIM modeler, BIM facilitator, and others) will emerge as affirmed by Sebastian (2011) and Barison and Santos (2010). There is an anxiety that some actors (example: quantity surveyors) will lose their roles.

Current procurement methodologies are also challenging and ill-suited for the rolling out of BIM in the construction industry. Majority of current procurement methodologies limit the participation of various actors' right from the early stages of construction. For BIM integration to be a success there is a need to involve all construction team members including contractors and sub-contractors from the early stages. In addition to the sustainability dimension, BIM and procurement processes constitute the three pillars that will drive the way forward for integrated Project Delivery (IPD).

2.27 Theoretical Framework

Construction professionals in Rwanda remain a considerable issue in the state and trends of BIM adoption in the country. Increase in career professionalism, with enough skills in planning and designing software platforms may positively impact the industry's projects. Additionally, various factors ─ such as cost, time, quality, productivity, client satisfaction, regular and community satisfaction, labor technical skills, health and safety, innovation and learning, environmental and institutional factors, ICT infrastructure, experience, and improper planning for facility management ─ may hinder the performance of any construction project. BIM contributes to the sustainable development in both developed and developing countries. Since the technology is not only limited to developed countries, developing countries like Rwanda should adopt this model to enhance the development of their construction industries. When the new methods and technologies are used, they are applied per project basis and are not adapted quickly in the construction industry. A structured process of applying BIM in construction projects in Rwanda could be a key point for adopting the model effectively in the construction industry. From the foregoing review of literature on BIM and its adoption in construction industry in various countries, a theoretical framework for this study can be formulated as illustrated in the flowchart in Figure 2.22.

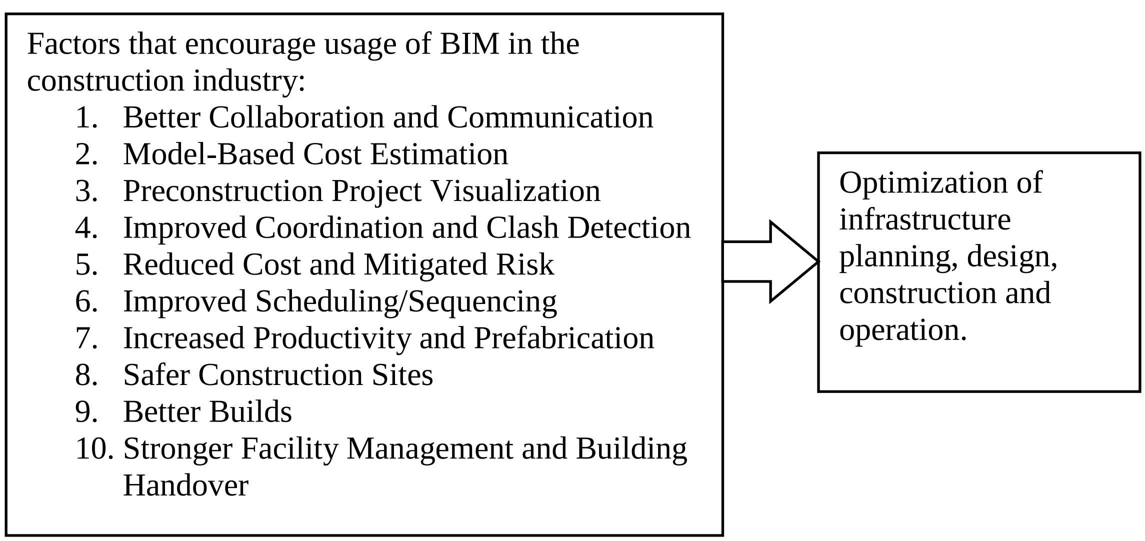

Figure 0.22 Theoretical Framework

Source: Author, 2019

2.28Conceptual Framework

From the theoretical framework, a conceptual framework for this study is derived, by amplifying the general motivators of BIM adoption (shown in Figure 2.22) in order to highlight and capture the specifics of the construction industry of Rwanda, as shown in Figure 2.23.

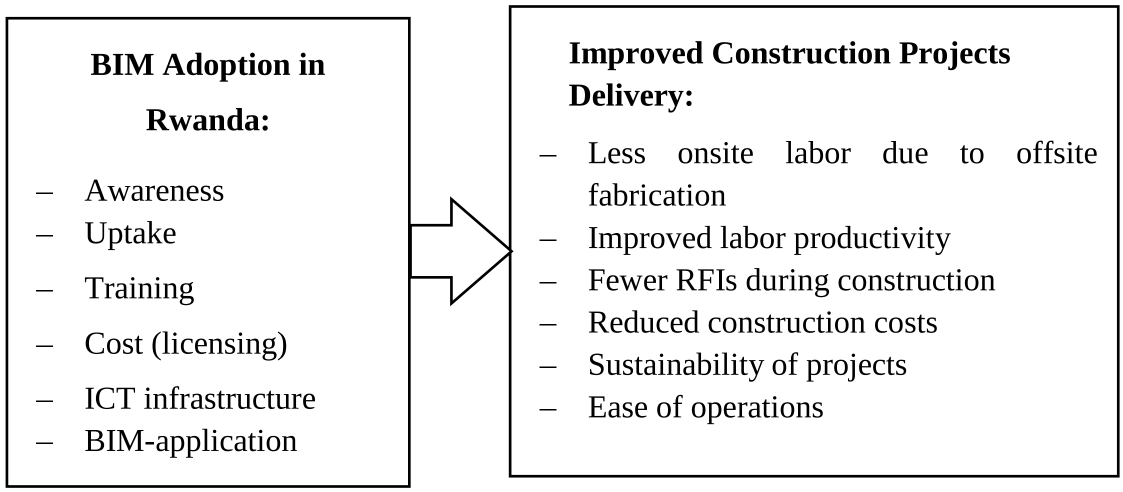

Figure 0.23 Conceptual framework

Source: Author, 2019

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methods that were followed in conducting this study. The sections are: the research design, variables in the study, population and sampling, data collection and analysis.

3.2 Study Site

This research intended to explore the adoption of BIM in construction projects delivery in Rwanda particularly in the City of Kigali because it is the busiest city in and most of country's construction projects are implemented in this city, and therein lives more construction professionals.

Figure 0.1: Map of the City of Kigali

Source: Building Permits Management Information System (BPMIS), 2019

3.3 Study design

The research is a cross-sectional study because it aimed at collecting information and opinions from respondents and highlight the prevalence and efficacy of implementing BIM in construction projects in Rwanda.

3.4 Study Variables

The independent variable is the adoption of BIM, while the dependent variable is the delivery of construction projects as a matter of factor that encourage the use of BIM in the construction industry that imply optimum performance.

Since, in this study, performance of construction projects is conceptualized to depend on the use of BIM. Adopting BIM will influence construction projects delivery as well as the sustainable development of the industry and long-term infrastructure for Rwanda.

3.5 Study Population

The target population in the study is registered professionals in Rwanda who are involved in planning, design, execution, and operation of the country's infrastructure such as construction project managers, engineers, architects, quantity surveyors, and urban planners in different public, private, contracting and consulting companies or institutions within the City of Kigali. According to the lists of registered and compliant professionals from the Institution of Engineers Rwanda (IER) (2019) and Rwanda Institute of Architects (RIA) (2019) there were 270 and 67 members respectively (BPMIS, 2019). Currently, in Rwanda, construction project managers are few and recognized by IER, while quantity surveyors and urban planners are recognized by RIA. The professionals in the targeted population are key contributors to infrastructure construction in Rwanda. Only registered professionals from the Institute of Engineers Rwanda (IER) and Rwanda Institute of Architects (RIA) (where the target population is based) were contacted. The study excluded any respondent who was not registered in any of the institutions of Engineers or Architects in Rwanda and whose contribution to country's infrastructural development was not therefore not in any way recognized by the Rwanda's construction industry.

The population size therefore comes to 337 members as outlined in Table 3.1 below.

Table 0.1 Population of the Study

Category	Number	Percentage
Construction Project Managers	10	2.9
Engineers	260	77.15
Architects	35	10.4
Quantity Surveyors	20	5.9
Urban Planners	12	3.6
Total	337	100

Source: Field Survey, 2019

3.6 Sample Size Determination

Sample size was estimated based on a proportion where it was calculated with an approximate 95% confidence level, the following formula was used:

$$n_{ir} = \frac{z^2 pq}{d^2} \text{ (SLC, 2006)}$$

Where:

z=1.96 at 95% of confidence

n_i = required sample size for infinite population

q = 1-p, p = proportion of the population having the characteristic, and

d = the degree of precision

The proportion of the population (p) is unknown from prior research or other sources; a value of p = 0.5, which assumes maximum heterogeneity was adopted in this study. The degree of precision (d) is the margin of error that is acceptable, which is 0.05 at the 95% confidence level

Thus, $n_i = \frac{1.96^2 * 0.5 * 0.5}{0.05^2} = 384.16$ say 384

According to Mugenda & Mugenda (2003), sample correction for the finite population is given by:

$$n_f = \frac{n_i}{1 + \left(\frac{n_i - 1}{N}\right)}$$

Where:

n_f= the desired sample size (when the population is less than 10,000)

n_i= desired sample size (when the population is more than 10,000)

N= the estimate of the finite population size.

Accordingly, $n_f = \frac{384}{1+\left(\frac{384-1}{337}\right)} = 179.73$ say 180

The sample size of 180, was distributed amongst the various categories of professionals, pro rata to their percentage in the population, as shown in Table 3.2 below:

Table 0.2 Distributed sample size

Category	**α (%)**	**Distributed sample size (N)**
Construction Project Managers	2.9	5
Engineers	77.15	139
Architects	10.4	19
Quantity Surveyors	5.9	11
Urban Planners	3.6	6
Total	100	180

Source: Field Survey, 2019

3.7 Sampling Techniques

Homogeneous Sampling was used because the research aimed at bringing together people of similar backgrounds and experience.

3.8 Data Collections Tools

A questionnaire was the tool to undertake the data collection for this research and was designed based on a status quo of BIM level of use and awareness by construction professionals in Rwanda especially in the city of Kigali and particularly intended to achieve the main objective of the study by answering the questions derived from it. The questionnaire is shown in appendix E.

3.9 Pre-Testing

The questionnaire was distributed to respondents and data entry and analysis was done in office. Expert' reviews were used as the pre-testing method in this research. To ensure validity and reliability of the research as well as enquiring whether the questionnaire was set properly to achieve the objective of the study, a pilot test of 10 responses to the questionnaire was done. This test group was excluded from the research.

The ten (10) responses were collected from one (1) construction project manager, five (5) engineers, two (2) architects, one (1) quantity surveyor, and one (1) urban planner. The results of the pilot study showed that 60% of the respondents (4 engineers and 1 quantity surveyor) were not aware of BIM, 10% (only 1 engineer and 1 construction project manager) were aware but don't use it, and 30% (2 architects and 1 urban planner) use BIM but not in full. Respondents also gave comments on the questionnaire. Comments were noted to establish whether the questions were clear to them and whether they were comfortable with them. The pilot survey results also formed the basis of modifying the questionnaire for the subsequent full-scale data collection. Several refinements were made to the questionnaire at that point, to produce the version presented in appendix E.

3.10Research Strategy

The questionnaire was divided into various sections that focus on fundamentals for BIM awareness and its adoption in Rwanda. It was designed to target knowledgeable, experienced and suitably qualified individuals who were currently engaged in implementation of construction projects in Rwanda. Hence, the information collection would be reliable since it was extracted from a reliable source of knowledgeable respondents. The questionnaire was pre-tested and relevant role-players confirmed the information collected from the various sources as accurate. The results were tested also with the practical staff to ensure significance and flow of the questions. This way, the construct validity and influence reliability were addressed.

Data collection consisted of selecting and training field workers and supervising, validating and evaluating the field work. The selection of field workers involved developing job specifications for the research, taking into account the mode of data collection. Field workers were trained to make opening remarks that would convince potential respondents that their participation was so important and field workers' supervision was done to make sure they are following the procedures and techniques in which they were trained. Regarding evaluation and validation of the field work, the supervisor was called out to conduct the process that helped the respondents to answer the whole. Completed questionnaires were evaluated and validated where necessary for the quality of data gathering.

3.11Data Analysis

Data analysis consisted of examining and summarizing data with the aim of extracting useful information and making conclusions. Data analysis comprised preparation of a preliminary plan of data analysis, by checking returned questionnaires; a questionnaire returned from the field would be unacceptable for several reasons. Editing and treating of unsatisfactory results (returning to the field or assigning missing values or discarding unsatisfactory respondents). A code was assigned, usually a number, to each possible response to each question. The code included an indication of the column position (field) and data record it occupied. Recording and data transcription involved transferring the coded data from the questionnaires or coded sheets directly into Microsoft Office Excel. No missing responses, no out-of-range data, no logically inconsistent or had extreme values were identified.

The data analysis procedure was frequencies/percentages and descriptive statistics (means). Additionally, expert views from the respondents ─ on strategies for enhancing BIM uptake in Rwanda ─were outlined. Finally, from the statistical analysis, results, and outline of the respondents' suggestions, a BIM adoption process for the construction industry of Rwanda was synthesized.

3.12 Ethical Consideration

Ethics refers to a system of principles which can critically change previous considerations about choices and actions. It deals with the dynamics of decision making concerning what is right and wrong. Scientific research work, as all human activities, is governed by individual, community and social values. Research ethics involve requirements on daily work, the protection of dignity of subjects and the publication of the information in the research (Bryman & Bell, 2007).

It was so important to undertake this research in a professional manner to ensure that individuals and communities who agreed to participate in this research were treated with respect and that their rights, dignity, and welfare were protected. Prior to undertaking this research and data collection, a permit letter from the university ─ that approves the research topic and allocates supervisors, and an invitation letter to respondents ─ that introduces the researcher and study to them ─ were provided.

3.13 Summary

In brief, the research methods adopted for the data collection and analysis in this study are suitable to address the research all objectives of the study sufficiently. Additionally, the study attempted also to develop a structured process of integrating BIM in the country's infrastructure projects life-cycle (planning, design, execution, and operation phases). The next chapter presents the data collected and the results of the data analysis.

CHAPTER FOUR

STUDY RESULTS AND INTERPRETATION

4.1 Introduction

This chapter presents results of the study and interpretation. The analysis was subdivided into sections in accordance to the questionnaire and related responses. It addressed the level of BIM usage, benefits and barriers of the usage in Rwanda, and expert views for enhancing the BIM uptake to improve construction projects delivery in the country. Finally, an outline was formulated and a schematic framework was given, for enlivening the adoption of BIM in Rwanda in a more structured manner.

4.2 Respondents rate

Response rate is the number of people participating in a survey divided by the number of people who were invited to respond, in the form of a percentage (Rubin & Babbie, 2009). The questionnaires were distributed to 180 respondents involved in the design and implementation of infrastructure within the construction industry in Rwanda. Out of this, 120 responses were received of which 3 were identified as invalid due to incomplete and/or invalid answers given. This represents a valid response rate of 65% which is considered adequate for analysis and reporting as shown in the table below.

Table 0.1 Response rate

	Frequency	**Percentage**
Valid responses	117	65
Invalid responses	3	1.67
Did not respond	60	33.33
Total	**180**	**100**

Source: Field Survey, 2019

4.3 Information about the respondents

As shown in Figure 4.1, from the 117 valid responses recorded, 76.9% of the respondents were engineers (where 94.9% of them were registered) while 11.1% and 3.4 % were architects and construction project managers respectively, and quantity surveyor and urban planner occupied 4.3% each. The public sector dominates other sectors at 33.3%, followed by private, contracting and consulting sectors follow at percentages of 24.8%, 21.4% and 18.8% respectively; respondents from higher learning institutions and others both combined occupied the least percentage of 1.7% as highlighted in Figure 4.2. About the services offered by the respondents, as presented in Figure 4.3, 74.4% and 20.5% were AEC and MEP respectively, and 5.1% was shared by manufacturing, construction projects financing, urban planning, geotechnical, and academia. In Figure 4.4, most of respondents had between 6-8 years of experience at 37.6%, followed by 4-6, 8-10, more than 10, and 0-2 with 20.5%, 19.7%, 15.4%, 6% and 0.9% respectively.

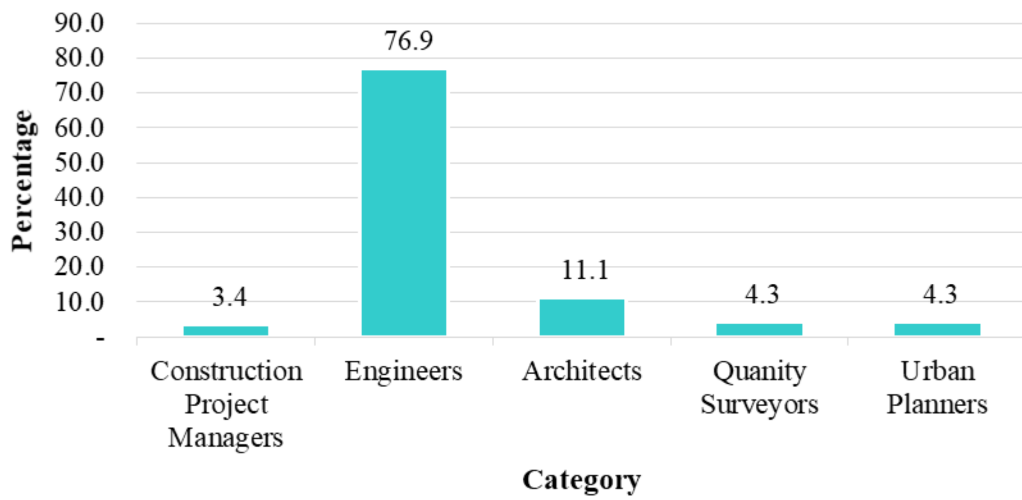

Figure 0.1 Respondents's category

Source: Field Survey, 2019

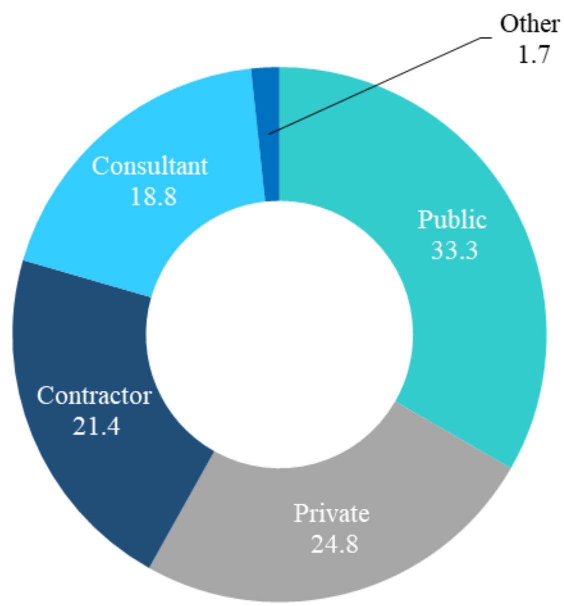

Figure 0.2 Sectors in which respondents work for

Source: Field Survey, 2019

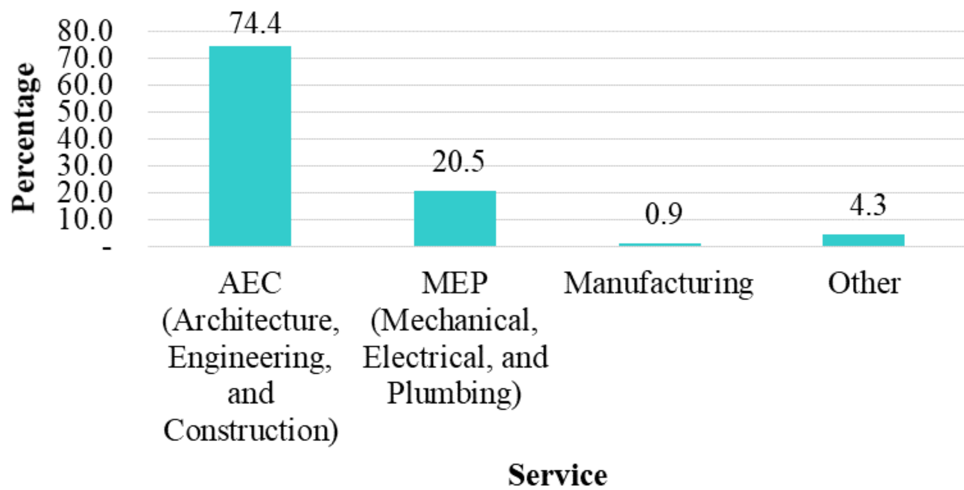

Figure 0.3 Services offered by respondents in the industry

Source: Field Survey, 2019

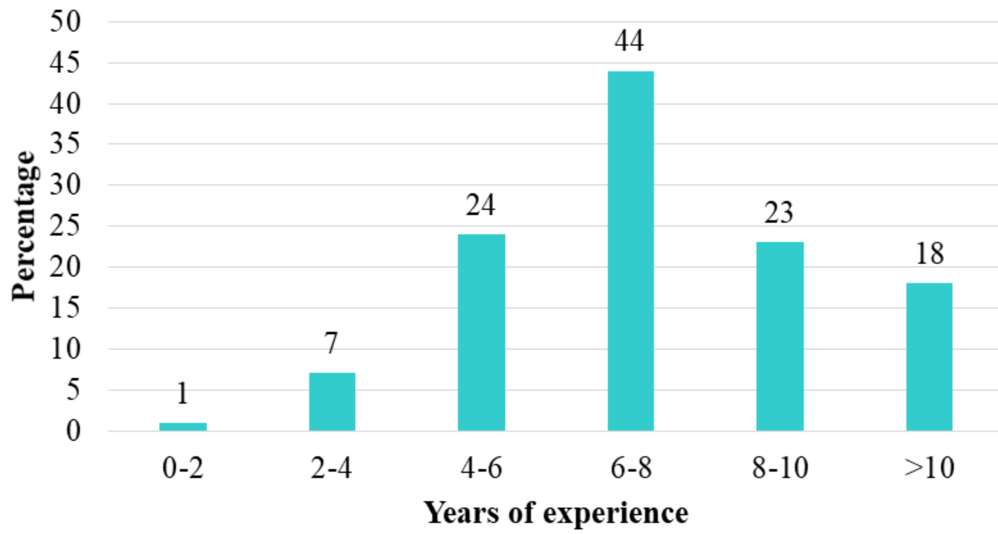

Figure 0.4 Experience of respondents in the industry

Source: Field Survey, 2019

4.4 BIM Awareness and Use in Rwanda

As presented in Figure 4.5, from the 117 received valid responses, 71% of the total respondents were not aware of existence of BIM while only 29% (equivalent to 35 respondents) knew about the new technology hereby understudied how it could be adopted in the construction industry in Rwanda. The responses from being aware of BIM was conditional where if the respondent responded yes, he/she would respond section two of the questionnaire, otherwise he/she would skip to respond remaining three sections. Based on 35 respondents who were aware of BIM, 82.9% of them have been using BIM and 17.1% have not as highlighted in Table 4.2. Results show that BIM tools have been somewhat less used in Rwanda.

Construction and design professionals who have been using BIM for more than 5 years dominated at 28.6% as shown in Table 4.2. Regarding commonly adapted BIM dimensions in Rwanda, results revealed that the three-dimension (3D) is the most BIM dimension used at a percentage of 60%, followed by the two-dimension (2D) at 28.6%, this shows that few professionals shifted from CAD to BIM. However, fourth and fifth dimensions are used at low level, while 6D, 7D, 8D and

9D have not been used in Rwanda. This may be due to several reasons such as lack of BIM awareness and training and among others. As highlighted in Figure 4.6 and in Table 4.2, activities such as existing conditions modelling, civil works design, review of designs, quantity and cost estimation and structural modelling, analysis and design are the commonly undertaken using BIM tools in Rwanda. None of respondents has been using BIM tools in energy analysis, code validation, digital fabrication, maintenance scheduling, nor using it in other engineering activities. From Figure 4.7, 0 to 5 office members have been using BIM at a scale of 74.3%. In addition, 0 to 5 projects have been undertaken using BIM tools at scale of 57.1% as presented in Figure 4.8.

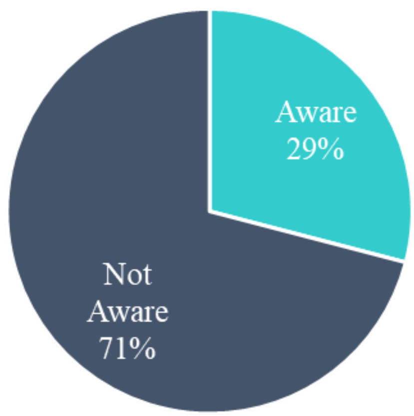

Figure 0.5 BIM awareness in Rwanda

Source: Field Survey, 2019

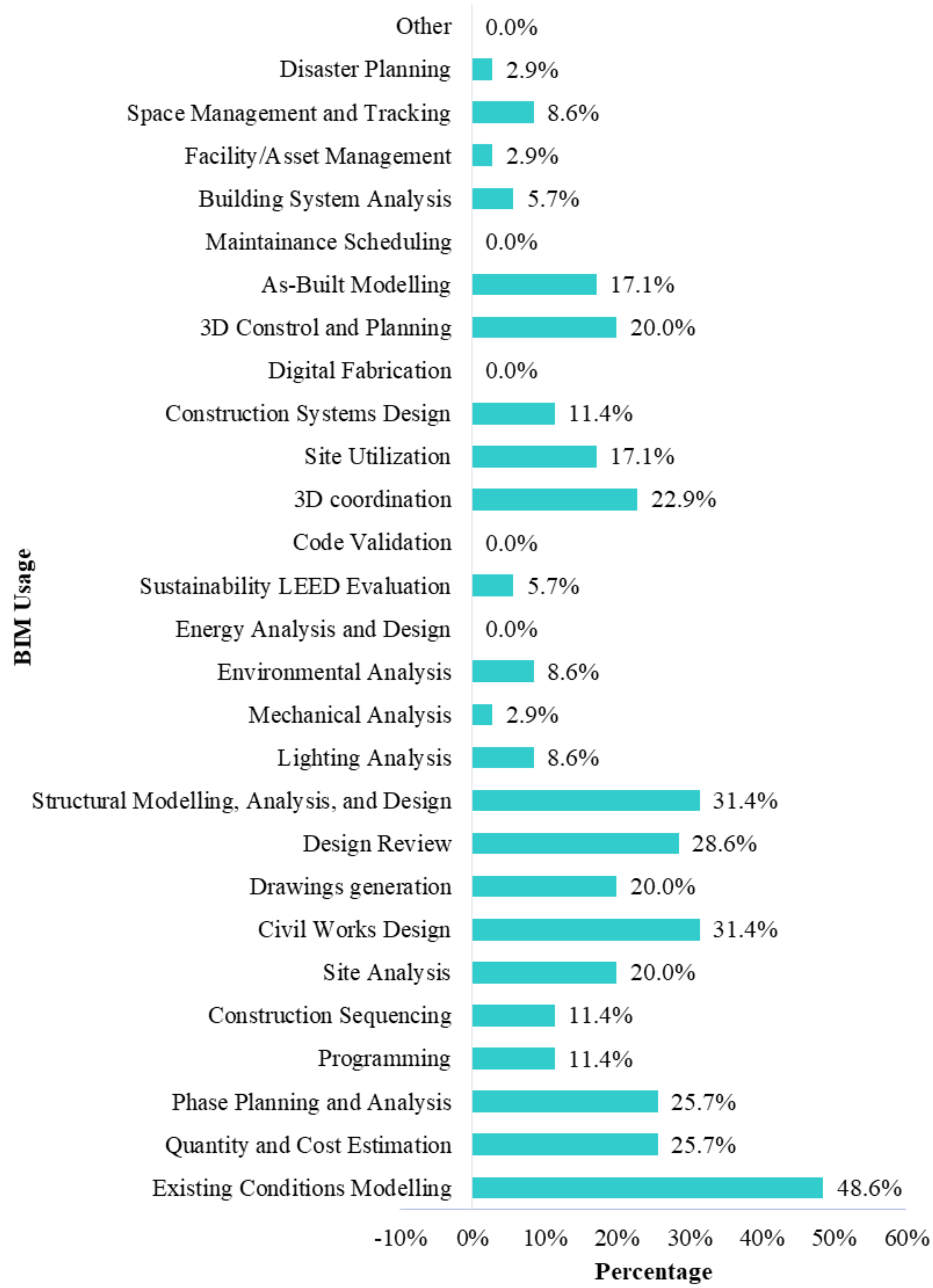

Figure 0.6 How BIM is used in Rwanda

Source: Field Survey, 2019

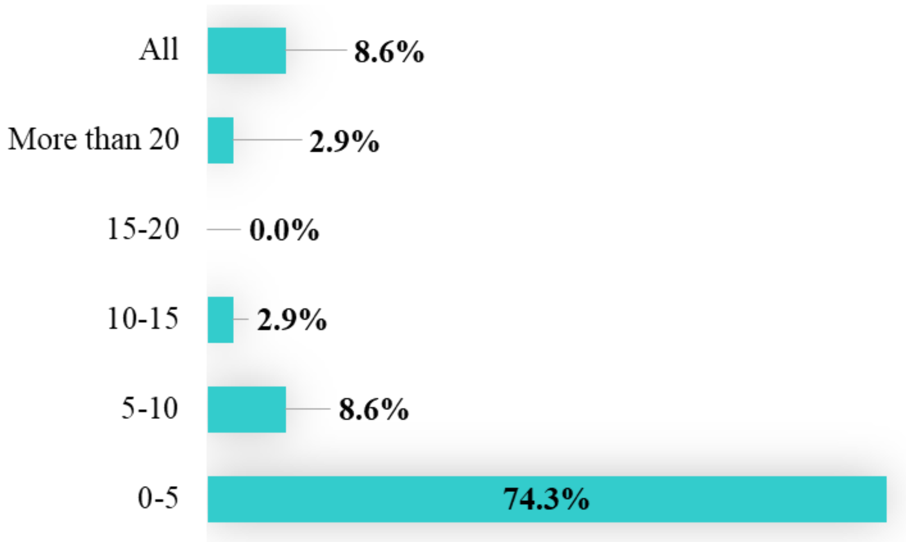

Figure 0.7 Office members who use BIM

Source: Field Survey, 2019

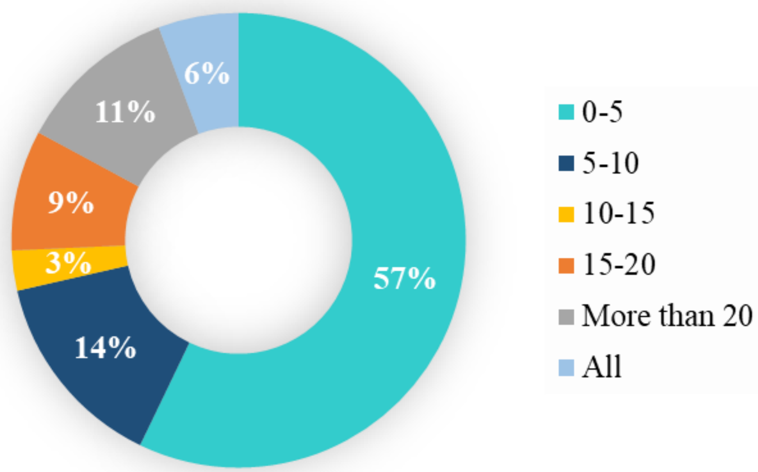

Figure 0.8 Projects undertaken using BIM in Rwanda

Source: Field Survey, 2019

The Table 4.2 below summarizes the BIM usage in Rwanda based on collected data from 35 respondents who agreed that they use it.

Table 0.2 Summary of BIM Use Statistics in Rwanda

Description	Response	Statistics	
		Frequency	Percentage
1. Use of BIM in Rwanda	Accepted	29	82.9%
	Refused	6	17.1%
2. The extent to which BIM is used in Rwanda	Much more	3	8.6%
	Somewhat more	4	11.4%
	Somewhat less	11	31.4%
	Much less	9	25.7%
	Don't use	8	22.9%
3. BIM use time (in years) in Rwanda	0	7	20.0%
	1	3	8.6%
	2	7	20.0%
	3	4	11.4%
	4	4	11.4%
	5	0	0.0%
	>5	10	28.6%
4. BIM dimensions used in Rwanda	2D	10	28.6%
	3D	21	60.0%
	4D	1	2.9%
	5D	1	2.9%
	6D	2	5.7%
	7D	0	0.0%
	8D	0	0.0%
	9D	0	0.0%
5. How BIM is used in Rwanda	Existing Conditions Modelling	17	48.6%
	Quantity and Cost Estimation	9	25.7%
	Phase Planning and Analysis	9	25.7%
	Programming	4	11.4%
	Construction Sequencing	4	11.4%
	Site Analysis	7	20.0%
	Civil Works Design	11	31.4%
	Drawings generation	7	20.0%
	Design Review	10	28.6%
	Structural Modelling, Analysis, and Design	11	31.4%
	Lighting Analysis	3	8.6%
	Mechanical Analysis	1	2.9%
	Environmental Analysis	3	8.6%
	Energy Analysis and Design	0	0.0%
	Sustainability LEED Evaluation	2	5.7%
	Code Validation	0	0.0%
	3D coordination	8	22.9%
	Site Utilization	6	17.1%
	Construction Systems Design	4	11.4%
	Digital Fabrication	0	0.0%
	3D Control and Planning	7	20.0%

Description	Response	Statistics	
		Frequency	Percentage
	As-Built Modelling	6	17.1%
	Maintenance Scheduling	0	0.0%
	Building System Analysis	2	5.7%
	Facility/Asset Management	1	2.9%
	Space Management and Tracking	3	8.6%
	Disaster Planning	1	2.9%
	Other	0	0.0%
6. Office members who use BIM	0-5	26	74.3%
	5-10	3	8.6%
	10-15	1	2.9%
	15-20	0	0.0%
	More than 20	1	2.9%
	All	3	8.6%
7. Projects undertaken using BIM	0-5	20	57.1%
	5-10	5	14.3%
	10-15	1	2.9%
	15-20	3	8.6%
	More than 20	4	11.4%
	All	2	5.7%

Source: Field Survey, 2019

4.5 Benefits and Barriers of BIM Implementation in Rwanda

Implementation of BIM in construction projects in Rwanda is very crucial, the industry has to undergo new technologies to tackle innovations and increasingly develop. Based on the survey conducted as discussed in section 4.3 and 4.4, it was remarkably proven that there is a need of BIM in Rwanda. Table 4.3 shows benefits of enabling BIM on country's infrastructure life cycle.

Generation of accurate and consistent 2D and 3D drawings at any stage takes the first position while greater productivity due to easy retrieval of information and easier quantity take-off and time scheduling both take the second as most beneficial as summarized in Figure 4.9.

Table 0.3 BIM Implementation Benefits in Rwanda

Benefit	Rating						Frequency	Score	Mean	Ranking
	0	**1**	**2**	**3**	**4**	**5**				
Improved cost estimating at each project stage, productivity of estimator in quantity take-off	3	7	15	17	37	38	117	426	3.64	4
Easier quantity take-off and time scheduling	2	6	10	23	46	30	117	429	3.67	2
Reduced cost from health and safety issues	3	7	10	26	41	30	117	419	3.58	7
Reduced overall project cost	3	6	17	26	41	24	117	402	3.44	11
Increased speed of delivering projects, productivity and quality	3	4	12	32	36	30	117	418	3.57	8
Allows increased energy analysis of the building	2	6	25	24	39	21	117	389	3.32	13
Allows accurate site logistics plans	3	5	14	31	37	27	117	409	3.50	10
Improved communication and coordination and collaboration between project parties	3	3	13	34	30	34	117	421	3.60	6
Potentially Improved whole life asset management (Involvement in operation and maintenance phase)	3	4	11	27	42	30	117	425	3.63	5
Generation of accurate and consistent 2D and 3D drawings at any stage	3	5	10	18	47	34	117	437	3.74	1
Greater productivity due to easy retrieval of information	3	3	12	27	39	33	117	429	3.67	2
Improved conflicts detection	3	6	11	34	35	28	117	410	3.50	9
Improved human resources management	3	5	21	34	28	26	117	391	3.34	12
Other	10	32	29	26	9	11	117	259	2.21	14

Source: Field Survey, 2019

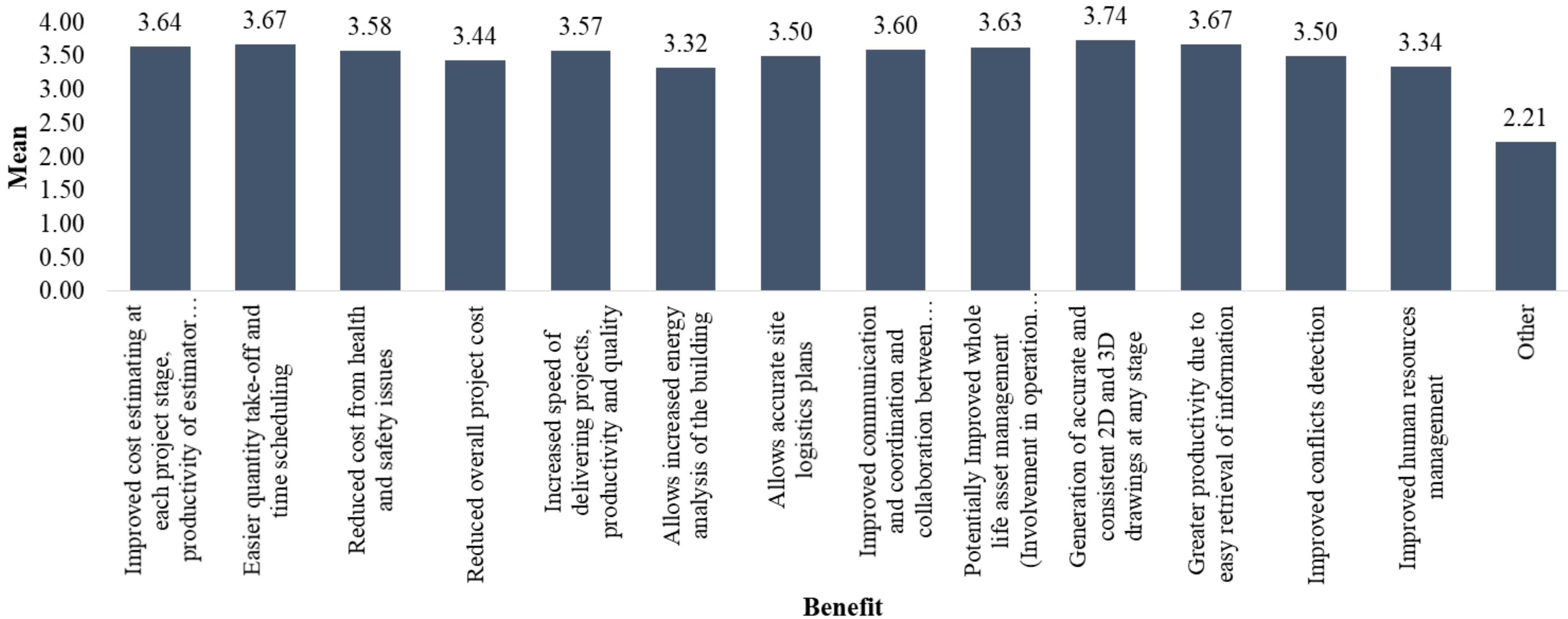

Figure 0.9 Overview of scores for BIM implementation benefits in Rwanda

Source: Field Survey, 2019

Different BIM implementation barriers in Rwanda such as lack of BIM training was ranked the first, followed by the need for suitable data sharing standards and unawareness of benefits BIM can bring to organization as highlighted in Table 4.4 and summarized in Figure 4.10.

Table 0.4 BIM Implementation Barriers in Rwanda

Barrier	Rating 0	1	2	3	4	5	Frequency	Score	Mean	Ranking
Unawareness of benefits BIM can bring to organization	0	10	11	24	29	43	117	435	3.72	3
The need for suitable data sharing standards	0	9	9	13	51	35	117	445	3.80	2
Lack BIM training	0	7	5	22	44	39	117	454	3.88	1
Insufficient ICT infrastructure	0	5	10	36	47	19	117	416	3.56	6
Lack of clear boundary of responsibilities between parties	0	4	13	34	43	23	117	419	3.58	5
The need to mandate BIM usage in specific contracts	0	8	19	29	35	26	117	403	3.44	9
Insufficient skilled personnel	0	5	13	28	46	25	117	424	3.62	4
People refusal/reluctance to learn	0	8	15	31	44	19	117	402	3.44	10
Client-driven limitations, example: due to unawareness of BIM benefits	0	7	16	28	41	25	117	412	3.52	8
Cost of new software and updates	0	6	24	27	34	26	117	401	3.43	11
Lack of integrated BIM Tertiary Studies Curriculum	0	7	13	36	33	28	117	413	3.53	7
Other	0	28	33	33	14	9	117	294	2.51	12

Source: Field Survey, 2019

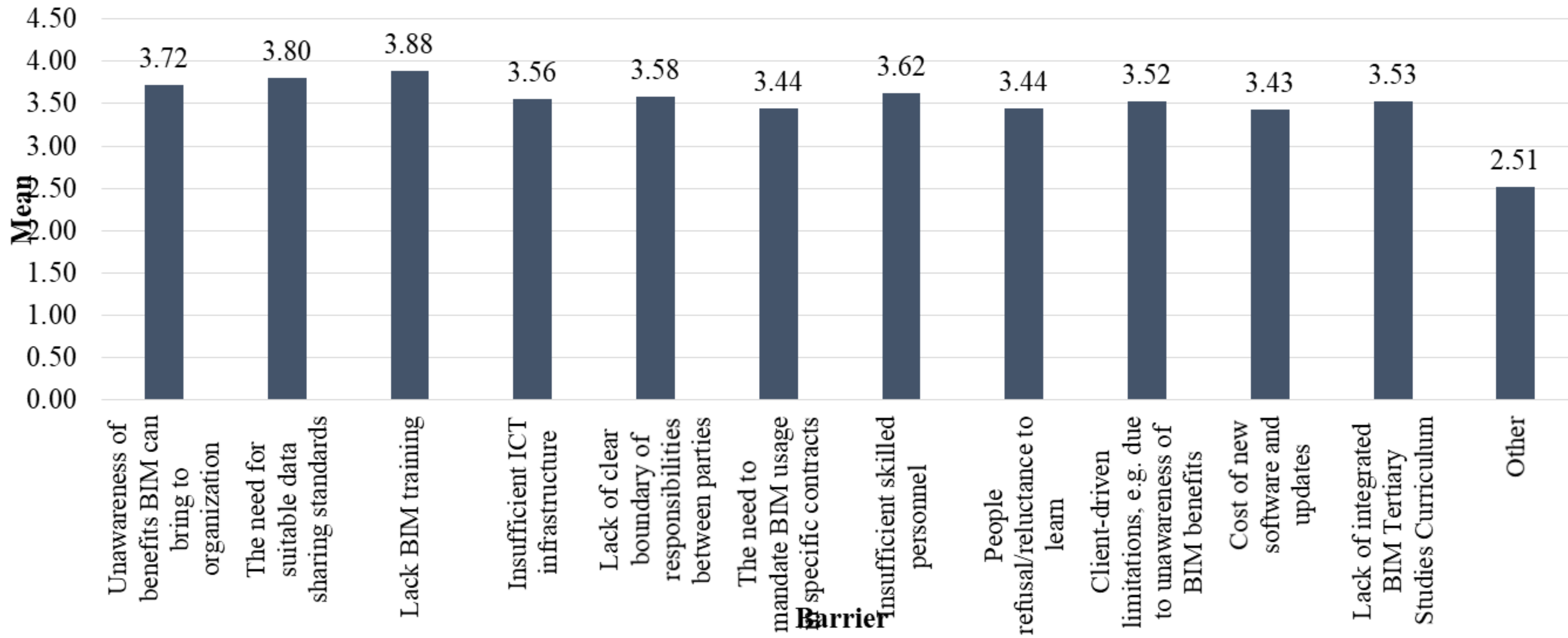

Figure 0.10 Overview of scores for BIM implementation barriers in Rwanda

Source: Field Survey, 2019

4.6 Expert Views Regarding BIM Uptake in Rwanda

Expert opinions and suggestions from construction and design professionals involved in planning and development of infrastructure in Rwanda were collected through an open-ended question. In a nutshell, all the respondents supported the idea of enhancing adoption of BIM in the construction industry of Rwanda. The benefits that the respondents expect to arise from the increased uptake of BIM, can be summarized as follows: -

1. Increased quality of works and productivity;
2. Boost performance and reliability;
3. The design process is speeded up;
4. Increased Accuracy;
5. Efficient project management;
6. Performance and effectiveness of construction industry;
7. Contribute to the country's development;
8. Reduced loss of outcomes due poor planning and increase competitiveness;
9. Help in gathering information easily and their analysis;
10. Ease construction simulation;
11. Facilitate employer/ owner for example to manage specific construction site and track milestones;
12. Time and cost management;
13. Optimum use of the resources;
14. Enhancement of project design and quality;
15. BIM plays various benefits in improving the project performance in terms of time, cost and, productivity;
16. Cost reduction of construction projects due clash detection;
17. Things are easy to monitor during implementation due to modelling and simulation;
18. The use of BIM increases the best performance of construction project implementation from the feasibility study to handover.

These expected benefits are similar to the benefits of BIM adoption, which have been realized elsewhere following increased BIM adoption as per reviewed literatures.

4.7 BIM Adoption Process in Rwanda

In addition to the list of respondents' expected benefits from BIM usage, expert views were also given on strategies for boosting the BIM uptake process in Rwanda. Those expert views have been considered in formulating the aforesaid process, and comprise the following: –

1. BIM dissemination and training
2. Include BIM uses in the tender document as a requirement in order to win a public contract
3. Make BIM mandatory to all professionals involved such as engineers and architects. They must be trained and certified.
4. Use BIM in construction projects and make sure all are performed by the use of BIM.
5. It should be part of modules to be learn by university students in all engineering and professional courses
6. The main one is the government to owner it and enforce the usage
7. Develop BIM usage related policies: The Ministry of Infrastructure and other institutions involved in construction rules and regulation implementation should introduce a policy that strongly support the use BIM in Rwanda.

These views touch on the micro-economic issues of individual projects and individual firms (consultancy and construction) and macro-economic issues of the construction industry as a whole. The implication of this fact is that a structured approach for BIM adoption in Rwanda and requires both the bottom-up approach and a top-down approach working simultaneously. Figure 4.11 below outlines the formulated process for adopting BIM in construction projects delivery in Rwanda.

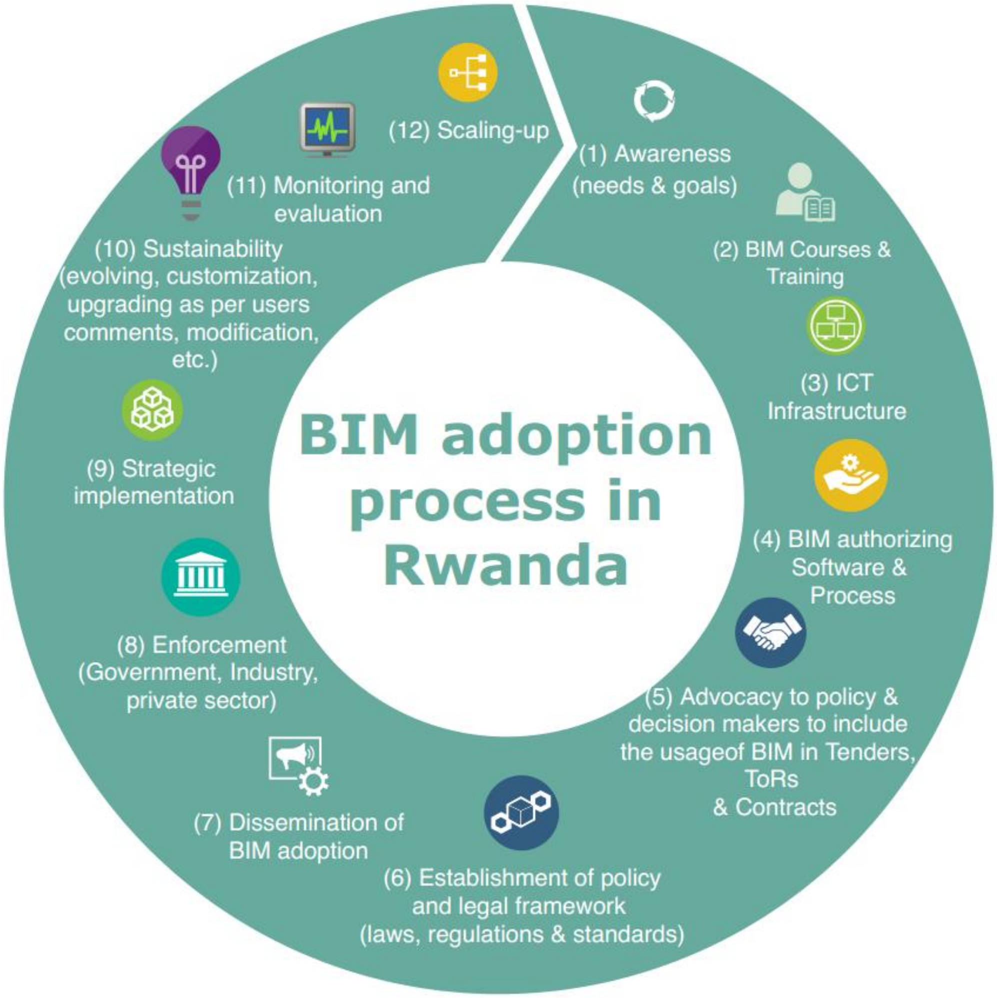

Figure 0.11 BIM Adoption Process in Rwanda

Source: Author, 2019

From these expert views, coupled with the literature reviewed in this study, a schematic model for the structured approach for BIM adoption in Rwanda is hereby formulated, as shown in Figure 4.11 above. The outlined process is explained in the following sections:

4.7.1 Awareness - Needs & Goals

It is so important to conduct public awareness on the benefits of fully using BIM in construction projects life-cycle in Rwanda through various pillars in construction highlighting the BIM processes, software tools, roles and responsibilities for the various team players involved in the planning, design, construction, and operation of infrastructure in the country.

4.7.2 BIM Courses & Training

Construction actors should learn the fundamental concepts of BIM processes and the BIM software tools available together with business benefits and the critical factors for successful BIM implementation on projects. Starting with the understanding of a BIM strategy and how working within a Common Data Environment platform can improve the project workflows and the importance of publishing information into one single source of the truth. Companies have to progressively understand the various BIM project delivery (critical processes, workflows and deliverables necessary for BIM in a project life cycle).

4.7.3 ICT Infrastructure

Aurecon (2014) explains that the smart ICT has the capacity to vastly improve the design, planning, quality and cost of new infrastructure and existing infrastructure by allowing for use of digital management. This has profound implications for planning, development, management and maintenance of infrastructure, with significant productivity benefits for governments and the community. In addition, smart ICT will revolutionize the planning and design of infrastructure and has the capacity to significantly increase the speed and accuracy of data collection for the mapping and modelling of infrastructure, making it much more efficient and cost effective, with huge benefits to the community as a whole. Aurecon (2014) adds that Smart ICT presents a range of new capabilities for the infrastructure sector, and in particular, the growing field of digital infrastructure, which brings together numerous technologies, such as:

– GIS and smart 3D models

- Advanced information management
- Mobile Technology and cloud-based storage and applications
- Augmented and virtual reality
- 3D printing of prototype models, components and structures
- Spatial mapping and monitoring, example: laser scanning, LiDAR and photogrammetry
- Drones
- Automated construction, 3D printing and prefabrication
- Quick Reference (QR) codes and RFID chips
- Real-time remote monitoring and 'The Internet of Things'

4.7.4 BIM Authorizing Software & Process

Gaurang (2017) explains that successfully implementing BIM relies on the 3 P's of BIM: people, processes and policies.

The first 'P' of BIM is people: For an organization to adopt BIM successfully, it requires the whole team to understand its importance and want to accept the change. It's the people aspect that has the potential to drag down the progress and so it should come before the processes and policies. It is important to understand that cultural change always begins offline from your team. Building strong relationships with professionals, in-house teams or a design support solutions provider has worked and will always be one of the most important factors when initiating technological change.

The second 'P' of BIM is processes: Even experienced AEC professionals who are well aware of the BIM benefits have struggled to implement it. The shortest and easiest way which they opt for is to use the new technology with old processes; one which is doomed to fail. They favour old processes as it's something they are used to and are more than comfortable with. As an example, you may find professionals or AEC firms with a building program in Microsoft Excel on one monitor, and on the other, they have Autodesk AutoCAD or Revit. They are busy creating and recreating the data when they can use Excel-to-Revit tools and create spaces from Excel in Revit automatically. Too many processes create a lot of data waste across the lifecycle of construction projects. It’s time to realise that better and effective ways of doing things do exist.

The third ‘P’ of BIM is policies: It’s not that everyone isn’t ready to adopt BIM. There have been instances where people were ready to embrace BIM-friendly processes, but company policies became the biggest hurdle which they were never able to overcome.

BIM works best when all those involved in the construction project can share information freely and collaborate. Contracts usually forbid information sharing under the clause of confidentiality, liability and litigation concerns. It is, therefore, important to understand that design solutions are required to not only protect companies but also encourage them to collaborate.

According to AUGI (2012), the process of using BIM models for collaborative purposes, leading up to and through construction, is a lengthy one. It involves a real investment on software and employees. In predesign, it is determined if BIM is going to be used on the project. Assuming that BIM is the approved method, the Architect gets started on the schematic model, either by using masses or real elements in a BIM environment. Once the schematic architectural model is prepared, a presentation will be given to the owner. A walkthrough or renderings is a necessity for this presentation. 3D Studio Max, in conjunction with Revit, helps in this task. The owner will then offer thoughts on the design, tweaks will be made, and the model is ready to enter into the design phase. During schematic design, scheduling(4D) and estimating(5D) really start to get involved. Scheduling must make sure that this building can be built in the time allotted and estimating needs to make sure that they constantly track the cost of the project. How can BIM help with this? The BIM models need to be set up correctly from the start. For scheduling, the model has to be built with building in mind.

It is very laborious for estimating to try and count all of the elements of a process project from a 2D plan. BIM has enabled the design and construction process to be a totally collaborative effort. Typically, this is why a design-build firm can take less time from schematic design through construction of a project than an Architectural & Engineering firm that doesn't have estimators or Construction Manager's on staff.

During detailed design, collaboration is key. It is imperative that weekly coordination meetings take place in order to ensure that everyone is on the same page. In these meetings, the architects and engineers, project manager, estimator, scheduler and Construction Manager are in attendance. In this phase of the design process, Interference Checks and Coordination Reviews are done weekly. This is an obvious step to take, but a lot of firms don't utilize the collaborative tools that BIM provides. Firms usually don't think they have enough time to run Interference Checks or Clash Detections. What they don't realize is that they will spend a lot more time and money fixing the mistakes in the field that could have been caught early in the design phase if they just would have spent the time.

Throughout design, there are certain modeling practices that need to be followed. For one, if you're going to the trouble of modeling the project, it is more efficient to have the model used for more than just plan work. Scheduling, sections, elevations, and walkthroughs are just some of the coordinated processes that can make your BIM model more efficient and, if done correctly, can save time and money. Another important factor is ownership of elements. Talking about ownership, it is to refer to which discipline originally modeled an element. The owner is also referred to as the Model Element Author (MEA). When it comes to copy/monitor, the disciplines that copy/monitor an element from a linked model may have input into that element, but are not the owners of that element. Therefore, the owner of an element needs to pay extra attention to the coordination of that element. One of the best uses of BIM's efficiency is one in which every element type is modeled only once. If there are multiple instances of the same element stretched across disciplines, this can be a headache for coordination and collaboration between models.

After the design is completed, construction is ready to begin. As discussed, throughout design, estimating and scheduling were updating their respective processes. This means that long-lead items have been purchased and the schedule has been modified to ensure project completion by the due date. Also, site work has already been started and foundations are ready to be poured. During the construction phase, Navisworks will be available in the field and the design models may have been replaced by models from the subcontractors. The Construction Manager and field superintendent will work with the design team to make sure that the design intent is followed, and they will run their own Clash Detections on all models. With Navisworks monitoring and workflow tools, identified problems can be reported and tracked through resolution. Construction can be simulated to make sure everything is being built on time. This process was made easier by the fact that BIM was used early in the design phase. It has been found that there are significantly less RFI's when BIM is used correctly in all phases of a project. Along with that, the owner has actually seen what he/she is getting with the aid of walkthroughs and accurate renderings.

BIM has created a solid connection between design and construction that had never been felt before. Instead of asking how the industry can get architects, engineers, and construction managers to collaborate efficiently, it is now asking how it can use BIM to make the process even faster and more efficient.

BIM is a factor of change that improves the collaboration among all the members of project teams. A more complete shared opinion is related to the concept that the true value of BIM stands on the combination of it as a tool and process. The simple equation-tool + process = value of BIM is expressed as the value of-BIM is in the important building efficiencies and initial cost savings and extends to the operations and maintenance of the facility (Team System, 2018). It is relevant to highlight that the more recent disengagement of-the construction industry from classing, time consuming, and-cost intensive activities was due to the introduction of new tools and processes. Therefore, being reluctant to innovation and change may lead to the same processes and no improvement.

It is strongly emphasized the extra value of BIM, interpreting it as more than a tool of technology, it should be incorporated in the-business as an aid for decision making to evaluate the quality of procedures, documentations as well as performance predictions and cost estimations

4.7.5 Advocacy to policy & decision makers to include the usage of BIM in tenders, ToRs & contracts

Matching the experience of private sector owners, one of the main benefits of BIM for government owners is reduction of costs and compression of schedules particularly during the development and construction of a building or infrastructure project. The collaborative processes at the heart of BIM take advantage of the talents and insights of all project participants (designers, engineers, contractors, and so on) to optimize project results, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. The most significant savings can be gained during the construction phase, by reducing rework through clash detection and visual analysis of spatially coordinated digital models. The result is a project that meets the budget, schedule, and needs of the government owner.

4.7.6 Establishment of policy and legal framework (laws, regulations, & standards)

It has to be found ways of maximizing the time that facilities and networks are available to be used by the public. This means using modern technologies to continuously monitor the condition and operation of infrastructure and to intervene before problems arise and to develop better solutions for the future. Because the digital process contains such rich and accessible data, government stakeholders will have much greater visibility into how the project is evolving and being built. If the owner is working with multiple contractors and design teams, this transparency can help ensure that all the stakeholders are coordinated and the project is on track.

According to Coventry University in Future Learn Report (2017), policy has a big role to play in identifying the standard measures that individuals and organizations must follow, and encouraging them to do so. In addition to government policies, companies set their own policies based on their own objectives.

In several countries, policy has influenced construction organizations to adopt Building Information Modelling (BIM). Equally, BIM policies have influenced people to adhere to certain measures that the companies put in place regarding BIM implementation. One of the most important things promoted by BIM is the ability to share information between teams within the same construction projects. This is beneficial for the Architecture Engineering and Construction (AEC) industry as contracts usually forbid information sharing under the clause of confidentiality, liability and litigation concerns.

In other words, contractors, suppliers and designers have to observe legal implications when sharing information relating to their projects. In contrast, BIM promotes collaboration and encourages not only making plans as clear as possible at all stages but also enabling greater sharing of information throughout a project’s lifecycle. As BIM is a relatively new phenomenon in the AEC industry, most companies may not yet have formed BIM implementation policies.

To create effective policy, it is important to understand government guidelines and standards. This means understanding and implementing principles of key standards such as EN ISO 19650-1, BS EN ISO 19650-2, PAS 1192 standards and BS 1192 (in the UK).

To establish and achieve effective policy, it is important to identify the goals regarding BIM in the company and, within that frame:

Gather information by:

- Identifying investment
- Identifying potentials for competitive advantage with BIM tools
- Identifying risks and challenges to be managed
- Identifying software solutions that are the most suitable for the team

Create, document and implement policy by:

- Creating guidelines and protocols for staff to follow, in order to establish a standard and consistent practice, as well as quality and effective communication
- Providing technical and knowledge support
- Applying principles suggested in BIM standards and setting the goals to start with BIM practice

In addition to the demand or desire to set company policies for BIM, existing company policies need to accommodate the new dimension of carrying out projects in the AEC industry (Coventry University, 2017).

4.7.7 Dissemination of BIM importance

The future with BIM is promising as it is cost effective, efficient, and allows for responsive building designs for the whole life-cycle of a building. However, with all these benefits there is one drawback with BIM; there are still professionals in the AEC industry who are soulfully attached to old ways of working. The industry should assist them to overcome the challenges of adopting BIM as it is the right and only chance they have.

Cost savings during planning and construction are only one element of the entire lifecycle benefits of a complex building or infrastructure project. When using BIM for design and construction, teams can develop the digital asset data to support operations and maintenance. Once the capital delivery phase is complete, government owners can utilise the coordinated digital Graphical and Non-graphical data to derive ongoing savings and better performance through improved management of the physical asset. Smart ICT technologies, when combined with aligned digital processes, present a diverse range of capabilities that offer significant benefits across the asset lifecycle for infrastructure, including:

- Planning and strategy
- Development
- Design

- Construction and commissioning
- Operations and maintenance

4.7.8 Enforcement; Government, Industry & Private Sector

According to Safety Fabrications (2017), a recent survey of more than a thousand construction industry professionals has revealed that the current government is not enforcing its BIM (Building Information Modelling) level 2 mandate. A worrying 51% disclosed that they believe that the government has not lived up to its target that all public contracts procured by central government need to be BIM level 2 compliant from April of 2016. This is cause for concern because enforcement is an essential part of the process when it comes to legislation and guidelines. Here in the UK we enjoy a stringent enforcement process in most areas, especially when it comes to health and safety. Legislation depends heavily on enforcement in order to be effective.

However, despite this, the survey did reveal that the government's BIM policy has helped to increase awareness of BIM and has played a significant part in its adoption by construction companies. More than 60% of respondents revealed that they now use BIM, which is a pronounced increase from the results returned in a similar survey carried out a year ago. There's been an 8% increase in BIM usage which is the largest increase recorded by the survey since 2014.

Of the companies that do use BIM, most are satisfied that it offers benefits, with a massive 70% believing that BIM helps to deliver a reduction in costs while 60% are convinced that BIM also helps to bring in projects on schedule, saving both time and money for project owners.

It seems that the construction industry as a whole is taking a positive approach towards BIM usage which means that the industry has risen to the challenge in an admirable manner. The adoption of BIM is an effective method of reaping commercial rewards as there's been a 90% increase in demand for level 2 projects over the past 18 months across both private and public sectors.

Some of the benefits of adopting BIM are:

- It streamlines the project from planning to implementation
- It can reduce risks and improve safety
- It can increase efficiency by up to 30%
- It improves productivity
- It offers an improvement in document co-ordination
- It offers an enhanced communication process between all stakeholders in the project
- It reduces waste and duplication
- It saves money in the long term, providing an effective return on investment (ROI)
- BIM reduces errors and the need for rework
- It reduces conflict and changes during the construction process
- It can improve client relationships
- BIM usage and skills represent a great marketing feature for construction companies

4.7.9 Strategic Implementation

There is no clear consensus on how to implement or use BIM. There is no single BIM document providing instruction on its application and use. It is imperative to standardize the BIM process and to define guidelines for its implementation (LetsBuild, 2016).

Therefore, there is a need to outline who should develop and operate the building information models and how the developmental and operational costs should be distributed.

The technical reasons, on the other hand, can be broadly classified into three categories:

i. The need for well-defined transactional construction process models to eliminate data interoperability issues,
ii. The requirement that digital design data be computable, and

iii. The need for well-developed practical strategies for the purposeful exchange and integration of meaningful information among the building information model components.

Generative designs and BIM not only change the way manufacturers create products but also how architects and designers create buildings. Along with design goals and leveraging various permutations and combinations for a solution to achieve the best way to optimize a building (from floor plans to light levels and by combining blueprints with external factors like neighboring buildings and traffic flow) is a result of what BIM can do. It is crucially important to cultivate positive, effective relationships not only with AEC professionals involved in the construction project but also with advanced AEC technology.

As discussed in Sub-section 4.7.4, construction stakeholders can further protect themselves by applying filters to the information they share; building plans could be shaded green, yellow, or red, for example, to indicate whether the information is final, provisional, or incomplete. By collaborating with stakeholders, all parties can agree upon definitions, processes, policies, and parameters at the start of construction projects. Doing so will reduce risk while streamlining the workflows that BIM relies on.

4.7.10 Sustainability (evolvement, customization, upgrading as per users comments, modification, and others)

BIM might ease the flow of information and connect processes but it will not solve the business challenges. Integrating design data in a model-based design-to-build process may eliminate potential conflicts but does not address the underlying lack of basic business process integration.

According to LetsBuild (2016), once business process and computability are resolved, the final prerequisite for BIM adoption is making the resulting data accessible to the relevant parties involved in the building process. This idea of sharing design information is referred to as “interoperability”. The past years, BIM techniques have been addressing this problem of meaningful interoperability with various integration software that support different BIM tool formats.

Researchers and practitioners in the industry have been developing solutions to overcome these BIM challenges and other associated risks. It is expected that BIM use will continue to increase in the architecture-engineering-construction industry.

4.7.11 Monitoring and Evaluation

As BIM adoption grows, the need for BIM implementation assessment arises to facilitate monitoring, measuring, and improving BIM practices. However, so far, no single study has comprehensively reviewed and reported the existing approaches, metrics, and criteria used for assessing BIM practices. It is imperative to review and analyze the literature and synthesize existing knowledge relevant to monitoring and implementation of BIM tools and process in Rwanda.

4.7.12 Scaling-up

The scale-up of technology is specifically identified as increased uptake among new user cohorts. It is not merely mass production and distribution from the supply-side; scale-up or spread is an ecological phenomenon involving interactions among groups and their environments. BIM scale-up comprise of:

i. Report lesson learned,
ii. Plan actions to increase scalability,
iii. Increase capacity of implementing user organization,
iv. Assess the environment and coordinate planning actions around success,
v. Increase capacity of resource team to support scale-up
vi. Make strategic choices to support vertical scale-up
vii. Make strategic choices to support horizontal scale-up
viii. Determine the role of diversification
ix. Plan actions to address spontaneous scale-up
x. Finalize scale-up strategy and identify the next steps.

According to Team System (2018), in a general overview of the application of the method BIM, it is possible to define three main areas for the identification of a domain in which players and services are present: technology, process and policy. The technology field includes all the parties that work for the improvement of-software, hardware, tools and networking systems all useful to the AEC industry. The process field contains-the-people that are involved in the building, design, use and management procedures. Lastly, the policy field is for organizations, which manage the preparatory phase, normative and contractual practices. As demonstrated in Figure 4.12, the three circles are linked to one another; they are all involved in the processes.

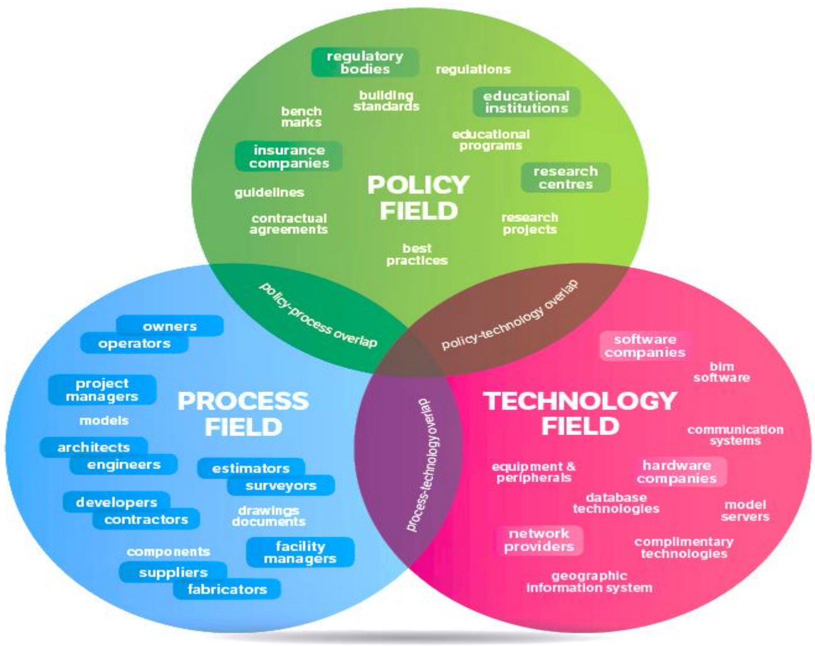

Figure 0.12 Three Activities & Fields of the BIM technology

Source: Team System, 2018

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions and recommendations of this study. It gives a summary of the research findings, conclusions in respect of each the research objectives, and recommendations based on the findings. Finally, areas for further study are given.

5.2 Validation of the research problem

The study focused on investigating the level of use of BIM in Rwanda and elaboration of a process to enable professionals adopting it in the delivery of country's construction projects. Results revealed the lack of awareness of BIM existence and insufficient use of BIM in the construction industry. The study validates the current shortage of building design professionals trained in collaborative design and construction practices. The study also reveals the need of BIM full adoption in construction projects in Rwanda.

5.3 Findings

The main objective of the study was to investigate and address the need of BIM adoption in construction projects in Rwanda. The specific objectives included to explore the current BIM usage level in constructions, to examine benefits in BIM use, to survey barriers in BIM use, and to develop a process for enhancing adoption and usage in construction projects delivery in Rwanda particularly in the City of Kigali.

To address these objectives, the study brought together ideas of different construction industry's key players, their concerns and recommendations on how BIM does impact the construction industry in Rwanda. Barriers for adopting BIM in the country were also recorded. Furthermore, they answered the four questions as per Section 1.4., which were derived from the study objectives.

The extent to which BIM is used in construction projects in Rwanda was explored: Results highlighted that only 21.9% of the total respondents were aware of BIM while 70.9% don't and 82.9% of these who are aware use the technology while 17.1% of them don't;

Benefits and barriers due to use of BIM in Rwanda was examined: Based on the statistics of the respondents who were qualified to reach and answer this section, different benefits and barriers were listed. The fact that BIM allows accurate site logistics plans, easier quantity take-off and time scheduling and greater productivity due to easy retrieval of information were chosen as the most probable benefits while lack BIM training, the need for suitable data sharing standards, unawareness of benefits BIM can bring to organization and insufficient skilled personnel was ranked as the most barriers to implement BIM in Rwanda;

A process that could be followed to ensure BIM is fully used in construction projects in the City of Kigali was formulated as shown in Figure 4.11. It consists of encouraging design and construction professionals to use BIM, BIM courses and training, ICT infrastructure, BIM authoring software and process, advocacy to policy & decision makers to include the usage of BIM in tenders, ToRs & Contracts, establishment of policy and legal framework (laws, regulations, & standards), dissemination, enforcement (Government, Industry, private sector), strategic implementation, sustainability (evolving, customization, upgrading as per users comments, modification, and others), monitoring & evaluation, and scaling-up.

5.4 Conclusions

The construction industry in Rwanda experiences low labor productivity due to the traditional project delivery approach, which involves the use of two-dimensional (2D) Computer Aided Drafting (CAD) technology and the size of construction firms. In addition to the country's limited resources, lack of full adoption of appropriate technologies in the construction industry is continuously affecting the development of the sector. Besides, the current shortage of building design professionals trained in collaborative design and construction practices, remains a barrier to universal adoption of collaborative working practices in the industry.

This research has brought together awareness on BIM need in Rwanda with aim of exploring the level of use, addresses related benefits and barriers, and a process of adoption which the industry can opt for enhancing construction projects delivery in the country. Results showed that:

BIM tools have been somewhat less used in Rwanda. The term BIM doesn't sound new to some professionals although it is not fully used. Only 29.1% of the total respondents were aware of BIM existence and 82.9% of those who were aware have been using it, while 17.1% have not. The study results also showed that only 2D and 3D are the only BIM dimensions used in Rwanda while the technology is continuously evolving and up to date the ninth dimension (9D) is under development. This addresses gaps in BIM dimensions usage in Rwanda. For our case study, BIM tools are used in existing conditions modelling, civil works design, review of designs, quantity, and cost estimation and structural modelling, analysis and design, while no respondent has been using it in energy analysis, code validation, digital fabrication, maintenance scheduling, nor use in other engineering activities. Therefore, there is need of raising BIM awareness and provide trainings to construction and design professionals in Rwanda.

As the best technology that emerges, BIM is used on most of construction activities in both developed and developing countries, this research explored impacts and challenges that the industry experiences due to BIM implication in construction projects life-cycle in Rwanda. Furthermore, a process of adopting the emerging technology in country's construction projects life-cycle and facility management was elaborated.

As discussed, the best delivery of construction projects in Rwanda depends upon AEC professionals' full usage of BIM tools. There are various factors that stimulate the adoption of BIM, namely: innovativeness, Block Chain (Smart Contracts) facilitation, less onsite labor due to offsite fabrication, Improved labor productivity, fewer request of information (RFIs) during construction, Reduced wastage of materials, lower final construction costs, fewer safety incidents, integrated emergency responses into designs, sustainability LEED analysis and evaluation, climate change mitigation and adaptation, ease of operations and big data management within the construction industry. Additionally, there are broader national/policy issues to consider before implementation of BIM in Rwanda, namely: awareness, uptake, training, cost (licensing), ICT infrastructure, application and BIM enablers or supporters.

5.5 Recommendations

Implementing BIM in country's infrastructure planning, design, execution, operation, and facilities management is vital to boom the Rwanda's construction industry. It is strongly recommended that MININFRA, IER, RIA and other institutions involved in developing infrastructure in Rwanda should substantially intervene in instituting the use of BIM in country's infrastructure life-cycle. Instituting BIM usage involves elaboration of new rules and regulations regarding BIM implementation in country's infrastructure considering existing BIM related policies from software authoring companies. Involved stakeholders should also stress on preparing tenders or Terms of References (ToRs) that focus on using BIM during setting consulting and contracting works. Contracts should also contain articles that highlight the obligations of contractors or/and consultant to fully BIM for a specific assigned construction or consulting work. Additionally, it is recommended that infrastructure development stakeholders to value and refer to the suggested BIM implementation process as highlighted in this study (see Section 4.7) and to opt for the use of BIM during the procurement and logistics (supply chain management) processes in Rwanda. Finally, the elaborated process might be important to other countries where BIM has not been fully employed. Thus, scaling up may be crucial.

5.6 Areas for Further Research

In the light of the foregoing, there are four several BIM research opportunities. Firstly, according to Goubau (2018), there is lack of clear consensus on how to implement or use BIM, and no single BIM document providing instruction on its application and use. Thus, it is an opportunity to conduct researches in standardizing the BIM process and defining guidelines for its implementation in the region. There is also the need to outline who should develop and operate the building information models and how the developmental and operational costs should be distributed within the construction industry in Rwanda and worldwide as well.

Secondly, there is a research opportunity to establish the harmony of the construction industry. Globally, BIM application and other aspects of ICT and construction technology are impacting the construction industry. These aspects include, but are not limited to Big Data, software and mobile applications in construction, artificial intelligence, wearables, drones and robots, augmented reality, prefabrication, modularization, and eco-friendliness.

Thirdly, the reality of anxiety that some actors (example of quantity surveyors) will lose their roles in construction industry when use of BIM is fully embraced in the industry. Since many are at risk due to fully BIM usage, the industry should eventually brace itself with this new technology to maintain the role that construction actors with the industry and prevent them losing their jobs.

Finally, it is necessary to do regression analysis of level of BIM implementation and the many variables that influence it. The factors operate at the project and firm levels, and also at the sectors levels of the construction industry. More rigorous statistical analysis than that which was doable in this study should give greater insight into this area, for the BIM policy design and enactment in Rwanda.

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Appendix I BIM Tools Matric

Software - Preliminary Design and Feasibility Tools					
Product Name	Manufacturer	BIM Use	Manufacturer's Description	Primary Function	Supplier Web Link
Revit Architecture	Autodesk	Creating and reviewing 3D models	Autodesk® Revit® technology is Autodesk's platform for building information modeling. Built on the Revit platform, Autodesk® Revit® Architecture software is a complete, discipline-specific building design and documentation system supporting all phases of design, from conceptual studies through the most detailed construction drawings, documentation and schedules.	Architectural Modeling and parametric design.	www.autodesk.com
DProfiler	Beck Technology	Conceptual Design and Cost Estimation	The company's flagship program, called DProfiler™, integrates conceptual 3D modeling with cost estimating intelligence enabling project teams to evaluate more alternatives in less time with better clarity before moving into design development	3D conceptual modeling with real-time cost estimating	www.beck-technology.com
Bentley Architecture	Bentley Systems	Creating and reviewing 3D models	Bentley's fully integrated multi-disciplinary products empower architects, structural engineers, civil engineers, electrical engineers, mechanical engineers, energy assessors, site designers, and other professionals to design, analyze, construct and manage buildings of all types and scales.	Architectural Modeling	www.bentley.com
SketchUp Pro	Google	Conceptual 3D Modeling	Google SketchUp Pro is used to quickly create accurate 3D models for pursuit and marketing, preliminary estimation, detailing, site logistics and staging, design and construction validation, sequencing and line of sight analysis. It enables collaboration and communication between the various stakeholders on a project.	Conceptual Design Modeling	www.sketchup.google.com
ArchiCAD	Graphisoft	Conceptual 3D Architectural Model	ArchiCAD was the first object oriented BIM Architectural application available in the commercial market, and the only BIM architectural application running on the MAC platform, as well as Windows	Architectural Model Creation	www.graphisoft.com
Vectorworks Designer	Nemetschek	Conceptual 3D Modeling	From design concept to construction documentation and every design phase in between, Vectorworks Designer marries precision 2D drafting and flexible 3D modeling with state of the art technology.	Architectural Model Creation	www.nemetschek.net
Tekla Structures	Tekla	Conceptual 3D Modeling	Tekla Structures is primarily a structural authoring tool, however it is possible to create conceptual models, as well.	A structural 3D Model Application	www.tekla.com
Affinity	Trelligence	Conceptual 3D Modeling	Trelligence Affinity focuses on architectural programming and schematic designs that fast-forward BIM into the pre-design phase; thereby providing both time and cost design concept to construction documentation and every design phase in between, Vectorworks Designer marries precision 2D drafting and flexible 3D modeling with state of the art technology.	A 3D Model Application for early concept design	www.trelligence.com
Vico Office	Vico Software	Conceptual 3D Modeling	Vico Office allows GCs to combine BIMs from Revit, Tekla, ArchiCAD, CAD-Duct, and IFC files. The "whole model" (whatever its level of detail) can then be coordinated, scheduled and estimated	5D conceptual model which can be used to generate cost and schedule data	www.vicosoftware.com
Software - BIM Authoring Tools					
Product Name	Manufacturer	BIM Use	Manufacturer's Description	Primary Function	Supplier Web Link
Revit Architecture, AutoCAD Architecture	Autodesk	Architecture and site design	Autodesk® Revit® technology is Autodesk's platform for building information modeling. Built on the Revit platform, Autodesk® Revit® Architecture software is a complete, discipline-specific building design and documentation system supporting all phases of design, from conceptual studies through the most detailed construction drawings, documentation and schedules.	Architectural Modeling and parametric design.	www.autodesk.com
Revit Structure	Autodesk	Structural	Same as above, but for Structural design	Structural Modeling and parametric design	www.autodesk.com
Revit MEP, AutoCAD MEP	Autodesk	MEP	Same as above, but for MEP design, modeling to support analysis	MEP modeling	www.autodesk.com
Bentley BIM Suite - Includes MicroStation, Bentley Architecture, Bentley Structural, Bentley Building Mechanical Systems, Bentley Building Electrical Systems, Bentley Building Electrical Systems for AutoCAD, Generative Design and Generative Components	Bentley Systems	Multi-discipline	Each discipline-specific application provides an informed work environment to support the design and documentation process throughout all phases of the project lifecycle-from conceptual design and construction documentation to coordination and construction and allow distributed teams to "build as one" within a managed environment. Building Information Modeling (BIM) is a way of approaching the design and documentation of building projects – by modeling and managing not just graphics, but also information. This information allows the automatic generation of drawings and reports, design analysis, schedule simulation, facilities management, and more – ultimately enabling the building team to make better-informed decisions and to produce better buildings. Generative design enables architects and engineers to pursue designs and achieve results that were virtually unthinkable before. Using associative parametrics and computational methods, designers can explore a broad range of "what-if" alternatives for even the most complex buildings, quickly and easily. Prerequisites: MicroStation® v8.1.2 or higher ; Microsoft Word & Excel (for reporting), Supports DGN, DWG, DXF, PDF, IFC, SKP, 3DS, CIS2, gbXML and more.	Architectural, Structural, Mechanical, Electrical and Generative Components - all within the 3D modeling environment	www.bentley.com
Digital Project	Gehry Technologies	Multi-discipline	Gehry Technologies combined FOA's 3D design and management capabilities with project experience gained with using Dassault Systemes' 3D solutions over the years to create Digital Project, a CATIA-based building information modeling (BIM) system. A platform which combines Dassault Systemes' solutions and dedicated software developed by Gehry Technologies specifically for building industry systems, Digital Project generates a single digital model which can be accessed and modified by all teams participating in the same building projects.	Digital Project Designer is a high-performance 3D modeling tool for architectural design, engineering, and construction. Designer provides an extensive set of tools for creating and managing building information throughout the building lifecycle.	www.gehrytechnologies.com
Digital Project MEP Systems Routing	Gehry Technologies	MEP	Digital Product Systems Routing is a design application that enables system planners to reserve the space needed for functional and detail layouts of HVAC, raceways, and plumbing. MEP planners can optimize their designs analyzing spatial needs and installation sequences.	MEP Design	www.gehrytechnologies.com
SketchUp Pro	Google	Multi-discipline	Google SketchUp Pro is used to quickly create accurate 3D models for pursuit and marketing, preliminary estimation, detailing, site logistics and staging, design and construction validation, sequencing and line of sight analysis. It	3D Architectural and Structural modeling	www.sketchup.google.com

AutoSPRINK VR	M.E.P. CAD	Fire Protection	[illegible]	3D Fire Sprinkler Design and Modeling	[illegible]
FireCad	[illegible]	Fire Protection	[illegible]	Fire piping network design and modeling	[illegible]
AutoCAD Civil 3D	Autodesk	Civil & Infrastructure and Site Logistics	[illegible]	Site development	[illegible]
PowerCivil	Bentley Systems	Civil & Infrastructure and Site Logistics	[illegible]	Site development	[illegible]
Site Design Site Planning	Eagle Point	Civil & Infrastructure and Site Logistics	[illegible]	Site development	[illegible]
Synchro Professional	Synchro Ltd.	Site Logistics	[illegible]	Scheduling (4D), sequencing	[illegible]
Tekla Structures	Tekla	Site Logistics	[illegible]	A fully integrated BIM solution based upon a structure centric approach	[illegible]

Software - BIM Analysis Tools

Product Name	Manufacturer	BIM Use	Manufacturer's Description	Primary Function	Supplier Web Link
Robot	Autodesk	Structural Analysis	[illegible]	[illegible]	[illegible]
Green Building Studio	Autodesk	Energy Analysis	[illegible]	Measure energy use and carbon footprint	[illegible]
Ecotect	Autodesk	Energy Analysis	[illegible]	[illegible]	[illegible]
Structural Analysis/Detailing (STAAD Pro, RAM, ProStructures), Building Performance (Bentley Hevacomp, Bentley Tas)	Bentley Systems	Structural Analysis/Detailing, Quantity Take-off, Building Performance	[illegible]	Measure, assess and report building performance	[illegible]
Solibri Model Checker	Solibri	Model Checking & Validation	[illegible]	Rules-based checking for compliance and validation of all objects in the model	[illegible]
VE-Pro	Integrated Environmental Solutions (IES)	Energy & Environmental Analysis	[illegible]	[illegible]	[illegible]
RISA	RISA Technologies	Structural Analysis	Links to Autodesk Revit Structure	[illegible]	www.risatech.com
Digital Project	Gehry Technologies	Structural Analysis	[illegible]	[illegible]	[illegible]
GTSTRUDL	Georgia Institute of Technology	Structural Analysis	Structural Analysis tool developed at Georgia Tech	Structural Analysis	[illegible]
EnergyPlus	U.S. Department of Energy & LBNL	Energy Analysis	[illegible]	Energy Simulation	[illegible]
DOE2	Lawrence Berkeley National Lab (LBNL)	Energy Analysis	[illegible]	Energy Simulation	[illegible]
Flovent	Mentor Graphics	Air Flow/CFD	[illegible]	Environmental simulation and analysis	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

GTSTRUDL	Georgia Institute of Technology	Structural Analysis	Structural Analysis tool developed at Georgia Tech	Structural Analysis	[illegible]
Energy Plus	U.S. Department of Energy & LBNL	Energy Analysis	EnergyPlus models heating, cooling, lighting, ventilating, and other energy flows as well as water in buildings.	Energy Simulation	[illegible]
DOE2	Lawrence Berkeley National Lab (LBNL)	Energy Analysis	DOE-2 is a widely used and accepted freeware building energy analysis program that can predict the energy use and cost for all types of buildings.	Energy Simulation	www.doe2.com
Flovent	Mentor Graphics	Air Flow/CFD	[illegible]	Environmental simulation and analysis	www.mentor.com
Fluent	Ansys	Air Flow/CFD	[illegible]	Environmental simulation and analysis	www.ansys.com
Acoustical Room Modeling Software	ODEON	Acoustical Analysis	[illegible]	Acoustic Simulation and Analysis	www.odeon.dk
Apache HVAC	IES	MEP Analysis	[illegible]	HVAC Plant Simulation	www.iesve.com
Carrier E20-II	Carrier	MEP Analysis	[illegible]	HVAC system analysis	[illegible]
TRNSYS	Solar Energy Lab(U. of Wisconsin & U of Colorado	Thermal Energy Analysis	[illegible]	Simulation of performance of thermal energy systems.	www.trnsys.com
Software -Shop Drawing and Fabrication Tools					
Product Name	**Manufacturer**	**BIM Use**	**Manufacturer's Description**	**Primary Function**	**Supplier Web Lin**
CADPIPE Commercial Pipe	AEC Design	Shop Drawing & Fabrication	[illegible]	Fabrication	[illegible]
Revit MEP	Autodesk	Shop Drawing	Creates detailed shop drawings	Detail Design for Shop Drawings	www.autodesk.com
SDS/2	Design Data	Shop Drawing	[illegible]	Detail Design for Shop Drawings	[illegible]
Fabrication for AutoCAD MEP	East Coast CAD/CAM	Fabrication	[illegible]	[illegible]	[illegible]
CAD-Duct	Micro Application Packages Ltd.	Fabrication	[illegible]	Use AutoCAD geometry for fabrication	www.cadduct.com
PipeDesigner 3D & [illegible]	QuickPen International	Fabrication	[illegible]	Use AutoCAD geometry for fabrication	[illegible]
Tekla Structures	Tekla	Shop Drawing	[illegible]	Structural centric fabrication	www.tekla.com
Trimble® Design Link	Trimble	MEP	[illegible]	[illegible]	[illegible]
Software - Construction Management Tools					
Product Name	**Manufacturer**	**BIM Use**	**Manufacturer's Description**	**Primary Function**	**Supplier Web Link**
Navisworks Manage	Autodesk	Clash Detection	[illegible]	Model-based Clash Detection between trades	www.autodesk.com
ProjectWise Navigator	Bentley	Clash Detection	[illegible]	Coordination between models and [illegible]	www.bentley.com
Digital Project Designer	Gehry Technologies	Model Coordination	[illegible]	[illegible]	[illegible]
Solibri Model Checker	Solibri	Spatial Coordination	[illegible]	[illegible]	www.solibri.com
Synchro Professional	Synchro Ltd.	Planning & Scheduling	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Product Name	Manufacturer	BIM Use	Manufacturer's Description	Primary Function	Supplier Web Link
QTO	Autodesk	Quantity Takeoffs	With QTO, cost estimators can create synchronized comprehensive project views that combine information from Autodesk Revit applications.	Generating takeoffs from multiple environments both 2D & 3D	www.autodesk.com
DProfiler	Beck Technology	Conceptual Estimates	The company's flagship program, called DProfiler™, integrates conceptual 3D modeling with cost estimating intelligence enabling project teams to evaluate more alternatives in less time with better clarity before moving into design development	Conceptual 3D modeling with cost estimating and life cycle operational costs forecasting	[illegible]
Visual Applications	Innovaya	Estimating	Innovaya Visual Quantification performs object quantity takeoff accurately, quickly, and intelligently from Autodesk's ADT/Revit	Extracting quantities and building estimates from ADT & Revit files	www.innovaya.com
Vico Takeoff Manager	Vico Software	Quantity Takeoffs	Vico Takeoff Manager™ generates quick and highly accurate model- and location-based quantity takeoffs derived from 3D models created with leading BIM authoring tools. Since quantity takeoff is a live view, newly published and activated model versions result in automatically updated quantities.	Quantity Takeoffs, feeding into estimating and scheduling	www.vicosoftware.com

BIM Software - Scheduling Tools

Product Name	Manufacturer	BIM Use	Manufacturer's Description	Primary Function	Supplier Web Link
Navisworks Simulate	Autodesk	Scheduling	Simulate allows the user to link popular project software with selected objects (or sets of objects) in the 3D model, then to simulate the project's progress.	Linking 3D model to popular project schedule applications (e.g. MS Project or Primavera)	www.autodesk.com
ProjectWise Navigator	Bentley	Scheduling	Schedule Simulator allows the linkage between the major project software and selected objects (or sets of objects) in the 3D model, then to simulate the project's progress	Linking 3D model to popular project schedule applications (e.g. MS Project or Primavera)	www.bentley.com
Visual Simulation	Innovaya	Scheduling	Visual Simulation makes it possible to link the Revit model with the leading project software, then to simulate the progress of the project	Linking 3D model to popular project schedule applications (e.g. MS Project or Primavera)	www.innovaya.com
Synchro Professional	Synchro	Scheduling	BIM for Delivery from concept to commissioning (versus BIM for Design or Facilities Operations); integrated and collaborative 3d model based scheduling, budgeting/cost and supply chain management.	Bi-directional linking to popular project schedule applications (e.g. MS Project or Primavera)	www.synchroltd.com
Tekla Structures	Tekla	Scheduling	It is a model based solution that supports contractors, sub-contractors and project management professionals by centralizing project data into a visual 3D and [illegible]	Schedule driven by link between model and project software	www.tekla.com
Vico Control	Vico Software	Scheduling	Using Control, planners can design significantly compressed schedules without increasing risk. The incorporation of locations, estimated quantities and productivity rates early in the planning phase yields clear, accurate, and feasible schedules.	Schedule is scientifically derived from the resource loaded, cost loaded, location based BIM	www.vicosoftware.com

BIM Software - File Sharing & Collaboration Tools

Product Name	Manufacturer	BIM Use	Manufacturer's Description	Primary Focus	Supplier Web Link
Digital Exchange Server	ADEPT Project Delivery	File Sharing and Communication	A user friendly environment for file sharing which can be customized for each user/project. Allows setting of security/access levels and versioning of all model (or generic document) files.	Project centric, auto-tracking, supports BIM production collaborative process	www.adeptprojectdelivery.com
Buzzsaw	Autodesk	File Sharing	Autodesk Buzzsaw collaborative project management streamlines the way your project teams work together	A repository for all project related documents and files	www.autodesk.com
Constructware	Autodesk	Collaboration	Delivered on-demand, helps construction organizations standardize and optimize business processes and control costs	Web-based suite of management tools for construction projects	www.autodesk.com
ProjectDox	Avolve	File Sharing	A central repository for all project communication and documents	Electronic plan submission, review, tracking and archiving	www.avolvesoftware.com
SharePoint	Microsoft	File Sharing, Storage, Management	Microsoft Office SharePoint Server is an integrated suite of server capabilities that can help improve organizational effectiveness by providing comprehensive content management and enterprise search, accelerating shared business processes, and facilitating information sharing across boundaries for better business insight.	Web-based portal for file storage, management and sharing	www.microsoft.com
Project Center	Newforma	Project Information Management	[illegible] environment for project managers and the project team by organizing technical project information, facilitating information sharing, and enabling more effective project process	Enterprise level, self hosted Project Information Management System	www.newforma.com
Doc Set Manager	Vico Software	Drawing Set Comparison	Doc Set Manager automatically collates and compares construction drawing sets. Users cloud changes and create RFIs.	Identifying changes between construction drawing sets	www.vicosoftware.com
FTP Sites	Generic Providers	File Sharing	Uploading and downloading of files, normally not a customized environment.	Web-based file sharing environment, limited security, limited flexibility	

Appendix II Research Approval Letter

JOMO KENYATTA UNIVERSITY
OF
AGRICULTURE AND TECHNOLOGY
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

P.O. BOX 62000
NAIROBI – 00200
KENYA
Email: director@bps.jkuat.ac.ke

TEL: 254-067-52711/52181-4
FAX: 254-067-52164/52030

REF: JKU/2/11/AB343-C010-6414/2015

05TH NOVEMBER, 2018

MUSABYIMANA ENOCK
C/o SABS
JKUAT

Dear Mr. Musabyimana,

RE: APPROVAL OF RESEARCH PROPOSAL AND OF SUPERVISORS

Kindly note that your MSc. research proposal entitled: **"ADOPTION OF BUILDING INFORMATION MODELLING (BIM) ON CONSTRUCTION PROJECTS IN RWANDA"** has been approved. The following are your approved supervisors:-

1. Dr. Abednego O. Gwaya
2. Dr. Titus Kivaa

Yours sincerely,

PROF. MATHEW KINYANJUI
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

Copy to: Dean, SABS
/cm

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Appendix111: Data Collection Letter

JOMO KENYATTA UNIVERSITY
OF AGRICULTURE AND TECHNOLOGY
Office of the Director
KIGALI CAMPUS

P.O Box 3373, Kigali-Rwanda Email: director .kigalicampus@jkuat.ac.ke

FROM: DIRECTOR **DATE:** 2ND FEBRUARY 2019

TO: TO WHOM IT MAY CONCERN. **REF:** JKU/13/05/752

SUBJECT: ENOCK MUSABYIMANA- AB343-C010-6414/2015.

The above named is a bona fide student of Jomo Kenyatta University of Agriculture and Technology (JKUAT) pursuing a Masters Degree course in Construction Project Management.

On behalf of JKUAT, I am writing to request your institution to allow him to access data and information that shall assist him in his research. We assure you that any data and information collected shall only be used for research purposes.

Any assistance accorded to him shall be highly appreciated.

Yours Faithfully

PROF.CHERUIYOT WILSON (PhD),
DIRECTOR.

JKUAT KIGALI CAMPUS Director P.O.BOX:3373 KIGALI

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Appendix IV: Invitation Letter to Respondents

Jomo Kenyatta University of Agriculture and Technology
(JKUAT)
School of Architecture and Building Sciences
Nairobi Kenya

January 30, 2019

Dear Respondent,
RE: INVITATION TO PARTICIPATE IN A RESEARCH STUDY

We do consider you as a potential contributor to this research, your responses to this questionnaire is of great importance to achieve meaningful results and guarantee the information that you provide will be kept confidential and will be considered for academic use only and some of the outcomes of this research will be shared to you as well as it is completed.

The study is part of the Master of Construction Project Management thesis entitled "**ADOPTION OF BUILDING INFORMATION MODELLING (BIM) ON CONSTRUCTION PROJECTS IN RWANDA**" at Jomo Kenyatta

University of Agriculture and Technology, Nairobi, Kenya.

BIM is a world widely used term in the construction sector and known as a managed process comprising gather, apply and showcase information of any construction project. Moreover, by definition, BIM is a computer-generated model that contains all the textual, graphical and tabular data about the design, construction and operation of any facility. Due to the increased importance and need of BIM and its benefits, we are conducting this survey to explore the its adoption on the country's construction projects. It is therefore important to address the actual benefits of BIM, relevant problematic issues, to enable the progressive use of the technology.

We thank you and value your responses!

Yours faithfully,

Enock Musabyimana

Master of Science in Construction
Project Management Researcher
Email: musanock@gmail.com
Tel: +250 788 888 847

Supervisors:

- Dr. Abednego O. Gwaya

Email: agwaya@jkuat.ac.ke

- Dr. Titus Kivaa

Email: tkivaa@jkuat.ac.ke

Appendix V Survey Questionnaire

1. What is your professional title?

- ◯ Construction Project Manager
- ◯ Engineer
- ◯ Architect
- ◯ Quantity Surveyor
- ◯ Urban Planner

Which sector do you work for?

- ◯ Public
- ◯ Private
- ◯ Contractor
- ◯ Consultant
- ◯

Other (please specify) ……………………………………………………………..

2. How many years of experience do you have in the construction industry?

- ◯ Between 0 and 4
- ◯ Between 5 and 9
- ◯ Between 10 and 14
- ◯ More than 14

3. Are you aware of Building Information Modelling (BIM)?

○ Yes

○ No

4. Do you use BIM in your professional work?

○ Yes

○ No

5. How long in years have you used BIM?

0	1	2	3	4	5	More than 5 years
○	○	○	○	○	○	○

How exactly have you been using BIM?

○ Project Management

○ Architectural Modelling

○ Civil Works Design

○ Structural Modelling and Design

○ Quantity and Cost Estimation

○ Other (please specify) …………………………………………………………..

6. To what extent do you use BIM tools?

Don't use	1	2	3	4	5 Use much more	
○	○	○	○	○	○	○

7. Which of the following BIM dimensions have you been using?

- ◯ Two Dimension (2D)
- ◯ Three Dimension (3D)
- ◯ Four Dimension (4D) (Time scheduling incorporated)
- ◯ Five Dimension (5D) (Estimating incorporated
- ◯ Six) Dimension (6D) (Sustainability (energy analysis, LEED) incorporated)
- ◯ Seven Dimension (7D) (Facility management application incorporated)
- ◯ Eight Dimension (8D) (Safety incorporated)

Nine Dimension (9D) (Emergency responses incorporated)

8. How many other members of your office use BIM in your projects?

0-5	5-10	10-15	15-20	More Than 20	all
◯	◯	◯	◯	◯	◯

9. How many projects has your organization so far undertaken using BIM in any capacity?

0-5	5-10	10-15	15-20	More Than 20	all
◯	◯	◯	◯	◯	◯

10. Based on project changes/results you have experienced using BIM, please rate the following factors on an importance scale of 0-5, where 0=Not important and 5= most important" at which BIM can be useful if implemented on every construction project in Rwanda**:**

	0	1	2	3	4	5
	Not at all important	Not so important	Somewha t Important	Importan t	Very important	Extremely important
Improved cost estimating at each project stage, productivity of estimator in quantity take-off						
Easier quantity take-off and time scheduling						
Reduced cost from health and safety issues						
Reduced overall project cost						
Increased speed of delivering projects, productivity and quality						
	0	1	2	3	4	5
	Not at all important	Not so important	Somewha t Important	Importan t	Very important	Extremely important
Allows increased energy analysis of the building						
Generation of accurate and consistent 2D and 3D drawings at any stage						
Improved communication and coordination and collaboration between project parties						

Potentially Improved whole life asset management (Involvement in operation and maintenance phase)						
Allows accurate site logistics plans						
Greater productivity due to easy retrieval of information						
Improved conflicts detection						
Improved human resources management						
Other specify	………………….					

11. Please assess the negative impact of the following barriers to implementation of BIM in Rwanda on a scale of 0-5, where 0=Not important and 5= most important"":

	0	1	2	3	4	5
	Not at all a barrier	A week barrier	An averag e barrier	A strong barrier	Very strong barrier	Extremely strong barrier
Unawareness of benefits BIM can bring to organization						
The need for suitable data sharing standards						
Lack BIM training						
Insufficient ICT infrastructure						
Lack of clear boundary of responsibilities between						

parties						
The need to mandate BIM usage in specific contracts						
Insufficient skilled personnel						
People refusal/reluctance to learn						
Client-driven limitations, e.g. due to unawareness of BIM benefits						
Cost of new software and updates						
Lack of integrated BIM Tertiary Studies Curriculum						
Other specify	……………………..					

Would you recommend implementing BIM on every construction project for improved performance in Rwanda**?**

◯ Yes

◯ No

Why? Explain your answer

12. What strategies do you suggest for enhancing BIM adoption and usage in the built environment of Rwanda?

-END-

Appendix VI: Paper Publication Certificate

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CERTIFICATE

This certifies that the research paper entitled '**Adoption of Building Information Modeling (BIM) on Construction Projects in Rwanda**' authored by '**Enock Musabyimana, Abedenego O. Gwaya, Titus Kivaa**' was reviewed by experts in this research area and accepted by the board of 'Blue Eyes Intelligence Engineering and Sciences Publication' which has published in '**International Journal of Innovative Science Modern Engineering (IJISME)**', ISSN: 2319–6386 (Online), Volume-5 Issue-12, June 2019. Page No.: 1-6.

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(Editor-In-Chief)