AN EVALUATION OF INFORMATION AND COMMUNICATION TECHNOLOGY APPLICATION IN SOUTH AFRICAN CONSTRUCTION INDUSTRY

by

TAWAKALITU BISOLA, ODUBIYI

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SUPERVISOR: PROF. C.O. AIGBAVBOA

CO-SUPERVISOR: PROF. W.D. THWALA

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TAWAKALITU BISOLA ODUBIYI

SUPERVISOR: PROF. C.O. AIGBAVBOA

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A **DISSERTATION** submitted in fufilment of the requirments for the award of the degree Magister Technologiae in Construction Management in the Faculty of Engineering and the Built Environment, Department of Construction Management and Quantity Surveying at the University of Johannesburg, Republic of South Africa.

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DECLARATION

I, **TAWAKALITU BISOLA ODUBIYI,** hereby declare that this Master's dissertation is wholly my own work and has not been submitted anywhere else for academic credit either by myself or another person. I understand what plagiarism implies and declare that this dissertation is my own ideas, words, phrase, arguments, graphics, figures, results and organization except where reference is explicitly made to another's work. I understand further that any unethical academic behaviour, which includes plagiarism, is seen in a serious light by the University of Johannesburg and is punishable by disciplinary action. It was submitted to the University of Johannesburg (Department of Quantity Surveying and Construction Management), as a requirement to obtain a **MAGISTER TECHNOLOGIAE** degree in **Construction Management**

Signed…………………...... **Date…………………**

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DEDICATION

I dedicate this DISSERTATION to my family, for their endless prayers and support.

ABSTRACT

The construction industry is evolving like other allied industries. New innovations are borne out of the quest to achieve more value for money, while also retaining a competitive edge in the international sphere. A comprehensive study on the application of information and communication technology (ICT) for construction work in South Africa, particularly the stages of construction work, is lacking. This study seeks to evalaute information and communication technology tools used for construction activities in the South Africa construction industry. The research evaluates the level of awareness of construction professionals as to the use of new ICT tools in the fourth industrial revolution era. It also discusses the ICT tools used at the planning stage of construction, the design and the construction stage. It employed the Professional Client/Consultants Service Agreement Committee (PROCSA) template but limited it to stage 0 to 5. It also discusses the challenges, drivers and benefits of using ICT tools for construction activities in South Africa. The primary data was collected through a questionnaire which was distributed online via Questionpro platform to South African construction professionals in Gauteng Province only. One hundred and fifty (150) questionnaires were distributed. One hundred and twenty (120) of the responses were valid and used for the analysis. This accounted for eighty per cent (80%) of the total survey. In ensuring the reliability of the research questionnaire, Cronbach's alpha coefficient reliability was conducted on the scaled research questions. Compare mean was used to address the level of awareness of ICT tools and ICT tools used at the planning, design, and construction stages. Factor analysis was used to analyze the factors which serve as challenges to, drivers of, and benefits of the effective use of ICT tools. The study revealed that professionals have different awareness levels of ICT tools. They are more aware of ICT tools that are the core of their professional duties. At the planning stage of construction work in South Africa, all professionals use design/estimation and simulation-based tool most. In the design stage, the most frequently used tools are the computer-based tools and the design/estimation-based tools which are used by engineers, architects, and construction project managers. At the construction stage, computer-based tools and administrative tools are the highest-ranked tools. The exploratory factor analysis revealed that the challenges to the use of ICT in the South African construction industry are classified into people, cost, standardization, and management-related problems. The measures to ensure the effective use of ICT tools for construction processes in South Africa are also grouped into user-related factors, ICT knowledge and end-uses. The benefits from the effective use of ICT tools for construction activities in South Africa include improvement of the construction industry, productivity-related benefits, and construction enterprises at advantage. The study concludes that the construction process is in South Africa is evolving owing to new ICT tool usage. Construction professionals use these ICT tools differently at the various stages of construction work. ICT users and the government play roles regarding the challenges, drivers and benefits of ICT tools.. There should also be tools to measure variables for ICT use on an organizational level. Lastly, it recommends that the government should intensify concerted measures to ensure effective use of ICT in the construction industry.

Keywords: Construction industry, ICT tools, Stages of construction work, Planning, Design, construction, South Africa

LIST OF ABBREVIATIONS

AEC	Architectural, Engineering and Construction
ANN	Artificial neural network
BEPs	Built environment professions
BIM	Building information modelling
BMS	Building Management Sytems
BRICS	Coalition of Brazil, Russia, India, China, and South Africa
CFA	Confirmatory factor analysis
CI	Construction industry
CM	Construction manager
CPM	Construction project manager
EFA	Exploratory factor analysis
GDP	Gross domestic products
GIS	Geographic information system
ICT	Information and communication technology
IoT	Internet of Things
IT	Information technology
JBCC	Joint Building Contract Committee
KMO	Kaiser-Meyer-Olkin
MIS	Mean item scores
PLM	Project lifecycle management
PROCSA	Professional Client/Consultants Service Agreement Committee
QS	Quantity surveyor
RFID	Radio-frequency identification
RIBA	Royal Institute of British Architects

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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

This introductory chapter discusses the general background of the study. The chapter also highlights the contents of the study and provides the organisation followed in the development of the dissertation on the evaluation of information and communication technology uptake and usage in the South Africa construction industry. This includes the aim, research problem statement, research questions, objectives, motivation, and purpose of the study.

1.2 GENERAL BACKGROUND

Construction involves the creation, renovation, alteration and maintenance of physical infrastructures such as buildings, utility systems, civil structures and the like (Bjork, 1999:5; Behm, 2008:175; Osei, 2013:56). Hence, the construction industry is defined by its activities and the region of operation (Foulkes and Ruddock, 2007:89; Ofori, 2015:115). The study by Townsend (2017:94) revealed that construction is the same worldwide. This implies that the platform for carrying out construction activities is influenced by the choice of technology and construction principles applied during the construction stages (Hendrickson and Au, 2008:537). Therefore, technology plays a role in the construction process.

The construction industry in Africa is slowly progressing. It is deploying strategies to catch up with its developed-country counterparts (Deloitte 2015:2). South Africa, for example, is described as a regional leader in Africa (You, Bianco, Lin and Amankwah-Amoah, 2019:268). Its construction industry is advancing as a result of information, communication and technology (ICT) applications and uptake. Laudon and Laudon (2012:46) described technology as a collection of computer-based information systems. It is an innovation applied in all spheres of life which makes it germane to every economic structure (Vidas-Bubanja and Bubanja, 2015:21). In addition, Gaith, Khalim and Amiruddin (2012:3323) pointed out that in this age, information technology (IT) is a tool that helps enterprises and the people involved to achieve better efficiency. Similarly, Shen and Liu (2004:385) and Alsafouri and Ayer (2018:176) added that the success of industries depends on ICT use. Construction is one of such industries. There is ease of access to information and enhanced the collaborative platform for construction stakeholders, which all leads to efficiency in the construction industry (Sardroud, 2014:56; Akinbile and Oni, 2016:164). Hence, ICT is beneficial to the construction industry.The dimensions of ICT tools keep changing daily to meet up with the construction industry need. For example, the study of Adwan and Al-Soufi (2018: 279) grouped ICT application into categories which revolves around the use of computer and the web. Some examples of ICT tools for construction activities include those which are modelling based (Oesterreich and Teuteberg, 2016:126), administrative based (Adwan and Al-Soufi, 2018:279) and big data-based (Bilal *et al.*, 2016), among others. There is, however, a growing perception that the current ICT tools are no longer competent to handle tasks at the various stages of construction work (Ahuja, Yang and Shankar, 2009:145; Oesterreich and Teuteberg, 2016: 128). In South Africa, the construction industry as a whole is criticised as being inefficient and slow to innovate as compared to the manufacturing sector (Abor and Quartey, 2010:221). Similarly, there have been challenges to measuring the investment cost attached to the use of ICT tools for construction work (Love, Irani and Edwards, 2004:521; Eadie and Perera, 2016:23). Therefore, there is a call for continual improvement of ICT applications for construction work.

There is also a call to introduce measures which will improve innovation at the various stages of construction work. These stages range from the planning stage, design, construction and in-use stage. For a developing country such as South Africa, it is essential to improve the ICT usage for construction activity (Ibem and Laryea, 2015: 365) and for the various construction stages. To achieve this, technological-environment influenced factors, organizational influenced factors, and external organizational influenced factors (Ricciardi, Zardini and Rossignoli, 2016:46) are needed. These described the relative advantage of the ICT tools used and the investment-yield ratio of the tool, which is the perceived benefit from the use of the ICT tools (Tan, Chong, Lin and Eze 2009:224; Chatzoglou, Vraimaki, Diamantidis, and Sarigiannidia, 2010:78; Kannabiran and Dharmalingam, 2012:187). In a developing country like South Africa, procurement cost is also vital to a construction enterprise owner (Olatokun and Kebonye, 2010:42), as well as the reliability of the tools. Also, Lambrecht, Vestergaard, Karlshøj, Haunch, and Mouritsen, 2016:11) pointed out that the complex nature of the construction industry (CI) makes it difficult to evaluate the benefits of using these tool. Therefore, this study was aimed at addressing the ICT applications at the various stages of construction work in the South African construction industry.

1.3 AIM OF THE STUDY

The aim of this study is to evaluate information and communication technology applications in the South African construction industry. The study assessed the level of awareness of ICT application in the South African construction industry, the ICT applications used at the different stages of construction projects in the South African construction industry as well as the challenges facing its effective application. This research study also evaluates the measures for ensuring the effective application of ICT at the different stages of construction projects in the South African construction industry and the inherent benefits that come from the effective applications thereof.

1.4 SIGNIFICANCE OF THE STUDY

This study provides insights into the understanding of ICT tools used at every stage of construction work. Specifically, this study is valuable for digitalization of construction activities in South Africa. It is imperative for standardization that policymakers in the South African construction industry are abreast with ICT applications used in the industry. This study is also beneficial to organisations or firms which apply ICT tools for construction e-commerce or e-firm. More importantly, the impact of this research study is appreciated more by the SMEs that saturate the construction industry. The importance of ICT tools cannot be over-emphasized. This study will have an impact on understanding ICT innovation as seen in a developing country. More importantly, this study will reflect recent innovation needed for construction 4.0.

1.5 PROBLEM STATEMENT

The diffusion of ICT and factors that influence it have been discussed in the past (Samuelson, 2008:247), as well as contextual influences on its application and use. Others also discussed the concept from the viewpoint of industrialised countries such as the United Kingdom (UK), the United States, Australia (Adriaanse, Voordijk and Dewulf, 2010: 74; Iddris, 2012:48), and the like. Other studies reported on the impact of ICT tools for e-commerce use for construction SMEs in developing nations and their counterparts (Iddris, 2012:84; Albeiro, 2015:84). Similarly, the concept of ICT is explained as the hardware and software computer components used mostly in developed countries. There is a need for an ICT tool evaluation in order to understand how construction project-based firms organize and cope with continuous waves of digital innovations to remain competitive in uncertain times and during changing environments and work process calling for new innovations to achieve their goals.

Voordijk and Adriaanse (2016: 536) posited that ICT usage faces problems in conveying its roles during construction processes. Although the underlying methods and techniques of executing construction have not changed much, the technologies for construction work are the ones continually evolving (Eadie and Perera, 2016:19). Alsafouri and Ayer (2018:176) added that in recent times, there has not been an in-depth evaluation of how ICT has been used to enable different modules of information flow on the project site. However, irrespective of successful - implementation of ICT technologies in construction, project stakeholders still encounter a wide range of communication challenges when implementing ICT on their projects (Alsafouri and Ayer, 2018:176). In the construction industry, it is also seen that ICT utilization ration is quite low (Dehlin and Olofsson, 2008:343). This is because ICT in construction has addressed more technical issues than managerial ones (Love, Irani and Edwards, 2004:507), especially the investment cost (Alshawi, Lou, Khosrowshahi, Underwood, and Goulding, 2010:2). There is, therefore, a need to evaluate the state of ICT applications in the construction industry.

Despite the inherent potential contribution of ICT, technological development in the construction industry lags behind that of other industries (Alkalbani, Rezgui, Vorakulpipat, and Wilson, 2013:62). There is a need to address this challenge which makes ICT usage in the construction industry fragmented since ICT tools are for specific tasks, stakeholders and work stages. It is imperative to achieve a holistic and integrated ICT structure for the construction industry. The main challenge for the construction sector is to achieve holistic and integrated ICT support (Dickinson *et al.*, 2009). The application of information and communication technology (ICT) in the architecture, engineering, and construction (AEC) sector has evolved over several years. These continue to invest in ICT in their bid to harness technology and streamline business processes. However, construction organizations continue to experience perennial problems that militate against the successful implementation of IT projects.

It is worth noting that every stage of the construction plan of work tallies with the construction life of a project. Each design stage specifically correlates with a part of the building. Likewise, each part of the building relates to an ICT application. It is important to identify the status of ICT application in the construction industry. It is also vital to identify these tools in building processes. The construction design process is grouped into stages or phases according to RIBA and Sinclair (2013:7). Therefore, this study is important in evaluating ICT applications at these stages.

1.6 RESEARCH QUESTIONS

The following research questions will be used to evaluate ICT applications in the South African construction industry. This research asked the following questions:

1. What is the level of awareness of ICT application among construction stakeholders?
2. What are the ICT applications used at the various stages of construction projects in the South African construction industry?
3. What are the measures for ensuring the effective application of ICT tools for construction projects in the South African construction industry?
4. What are the challenges facing the effective application of ICT tools used for construction projects in the South African construction industry?
5. What are the benefits in the effective application of ICT tools used for construction projects in the South African construction industry?

1.7 RESEARCH OBJECTIVES

In order to evaluate ICT applications in the construction industry and to provide answers to the proposed research questions, the following objectives were determined:

1. To evaluate the level of awareness of ICT application among construction stakeholders;
2. To determine the ICT applications used at the different stages of construction projects in the South African construction industry;
3. To assess the challenges facing the effective application of ICT for construction projects in the South African construction industry;
4. To determine the measures for ensuring the effective application of ICT for construction projects in the South African construction industry; and
5. To determine the benefits of the effective application of ICT for construction projects in the South African construction industry.

1.8 MOTIVATION FOR THE STUDY

This research study is motivated to address the various ICT tools used for construction activities in South Africa. This is necessary to better position the construction industry in the era of Industry 4.0, referred to as construction 4.0. various ICT tools currently used are addressed. This study is also motivated to address stages of construction work in South African and the corresponding ICT tools used at the stages. The outcome of this research work will assist construction stakeholders, SMEs, government and the client in their decisions about the construction industry. This will hopefully motivate and improve policies that will support ICT use in the construction industry of a developing country like South Africa.

1.9 PURPOSE OF THE STUDY

The era of the fourth industrial revolution demands that the construction industry is more innovative. Therefore, there is a need for modern ICT tools for construction activities. There is also a need for construction stakeholders to have the necessary skill and expertise to use modern ICT tools. Construction enterprise needs recent ICT tools to remain competitive, while the construction industry as a whole needs to move towards construction 4.0. The application of various ICT tools at the different stages of construction work is therefore imperative. Therefore, the purpose of this study is to determine how well ICT tools are used at the various stages of construction to meet the demands of construction 4.0.

1.10 DELIMITATIONS OF THE STUDY

Study scope or delimitation is required to focus on a research study to a specific target group (Bell, 2014:29). This research study was limited to Gauteng Province in South Africa. Gauteng Province was selected owing to the high influx of construction activities being carried out. The study was also confined to computer literate construction industry professionals. The computer-literate segment of the population was selected because there is a need to be competent in the use of computer ICT tools to be able to be relevant to the study

1.11 RESEARCH METHODOLOGY AND DESIGN

1.11.1 Research methodology

The research methodology is the procedure for collating evidence for a research study (Kumar, 2011:26) by describing, explaining and predicting the phenomena. This section outlines the research approach and design, the population sample and the geographical area where the work was being conducted. This section also discusses the instruments used in data collection. The method of ascertaining data validity and reliability is also discussed.

1.11.2 Research design

The research approach is the means by which idea, data and information are gathered, used and justified. Shanti and Shashi (2017:7) indicated that research design comprises the outline for data collection, measurement and data analysis in a consistent and logical pattern. Therefore, it is the conceptual structure within which research would be conducted. There are two approaches to research. The first is the positivist approach which aims to describe observed phenomena in a scientific and objective way, thus assuring that all observations can be explained through scientific means (Bryman, Bell and Harley, 2018:156). The other approach to research is the post-positivist approach which is a range of perspectives that have in common a rejection of the positivist claims to be able to discern a single social reality and of observation as the sole technique for its discernment (Ryan, 2006:18; Henderson, 2011:341). Using a post-positivist approach, qualitative research is more valuable than quantitative research and scientific deduction does not differ significantly, and vice versa.

This research used a positivist approach as the aim was to evaluate ICT application in the South African construction industry through a quantitative approach by eliciting information from a group of subjects about their application of ICT in their construction processes. Quantitative research, according to Bryman and Bell (2011:383), is defined as a formal, objective, rigorous, systematic process conducted to describe, examine and test relationships causes and effects interactions among variables. A descriptive survey design was adopted to design a structured questionnaire. The descriptive design gives an accurate account of the characteristics of the respondents (Yin, 2014:280). Questionnaires were distributed to concerned stakeholders who apply ICT in the South African construction industry.

1.11.3 Research area and target respondents

This study was conducted in the Gauteng Province of the Republic of South Africa. The targeted respondents were professionals in the construction industry who were actively involved in the use of ICT in the South African construction industry. They included core professionals who can relate to ICT applications in the construction industry. These comprised quantity surveyors, architects, engineers, construction managers and construction project managers.

1.11.4 Sample size

Kumar (2019:256) defined sample size as the number of observations to be selected from the universe to constitute a statistical sample. The probability (random) sampling technique was adopted in this study because it affords each element in the population sample an equal chance of being included in the sample with choices independent of one another and gives each sample combination an equal chance of being chosen. The research participants were selected based on their professional use of ICT application in the Gauteng Province's construction industry.

1.11.5 Data collection and instrument for data collection

This study employed a probability random sampling technique. The technique allowed all equal audience of participation for the respondents. A structured close-ended question questionnaire was the preferred tool used for data collection in this study. It was administered as an online survey via the QuestionPro online survey platform over a one month period. A total of 150 questionnaires was received at the end of the survey while 120 were valid and usable. Thereafter, the data collected was analysed statistically using a quantitative approach.

1.11.6 Research limitation

The research study was limited to the Gauteng Province of the South Africa construction industry. The construction stages in which ICT application was evaluated was limited to the brief stage, concept design stage, developed design stage, technical design stage, and construction stage. The questionnaires were structured in sections and administered in the English language to the respondents. They included practising professionals in the South Africa construction industry (architects, quantity surveyors, civil engineers, construction projects managers, and construction managers). The research study investigated the level of awareness of ICT application South African construction industry, the ICT applications used at the different stages of construction projects in the South African construction industry as well as challenges facing its effective application. This research study also evaluated the measures for ensuring the effective application of ICT at the different stages of construction projects in the South African construction industry and the inherent benefits that come from the effective application.

1.11.7 Ethical consideration

It was ensured that internationally accepted ethical standards were complied with while undertaking this research study. Hence, only individuals who had given informed consent participated in the research while their names were not recorded on any research instrument, thereby ensuring their anonymity. This study was subjected to independent review by the supervisors to ensure that the researcher did not neglect cogent ethical issues with potential legal implications. Quality assurance was further observed in the study by focusing on the correctness and completeness of questionnaires, the quality and accuracy of data capturing and analysis, and the originality of data captured and information collected.

1.12 OVERVIEW OF THE CHAPTERS

The research study was presented in nine (9) chapters which are titled as follows:

CHAPTER 1: Introduction

This chapter outlines the background to the subject of study, aim, and purpose of the study. The research problems, research questions, and the research objectives are also evaluated in this chapter. In summary, this chapter gives a framework for the entirety of this research study.

CHAPTER 2: Overview of Information and Communication Technology

This chapter reviews the literature on information and communication technology (ICT) by researchers, scholars and certified professionals, exposing the readers to the knowledge and ideas already established on the topic. Hence, this chapter presents a thorough investigation of the extant literature on ICT. It addresses the historical formation, definitions, ICT and economic activities, ICT in the construction industry, and ICT tools used in stages (RIBA) of construction. In addition, the drivers, benefits, and barriers, of ICT are detailed in this chapter. In summary, this chapter presents ICT as a panacea for improved construction activities wherever it is applied.

CHAPTER 3: Information and Communication Technology application across RIBA stages of work.

This chapter reviews related work on the application of ICT in the construction industry in the RIBA stages of the work plan while relating it to PROCSA template as well.

CHAPTER 4: Case studies of Information and communication technology in the African context

This chapter reviews the literature on ICTC in some African construction industries.

CHAPTER 5: Information and communication technology in South Africa Construction Industry

This chapter reviews literature ICT application in the South African construction industry as established by scholars and researchers. Hence this chapter gives the reader an overview of the South Africa construction industry with respect to legislation and policies support on ICT.

CHAPTER 6: Research Methodology and Design

This chapter presents the approach and method according to which the research study was conducted. It pointed out the research area and targeted respondents which are construction industry professionals in South Africa. The method employed for sampling and data collection was also discussed in this chapter.

CHAPTER 7: Data Analysis and Interpretation

Once an appropriate design and suitable means of measuring relevant variables had been identified and adopted, the findings were analyzed using an appropriate procedure. Statistical techniques were adopted to analyze data and draw up findings. The analyzed results then provided feedback with respect to the originally formulated questions.

CHAPTER 8: Discussion of Findings

In Chapter 8, the findings analyzed in Chapter 7 are discussed and related to the literature in order to establish whether the research objectives have been achieved and whether all the research questions were answered.

CHAPTER 9: Conclusions and Recommendations

In Chapter 9, the findings investigated in Chapter 8 are discussed and related to the literature in order to establish whether the research objectives have been achieved. This chapter further concludes the study and gives recommendations on the review of the application of ICT in solving South Africa's triple challenge.

1.12 CONCLUSION

This chapter introduced the various components of the research study and presented the structure of the study. The aim of the research, motivation, purpose, questions, and objectives was discussed in this chapter.

The next chapter extensively explores ICT.

CHAPTER TWO

OVERVIEW OF INFORMATION COMMUNICATION AND TECHNOLOGY

2.1 INTRODUCTION

In this chapter, the history of ICT is discussed. It briefly defines ICT and described it as it relates to globalization and digitalization. It also gives an overview of ICT applications in germane economic sectors.

2.2 HISTORY OF INFORMATION AND COMMUNICATION TECHNOLOGY

Information and Communication Technology (ICT) has come a long way. Sonka (2014:2) described how ICT has evolved over time. Questions about the origin, adoption and eventually use have been posed over the last three decades. In the 1980s questions were asked about a microcomputer, the essence of word processing or the capacity of any random access memory (RAM). This explains that ICT comes in the hardware and software forms. Subsequently, new ICT innovations came to the fore. Enquiries were made about the use of an e-mail as opposed to a phone voice mail or about understanding the Internet in the 1990s (Dai, 2018:120), while in the 2000s queries on why buy a book online instead of at the traditional bookshop or why to buy a Smartphone were raised.

ICT can be traced to the beginning of mankind. People communicated via the available technological tools. The history of information and communication technologies described the era of invention of these tools (Butler, 1998:2; Brady and Elkner, 2017:14). Several ICTs will be discussed, ranging from the earliest technological era to this present digital revolution. The ICT era is grouped into pre mechanical, mechanical, electromechanical, electronic and digital revolution eras (Brady and Elkner, 2017:17; Dai, 2018:12). The innovations in the first era serve as a baseline for innovations in the subsequent eras.

2.2.1 Pre-mechanical era

The use of ICT is not recent, having possibly been described as the pre-mechanical age. It covers the time between 3000 B.C and 1450 A.D when the communication exchange first started (Butler, 1998:4; Brady and Elkner, 2017:3). During this time there was a continual improvement on tools for communication. This improvement started from pictorial language (petroglyphs) to writing on scrolls, then to numbering which led to the invention of the abacus, the first calculator (Brady and Elkner, 2017:3). The end of this period welcomed the mechanical era.

Figure 2. 1: Petroglyph

Source: Britannica ImageQuest (2019)

Figure 2. 2: Abacus

Source: Britannica ImageQuest (2019)

2.2.2 Mechanical era

The mechanical era introduced information and communication technologies known today. It spans the time between 1450 and 1840 when technologies such as the slide rule, the pascaline, Leibniz's machine, the difference engine, the analytical engine, and Joseph Marie Jacquard's loom were invented (Butler, 1998:5; Brady and Elkner, 2017:4). The slide rule, the analogue computer used for multiplying and dividing, was invented in the early 1600s by William Oughtred; Blaise Pascal (1623-1662) invented the pascaline which was a very the popular mechanical computer; and Gottfried Wilhelm von Leibniz (1646-1716) invented the reckoner (reconstruction), also called the Leibniz machine. It is also used for calculations too. Charles Babbage developed the difference engine and analytical engines. which a are automatic mechanical calculators designed to tabulate polynomial equations using the method of finite differences. Analytical engines succeed the difference engine. Also, during this era, Joseph Marie Jacquard (1752-1834) introduced the loom. It is a programming machine that does binary logic and real-time fixed programming (Butler, 1998:4; Brady and Elkner, 2017:4). This is an important era which is also called the first industrial revolution (Kang *et al.*, 2016:111). It is the start of the industrial revolution.

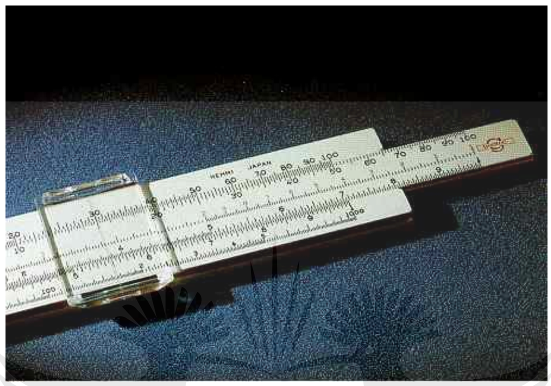

Figure 2. 3: Slide rule

Source: Britannica ImageQuest (2019)

Figure 2. 4: Pascaline

Source: Encyclopædia Britannica ImageQuest

Figure 2. 5: The reckoner/ Leibniz's machine

Source: Encyclopædia Britannica ImageQuest (2019)

Figure 2. 6: Difference engine

Source: Encyclopædia Britannica ImageQuest (2019)

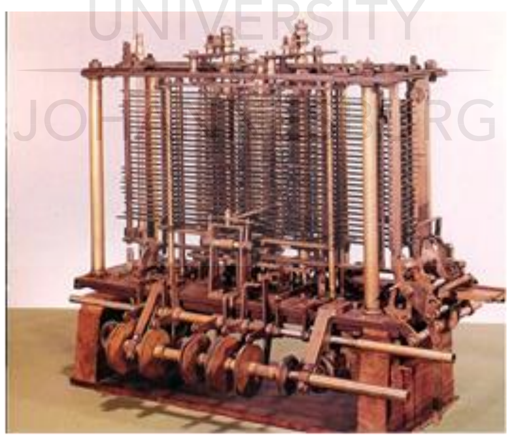

Figure 2. 7: Analytical engine

Source: Encyclopædia Britannica ImageQuest

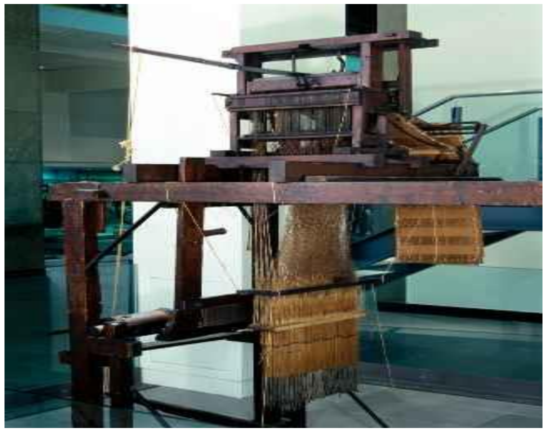

Figure 2. 8: Jacquard's loom

Source: Encyclopædia Britannica ImageQuest

2.2.3 Electromechanical age

The discovery of electricity facilitated more enhanced ICT inventions in this era. This era records the beginning of telecommunication and electromechanical computing. This age, between 1840-1940, welcomed the inventions of telecommunication ICT such as the telegraph in the 1800s, Morse code by Samuel in 1835, Alexander Graham Bell's telephone in 1876 and the radio by Guglielmo Marconi in 1894 (Brady and Elkner, 2017:4; Dai, 2018:1; Butler, 1998:6).

Figure 2. 9: Morse code

Source: Encyclopædia Britannica ImageQuest

Figure 2. 10: Telephone

Source: Encyclopædia Britannica ImageQuest

Figure 2. 11: Radio

Source: Encyclopædia Britannica ImageQuest

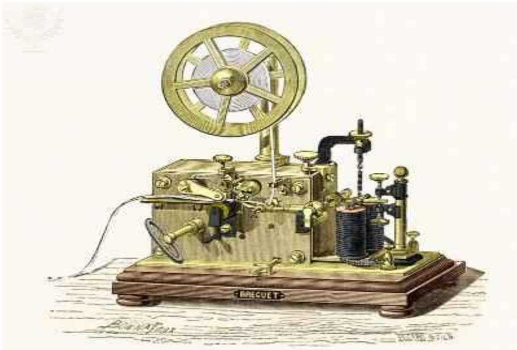

Figure 2. 12: Telegraph machine

Source: Encyclopædia Britannica ImageQuest

The electromechanical computing in this era consisted of Herman Hollerith's (1860-1929) census machine and punch card; the International Business Machine (IBM) and Mark1 (Butler, 1998:6; Brady and Elkner, 2017:12). These information and communication technologies opened up the huge advances in the succeeding eras.

Figure 2. 13: Censusmachine

Source: Encyclopædia Britannica

Figure 2. 14: Punch Card

Source: Encyclopædia Britannica ImageQuest

Figure 2. 15: IBM

Source: Encyclopædia Britannica ImageQuest

Figure 2. 16:Mark 1

Source: Encyclopædia Britannica ImageQuest

2.2.4 Electronic era

The electronic age welcomed the massive use of the digital computer. This age records four phases of transition in the digital computer. From the period of 1940- 1980 there were inventions such as ENIAC, the first high-speed digital computer; programming languages; high-level programs such as FORTRAN and COBOL; advanced programming language called BASIC; the central processing unit (CPU); and Apple II, a personal computer and graphical user interface (Butler, 1998:7-10; Brady and Elkner, 2017:8). This is also a key part of the third industrial revolution.

Figure 2. 17: Apple 2

Source: Encyclopædia Britannica ImageQuest

2.2.5 Digital revolution

The era that follows the electronic age is the digital revolution. It is also referred to as the third industrial revolution. This is the period from 1980 to 2010. The beginning of the digital revolution age welcomed innovations such as the electronic mail (e-mail); World Wide Web (www); digital television; the digital versatile disc (DVD); the Internet, and 3rd generation mobile computing (3D), among others (Ramasubramanian, 2010:102) as presented in Figure 2.18. After this, the era also welcomes advanced digital telecommunication and broadcasting (Hilbert and López, 2011:609). The third industrial revolution includes a personal computer, the Internet, and ICT. The progress in innovation has led to mechanization, electrification, motorization, the 3rd industrial or digital revolution and the latest, the 4th industrial revolution (Bojanova, 2014: 8).

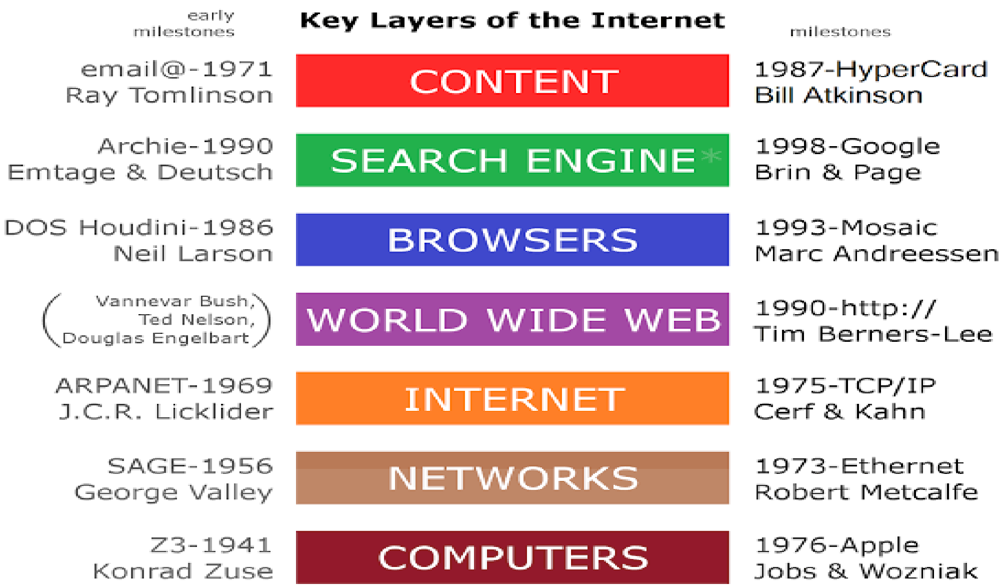

Figure 2. 18: Example of some digital revolution innovations

Source: Encyclopædia Britannica ImageQuest

2.2.6 Industry 1.0 to Industry 4.0 (ICT revolution)

Industry 1.0, propelled by mechanical production, began in the 18th century. A the beginning of the 20th-century industry 2.0 emerged which is concerned with mass production using electrical power. The third industrial revolution in the 1970s involved programmable automation which is done through improved IT automation, while the latest industrial revolution is Industry 4.0 which involves remote management of the value-chain using cyber-physical systems. Mendonça (2006:780) explains the major characteristics of these industrial revolutions before the industry 4.0 are a few key technologies, the influx of invention and innovations, the accelerated growth of several key technologies, new and improved structures of economic activities, and improved support infrastructure.

The current era of information and communication technology is termed the fourth industrial era. This idea was originally conceived in Germany around 2011 (Kagermann, 2015:23). It is based on concepts and technologies such as cyber-physical systems, the Internet of Things (IoT), the Internet of Service, and the like (Lasi, Fettke, Kemper, Feld, and Hoffmann, 2014:240; Ning and Liu, 2015:9). IoT is a concept representing major changes within a short time span which causes basic economic and societal change. As such, the fourth industrial revolution has been referred to as Industry 4.0, digital sustainability, Smart Factory, and the Internet of Things (IoT) among other names (Roblek, Meško and Krapež, 2016:4).

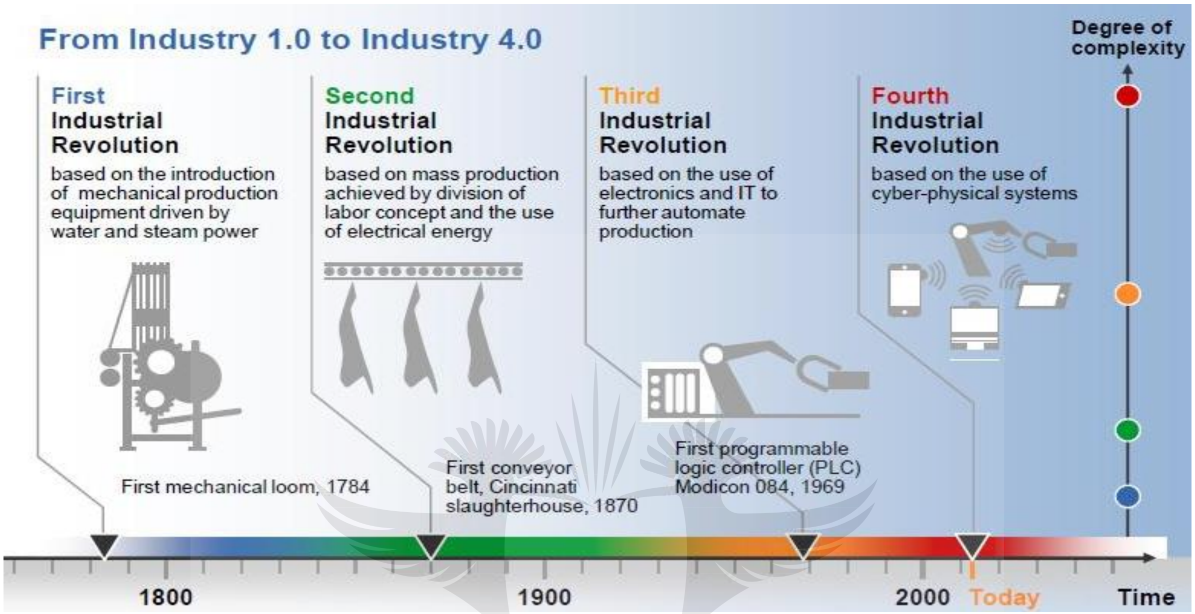

Figure 2. 19: ICT revolutions

Source: Domhnall (2014)

2.3 TECHNOLOGY INNOVATION ACCEPTANCE AND DIFFUSION

The premise for technology innovation acceptance is a discussion on innovation and its diffusion. Innovation has been a central issue for industries globally. Innovation is defined in terms of technology diffusion, assessment, adoption, and implementation (Rankin and Luther, 2006:1541) while diffusion of innovation theory addresses the flow of new ideas in a working system (Shibeika and Harty, 2015:454). The literature on innovation diffusion has highlighted personal innovation adoption and technological innovation on business and firm innovation processes (Rogers, 2004:13; Dearing and Cox, 2018:183). It is argued that innovation is threefold, namely people, business and organization. It spreads from people to their business life and then the firm. There are vital features of present-day technology that influence its diffusion and adoption. These features influence the definition of diffusion (and adoption) in a particular system (Shibeika and

Harty, 2015:455). Definitions of technology innovation diffusion and adoption in construction depend on people's acceptance and process adoption and standards.

Influential theoretical frameworks to study new technology adoption are the technology acceptance model (TAM) and the diffusion of innovation (DOI) theory. The TAM is used to describe an individual's acceptance of information systems (Taherdoost, 2018:960)). Originally, TAM assumes that an individual's information systems acceptance is determined by three major variables: perceived usefulness (PU), perceived ease of use (PEOU) and attitude toward use (Taherdoost, 2018:963). Recently, the heterogeneous nature of technology requires the continual inclusion of variables for TAM on the subject of discussing (Beldad and Hegner, 2018:831).

The DOI theory examines the spread of new innovation through time, channels, communication, and social system. It was majorly influenced by Roger's theory of diffusions of innovation in 1995. DOI has been used at organizational, individual and global levels (Taherdoost, 2018:963). The model explains that innovation is mainly dependent on users or concerned stakeholders. For example, the construction industry uses ICT innovation for smart innovative data integration in a sustainable built environment (Ashworth and Perera, 2015:4). It is argued that construction activities are complex and tedious with manual operations (Pauget and Wald, 2013:2014; Musa *et al.*, 201:1001). Therefore, for example, ICT as a panacea for industrial development can be understood properly through the TAM and theory of DOI.

2.4 DEFINITION OF INFORMATION AND COMMUNICATION TECHNOLOGY

A fit-in-all definition of ICT is broad and difficult since there are several contexts and applications of the term (Zuppo, 2012:12). In its simple form, ICT is easily defined by its acronym, namely ICT. Information is processed data, communication described conveying the processed data while technology is a way of having things done effectively while saving time, energy and other resources. Therefore, ICT are tools, devices or knowledge (hardware and software) that bridge the gap between inputs and outputs of communication (Gossart, 2015:435).

The fundamentals of defining ICT are the devices and infrastructures that enhance the transfer of electronically interposed communication through a digital channel (Tiwari and Singh, 2018:34)). The definition of ICT can be influenced by the characteristics of the context in which it is been used. As such, the attributes of ICT are an important consideration. One key characteristic of ICT as innovation is communication (Bras, Aldewereld, Quinten, Warnier, and Marijn, 2016:6). Also, the study on the DOI described some characteristics of innovation as a relative advantage (the extent to which an innovation is better than others), compatibility, complexity, trialability, and observability (Tan *et al.*, 2009:227). These characteristics of ICT may be context-bound yet, they fulfil the same purpose of increasing the connectedness of society. The connectedness of society is thus referred to as globalization.

Globalization was not a popular word several decades ago. It is a phenomenon that has evolved from zero to be a hero of every facet of life. It has been described in various ways. Globalization, according to Hirst, Thompson and Bromley (2015:200), is an idea that captures the ever-increasing interconnected societal life of people which is supported by ICT revolution and integration of the market globally. Information and communication technology can be addressed as a panacea for globalization (West and Heath, 2011:209). It is clear that ICT and globalization are interrelated.

Although ICT is an entity different from globalization, they have become clichés or buzz words. ICT has helped globalization become a reality as it plays an important role in its development (Jianqiu *et al.*, 2017:2). Technology serves as both catalyst and response to globalization as such; technology and globalization drive each other in a continual cycle (West and Heath, 2011:210-211). These two, ICT and globalization, are seen in the interconnected business life. The interconnected life is experienced by contemporary populations in daily activities. As an example, ICT and globalization have effects on the workplace or business environment. Chary (2007:182) explains that ICT and globalization have jointly increased the concentration power and decision-making authority in an organization. ICT reduces potential manual manpower while globalization in itself encourages virtual corporation. This can either be termed as a merit or demerit: the perspective from which it is addressed is important for proper definition.

Construction work can be described as a typical organization or business environment. In the context of globalization, several new innovations have emerged. These include virtual teams, a type of new ICT-enabled organizational form, competition in business, corporate development and a positive effect between ICT-induced stress and role stress (Arditi *et al.*, 2000: 127; Tarafdar *et al.*, 2007:309). This explains further that there is a link between ICT application, organizational role, and people. These links could serve as both opportunities and threats. On the other hand, the effects of ICT application and globalization on the workplace could also be negative. They include a threat to construction in developing countries and the negative effect of ICT-induced stress on productivity (Raftery et al., 1998:176; Ofori, 2000:260). Therefore, ICT and globalization are connected through economic activities.

2.5 INFORMATION AND COMMUNICATION TECHNOLOGY IN ECONOMIC ACTIVITIES

The literature of ICT has highlighted its connection with economic activities. Some germane economic activities have been listed to be agriculture, manufacturing, transportation, and construction (Statistics South Africa, 2012:26). ICT generates wide-ranging impacts across all economic activities (Gossart, 2015:5), for example, for manufacturing activities, ICT enhances the effective process through the opportunities it presents (Olamade, Oyebisi and Olabode, 2014:5).

ICT also enhances agricultural activities by increasing farm productivity and monitoring production (Deloitte, 2012:27). However, Sonka (2014:8) pointed out that the path by which ICT applications can influence agriculture has not been fully determined. The expectation of ICT in agriculture is very high. It is expected that ICT applications will be well utilised in agriculture. On the other hand, that does not imply that all ICT applications will change the basis of competition. ICT application has various effects on these economic sectors.

All sectors of the economy are interrelated. They depend on each other for maximum survival. In essence, there are several common catalysts to their fulfilment. In this context, ICT will be one such catalyst. The transportation activities of an economy is another giant. The role of ICT in this sector cannot be overemphasized. The transportation and logistics sector are interwoven. These two sectors have also benefited from new ICT advancement. Harris, Wang and Wang (2015:88) posited that cloud computing, social networking, and wireless communication have helped structure this industry better. However, it observed that despite the advancement in ICT technology, the application is slow in the transportation industry.

The new ICT innovation in the manufacturing process is referred to as the fourth industrial revolution. It is a concept changing the face of economic and societal activities. This concept is called by other names such as “Internet of Things”, “smart manufacturing”, “smart production”, "Internet of everything", "industry 4.0" (Roblek, Meško and Krapež, 2016:4). ICT started affecting the industrial revolution from the 1970s until now, mainly in manufacturing. Its application is also seen in another thriving sector of the economy, which is the construction industry since it is a large provider of employment, either skilled or unskilled. Construction, in turn, gives back to the economic GDP.

2.6 OVERVIEW OF THE CONSTRUCTION INDUSTRY

The construction industry is a key sector in any economy. Irrespective of its fragmented nature, it supports the economy through the provision of infrastructure and employment creation globally. For example, in developed countries such as the USA and the UK, it provides a substantial amount of employment (Rhodes, 2015:3). Evidence from the literature of the UK, USA, Japan, and Finland (Oyegoke, 2006:13) shows that construction activities are carried out by both the private and public sectors. On the other side of the developing world, for example, Africa, the construction industry plays an active role in economic development (Deloitte, 2018:25). Construction industry activities by its seasoned professionals include construction and maintenance of buildings and infrastructure (Anyanwu, 2013:2319). These construction activities are achieved as a result of deliberate planning and the use of project-enhancing infrastructure such as ICT. Deliberate planning involves the process of execution of construction work in phases or stages.

Construction works are better organized in stages. These aids the organization of construction processes, especially through the use of ICT. In the opinion of Afolabi, Oyeyipo, Ojelabi, and Tunji-Olayeni, (2017:18), ICT has changed the processes of construction activities to more sophisticated ones. This is because the stages of construction work need a more novel approach to their execution. For example, the plan of work template of the Royal Institute of British Architects (RIBA) has been popular in industries across the world. Specific to construction work execution, the need for an outline or plan for construction activities cannot be overemphasized.

2.6.1 Royal Institute of British Architects (RIBA) stages of a work plan

A construction process begins with the production of detailed specifications for the steps to be followed and the constraints to be observed in the project's execution. RIBA has been seen as a standard for defining construction activities. Several authors have described construction work based on the RIBA plan of work (Sacks *et al.*, 2015; Shahrestani, Yao, Cook, and Clements-

Croome, 2018:134). Since 1963 the RIBA plan of work has been the UK standard for building models and construction activities. This also has an impact on the international audience (RIBA and Sinclair, 2013). This work plan continually improves with time, seeking to incorporate newer arrangements. The current standard is the RIBA 2013 plan. RIBA 2013 was drawn up to address the recent trends in the built environment. These include sustainable design principles and the building information model (BIM). Also, in this plan, an array of cost and value methodology from the inception through to the in-use phase (Ashworth and Perera, 2015:4) is being introduced through ICT applications. This plan of work organizes the process of briefing, designing, constructing, maintain, operating and using building projects into a number of key stages (RIBA and Sinclair, 2013). However, there have been various versions of the RIBA plan of work.

They were RIBA 1973, 1997, RIBA 2000, and RIBA 2007/2008. RIBA 2013 is an improvement on the previous types. It incorporates issues on sizes and types of projects, procurement types, project teams and the flexibility of using planning procedures. It comprises eight stages of work. They range from stage 0 to stage 8. Stage 0 is termed the strategic definition stage. Stage 1 is the brief stage and stage 2 is termed the concept design stage. The stages that follow next are stage 3 (developed design stage) and stage 4 described as the technical design stage. Stage 5 is the construction stage and the last two stages are stages 6 (hand over) and 7 (in-use stage) (RIBA, 2013:7) as represented in Figure 2.20. These stages move in a circular process from stage 0 to stage 8. The aim of the RIBA plan of work at each stage is to bridge the performance gap between planning and execution.

RIBA

The RIBA Plan of Work 2013 organises the process of briefing, designing, constructing, maintaining, operating and using building projects into a number of key stages. The content of stages may vary or overlap to suit specific project requirements. The RIBA Plan of Work 2013 should be used solely as guidance for the preparation of detailed professional services contracts and building contracts.

www.ribaplanofwork.com

RIBA Plan of Work 2013 — Stages / Tasks	0 Strategic Definition	1 Preparation and Brief	2 Concept Design	3 Developed Design	4 Technical Design	5 Construction	6 Handover and Close Out	7 In Use
Core Objectives	Identify client's **Business Case** and **Strategic Brief** and other core project requirements.	Develop **Project Objectives**, including **Quality Objectives** and **Project Outcomes**, **Sustainability Aspirations**, **Project Budget**, other parameters or constraints and develop **Initial Project Brief**. Undertake **Feasibility Studies** and review of **Site Information**.	Prepare **Concept Design**, including outline proposals for structural design, building services systems, outline specifications and preliminary **Cost Information** along with relevant **Project Strategies** in accordance with **Design Programme**. Agree alterations to brief and issue **Final Project Brief**.	Prepare **Developed Design**, including coordinated and updated proposals for structural design, building services systems, outline specifications, **Cost Information** and **Project Strategies** in accordance with **Design Programme**.	Prepare **Technical Design** in accordance with **Design Responsibility Matrix** and **Project Strategies** to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with **Design Programme**.	Offsite manufacturing and onsite **Construction** in accordance with **Construction Programme** and resolution of **Design Queries** from site as they arise.	Handover of building and conclusion of **Building Contract**.	Undertake **In Use** services in accordance with **Schedule of Services**.
Procurement *Variable task bar	Initial considerations for assembling the project team.	Prepare **Project Roles Table** and **Contractual Tree** and continue assembling the project team.	<---- The procurement strategy does not fundamentally alter the progression of the design or the level of detail prepared at a given stage. However, **Information Exchanges** will vary depending on the selected procurement route and **Building Contract**. A bespoke **RIBA Plan of Work 2013** will set out the specific tendering and procurement activities that will occur at each stage in relation to the chosen procurement route. ---->			Administration of **Building Contract**, including regular site inspections and review of progress.	Conclude administration of **Building Contract**.	
Programme *Variable task bar	Establish **Project Programme**.	Review **Project Programme**.	Review **Project Programme**.	<-- The procurement route may dictate the **Project Programme** and may result in certain stages overlapping or being undertaken concurrently. A bespoke **RIBA Plan of Work 2013** will clarify the stage overlaps. The **Project Programme** will set out the specific stage dates and detailed programme durations. -->				
(Town) Planning *Variable task bar	Pre-application discussions.	Pre-application discussions.	<------ Planning applications are typically made using the Stage 3 output. A bespoke **RIBA Plan of Work 2013** will identify when the planning application is to be made. ------>					
Suggested Key Support Tasks	Review **Feedback** from previous projects.	Prepare **Handover Strategy** and **Risk Assessments**. Agree **Schedule of Services**, **Design Responsibility Matrix** and **Information Exchanges** and prepare **Project Execution Plan** including **Technology** and **Communication Strategies** and consideration of **Common Standards** to be used.	Prepare **Sustainability Strategy**, **Maintenance and Operational Strategy** and review **Handover Strategy** and **Risk Assessments**. Undertake third party consultations as required and any **Research and Development** aspects. Review and update **Project Execution Plan**. Consider **Construction Strategy**, including offsite fabrication, and develop **Health and Safety Strategy**.	Review and update **Sustainability**, **Maintenance and Operational** and **Handover Strategies** and **Risk Assessments**. Undertake third party consultations as required and conclude **Research and Development** aspects. Review and update **Project Execution Plan**, including **Change Control Procedures**. Review and update **Construction and Health and Safety Strategies**.	Review and update **Sustainability**, **Maintenance and Operational** and **Handover Strategies** and **Risk Assessments**. Prepare and submit Building Regulations submission and any other third party submissions requiring consent. Review and update **Project Execution Plan**. Review **Construction Strategy**, including sequencing, and update **Health and Safety Strategy**.	Review and update **Sustainability Strategy** and implement **Handover Strategy**, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of **'As-constructed' Information**. Update **Construction** and **Health and Safety Strategies**.	Carry out activities listed in **Handover Strategy** including **Feedback** for use during the future life of the building or on future projects. Updating of **Project Information** as required.	Conclude activities listed in **Handover Strategy** including **Post-occupancy Evaluation**, review of **Project Performance**, **Project Outcomes** and **Research and Development** aspects. Updating of **Project Information**, as required, in response to ongoing client **Feedback** until the end of the building's life.
Sustainability Checkpoints	**Sustainability Checkpoint — 0**	**Sustainability Checkpoint — 1**	**Sustainability Checkpoint — 2**	**Sustainability Checkpoint — 3**	**Sustainability Checkpoint — 4**	**Sustainability Checkpoint — 5**	**Sustainability Checkpoint — 6**	**Sustainability Checkpoint — 7**
Information Exchanges (at stage completion)	**Strategic Brief.**	**Initial Project Brief.**	**Concept Design** including outline structural and building services design, associated **Project Strategies**, preliminary **Cost Information** and **Final Project Brief**.	**Developed Design**, including the coordinated architectural, structural and building services design and updated **Cost Information**.	Completed **Technical Design** of the project.	**'As-constructed' Information.**	Updated **'As-constructed' Information.**	**'As-constructed' Information** updated in response to ongoing client **Feedback** and maintenance or operational developments.
UK Government Information Exchanges	Not required.	Required.	Required.	Required.	Not required.	Not required.	Required.	As required.

*Variable task bar – in creating a bespoke project or practice specific RIBA Plan of Work 2013 via www.ribaplanofwork.com a specific bar is selected from a number of options.

Figure 2. 20: RIBA plan of work (RIBA and Sinclair, 2013:7)

2.6.1.1 Strategic definition stage

The first stage, stage 0, is called the strategic definition stage. RIBA and Sinclair (2013:7) described that this stage as a new one in which a projected is critically evaluated to the client's specification. Stage 0 particularly is useful when ideas like sustainability, refurbishment or extension, or a rationalized space plan are conceived (RIBA and Sinclair, 2013:7). The core task for construction activities is also identified in this stage. Additionally, the task includes initial consideration for assembling the required project team and establishing a project programme through a pre-application discussion (RIBA and Sinclair, 2013:7). Payne *et al.* (2015:264) posited that a proper strategic definition of work helps with the evaluation and amendment of designs as the project progresses. The implication is that an ideal construction or architectural work should commence from this stage. It is argued that facility management, a core aspect of building dynamics, should be included from this stage of the work (Lahidji and Tucker, 2016:39).

2.6.1.2 Preparation and brief stage

Stage 1 is typically referred to as the preparation and brief stage. According to RIBA and Sinclair (2013:14), stage 1 develops project objectives that include quality objectives and project outcomes, sustainability aspirations, project budget, the initial budget brief, feasibility studies, and a review of the site information. These are all executed through a pre-application discussion about the components of the main elements of a building (Shahrestani *et al.*, 2018:134). Therefore stage 1 is fundamental in any building construction activity. This is because the outcome of this stage determines the other stages. Hence, it is described as an iterative, innovative and creative stage (Knotten, Svlestuen, Hansen, Lædre, 2015:122). This stage proceeds to prepare the way for stage 2.

2.6.1.3 Concept design stage

Stage 2 is the concept design stage. The concept design includes the implementation of the project brief into the project concept design (Shahrestani *et al.*, 2018:134). RIBA and Sinclair (2013:7) indicate that this stage is divided into developing the initial project brief and feasibility studies, and the information exchange where the project team is assembled. This stage defines the maintenance and operation strategy, third-party consultancy, risk assessment, and research and development (R & D) aspects while still carrying out the pre-application discussion among concerned stakeholders to review the project programme. When using the RIBA plan for the execution of the project, the stages outlined will describe the project life-cycle. Therefore, Lahidji and Tucker (2016:340) maintain that critical issues like facility management should be incorporated in stages 0-6 of the RIBA plan of work.

2.6.1.4 Developed design stage

Stage 3 is defined as the developed design. The developed design stage is a cumulative result of decisions initially made in the preparation and brief stage (Shahrestani *et al.*, 2018:134). It considers the clients' needs and specifications as they relate to project objectives. This initial decision is gradually fine-tuned and frequently adjusted based on the developments in the project up to the end of RIBA stage 2. In the RIBA stage 3, the initial decisions may be changed based on the project needs constraints (RIBA and Sinclair, 2013:8). Stage 3 reviews and updates the sustainability and operation strategy of the previous stages. It also finalizes the R&D aspects.

2.6.1.5 Technical design stage

Construction projects range from simple residential buildings to heavy engineering works and the likes. Specifically, RIBA pays more attention to the design phase of construction. Stage 4 is termed the technical design stage. It is a stage where construction concepts such as sustainability, maintenance, operational and handover strategies and risk assessments are thoroughly evaluated (RIBA and Sinclair, 2013:7). This agrees with the views of Osmani *et al.* (2006:68) that the RIBA plan of work should cover sensitive issues such as waste management from its planning stage to the design stage.

2.6.1.6 Construction stage of work

Stage 5 is the construction stage. This stage checks out the completeness of the previous stages from stage 0 to stage 4. This stage executes offsite manufacturing and onsite construction as stipulated by the prepared construction programme in the strategic design and briefing stages (RIBA and Sinclair, 2013:7). It considers key concepts of construction health and safety while it also incorporates a system that will be useful for commissioning, training, handing over, asset management, future monitoring and maintenance. This stage also executes administrative activities such as site inspection (since project construction is ongoing) and reviewing the progress of work done.

2.6.1.7 Handover stage

Stage 6 is described as the handover stage. This implies that every technical construction work is complete. It is ready for the client to receive his project in the finished form. According to

RIBA and Sinclair,(2013:7; RIBA, 2013:7), stage 6 is the conclusion of the administrative and technical aspects of the building contact. This is benchmarked against the handover strategies and feedback as planned in the technical stage.

2.6.1.8 In-use stage

The RIBA stage 7 plan of work is termed the in-use stage. It does the post-occupancy evaluation, and review of project performance and project outcomes. It also observes the building in use while assisting the occupants to reside. According to RIBA (2013:7), it executes activities relating to post-occupancy, reviews performance of the project (while being occupied), and conducts R & D necessary for facility management.

2.7 OVERVIEW OF INFORMATION AND COMMUNICATION TECHNOLOGY TOOLS IN THE CONSTRUCTION INDUSTRY

In the earliest industrial revolutions, ICT was used more for reporting purposes rather than for innovation (Roztocki and Weistroffer, 2015:333), for example, telegraph and telephone served as reporting and communication tools. The first industrial revolution introduced automation to construction activities (Bjork, 1999:7). During the third of the industrial revolutions, also termed the information revolution, a key innovation was the electronic processor Mendonça-inspired ICT tools (2006:780). Thus, the earliest ICT tool in the construction industry was the CAD machine and construction drawings were produced by using CAD draughting as a tool instead of a drawing board (Ingham, 2016: 47). Subsequently, construction ICT tools have been progressive in use and capacity. In the past two decades, ICT tools for construction worldwide have advanced (Orihuela, Orihuela and Pacheco, 2016:151). They have improved from the 18th-century automation machine to the computer-aided design (CAD) machine in the mid-20th century, to the object-oriented CAD system and innovation attributed to the present industrial revolution (Bjork, 1999:7; Orihuela, Orihuela and Pacheco, 2016:151). Therefore, ICT in the construction industry has evolved from the first industrial revolution to the current industrial revolution.

In recent times, ICT tools in the construction industry revolve around the use of computer systems. The rapid advancement of technology through computers continues to harness change and innovation in the construction industry (Azhar *et al.*, 2016:2). For instance, operations such as video conferencing, convergence networking, data mining and project management (Adwan and Al-Soufi, 2016:3) are computer-based ICT tools. They are also tools used to design, construct, operate and manage construction, as well as implementing ICT in the completed projects. They include Industry 4.0 elements (Oesterreich and Teuteberg, 2016:126), simulation and modelling tools (BIM, augmented reality, virtual reality, simulation tools, and mixed reality), digitization and virtualization tools (e.g. cloud computing, big data), and smart factory-inclined ICT tools (for instance, the product-lifecycle management [PLM] tool, robotics, Internet of Things (IoT),cyber-physical systems) (Bilal *et al.*, 2016:512) see Table 2.1. Therefore, ICT use in the construction industry can be discussed as information processing medium and the latest trends in the construction industry.

Table 2. 1: Examples of ICT Tools in the construction industry

ICT Applications	**Author (s)**
e-procurement technologies	(Arnold and Javernick-Will, 2013:510; Ibem and Laryea, 2015:364; Afolabi, Ibem, Asuwo, Tunji-Olayeni, Olawunmi, 2019:1)
Project management tools	(Froese, 2010:531; Chan and Mills, 2011:93; Arnold and Javernick-Will, 2013:510)
Big data tools	(Rezgui *et al.*, 2011:502; Bilal *et al.*, 2019:1; Lee, Jeong and Ryoo, 2019:744)
Communication software	(Bigliardi, Ivo Dormio and Galati, 2010:16; Ballan and El-Diraby, 2011:745)
Simulation tools/ 3D modelling/BIM tools	(Froese, 2010:531; Jardim-Goncalves and Grilo, 2010:388; Redmond, Hore and West, 2010:420; Falch, 2014:282; Asmi *et al.*, 2015:496; Nursal, Omar and Mohd Nawi, 2015:1; Kunieda and Codinhoto, 2018:773; Avan *et al.*, 2019)
Estimation and quantity take-off tools	(Benjaoran, 2009:270; Taghaddos, Mashayekhi and Sherafat, 2016:2218; Kunieda and Codinhoto, 2018:773; Martini, Sikander and Madlani, 2018:264)
Robotics/ Augmented reality	(Kose and Sakata, 2017:1; Bademosi, Nathan and Issa, 2018:58; Tavares *et al.*, 2019:1; Yang, Pan and Pan, 2019:24)
Convergence network	(Lee, Hwang and Hong, 2017:97)
Cloud computing	(Redmond, Hore and West, 2010:420; Redmond *et al.*, 2011:1033)

2.7.3 Skill sets for construction information and communication technologies

The basic skill sets necessary for the use of ICT are computer skills. However, in South Africa, the skill sets necessary to implement modern industrialization in the construction industry are missing (Bose, 2016:24). A study by Kazi, Hannus, Zarli, and Martens (2007:40) a road map for ICT skills in the construction industry (See Fig.2.2). Skills for ICT usage in the construction industry are those acquired by basic e-learning, the use of the Internet and basic skills. The end goal of these ICT tools is to create an ICT integrated culture that has a positive effect on the firm and the construction industry.

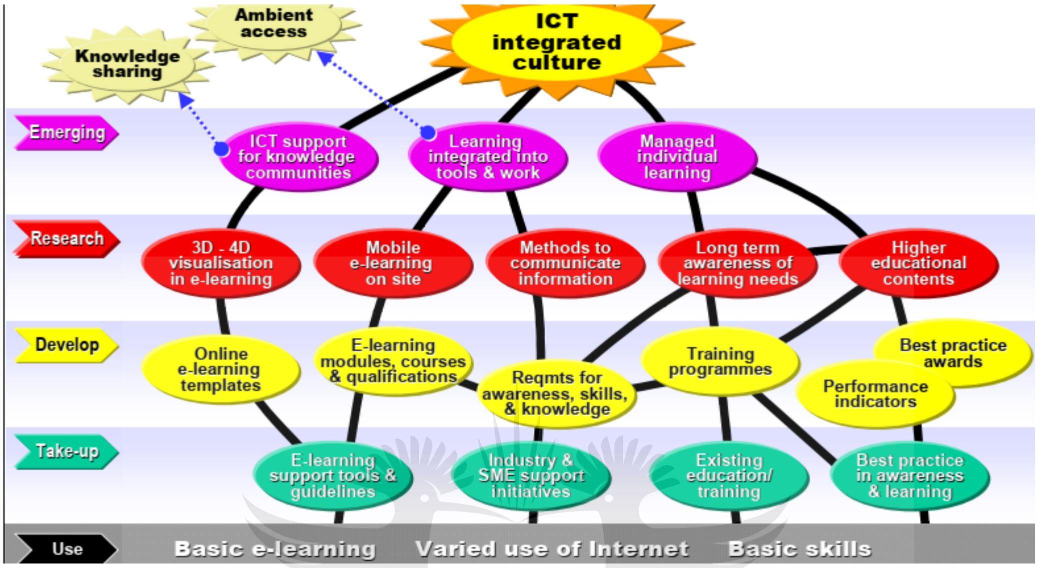

Figure 2. 21: Roadmap for ICT skills

(Hannus, Blasco, Bourdeau, and Böhms 2003:40)

A report by BRICS (2016: 26) described the framework for the skill sets required for the fourth industrial revolution.

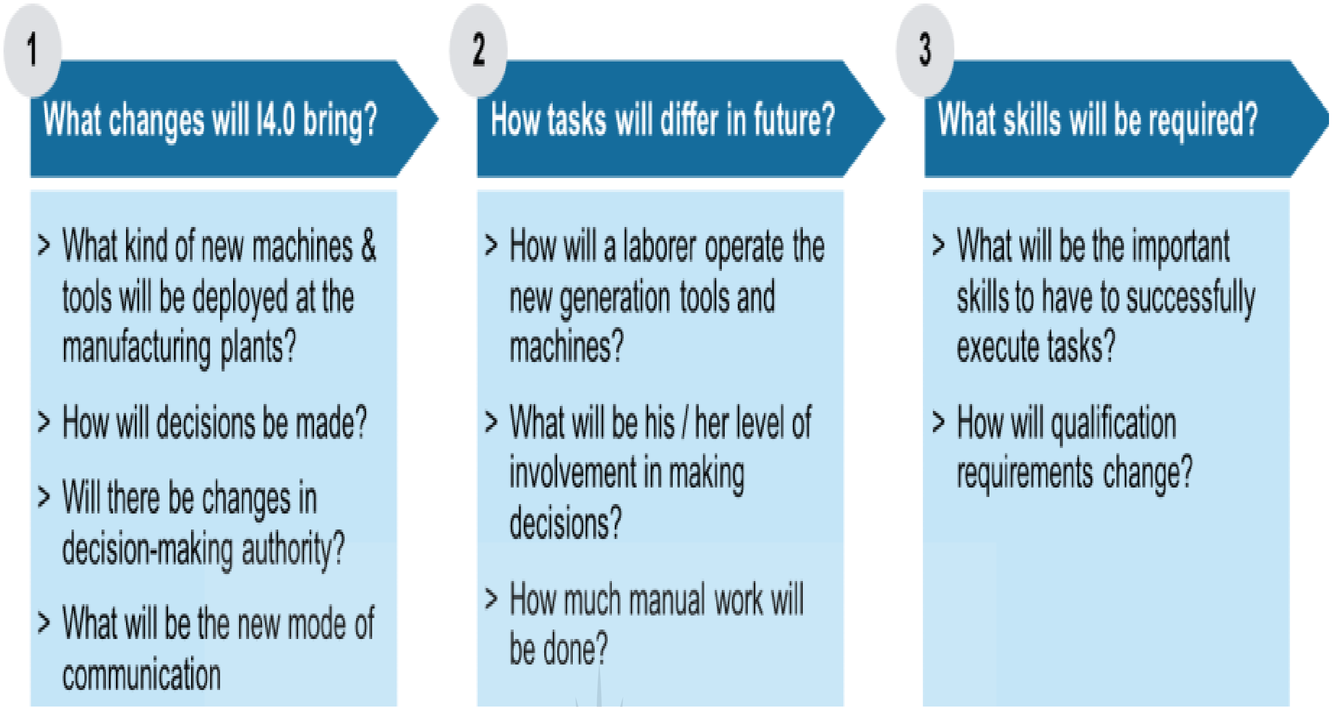

Figure 2. 22: Framework for industry 4.0 skillsets

(Bose, 2016)

Therefore, the available skillsets for ICT applications will influence the choice of ICT tools used for construction activities.

2.7.1 Drivers of ICT application in the construction industry

The drivers of ICT application are factors which influence its use. A study by Ricciardi, Zardini and Rossignoli (2016:46) indicated that drivers of ICT application in the construction industry can be grouped into technological environment-influenced factors, organizational-influenced factors, and external organizational-influenced factors. This agrees with Rogers's diffusion of innovation model (Rogers, 2004:13). Technological environment-influenced factors consider the relative advantage of the ICT tools (Chatzoglou *et al.*, 2010:78), compatibility of the tool at the firm level (Kannabiran and Dharmalingam, 2012:187) trialability, where the ICT tool users contemplate on the investment-yield ratio (Kendall *et al.*, 200:223); observability, which is the perceived benefits from the use of the ICT tools (Sin Tan *et al.*, 2009:224); procurement cost, especially in developing countries (Olatokun and Kebonye, 2010:42); and the reliability of the applications (Ricciardi, Zardini and Rossignoli, 2016:46), which described the security and privacy of such applications. Therefore, technology environmental factors are also propelled by factors arising from the organization.

Drivers of ICT applications can also be categorized under organization-influenced factors. The SMEs and bigger organizations in the construction industry, for instance, depends on their top management to make decisions concerning ICT applications (Serpell *et al.*, 2007:238) while also considering the size of such firm (Adriaanse, Voordijk and Dewulf, 2010:77). In addition, the educational and professional experience of members of an organization also drives the use of ICT tools (Chuang, Nakatani and Zhou, 2009:184), and this will influence their attitude towards ICT application (Olatokun and Kebonye, 2010:43) other organizational factors that drive the use of ICT application are the firm's propensity towards innovation as determined by the organization's flexibility, its response to environmental change and the reconfiguration of the firm's funds (Adriaanse, Voordijk and Dewulf, 2010:77) to meet up with newer innovations in the use of ICT tools for external competitiveness.

External factors also drive information and communication technological application in the construction industry. Evidence from the literature pointed out that the users of ICT face competitive pressure which leans towards ICT application investment (Kannabiran and Dharmalingam, 2012:187) since clients' requirements propel construction SMEs to adopt specific ICT tools (Oliveira and Martins, 2010:1337). The implication of this external influence is that it enables a construction organization to achieve a competitive advantage over others. Therefore, ICT application users will be compelled to follow industrial standards (Kartiwi and MacGregor, 2007:35), since these standards are in line with ICT consultants standards (Nguyen, 2009:162). Therefore major ICT drivers revolve around the technological environment, the organization and users of such tools and other external factors.

2.7.2 Problems of ICT application in the construction industry

Over time, the construction industry has repeatedly been criticized for being inefficient and slow to innovate. Fundamental methods and techniques of construction have not changed much. The technologies for construction work are the ones continually evolving (Eadie and Perera, 2016:19). For example, the construction of smart buildings is now taking this intensive demand for ICT applications to other building types, with requirements for automated systems, intelligent building management, adaptive energy systems, assistive technologies, remote monitoring, among others (Park and Kim, 2013:95), while also considering the investment costs attached to the applications (Love, Irani and Edwards, 2004:521; Eadie and Perera, 2016:23). In addition, unique identification characteristics of the Internet of Things (IoT) enable almost anything to be connected to a network. This presents particular difficulties, as the design life of a building maybe 50 years or more whereas ICT tools may become redundant within a very short period (Sardroud, 2014:56), sometimes even before the construction has been completed and the development occupied (Van Reijswoud, 2009:13). In essence, construction projects outlive the ICT tools used. As a consequence, there is a need for buildings and the wider built environment to be both future-proof and flexible.

Therefore, in the construction industry in developed and developing countries Sardroud (2014:56) classified the barriers to ICT application into cost-related, technology-related, process-related and other categories of issues which include geographical regions. The listed barriers in table 2.2 fall into these categories. A notable barrier is a difficulty in measuring its financial returns. These barriers are due to intangible factors (Rankin and Luther, 2006:1539), low ICT literacy and investment levels (Peansupap and Walker, 2006:15).

Also, justifying investment benefits and cost becomes a barrier to ICT adoption (Love, Irani and Edwards, 2004:521; Rankin and Luther, 2006:1539). Benefit-evaluation methods in the construction industry are not adequate and underutilized (Alkalbani, Rezgui, Vorakulpipat, and Wilson, 2013:66). Lack of established IT systems standards, the traditional business practice of the construction industry and the fragmented nature of the construction industry are also contributing factors (Barthorpe, Chien and Shih, 2003:370). It is also difficult to choose an evaluation tool that evaluates ICT investment on a particular level at a specific time in the adoption cycle (Barba-Sánchez *et al.*, 2007:102). Also, Oesterreich and Teuteberg (2016:136) mention the challenges faced by construction ICT tools in the 4th industrial revolution era.

Diverse innovative technologies improve daily. Therefore, researchers have posited ways of overcoming the barriers to ICT application. These include increased awareness of innovative technologies application and closely managed ICT initiative decisions (Zhou, Irizarry and Li, 2013:606). The integration of the building information model (BIM), location tracking, augmented reality (AR) and other technologies can enhance construction activities (Park and Kim, 2013:97). These drive ICT better.

Table 2. 2: Problems facing ICT application in the construction industry

S/N	Barriers
1	Hesitation to adopt ICT e.g. BIM adoption
2	The high cost of implementation
3	Organizational and process changes
4	Need for enhanced skills/staff training
5	Knowledge management
6	Acceptance by the workforce
7	Lack of standardisation (software incompatibility problem) and reliable construction team
8	The higher requirement for computing required
9	Data security and data protection
10	Enhancement of existing communication networks
11	Regulatory compliance e.g. RFID technology, BIM
12	Legal and contractual uncertainty

(Peansupap and Walker, 2006:364; Reijswoud, 2009:13; Alaghbandrad and Preece, 2012:93; Oesterreich and Teuteberg, 2016:136)

Designers need to ensure that every opportunity is taken to identify the most efficient solutions and take advantage of the new opportunities offered by technology, whilst also creating a resilient and adaptable infrastructure capable of many years of operation without costly upgrades. This requires that designers work across a number of different timescales, devising short, medium and long-term strategies for ICT.

2.7.3 Benefits of information and communication applications in the construction industry

The paramount motivation for the use of an innovation is the benefits that will be derived from the use. These benefits will influence the user, the process for which it is used and the industry or organization where it is used. The study of Akinbile and Oni (2016:164) highlighted the benefits of ICT tools for the construction industry. They include increased productivity, time-saving, reduction in transaction costs, accessibility to infrastructure, immediate connectivity, improved productivity, competitive edge for the organization, and it also serves as a substitute for more expensive means of communication

In terms of users, ICT tools have been beneficial. The use of ICT tools improves a task at hand, thereby making such a user efficient at his or her activity (Akinbile and Oni, 2016:164). As a result, there is ease and efficiency of the decision-making process on an individual, team and organizational level.. Subsequently, it leads to improved productivity. For instance, BIM as an ICT tool has several advantages to the user, process and organization. It reduces time wasted when using manual techniques for project execution, reduces safety risk at the design stage, predicts project time, improves construction team communication, minimizes rework, improves visualization of the project, and reduces missing data (Hamada, Haron, Zakiria, Humada, 2016:76), among other benefits.

2.9 LESSON LEARNT

Information and communication technology tools have been in use since the beginning of civilization. Several tools have been in use from the pre mechanical, mechanical, electromechanical, and electronic era until the present industrial revolution era. Tools for computing such as the abacus, pascaline and slide rule, opened up a way for modern ICT tools during the early era of industrialization and digitalization. During the early eras, ICT tools such as the radiotelegraph were used for conveying the information needed for construction activities. Modern tools evolved afterwards into software and hardware, the mechanical drawing board, and the CAD system. Therefore, ICT evolved with industrial revolutions. It is therefore pertinent that the skillset for construction stakeholders be upgraded to meet up with that which is required for the present industrial revolution. The use of ICT cuts across every facet of the economy, from agriculture to construction, as well as other key sectors of the economy. Construction industry being an industry with numerous interwoven task requires a strategic process system, an example of which is the RIBA plan of work. The RIBA plan of work organizes construction work into stages. Across these stages, ICT is used for executing the task. These ICT tools are driven by technological-influenced factors, organization-influenced factors and external environmental factors. Therefore, the benefits of ICT tools are seen in the user, process and the organization.

2.10 CONCLUSION

The review of literature in this section discussed the history of information and communication technology. It traced ICT from the first industrial revolution to the fourth industrial revolution. In the construction industry, ICT tools and their use have evolved across the first industrial revolution to the present industrial revolution. It also discussed the challenges posed to the effective application of ICT tools in construction work stages. The measures to ensure effective use of ICT tool were also mentioned as well as a consideration of the benefits derived from the use.

The next chapter gives an overview of ICT applications used in the UK construction industry as an international context.

CHAPTER THREE

INFORMATION AND COMMUNICATION TECHNOLOGY APPLICATIONS IN THE CONSTRUCTION INDUSTRY: A UNITED KINGDOM VIEW

3.1 INTRODUCTION

This chapter gives a theoretical review and conceptual perspective of ICT application in the United Kingdom's construction industry. This chapter firstly reviews literature which looks at the overall state of the construction industry in the United Kingdom (UK). Secondly, the chapter focuses on the general overview of the applications of ICT tools in the construction industry. Lastly, it discussed lessons learnt on ICT application in the UK construction industry.

3.2 UNITED KINGDOM

3.2.1 Background

The United Kingdom (UK) is an island country located off the north-western coast of mainland Europe. The term the UK refers to the collection of England, Northern Ireland, Scotland, and Wales. Geographically, the UK shares boundaries with Scotland, France, and Ireland. The capital of the UK is London, which is among the world's leading commercial, financial, and cultural centres. The UK has a population of about 66 million people (World Population Review, 2019) which makes it the third-highest population density country in Europe (Park, 2018:19). The UK has one of the largest national economies in the world. It has a 1.5 gross domestic product (GDP) projection in 2019 (International Monetary Fund, 2018:62). This makes it a strong contributor to the world's financial economy as enhanced by industrialization.

Map 3. 1: Map of United Kingdom

Source: Operation World: 2019

Industrialization has come a long way in the UK. It was the first country to welcome the first industrial revolution by using steam power to improve productivity (Crafts, 2004:521; Perry *et al.*, 2013:503). Afterwards, it had a central role in the global economic industrialization during the 19th century (Hoffmann and Ferguson, 2010:12; Buzan and Lawson, 2012:1-2). This enhanced the UK economy to account for 9.1% of the world's GDP in 1870 (Maddison, 2001:263; Broadberry, 2016:263). This made the economy a global influencer. The influence and position were marred by the productivity of other countries such the USA and Germany in the second industrial revolution era, and the activities of World War I and II. However, in the 21st century, it revived its global economic influences (Robin, 2015). These economic influences are evident in the UK's major economic sectors.

The major economic activities in the UK drive the economy. Agriculture, manufacturing, services, and construction have been identified as part of the key sectors in the UK economy (CEBR, 2016:4-5). Agriculture is intensive and highly mechanized in the UK. It contributes a GDP of 0.52% to the economy (Assembly, 2018:18). Likewise, the manufacturing sector is a significant sector globally. In the UK, the manufacturing industry includes the automotive, aerospace and pharmaceutical industries. It contributes about 19% of the GDP to the economy while it provides about 10% employment rate of the population in the economy (Assembly, 2018:18). The service sector comprises banking, insurance and professional services. The service sector is the dominant sector of the UK economy (Rhodes, 2015:3). It contributes around 70% of the GDP (Assembly, 2018:18). Another important sector of the UK's economy is the construction industry which contributes to employment in the economy.

3.2.2 United Kingdom's construction industry

The construction industry (CI) is a major part of the UK economy. Its output is more than £110 billion per annum. It also contributes 7% to the GDP in the country (CEBR, 2016:14). This makes it one of the largest in Europe (Woodley, 2018:14). The impact of the industry is also felt in the employment sphere. It accounts for approximately 3 million jobs which are 10 % of total UK employment (Rhodes, 2015:3). This employment is provided through the various divisions of construction activities. The divisions are the construction of buildings, civil engineering, and allied construction activities (Park, 2018:8). These divisions make the CI in the UK a highly prioritized industry in the economy.

The major business operations in the UK construction industry are through small and medium enterprises (SMEs). According to Hawksworth and Chan (2015:11), SMEs face barriers of financial viability and cost for construction. The reliance of the CI on SMEs makes it highly fragmented (Alshawi *et al.*, 2010:1531) causing decreased productivity and other problems (KPMG, 2016:8). Most challenges faced by the construction industry are broad and industry-wide as is reflected in the UK construction industry. This then requires a deliberate effort involving all stakeholders to address the challenges.

The UK government aims at improving the construction industry productivity through technology and innovation (Dainty, Leiringer, Fernie, and Harty, 2017:296). It is open to ideas such as smart construction and digital design, low carbon and sustainable construction, global trade, the image of the industry, skills and capacities, future work opportunities, supply chain, and research and development (R&D) (Berg, 2017:6). These new concepts are intended to improve construction activities for development. It is against this backdrop that a discussion on technology and innovation assumes tremendous importance.

3.3 INFORMATION AND COMMUNICATION TECHNOLOGY TOOLS IN UNITED KINGDOM'S CONSTRUCTION INDUSTRY

The definition of ICT for construction activities could be region influenced. The UK is one of the world's largest ICT markets with a 2.6 times faster growth rate in its local economy (Theresa *et al.*, 2018:5). From an international context, there are a handful of innovative projects within the UK. Evidence gathered from literature emphasises that the UK is an embracer of smart building construction. Smart buildings are intelligent buildings constructed with advanced materials and expertise (Buckman, Mayfield and Beck, 2014:96). From a holistic angle, ICT in the UK construction industry (CI) refers to the ICT applications adopted by the project team to execute construction work from conception to completed development. Therefore, the onus for the completion of these construction activities lies in the ICT tool used, and the factors influencing such applications.

The literature review identified that in the UK construction industry, the barriers to ICT applications are categorised into investment and people factors. Insufficient ICT tool research and development (R&D), confidence using new technologies, cultural influence, organizational culture, insufficient technical skills, and socio-economic hindrances are addressed as people factors facing ICT tool application in the UK construction industry (Eadie and Perera, 2016:19). The investment-related factors are significantly reduced funds for ICT tools and cost investment of such tools.

Most construction companies in the UK are SMEs, therefore the cost of procuring ICT tools for construction activities are potential barriers. But this investment cost can be overcome by addressing ICT investment problems. The benefits of ICT tools in the UK construction industry are evident in the e-business performance (Stankovska, Josimovski and Edwards, 2016:217). These benefits are harnessed through reengineering ICT tools to suit construction processes, obtaining advice on ICT tools for IT investment from professionals or the IT department, advice from university or research bodies, implementing investment through government or third party recommendation, more organizational expenditure on IT infrastructure and connecting ICT tools to e-business and organizational performance (Eadie and Perera, 2016:20). These benefits of ICT for the UK construction can be discussed the through ICT paradigm like the Internet of Thing (IoT), augmented reality, smart building, virtual reality, building information modelling (BIM), 3D printing and the like (Sardroud, 2012:54). This establishes that there are various ICT tools used in the UK construction industry. Literature also pointed out that the ICT tool in the UK construction industry is both an infrastructure and tool for transformative development (Li, Xue, Li, Hong, and Shen, 2018:1). Frequently these tools are interwoven and diversified in their use in the stages of construction works.

3.3.1 ICT tools used in RIBA/PROCSA stages of construction work

The RIBA plan of work is a UK template. In the South African context, a similar template for construction work plan is the PROCSA document (see chapter 5 for further description). These templates are similar. Therefore, the ICT tools described at the RIBA stages of work can be iterated for the PROCSA stages of construction work in South Africa. ICT applications play crucial roles in each stage of construction work. The RIBA stage of a work plan divides construction into stages 0 to 7. This literature the ICT application used from stage 0 to stage 5 as synonymous to the PROCA stages (see chapter 5). This is because these stages are described as crucial stages of construction activities (RIBA and Sinclair, 2013:8). Stage 0 is the strategic design stage, stage 1 is the preparation and briefing stage, stage 2 is the concept design stage, stage 3 is the developed design, stage 4 is the technical design stage while stage 5 is the construction stage (RIBA and Sinclair, 2013;7). The CI in the UK as an international example uses different ICT tools at each stage of construction activities.

3.3.1.1 ICT tools used in RIBA/PROCSA stage 0, stage 1 and stage 2

It is accepted that ICT tools are important components of technological diversification. The RIBA stages 0, 1, 2 are the basic planning stages of construction work. Stage 0 and stage 1 require administrative planning while stage 2 is a conceptual planning stage. In stages 0 and 1 the decisions are made for construction activities through group participation, project team procurement and drawing project programs (RIBA and Sinclair, 2013:7). These stages can be addressed together since their tasks are similar and executed with similar ICT tools.

In the construction of a health facility project in the UK, Payne, Mackrill, Cain, Strelitz, and Gate (2015:264) described that 2D and 3D designing tools were used for stakeholder's discussions. Internet-oriented ICT tools such as electronic email (e-mail), video conferencing (convergence network), and mobile computing are useful tools for a business case and strategic brief in the UK construction industry (Wong and Sloan, 2004:62). BIM, 2D and 3D CAD tools (design tools) are also used for bridging communication on construction projects (Ganah and John, 2015:14). However, in the UK CI, BIM an ICT tool is preferred to 2D and 3D CAD tools because it represents and manages both graphics and information (Ganah and John, 2015:41). This allows/enables? proper stakeholders' discussions for decision making in this stage of construction work.

Most construction companies are the SMEs, hence there is cost reduction, system flexibility, system mobility and reduced cost on system maintenance (Silverio, Renukappa, Suresh, and Donastorg, 2017:90) when using ICT tools for strategic definition. This is an advantage over traditional business communication techniques in the construction industry. However, ICT tools ICT for strategic definition construction activities pose threats such as information security, few user access, standardized compliance, data location, availability, and disaster recovery (Silverio *et al.*, 2017:85). This is because the ICT tool is quick to expire as newer construction concepts surface. However, the ICT tool is preferred for communication when selecting the project team in the strategic definition stage.

Project team member selection is vital for construction success. This explains why it is incorporated into the strategic definition stage of the RIBA plan of work. Pre-construction stages of construction activities are known for widely adopting the BIM an ICT as well (Bilal *et al.*, 2016:512). In addition, Rezgui, Beach and Rana (2013:254) also described the stage 0 and 1 as a BIM adoption stage. The selection of the project team can also be done using various computer-based and web-based ICT applications (Adwan and Al-Soufi, 2018:281). After the procurement of the project team in the strategic definition stage, the programme for the execution of the project can be drawn up.

It is important to have a clear project programme which is incorporated in stage 0 and stage 1 of the RIBA plan. In the UK construction industry, an ICT tool that is inclined towards project management is used. The major tools for drawing up a project programme fall under computer-oriented ICT tools and BIM-oriented ICT tools (Alkalbani *et al.*, 2013:254; Adwan and Al-Soufi, 2018:8). They include using Microsoft Excel, Microsoft Project Office, Primavera, PriMus KRONO and BMI-oriented tools (Oyedele *et al.*, 2019:3). These ICT tools are used for preparing and reviewing time schedule activities, time schedule management, financial management, and the execution of these schedules to prepare the way for the technical designs and the actual construction activities.

Studies indicated that in the UK CI, ICT application can be discussed from an e-business and investment standpoint. Work items which fall in the RIBA stages 0 and 1 such as specification writing, project programming, labour procurement, plant procurement, material procurement, and administrative document preparations are vital for construction e-business. E-business is explained as an ICT-led innovation in the construction industry (Ashworth and Perera, 2015:5). There is a high level of document exchange through ICT tools for activities such as specification writing, tender document preparation, project management and contract document preparation (Eadie and Perera, 2016:10). A survey, however, indicated that ICT tools for carrying out RIBA stages 0 and 1 activities such as labour procurement, material, and plant procurement are underutilized. In the UK construction industry, it is also observed that ICT tools for project management are well utilized. This shows that ICT has encouraged computerized systems to deal electronically with the planning activities of an organization.

3.3.1.2 ICT tools used in RIBA/PROCSA stages 2, 3 and 4 in the UK construction industry

RIBA stages 2, 3 and 4 have a term in common, namely 'design'. Stage 2 is the concept design, stage 3 is the developed design while stage 4 is the technical design (RIBA and Sinclair, 2013:8). This implies that there will be similarity in the ICT tools used at these stages. These stages deal with cost estimating, risk management and designing.

In the UK construction industry design tools such as BIM-based tools, computer-assisted design (CAD), AutoCAD, ArchiCAD, REVIT, Sketchup, and Autodesk are very useful in these stages (Lam, Mahdjoubi and Mason, 2017). Evidence pointed out that there is high-level usage of ICT tools for activities such as the exchange of design documents in the UK CI (Eadie and

Perera, 2016:14). Design ICT tools are thus well implemented in the RIBA stages 2, 3 and 4 of the work plan.

Cost estimating tools include WInQS, QsCAD, AutoDesk, MasterBill, Microsoft Excel and BIM-oriented ICT tools in 3D, 4D, and 5D. Using technologies attached to big data is also useful for construction activities. For instance, multivariate regression analysis, a predictive ICT tool, is used for predicting the accuracy of estimate during the early stages of construction projects (Bilal *et al.*, 2016:502). BIM is also used to keep track of construction cost and time (Jrade and Lessard, 2015:10). This indicates that there is high-level usage of ICT tools for activities such as the exchange of estimation, cost planning, and cost control. It will help solve the problem of inaccurate estimates in the UK construction industry (Ashworth and Perera, 2015:6). These ICT tools keep improving in their functionality to minimize problems attached to estimation and costing.

Risk assessment is also considered in these stages of construction. In the construction industry in UK Primavera is an ICT tool commonly used for risk management construction activities. Risk assessment is one of the serious subjects in the discussion of ICT application in the UK construction industry. Literature highlights that construction activities in the UK are described from the perspective of e-business and IT investment. Internet, CAD system, BIM and Cloud computing are high ranking e-business ICT-enabling technologies which can be used for the risk assessment processes (Eadie and Perera, 2016:20). For ICT tool investment in the UK construction industry, that there is under-investment in keeping up with or updating ICT technologies. This shows that there is a considerable level of usage of ICT tools in UK CI; however, there is underinvestment.

3.3.1.3 ICT tools used in RIBA/PROCSA stage 5

RIBA stage 5 involves construction activities. According to RIBA and Sinclair (2013:23), stage 5 incorporates construction work, health, and safety, sustainability strategy, planning handover strategy, planning asset management, and planning future monitoring and maintenance. Stage 5, therefore, involves ICT tool integration. The use of ICT tools such as drones, geospatial imagery for site surveying, GIS, RFIDs, sensors, BMS, robotics and automation, Virtual reality,3D printing for Formwork (Sacks *et al.*, 2015:71), are employed in the UK construction industry. It is argued that utilizing these tools to optimize construction activities is the next frontier of innovation in the construction industry (Bilal *et al.*, 2016:501). Some of these ICT tools can be combined together to achieve some tasks. However, it is observed that most of these tools for construction activities are still in the pre-implementation stage (Kurien *et al.*, 2018:125) e.g. robotics, GIS and BIM. In the US, for instance, Park, Cho and Martinez (2016:12) described a plan for combining BIM and robotics for construction work. This would mean that a large number of ICT tools in the construction industry have been acknowledged more in academia than in practice. Although the use of this ICT is more pronounced in the manufacturing sector than in that of the construction industry, the activities for both are interwoven.

Health and safety is a core point of discussion in the subject of construction activities. The stakeholders' health and safety determine to achieve the goals of construction activities to meet costs while still achieving value. Therefore, RIBA and Sinclair (2013:23) described the need to incorporate health and safety in RIBA stage 5 of construction work. There are ICT tools used in the UK construction industry for safety management in the construction phase specifically compared to other stages (Zhou, Irizarry and Li, 2013:7). Findings from the literature indicated that the ICT tools used for addressing safety issues in the construction phase include BIM inclined ICT tools, computer-based ICT, and the like. It was also indicated that these tools are utilised more in construction work than in designs for construction safety (Zhou, Irizarry and Li, 2013:606). This explains that there is a gap in the use of ICT tool in the UK CI.

The subject of sustainability is usually incorporated in the RIBA stage 5. In the UK construction industry, in the construction phase ICT tools such as those described earlier in the study are designed to incorporate sustainability. A study by Pan *et al.* (2018:94) developed a framework of indicators for assessing construction automation and robotics in the sustainability context. This indicates that ICT tools in the construction industry are designed and used with respect to sustainability.

According to the RIBA stage 5 of construction work, there is a need to plan for the future handover of the project when it has been completed. The construction team is aware that there should be proper planning for activities such as handover while construction work is going on (RIBA and Sinclair, 2013:23). Therefore in the UK construction industry ICT tools used for planning processes are used to plan and draw up the handover documents. The ICT tools include the Microsoft suites, sensors, automation and robotics, especially for checking for errors in the handover stage. ICT tools in the UK CI are used for planning asset management during stage 5.

The activities of monitoring and maintenance are usually incorporated in RIBA Stage 5. Monitoring and maintenance have actually been completed by this stage; it is just a matter of planned ahead (RIBA and Sinclair, 2013:23). It is posited that the stages of construction activities follow in an orderly manner (Oesterreich and Teuteberg, 2016:131). This explains the need to plan for the activities in the next stage of construction activities. In the UK construction industry, when in the construction phase, ICT tools such as Microsoft Excel, product lifecycle management (PLM) tools and BIM are employed for planning future monitoring and maintenance.

Project inspection or reporting of progress is an activity continually carried out during the construction stage. Race (2013:23) states that project inspection is vital to ascertain whether construction work is executed as drawn up in the planning and design stages. ICT tools such as Microsoft Excel and Primerva, are used to compile progress reports while tools such as administrative-based ICT tools are used during the inspection processes. Figure 3.1 below shows the relationship between ICT tools in the construction industry and the stages they are used according to RIBA classification. This diagram described some categories of ICT tools, examples of the tools and how they are interconnected to the RIBA stages of work. It finally shows that ICT tools are infrastructure for development in a firm or organization.

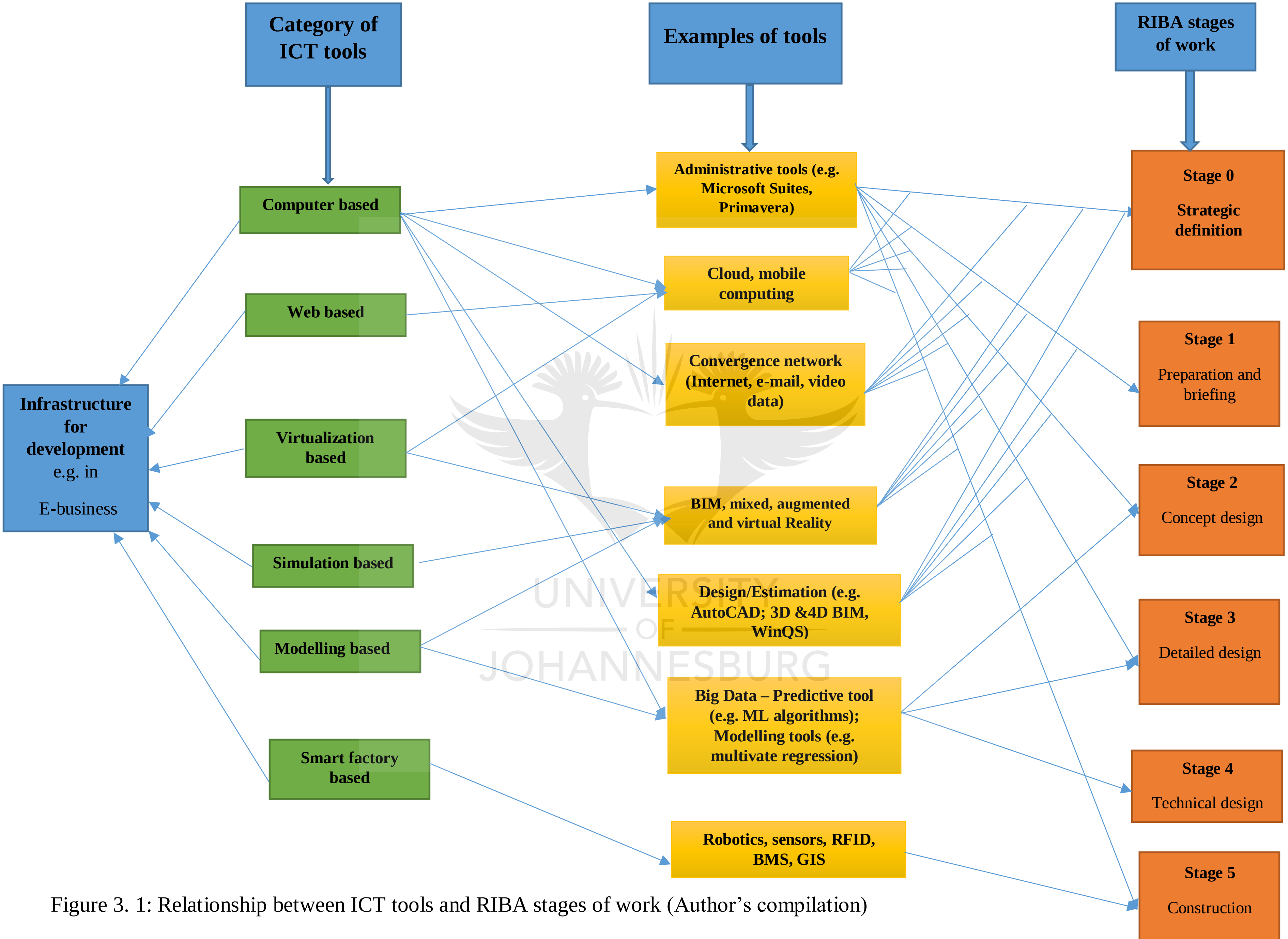

Figure 3. 1: Relationship between ICT tools and RIBA stages of work (Author's compilation)

3.3.1.4 A use case diagram for planning, design, and construction stage

A use case diagram is a tool used to analyse document functional requirements. It is part of the Unified Modeling Language (UML) (Swain, Mohapatra and Mall, 2010:21). Use case depicts how a user relates to a system. It is an analysis tool that brings business and ICT together (Jacobson, Spence and Kerr, 2016:61). It is a project management tool that can be used at the early stage of planning (Nassif, Capretz and Ho, 2010:10). A shortcoming of a use case diagram is that it does not provide a detailed behavioural pattern of the use case (Misbhauddin and Alshayeb, 2015:813). To counter this shortcoming, variants of use case are proposed and combined with other machine learning languages (Nassif, Capretz and Ho, 2010:18). However, a use case diagram is a viable tool since it answers the question of who, what, and how system goals can be achieved.

There are four elements to a UML use case diagram, namely systems, actors, use cases and relationships. A system is a component that is being developed (Swain, Mohapatra and Mall, 2010:51). It could be a business process, application or any other. It is represented by a rectangle. The name of the system is placed at the top of the rectangle. Anything outside the rectangle does not happen in the system.

Another element is the actor. It is represented as a stick figure. An actor is someone or something that uses the system to achieve a goal (Nassif, Capretz and Ho, 2010:11). It could be a person, organization, another system or a device. Actor(s) are external objects. therefore they are placed outside the system (i.e. the rectangle). They are named in categories or by generic nature. Categories here would mean specific names of the actors are avoided. There could also be the primary actor(s) and secondary actor (s). The primary actor(s) is placed on the right side of the system. It initiates the use of the system (Misbhauddin and Alshayeb, 2015:814). The secondary actor(s) is placed at the left side of the system. It plays a more reactionary role. The secondary actor will act once the primary actor does something on the system.

The third element of a UML use case diagram is the use case itself. The use case described what the system does (El-Attar, 2019:136). It is depicted as an oval shape. It represents an action that accomplishes a task in a system (Nassif, Capretz and Ho, 2010:12). It is placed in the system since it shows the actions happening. Separate cases are used to describe separate actions in the system. These cases are arranged in a logical order of function.

The last element is termed relationships. It shows what happens between the case and the actor (Nassif, Capretz and Ho, 2010:16). The types of relationships are an association, include, exclude and generalization. Association relationship is depicted with an arrow. It signifies a basic communication or interaction. Include relationship happens when an action is initiated by a use case. It is depicted by a dotted arrow pointing right. An include relationship happens all the time in a system (Kim *et al.*, 2015:3). On the other hand, the exclude relationship is the opposite of the include relationship. The last type, the generalization relationship is also known as inheritance or specialized relationship. It mimics the behaviour of a parent use case.

A use case diagram can be used to show the relationship between the construction process, the construction professionals and the ICT tool used. Figure 3.2 depicts the diagram. It represents the system as a construction Process, the actors as construction professionals used in this study, the association relationship as an arrow", and the include relationship as the dotted arrow. Past studies have described the use case diagram for project management activities. For instance, Nassif, Capretz and Ho (2010:11) described augmenting use case with soft computing when estimating for software. Also, Colburn *et al.* (2019:45) described the drilling process in engineering with a patent invention in the USA. This explains it as a viable tool for this study.

Here, the construction process is a system that has three use cases, namely the planning, design and the construction stage. All the actors, namely architects, quantity surveyors, engineers, construction project managers, and construction, managers initiate actions and tasks performed at the three stages. There is another system in the major system called the ICT tools. An include relationship happens between the actors and the ICT tools. This implies that these tools are necessary to achieve the tasks by the use cases, as well as the planning, design and construction stages. A similar study by Laplante, Laplante and Voas, (2018:4) described how a case diagram can be used to model IoT into a hospital system. Also, Thramboulidis and Christoulakis (2016:259) described how the UML case diagram can be used for IoT in the manufacturing process. Likewise, this approach can be employed for the construction process, bearing in mind the stages of construction and the ICT tools to be used.

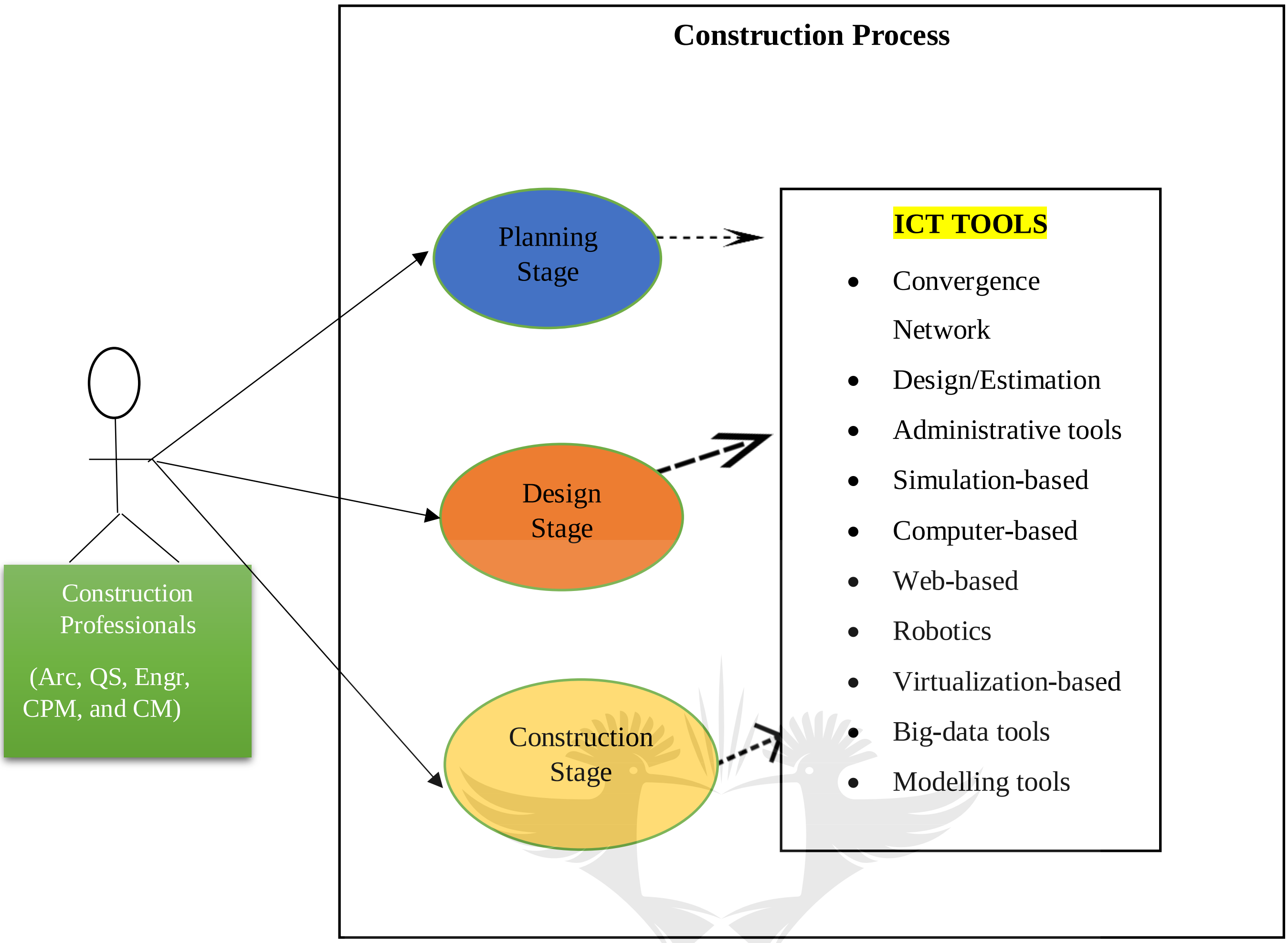

Figure 3. 2: Case diagram for construction process (Author's compilation)

3.4 LESSONS LEARNT

The literature revealed that the UK is a strong contributor to the world's financial economy. It is regarded as the first embracer of industrialization. The construction industry in the UK is saturated by SMEs which also contribute immensely to the economic system. ICT tools are highly engaged in the UK construction industry. They are regarded both as infrastructure and as tools for development. Irrespective of the use of these tools, the challenges to their use include underinvestment cost and updating cost. ICT tools for safety management are more incorporated more in the construction stage than in the design stage. However, this investment cost can be overcome by addressing ICT investment properly

The RIBA stages are divided into stages 0, 1, 2, 3,4,5,6, and stage 7. The literature reviewed showed that there are relationships between the RIBA stages of construction and ICT tools as infrastructure for the development of the construction industry either on an organizational level or the construction industry as a whole. Stage 0 and stage 1 have ICT tools that enhance decision making, project procurement, project planning, and for activities that fall into these stages. For activities that fall under the design stages, BIM-based tools, estimating and risk assessment tools are used. Finally, RIBA Stage 5 is the construction stage. In this stage of construction work, several ICT tools are incorporated. However, most tools are still in the theoretical definition phase. In addition, most ICT tools are used more in manufacturing or for off-site use than in the construction industry.

3.5 CONCLUSION

This chapter presented a review of the literature relating to the UK construction industries. The chapter further provided an in-depth review of ICT tools used at the RIBA stages 0, 1, 2, 3, 4, and5 of construction work in the industries of both countries. The findings revealed the challenges and reward of ICT tool application in the organization in the construction industries of these nations. The following chapter will review the literature relating to two African countries, their construction industries, ICT tools employed in their construction industries as well as lessons which can be learnt from both countries.

CHAPTER FOUR

INFORMATION AND COMMUNICATION TECHNOLOGY APPLICATION IN CONSTRUCTION INDUSTRY IN AFRICA

4.1 INTRODUCTION

This chapter gives a theoretical review and conceptual perspective of information and communication technology application in two African countries, namely Botswana and Ghana. This chapter firstly reviews literature which looks at the overall state of the construction industry of these countries. Secondly, the chapter focuses on a general overview of the information and communication technology applications in the respective countries. It supports this with case studies of information and communication technologies some other African countries' construction industries. In addition, the lessons learnt from each review are discussed.

4.2 BOTSWANA

4.2.1 Background

Botswana is one of the countries in sub-Saharan Africa. It is a landlocked, flat rolling tableland country (Ranganathan, and Briceño-Garmendia, 2011:12) located in the centre of Southern Africa. Geographically, it is bordered by South Africa, Namibia, Zimbabwe, and Zambia. It is has a population of around 2million. The country covers an area of 581,730 km^2 which makes it the 48th largest country in the world in terms of area. It is also one of the most sparsely populated countries in the world (2.3 million) accounting for 0.03% of the total world population (Cross Border, 2018:5)

Map 4. 1: Map of Botswana

Source: Operation World, 2019.

Botswana was one of the poorest countries in the world at its independence (Mbulawa, 2017:15). Surprisingly, over the last fifty years, it has recorded an average annual growth rate of about 8% (Ssegawa, 2013:157). Hence, this economic growth moved it to a middle-income country (Jagadeesh, 2015:11). The economy of Botswana is therefore regarded as one of the most successful in Africa. Economic growth is largely dependent on the mining of diamonds. Studies show that diamond deposits have influenced economic growth (Jefferis, 2017:1). However, the economy is shifting its focus from the mining sector through “diamond-power” (Ssegawa, 2013:2) to other sectors. Other key contributors to economic growth in Botswana are the construction sector and the manufacturing sector (UNDP, 2012:2). These sectors aim at infrastructure development.

The importance of infrastructure cannot be overemphasized. It is noticed in some developing countries that some infrastructure and construction work has usually been put in place by colonial masters. Evidence of this is seen in Nigeria, Ghana, and some other colonized countries (Obiakor and Agajelu, 2016:12). However, Botswana can be described as an economy that started its own infrastructure and construction activities from scratch. Nevertheless, Botswana’s infrastructure backbones are ICT, roads and rail transport systems, and the electricity grid (Ranganathan and Briceño-Garmendia, 2011:12). They provide infrastructure for connectivity across the nation and as well as international competitiveness.

4.2.2 Botswanan construction industry

Botswana’s construction industry comprises small and medium enterprises (SMEs), which is typical of a developing country. These SMEs are run by stakeholders such as the government, clients, and contractors. In Botswana, the government is the major client while the contractors are dominated by foreign expatriates such as those from China (Sabone and Addo-Tenkorang, 2016:1490). The government provides funds for the activities of the construction industry, mainly from the output of the mining sector. The industry is noted for the provision of infrastructure and employment for the citizens.

The construction industry worldwide is known for contributing to the social and economic development of any nation. is done through the provision of employment, revenue generation and gross domestic product (GDP) growth, a 4.2% GDP growth rate in 2018 (Cross Border, 2018:16). Like any other construction industry, Botswana’s construction industry equally contributes to the country’s economic development. For example, in 2018, the construction industry’s contribution to the GDP was estimated at US$432 million. It also employs about 12

% of the total population economy. In addition, the annual percentage variation in real GDP by economic activity of the construction industry was calculated as 4.2% in 2017 (Motsemme, 2018:18). This further explains the importance of the construction industry.

Construction worldwide is faced with some challenges. Literature records that Botswana's construction industry faces problems such as corruption in the procurement system (Legae and Adeyemi, 2017:62), performance quality (Sabone and Addo-Tenkorang, 2016:1489) and delay in project execution (Himayumbula and Prinsloo, 2010:32), among others. However, Botswana is making conscious efforts to reform activities in the construction industry (Ssegawa, 2013:158). This is aimed at improving the declining construction industry performance. Literature also pointed out that major challenges faced by the construction industry are due to the saturation of SMEs. Like other developing countries, construction SMEs in Botswana record insignificant growth (Mutoko and Kapunda, 2017:8) which also contributes to the poor performance of the industry. SMEs are also confronted with low capacity to deliver large-scale construction projects. This leads to the employment of foreign expatriates such as those from China.

The China-Botswana relationship has been widely discussed in the literature. The literature posited that China as a nation is not only interested in the infrastructural development of Botswana alone. The contribution of China to infrastructure is also seen in nations such as Nigeria, Zambia, and some other developing countries (Zheng, 2016:18). The vast resources of these African countries are leveraged upon by China for its national growth while in turn providing infrastructure for these developing economies. In Botswana, China-Botswana collaboration is seen in Botswana's print-media (Moahi, 2015:61), trading activities and infrastructure (construction activities inclusive) development (Sekakela, 2016:19). Although this relationship has been described as domineering, it has brought about advances in the use of ICT tools used in activities such as construction work. Examples of infrastructure projects through the China-Botswana relationship are the construction of a power plant in Palapye (African Development Bank, 2009:20); the construction of the main international airport, Sir Seretse Khama airport; the construction of stadia in the towns of Lobatse, Gaborone and Francistown; and the trans-Kalahari railway (Kaboyakgosi and Marata, 2013:216), among others. Botswana ranks high among the globally competitive economies in Africa. It can be described as an innovation-driven economy. This is achieved through the liberalization of its ICT sector. Ranganathan and Briceño-Garmendia (2011:13) predict that there will be a continual increase in mobile penetration through ICT and research in innovation. Innovation through ICT has been recorded in the activities of SMEs for better productivity (Olatokun and Kebonye, 2010:42).

4.2.3 ICT applications in Botswana's construction industry: A case study

Khanda and Doss (2018:468-478) studied the challenges and benefits of adopting cloud technologies by SMEs. The study was conducted through a review of the literature and a field survey. The study population involved SMEs who use cloud computing technologies in Botswana. In most developing countries, SMEs saturate the construction industry. This is also the case in Botswana's construction industry (Mutoko and Kapunda, 2017:624). Botswana has seen the growth in economic activities through the use of cloud technologies. This growth is attributed to the level of Botswana's e-readiness to adopt ICT technologies.

This case study found that 60% of the respondent SMEs use cloud technologies of different types. Despite this number of cloud technology users, challenges such as location access and organization-based challenges like security and lack of awareness of the ICT tool hinder the respondents' use of cloud technology. Irrespective of these challenges, cloud technology enhances the secured saving of data in the cloud, has low procurement costs and leads to higher productivity, among others. This study, however, contends that there is a gap in how cloud technology is used as well as other ICT tools in SMEs.

4.3 GHANA

4.3.1 Background

Ghana is a sub-Saharan country in West Africa. Geographically, it shares its boundary with the Ivory Coast, Burkina Faso, Togo, the Gulf of Guinea and the Atlantic Ocean. The capital of Ghana is Accra where the seat of its democratic constitutional government is located (Smith *et al.*, 2014:20). Ghana had a population of about 26 million people in 2014 which makes it the 13th most populated country in Africa. It had a GDP of about 6.3% in 2018, according to the IMF (2019:15). Over the past three decades, the economic performance of Ghana has been remarkable (Alagidede, Baah-Boateng and Nketiah-Amponsah, 2013:6). Economic performance has been triggered by the development of improved industries.

Map 4. 2: Map of Ghana

Source: Operation World (2019)

The industrial evolution in Ghana can be traced back to the post-independence era. The pre-economic recovery era was the period from 1960 to 1983 in Ghana where import substitution from Britain was strategized (Ackah, Adjasi and Turkson, 2014:1). The outward liberalized strategy for the industry was also formed during 1984- 2000 while the private sector-led accelerated industrial development was strategized from 2001. The purpose of these industrial strategies was to firstly define and refine industrial activities while reducing the dependence of Ghana on external borrowing. However, the IMF (2019:1) records that the country is still at high risk of external debt.

Technology and innovation are key themes that have been incorporated into the industrial framework in Ghana to achieve better industrialization (Ackah, Adjasi and Turkson, 2014:26). As such, literature indicates that since independence, Ghana has thrived in its key industrial sectors as it continually improves in its purpose through new technology and innovations. Studies posited that the key sectors in Ghana include agriculture, industry (mining and construction), manufacturing and services (Aryeetey and Baah-Boateng, 2015:4). These industrial sectors have been pivotal for economic growth in Ghana.

4.3.2 Ghanaian construction industry

The growth of economic activities in Ghana has positioned it as an evolving market in sub-Sahara Africa. This can be attributed to the impact of the construction industry (Owoo and Lambon-quayefio, 2018:2). Literature also described that the construction industry in Ghana is dominated by physical infrastructure with asset-based institutionalized systems (Ofori, 2018:26) as a means for growth and development. This industry contributes about sixteen per cent of the gross domestic product (GDP) and employs about seven per cent of the working population. The construction industry in Ghana is divided into subsectors which help define construction activities independently.

Vital construction subsectors in Ghana are grouped into housing and urban development, infrastructure, and transport infrastructure. Housing and urban development include residential buildings and municipal and commercial buildings; infrastructure describes the structures for water, sanitation, and energy while transport infrastructure includes rails, roads airports, ports and harbours (Owoo and Lambon-Quayefio, 2018:4). These are achieved through the construction stakeholders in Ghana. They are clients (private individual and government), professional consultants and contractors.

Contractors are mostly small indigenous firms and foreign contractors in Ghana. The indigenous contractors are described to be SMEs while the foreign contractors are larger firms (Ofori-Kuragu, Owusu-Manu and Ayarkwa, 2016:131). All construction stakeholders collaborate on a project (either the contractor is a foreign company or an indigenous firm) to achieve the goal of constriction activities in Ghana through technology and innovation. Technology as an important innovation helps construction activities worldwide. However, since most construction activities are conducted by the SMEs, PwC (2018:11) states that SMEs face barriers of financial viability and cost of construction. The reliance of CI on SMEs makes it highly fragmented, causing decreased productivity and other problems (Wedawatta, Ingirige and Amaratunga, 20s10:362).

In developing countries, the construction sector, like other sectors, is built on technology transfer by the SMEs from developed nations. For instance, Ghana as a developing country implements such technology as ICT in the construction industry (Bui, Merschbrock and Munkvold, 2016:488). According to Agboh (2015:1), the use of ICT is also faced with problems such as lack of internal capabilities, high cost of ICT, poor infrastructure, financial constraints, lack of information about suitable ICT solutions and lack of time for implementation. This is consistent with the findings of Iddris (2016:48), namely that ICT faces problems such as lack of right technical skills, initial cost, resistance by people and culture, and lack of interest by management for e-business activities in construction. Irrespective of the challenges posed to ICT in the Ghanaian construction industry, the SMEs who implement ICT is, however, its drivers.

The drivers of ICT in Ghana construction industry influence its adoption. Agboh (2015:6) maintains that ICT adoption among SMEs (e.g. construction industry) in Ghana is driven by a desire to increase client service and responsiveness, competitiveness, and modify communication. However, compared with other industries, the Ghanaian construction industry is low-tech and labour intensive (Fugar, Ashiboe-Mensah and Adinyira, 2013:464). Therefore, ICT in the construction industry is still backward since human capital development remains inclined towards manual labour rather than tech skills. It is pertinent to investigate the usage of ICT tools used construction stages of work.

4.3.3 ICT tools in Ghanaian construction: A case study

Oppong, Botchway and Gyimah (2017:1-13) conducted a study on cyber technology used for construction. Cyber or Internet-based technology is a type of ICT tool used in the construction industry (Silverio *et al.*, 2017:87). A case study in Ghana related the use of cyber technology according to the RIBA 2007 plan of work. RIBA 2007 has the plan grouped into five stages - the preparation stage, pre-construction, construction, in-use stage and de-occupation stage (RIBA 2007:1). Although the RIBA 2007 has been improved on as RIBA 2013, the discussion on ICT tools as used in the stages of work still follows suit.

In this study, multiple methodologies such as case studies (literature review, field studies, and interview guide), narrative modes, surveys, and philologies were employed. It reviewed the use of cyber-based technologies for architectural buildings in the Ghanaian construction industry (Oppong, Botchway and Gyimah, 2017:1-13). The study discovered that the use of cyber- or Internet-based ICT tools like the cyber architectonic (hardware, software, and networks) are used at different rates during the stage of construction work when following the RIBA 2007 plan of work. Cyber-architectonics is a computer-enhanced architectural tool used for the construction process and the post-construction stages of building. In this study, the use of these tools in the preparation stage was the highest at a 30% ranking. In the pre-construction and construction stages, their usage was at 20% each, while the in-use and de-occupation stages had a ranking of 15% usage level. However, the availability of these ICT tools influenced their ranking in terms of usage in the Ghanaian construction industry.

In terms of usage of these ICT tools in the Ghanaian construction industry, the study discovered that these tools are used at different levels for public infrastructural development. Some public sector companies use cyber-architectonics in the RIBA in-use stage and the de-occupation stage. In addition, when ranking the use of three categories of the cyber-architectonics tool in the Ghanaian construction industry, the study pointed out that the construction stage is devoid of the use of these tools.

4.4 INFORMATION AND COMMUNICATION TECHNOLOGY APPLICATION REVIEW FROM OTHER AFRICAN COUNTRIES

4.4.1 A case study of Nigeria

The study of Afolabi *et al.* (2017:13-19) described the use of ICT tools for material planning in the Nigerian construction industry. The study addressed the drivers of and barriers to the adequate use of web-based technologies in the planning and control of building materials. In addition, it discusses how ICT applications can be used for managing building material's planning and control processes using web-based technologies. According to RIBA (2013: 7), planning is essential for adequate construction project delivery; as such, the subject of material management is core to construction project execution.

The study employed a desktop review of the literature to answer the research questions. It also used a case diagram to depict the interactions involved in the use of ICT tools for material planning and control. A desktop literature review is a non-quantitative method of secondary data collection for a study. It involves a search and study of relevant and updated literature from cogent databases (Shen *et al.*, 2009:16). As such, it is a viable method of literature review, since the result of the desktop literature review can also be integrated with primary data for a more robust study. Moreover, case diagrams are good representations of users' interaction with a system (Wolters, Gerth and Engels, 2016:92). This also makes it a viable method for illustrating concepts in a study.

This case study reviewed the literature on management ICT applications in the Nigerian construction industry. It developed a case diagram for drivers of web-based ICT applications in the construction industry and a framework for system design and implementation of web-based material planning and control ICT applications (Afolabi *et al.*, 2017:15-17). Drivers of ICT applications for material planning were identified using a case diagram. The diagram illustrates the relationship between the users of ICT application in the construction industry, and the factors that drive ICT applications for material planning and control in Nigeria. According to the authors, the drivers of web-based ICT application are a reduction in the procurement price of ICT tools, Internet access, computer literacy, ICT applications' user-friendly tools, and inherent benefits, among others. This is consistent with the studies of Olatokun and Kebonye (2010:42) and Rossignoli, Gatti and Agrifoglio (2016:46).

This study further outlined the challenges facing web-based ICT applications in the Nigerian construction industry. A relationship between the users of ICT tools and these problems is depicted using the case diagram. The diagram identified the barriers as poor user acceptance, high maintenance cost, erratic power supply, and the small size of the company (most are SMEs), among others (Afolabi *et al.*, 2017:16). This is in line with the studies of Oesterreich and Teuteberg, (2016:136) and Sardroud (2014:56). A framework describing the implementation of web-based ICT applications for material planning and control was illustrated in this case study. It showed an interface for construction professionals to execute activities such as estimation and storage of material numerical quantities while planning and controlling materials per time. This agrees with the study of Adriaanse, Voordijk and Dewulf (2010:77) on the developed framework for ICT application in the construction industry.

4.4.2 A case study of Egypt

The study of Fahim, Gazzar and Gomaa (2014:816-822) described how ICT can be used to improve waste management in cities in Egypt. The study used primary sources, secondary sources and data analysis for conducting the study. Primary data was collated from interviews and videos. Secondary data was obtained from academic literature, while the data analysis involving coding of themes formed from the primary and secondary sources used. Like other developing countries, waste disposal is a concern in their construction activities. This gap is attributed to the absence of an integrative system such as ICT for waste data management. A city or municipality is built on infrastructural projects. This study discussed barriers to the use of ICT for waste material management in Egypt. It identified that ICT tools can be improved on through a medium like planning and control of waste material and the use of GIS for tracking. Furthermore, big-data inclined ICT tools can be used for addressing the problem of waste in Egypt. The study concludes that modern technologies can reduce the cost incurred for waste management. In the same way, these ICT tools for waste management can also be incorporated into the construction industry.

4.5 LESSONS LEARNT

Botswana is one of the thriving economies in Africa. Its leverages resources from its mineral sector and other sectors to develop the infrastructure needed for economic growth. This earned the country a top ranking among the global competitive economies. Infrastructure and construction projects are usually executed by a few indigenous firms and mainly expatriates, like those from China. The construction output from Botswana is enhanced through the impact of the ICT sector. The case study described the importance of cloud computing, an example of an ICT tool used in Botswana. It also indicates that there is still some non-adoption of cloud computing technology by some SMEs. The study also pointed out that there is a gap in how cloud technology is used and another ICT tool is driven in SMEs. These gaps are the barriers to the use of cloud computing by SMEs which includes the construction industry. These challenges can be overcome by utilizing the benefits of ICT tools.

Ghana as a nation has passed through the industrial revolution period. This transition was driven by technologies and innovations. As such, these technologies and innovations positioned Ghana as an emerging market. The economic growth of Ghana can also be attributed to the activities of the construction industry. Although this industry is saturated by SMEs, the technology and knowledge transfer is from developed nations. This poses several problems for the use of information and communication applications in the construction industry. In addition, the case study described an example of an ICT tool used in the Ghanaian construction industry. This tool was also assessed as it is used in each RIBA stage of construction work. Cyber-architectonics is an example of an ICT tool used in the Ghanaian construction industry. The use can be assessed according to the different stages of the RIBA plan of work. At present, the use of such ICT tools is relatively low in Ghana There is a tendency for the use of such ICT tools to improve construction activities. Moreover, such an ICT tool will enhance the accuracy of construction activities. In the long run, these ICT tools aim at achieving sustainability in the Ghanaian construction industry.

Material management is was for a successful construction project delivery. Inadequate planning for material management causes several problems such as cost overrun and construction waste, among others. To avoid this, it is necessary to introduce adequate material management during a plan of work (e.g. in RIBA stage 3 plan of work). ICT applications can be used for estimation, quantifying construction material, planning controls is driven by several factors. In the same way, there are also challenges to the use of ICT application for these processes. It was also gathered from this review that a relationship exists between construction users and ICT application for material planning. This relationship helps to overcome the barriers to ICT applications for material planning and management.

An adequate waste management tool is vital for a country. This study recognized that there is no integrated system for waste management in Egypt. This is owing to the lack of use of ICT tools for waste management processes. The country used the traditional waste management tool, which is not financially prudent. It is therefore suggested that the use of modern ICT tools such as big-data inclined ICT tools and tracking tools such as GIS and similar tools can help improve waste management in Egypt. Therefore, since the construction industry is vital for any economy, these tools can be incorporated into the construction industry.

4.6 CONCLUSION

This chapter presented a review of the literature relating to the African construction industry. It reviewed Botswana and Ghana, and their construction industries. It supported the literature from these countries by case studies of ICT applications in these countries. This chapter further conducted a case study analysis of other African countries such as Nigeria and Egypt. The following chapter will review the literature relating to South Africa, its construction industry, ICT policies, e-business, as well as lessons which can be learnt from it.

CHAPTER FIVE

INFORMATION AND COMMUNICATION TECHNOLOGY APPLICATION IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

5.1 INTRODUCTION

This chapter gives a theoretical review of ICT application in the South African construction industry. This chapter firstly reviews literature which examines the overall state of the South African construction industry. It addresses small and medium enterprises in the South African construction industry. Secondly, the chapter focuses on the skill sets for constructions ICTs. In addition, this chapter discusses the legislation and policies for ICT applications in the construction industry of the country. Lastly, lessons learnt from the overview of ICT tools which can be applied in the construction industry to better project delivery will be indicated and examined.

5.2 BACKGROUND

The Republic of South Africa is a country at the southern end of the Eurasian-African landmass (Monteath, 2001:120). It is located at the borders of Namibia, Botswana, Mozambique, Lesotho, Zimbabwe, and Swaziland. The country has a surface area of about 121.9 million square kilometres, (Strategic Plan DoA, 2007:12), which makes it the 25th largest country in the world. It is the 24th most populated country in the world as it has about 57.73million people in it as of 2018 (Stats SA, 2018:1). South Africa is a diverse nation in terms of language and ethnicity. It has a large share of Europeans, other racial nationalities and those from other similar African countries.

Map 5. 1: Map of the Republic of South Africa

Source: Operation World (2019)

The population groups in South Africa are classified into Black African, Coloured, Indian/Asian and white (Stats SA, 2018:1), while major languages in South Africa are Afrikaans, English, IsiXhosa and isiZulu (Stats SA, 2017:9). Among the major cities in South Africa are Johannesburg, Cape Town, (SACN, 2017:10), Pretoria and Port Elizabeth (also known as Nelson Mandela Bay), among others, while the provinces are Gauteng, KwaZulu-Natal, Eastern, Northern and Western Cape, Limpopo, Mpumalanga, North-West, and Free State (STATS SA, 2018:2).

From an economic standpoint, South Africa has a relatively high GDP per capita compared to other countries in sub-Saharan Africa. It has one of the high ranking economies in Africa (Thompson, 2001:200). Despite this, the World Bank (2018:12) opined that South Africa still lags behind in global economic growth, as its global GDP has been stagnant at about 0.5% over the past few years. Construction is a form of special manufacturing, declined to about 0.5% in 2014 (BRICS, 2016:24). Hence, the rate of unemployment is still high. To counter this, the country seeks to reduce unemployment by 6% in its 2030 vision by diversification of the economy (Manuel, 2019:215). It is hoped that industries such as manufacturing will benefit from this, as well as the construction industry.

5.3 The South African construction industry

The construction industry plays a vital role in any economic system. In South Africa, the construction industry also contributes to the economy. According to the World Bank Group, (2018:13), the construction industry provides about 2.5% employment for the economy. This low level of contribution is due to the impediments facing the construction industry. The study of Windapo and Cattell (2013:73) pointed out that the construction industry in South Africa faces several challenges such technology, and external influences such as government legislation, skill sets, and procurement facilities, among other problems. In addition, a study conducted by Rossouw (2016:16) showed the challenges encountered by South African construction industry include a lack of expertise, the external effect of the labour force, inherent health and safety risks, the risk attached to tender awards, and method and tools for project execution. Particularly, the method and applications for project execution have faced some challenges in the South African construction industry as a developing country. Also, as part of the BRICS nation, industrial automation is low in South Africa (Banga and Singh, 2019:11) . This can account for the recent downturn of construction firms in South Africa.

5.3.1 Small and medium enterprises in the South African construction industry

The construction industry in developing countries is saturated by a particular group of small private business owners. They are referred to as small and medium enterprises (SMEs). Construction SMEs apply ICT tools such as the Internet to carry out e-commerce and e-procurement, among others (Ibem and Laryea, 2015:364). ICTs have the potential to help SMEs to be more competitive and innovative. However, at the current ICT usage level, not all SMEs will catch up with larger firms (Barba-Sánchez *et al.*, 2007:106) since the level of automation use is low compared to that of the larger enterprises. In recent times in South Africa, these businesses are obliged to improve the workplace using new solutions like the 4th industrial revolution (Witkowski, 2017:769).

Industry 4.0 (4IR) refers to recent technological changes that integrate the Internet and ancillary technologies to improve the workplace. It offers improved performance and efficiency gain, among others. Despite the inherent benefits of 4IR, SMEs consider the concept is considered as disruptive since they are not sure of the financial implications of such new technology on their business (Mittal *et al.*, 2018:194), or of a guarantee of not displacing job opportunities (Sackey and Bester, 2016:106). In the construction industry, in particular, the level of automation of ICT tools is not yet connected to the fourth industrial revolution; as such, there is a shortage of ICT skills for construction professionals, especially the SMEs.

5.4 Legislations, policies and support structure for ICT application in the South African construction industry

South Africa is a member of BRICS, (a coalition of Brazil, Russia, India, China, and South Africa) which seeks to improve the workspace through the implementation of Industry 4.0. However, the majority of the elements of Industry 4.0, seen mainly in the automotive industry of South Africa, have been without the efforts of the government (Bose, 2016:24). The larger picture of ICT is from the ICT sector. In South Africa, the ICT sector (mainly through the Internet and telecommunication ICT) contributes about 6% to the national GDP (Gillwald, Moyo and Stork, 2012:31), yet ICT policies have not created a conducive environment for ICT investment.

The construction industry in South Africa has been faced with the challenge of application and implementation of the supportive policy for industrialization defined by the Department of Trade and Industry (Banga and Singh, 2019:24). In the UK, for example, the Industrial Strategy

(IS) is used to reform the agenda in its construction industry (Dainty *et al.*, 2017:699). Similarly, China has a standard parameter for industrialized building (Li and Zhang, 2017:7), but such policies and framework are missing in the South African construction industry. The policies and legal framework for ICT have not been effective. Hence, this ineffective policies implementation hinders the reform process for ICT.

5.4.1 Construction documents and stages of construction work in South Africa

There are several documents that guide the operation of construction work in South Africa. Some of the documents that guide construction activities in South African CI include the following:

- Standard Client Architect Agreement document: The South African Institute of Architects (SAIA) designed this document to administer design and building projects of various sizes and complexity in South Africa (SAIA, 2019:1). The document described construction work in stages. Stage 1 is the appraisal and definition of the project, stage 2 is the design concept, stage 3 described the design development, the fourth stage is the technical documentation, while stage 5 described the contract administration and inspection (SAIA, 2007:4).

- The Joint Building Contract Committee (JBCC) documents: The Construction Industry Development Board (CIDB) approved all documents of the JBBC for construction activities across South Africa. Previous studies have indicated that the JBCC documents have been used to address risk attached to construction work from the contractors' perspective (Othman and Harinarain, 2009:83), adjudication (Maritz and Hattingh, 2015:45), dispute resolution (Bvumbwe and Thwala, 2011:32), and construction mediation (Rwelamila, 2010:135) among others.

- The Professional Client/Consultants Service Agreement Committee (PROCSA) document: This document regulates engagement between the client and the consultants (PROCSA, 2019:1). The document described the scope of construction services into six stages spanning from stage 0 to stage 6. Stage 0 is the project initiation, stage 1 described the project inception, stage 2 described the concept and its viability, stage 3 is the design development stage, documentation and procurement are stage 4, construction is described as stage 5, while stage 6 is the close-out of the project

(PROCSA, 2012:23-29). The breakdown of ICT tools used at the different stage of construction work when following the RIBA plan can be iterated here as well (see chapter three)

All these documents are all linked to one another in six stages of construction work with which all SA BEPs (built environment professionals) are familiar. This grouping of stages of construction work used in South Africa are the following:

- PROCSA described the first division (Stage 0) of construction work in South Africa as the project initiation stage. Here, the activities that involve securing appropriate land for the construction project are carried out in accordance with the project initiation programme (PROCSA, 2012:23). The difference between the South African classification of construction work and RIBA's is that while the PROCSA document described stage 0 as the project initiation stage, RIBA described stage 0 as the strategic definition stage (RIBA and Sinclair, 2013:8). Therefore, the description of activities in this stage is the only difference.

- Stage 1, according to PROCSA (2012:24), is the inception of construction work. This stage initiates all that a client requires for the project. It forms the project brief which incorporates the aims of the project, priorities, constraints, assumption, aspirations and strategies. Similar to stage 0 (strategic definition) of the RIBA plan of construction work, activities such as the identification of the client's specification and identification of project constraints (RIBA and Sinclair, 2013:7) are also included.

- Stage 2 scope of construction service in South Africa is the concept and viability stage. This stage prepares and finalises the project concept in accordance with the brief including the scope, scale character, firm function, development programme and viability of the project (PROCSA, 2012:25). This classification is similar to the RIBA stage 2 which is also called the concept design stage (RIBA and Sinclair, 2013:8).

- Stage 3, according to PROCSA (2012:26), is the design development stage that develops the approved concept to finalising the design outline specification and describing the cost and financial plan. This is also similar to the developed design stage of the RIBA stage 3 of construction work (RIBA and Sinclair, 2013:8).

- Stage 4 scope of construction service in South Africa is the documentation and procurement stage. This described the construction and procurement documentation, the implementation of the procurement programme and strategies and procedures for effective and timely delivery of plant and equipment for the project (PROCSA, 2012:27). In contrast, the RIBA stage 4 technical design stage (RIBA and Sinclair, 2013:8) described concepts such as sustainability, maintenance and operational and handover strategies to be considered for the project.

- Stage 5 scope of construction service in South Africa is termed the construction stage. This stage establishes contract processes which include the preparation and coordination of the procedures to facilitate practical completion of the works (PROCSA, 2012:28). This is also similar to RIBA stage 5 (RIBA and Sinclair, 2013:28) which described the actual construction of the project at hand.

- Stage 6 ends the construction work. It is referred to as the close-out stage. PROCSA (2012:29) indicates that this stage prepares the necessary documentation to facilitate effective completion, handover and operation of the project. Similarly, RIBA stage 6 (RIBA and Sinclair, 2013:8) is the handover stage.

5.5 LESSONS LEARNT

Literature revealed that the construction industry in South Africa is saturated by SMEs. In recent times, the output of the construction industry has declined. This can be attributed to the current level of automation of construction work. The study revealed that the automation of ICT in the South African construction industry is low compared to the global standard. To improve the automation of the industry, the country needs to apply elements of the fourth industrial revolution. Also, the current policies and legislation that is supposed to serve as a support structure for ICT application in the South African construction industry are ineffective. Therefore, the current ICT tools used for the construction industry can be upscaled. This study also revealed that there are documents which guide construction activities in South Africa, some of which include the JBCC, PROCSA, and Standard Client Architect Agreement document. These documents uniformly group construction activities in stages 0 to stages 6. Theses division of construction work is similar to the stages used in the RIBA plan of work.

The major difference noticed in the South African classification of work and the RIBA classification is the naming of the stages and some activities which are slightly different.

5.6 CONCLUSION

This chapter presented a review of the literature relating to ICT application in the South African construction industry. It reviewed the overall state of the South African construction industry. It also addressed small and medium enterprises in the South African construction industry. Secondly, the chapter focuses on the skill sets for constructions ICTs. In addition, this chapter discussed the legislation and policies for ICT applications in the construction industry of the country. The following chapter will discuss the research methodology and design used for this study.

CHAPTER SIX

RESEARCH METHODOLOGY AND DESIGN

6.1 INTRODUCTION

This chapter explains the research methodology adopted in relation to the problem statement in order to fulfil the requirements of this study. Furthermore, the geographical area where the study was carried out, and the design and population sample of the study are defined. In addition, the data collecting instrument used, including methods implemented for the maintenance of legitimacy and reliability, is described in this chapter.

6.2 RATIONALE OF THE STUDY

The rationale of the current study is to contribute to the body of knowledge on ICT application in the South African construction industry by evaluating the state-of-the-art ICTs in the construction industry in relation to the PROCSA document on stages of construction work.

6.3 RESEARCH APPROACH AND STRATEGY

Research design is a tool to draw up a plan to answer the outlined research questions. According to Shanti and Shashi (2017:7), the function of research design is to provide for the collection of relevant evidence with minimal expenditure of effort, time and money; it is the conceptual structure within which research would be conducted. Bryman and Bell (2011:156) opine that there are two main research paradigm for acquiring knowledge, namely positivism and post-positivism. The positivist approach is qualitative in nature while the post-positivist approach used the quantitative research design.

This research used a post-positivist approach, as the aim is to evaluate ICT applications in the South African construction industry through a quantitative approach by eliciting information from a group of subjects about their application of ICT in their construction processes. Quantitative research, according to (Grove and Berg, 2014:15), is defined as a formal, objective, rigorous, systematic process conducted to describe, examine and test relationships' causes and effects interactions among variables. The quantitative research approach was also adopted because it can cover a large portion of the selected sample population in a short time frame. The quantitative approach also uses a fixed procedure to gather information through self-report (De Vos *et al.*, 2017:400).

A descriptive survey design was adopted to design a well-structured questionnaire. Yin (2014:280) pointed out that a research design can be descriptive, exploratory or explanatory. A descriptive study was selected because it gives an accurate account of the characteristics of the respondents. This method was chosen to meet the objectives of this study, which are to examine ICT applications used at the different stages of construction projects in the South African construction industry, to evaluate the level of awareness of ICT application among construction stakeholders, to address the measures for ensuring the effective application of ICT at the different stages of construction projects in the South African construction industry, to assess the challenges the effective application of ICT at the different stages of construction projects in the South African construction industry is facing and to determine the benefits in the effective application of ICT at the different stages of construction projects in the South African construction industry.

6.4 RESEARCH AREA

The study was carried out in Johannesburg, in Gauteng Provinces, South Africa. The Gauteng Province is saturated with construction activities, construction professionals, and allied professionals (South African Government, 2019:1). In addition, the research participants are selected based on their professional use of ICT applications in the Gauteng Province of South Africa's construction industry. The research study incorporated vital construction professionals in both the private and public sectors of the industry.

Map 6. 1: Map of Gauteng Province, South Africa

(Source: Rooms For Africa, 2019:1)

6.5 TARGETED POPULATION

A research population refers to the total number of individuals or objective groups which are subjected to be sampled (Grove and Berg, 2014:16). The target population refers to a group in the universe which possess specific characteristics – the universe being all subjects. It is the total of all individuals who possess certain characteristics, are of interest to the researcher and who meet the sample criteria for inclusion into the research study.

The targeted respondents for the study were architects, quantity surveyors, engineers, construction managers, and construction projects managers who are involved in construction projects in Gauteng Province, South Africa. These construction professionals were selected because they tend to have a substantial level of knowledge in contributing to the objectives of this study. This was achieved with the aid of a well-structured questionnaire distributed to the respondents who are professionals in the South African construction industry.

6.6 SAMPLING AND SAMPLE SIZE

Sampling is a technique used to simplify the larger population by a representative of the population (Alvi, 2016:11) which is termed the sample size. The sample size is the relative smaller selection from a larger universal set to form a sample which is neither too large nor too small (Etikan, Musa and Alkassim, 2016:2). There are two approaches to statistical sampling, namely probability sampling and non-probability sampling (Alvi, 2016:12). The examples of probability sampling are simple random samples, stratified random samples, systematic samples, and cluster samples, all of which are used for quantitative research design. Also, the examples of non-probabilistic sampling technique are accidental or incidental samples, purposive samples, convenience sampling, quota samples, and snowball samples.

This study adopted the purposive sampling technique instead of the cluster sampling, stratified sampling or the sampling using multiple probability techniques (Kumar, 2019:159) since it gives all the participants an equal chance to be selected for the study with the same criteria i.e.

construction industry professionals in Gauteng, South Africa. Other advantages of using the random sampling probability technique include its ability to avoid bias in the response of the population.

6.7 DATA COLLECTION

The data for this study was gathered through secondary sources (review of relevant literature) and a primary source (a well-structured questionnaire). The questionnaire which is used for quantitative research is drawn from the secondary sources (Kumar 2011:147). The study supervisor scrutinized the structured questionnaires for validation, upon which it generated a list of likely and relevant respondents. The questionnaire was then presented as an online survey through Questionpro software survey tool. This survey tool was chosen because it has adequate strategies for data collection, data presentation, and options for data analysis and data interpretation (Bhaskaran, 2005:21). In the design of the online survey, respondents were given the liberty to answer all or some of the questions. Potential respondents in Gauteng were contacted via the Linkedin platform. Some dropped their email addresses for the survey link to be emailed to them, while others filled the questionnaire form directly in their Linkedin message page

6.8 INSTRUMENTS OF DATA COLLECTION

A questionnaire was chosen for this research as the preferred data collection instrument. Questionnaires are considered a valuable method of collecting a wide range of information from a large number of respondents. Brace (2018:40) defined a questionnaire as a form which is prepared with questions and is distributed for respondents to fill in or tick their opinions. It is an instrument of data collection which is cost-effective and provides greater anonymity for the respondents (Kumar, 2011:159). Questionnaires can either be closed-ended (restricted) or open-ended (unrestricted). Respondents in the open-ended questionnaires answer the questions in their own word while for a closed-ended questionnaire the answers are set out for the respondents to tick or mark (Kumar, 2011:161). Hence, a closed-ended questionnaire provides a substantial level of information and freedom for the respondents to express themselves without any criticism for bias. Closed-ended questionnaires also involve answering "Yes" or "No", or ranking of choices. This study used restricted or closed questionnaires. It was constructed in a precise and concise English language. It avoided ambiguous questions, double-barrelled questions, leading questions and presumptuous questions (Adler and Clark, 2011:244).

The questionnaire was assembled through the design of seven sections: A, B, C, D, E, and F. Section A was aimed at knowing the background information of the respondents through obtaining demographic data and biographical data. Section B aimed at evaluating the level of awareness of ICT application in construction. The third section examined ICT applications used at the various stages of construction projects in the South African construction industry. Section D addressed challenges facing the use of ICT for construction work in South Africa. Section E focused on the measures to ensure the effective use of ICT tools in the South African construction industry, while Section F, the last section, determined the benefits of effective ICT tool usage in the South African construction industry. Also, attached to the questionnaire were guidelines and instructions to aid the respondents in answering the questionnaire successfully (See appendices 1 and 2 for the questionnaire). Validity and reliability of data-measuring instruments are crucial to scientific research (Mohajan, 2017: 58). Before analysis could be initiated, the collected data from the respondents had to be cleaned and screened. Frequency analysis of the raw data was then done using the Statistical Package for Social Sciences (SPSS) version 25.

6.8 PERIOD OF COLLECTION

The online distribution of the questionnaire spanned from 07 June 2019 to 05 July 2019.

6.9 DATA ANALYSIS

This research study focuses on the review of ICTs in the South African construction industry. Using a five-point Likert scale, the respondents were asked to rate the various ICT applications used at the different stages of construction projects in the South African construction industry. The respondents were also asked to rate their level of awareness of these tools. Their respondents were additionally asked to rate the challenges to the application of ICT tools at the various stages of construction work. The respondents were further asked to identify the various measures to ensure the effective application of ICT at the different stages of construction projects. Lastly, the respondents were asked to scale the benefits of the effective application of ICT tools at stages of construction work. The data was then analysed by using quantitative techniques of mean item score (MIS) and factor analysis.

6.9.1 Mean item score

For this current study, a five-point Likert scale was used to review the ICTs used in the South African construction industry from sections B to F. The adopted extant scale was:

- **Section B**: 1 = Not aware; 2 = Sightly aware; 3 = Somewhat aware; 4 = Moderately aware; 5 = Very aware

- **Section C:** 1 = Never use; 2 = Almost never; 3 = Occassionally use; 4 = Almost every time; 5 = Every time.

- **Section D:** 1 = To no extent; 2 = Small extent; 3 = Moderate extent; 4 = Large extent; 5 = Very large extent

- **Section E:** 1 = To no extent; 2 = Small extent; 3 = Moderate extent; 4 = Large extent; 5 = Very large extent

while;

- **Section F:** 1 = To no extent; 2 = Small extent; 3 = Moderate extent; 4 = Large extent; 5 = Very large extent

The five-point scale was transformed into a mean item score (MIS) for each of the ICT applications used at stages of construction work in South Africa. The relative MIS was calculated from the total of all the weighted responses and then related to the summed responses on a specific aspect. This action was based on the principle that the respondents' scores on the specific criteria when measured together are the empirically determined indices of relative importance. According to Singh (2006:208), the index of MIS of a specific factor is the total of the respondents' actual scores (on the five-point Likert scale) given by the respondents as a proportion of the sum of all the maximum possible scores on the five-point Likert scale that all respondents could possibly give to that specific criterion. Weighting was then assigned to each response, ranging from one to five for the responses of 'Unimportant' to 'Extremely important', 'Very dissatisfied to 'Very satisfied' and 'Strongly disagree to Strongly agree'. This is expressed in a mathematical form below. The mathematical computing of the mean item core (MIS) was then illustrated as follows:

$$MIS = \frac{1n1 + 2n2 + 3n3 + 4n4 + 5n5}{\Sigma N} \quad \text{……………………. Equation 1.0}$$

Where:

n1 = Number of respondents for ‘Unimportant’, ‘Very dissatisfied’ or ‘Strongly disagree’

n2 = Number of respondents for ‘A little important’, ‘Dissatisfied’ or ‘Disagree’

n3 = Number of respondents for ‘Moderately important’ or ‘Neutral’

n4 = Number of respondents for ‘Important’, ‘Satisfied’ or ‘Agree’

n5 = Number of respondents for ‘Extremely important’, ‘Very satisfied’ or ‘Strongly agree’

N = Total number of respondents

After the mathematical computations had been carried out, the individual criteria were then ranked in descending order of their mean item score (MIS) which is from the highest to the lowest.

6.9.2 Compare mean

This is a statistical technique also referred to as the compare means t-test. It is used to compare the mean of a variable in one group to the mean of the same variable in one, or more, other groups. Gerald (2018:50) opined that the one-sample t-test is used for the mean comparison of a prefined value in a sample. A t-test assumes that the population sample is normal (Pallant, 2016:18), therefore means can be compared.

6.9.3 Factor analysis

There are techniques in research to explore relationships among variables, one of which is factor analysis. Factor analysis is a statistical technique used to reduce the number of variables in a study, to find a relationship between these variables, and categorise the similar ones (Pallant, 2016:126). Factor analysis can either be exploratory factor analysis (EFA) or confirmatory factor analysis (CFA) (Gie Yong and Pearce, 2013:79). The distinction between the EFA and the CFA is that EFA is a simple approach used in the early stages of a research study while the latter is a more complex approach used in the later phase of research.

The study used the exploratory factor analysis to explore the overall data and determine the factors and clusters of factors measured by the research instrument. In addition, EFA is also a method used to provide evidence of the validity and reliability of the various ICT application at the stages of construction work. The eigenvalues and scree plot were studied to determine the number of factors. For this study, factor loadings higher than 1.0 were deemed as significant, as the significant factor loading is greater than 0.5. From this, the conceptual factors and cluster factors measured by the questionnaire were identified. The EFA was conducted using SPSS version 21. This research study adopted the principal axis factoring as the extraction method used for the data. The data also underwent both the 1st order factor analysis and 2nd order factor analysis. However, the rotation method used for the 1st order factor analysis was varimax Kaiser normalisation while direct oblimin with Kaiser normalisation was used for the 2^{nd} order factor analysis.

6.9.4 Validity and reliability tool

A validity test is conducted to ensure that the completed questionnaires meet with standard high-quality measures. Survey results from past studies on the subject were adopted when needed in the questionnaire development for validity purposes. Also, the completed questionnaires were examined by an expert statistician to confirm the quality of the items to ensure standard high-quality measures. This agrees with Olson (2010:313) that expert reviews and validation enhance the validation and quality of the survey. The reliability test ascertains the degree of consistency of a research instrument, in this case, a questionnaire. Cronbach's alpha is commonly used for internal consistency for reliability measurement (Tavakol and Dennick, 2011:53). For the reliability test, the scale of the correlation ranges from 0 to 1. DeVellis (2016:106) indicates that Cronbach's alpha of above 7.0 is an acceptable value for the test of reliability.

6.9.5 Non-parametric test

It is necessary to compare groups using statistical techniques for this study. There is the parametric technique and the non-parametric technique. Pallant (2016:206) contends that the parametric technique makes assumptions about the population of the sample and data while the non-parametric test is appropriate for testing the significant difference or relationship existing in smaller groups of respondents. Some parametric techniques include independent-sample t-test, paired sample t-test and one-way ANOVA while some non-parametric technique includes chi-square for the goodness of fit, Mann-Whitney u test, and the Kruskal-Wallis test, among others.

This study used the non-parametric technique since it is ideal when the data measured are nominal and on ordinal ranked scales (Pallant, 2016:214). The Kruskal-Wallis H test, a type of non-parametric test, was conducted to check the consistency in the opinions of the group of respondents. It is a suitable non-parametric test when comparing three or more groups (Pallant, 2016:236). A significance value (p-value) indicates the probability of the null hypothesis is true. If the p-value is greater than 0.05, then there is a statistical difference, hence the null hypothesis is accepted. Conversely, if the p-value is less than 0.05, the null hypothesis is rejected since there is no statistical difference in the mean (McCormick, Salcedo and Poh, 2015:228).

In this study, three hypotheses are formulated after the EFA. A hypothesis is used to tentatively predict the relationship between two or more variables. The two types of hypothesis are the null hypothesis (H_0) and alternate hypothesis (H_1). The null hypothesis does not have an effect on the study while the alternate hypothesis is the one in which the researcher is interested (McCormick, Salcedo and Poh, 2015:132):

Hypothesis 1

- H_0: There is no statistical difference in respondents' use of ICT tools at the planning stage
- H_1: There is a statistical difference in respondents' use of ICT tools at the planning stage

Hypothesis 2

- H_0: There is no statistical difference in respondents' use of ICT tools at the design stage
- H_1: Alternate hypothesis: There is a statistical difference in respondents' use of ICT tools at the design stage

Hypothesis 3

- H_0: There is no statistical difference in respondents' use of ICT tools at the construction stage
- $H_{1:}$ There is a statistical difference in respondents' use of ICT tools at the construction stage

6.10 DELIMITATION OF THE STUDY

Delimitations refer to those factors that restrict the scope of the research study (Simon, 2011). The research study was limited to the South Africa construction industry. The construction stages in which ICT applications were reviewed were limited to the brief stage, concept design stage, developed design stage, technical design stage, and construction stage. The questionnaires were structured into sections and administered in the English language to the respondents. They included practising professionals in the South Africa construction industry (architects, quantity surveyors, civil engineers, construction projects managers). The research study determined the level of awareness of ICT application in the South African construction industry and the ICT applications used at the different stages of construction projects in the South African construction industry as well as challenges facing its effective application. This research study also evaluated the measures for ensuring the effective application of ICT at the different stages of construction projects in the South African construction industry and the inherent benefits that come from the effective application.

6.11 ETHICAL CONSIDERATION

Ethical considerations in the field of research are important in protecting and ensuring the integrity of the researcher (Homan, 1991:148). This study did not identify or encounter any ethical issues. The ethical considerations in this research study took into cognizance the obligations to the authors whose work had contributed to the review of the literature to ensure they had been properly acknowledged and cited. The obligation to the respondents in the questionnaire survey was that their responses were to be strictly confidential and used solely for academic purposes. The respondents to the questionnaire also had the right not to answer questions they felt were not fitting, without any form of coercion. Participants were also assured that there were no potential risks or costs involved in participating in this research study.

Confidentiality and anonymity were maintained throughout the course of this study. According to Burns and Grove (1993:762), anonymity is a situation in which the respondents cannot be connected or traced, even by the researcher, to their individual responses. In this study, confidentiality was maintained by keeping the collected data confidential and not revealing any identities during publishing or any form of reporting. No additional information was required on the questionnaires, and questionnaires were only numbered after the data had been collected. Also, attached to the questionnaires was a written cover letter of permission to carry out the research study. This had been obtained from the Department of Construction Management and Quantity Surveying, Doornfontein Campus, University of Johannesburg.

6.12 CONCLUSION

This chapter described the research methodology adopted in this research study, including the population, sample, data collection instruments and strategies used to ensure ethical standards. The next chapter presents the data analysis and interpretation of this research study.

CHAPTER SEVEN

DATA ANALYSIS AND INTERPRETATION

7.1 INTRODUCTION

This chapter presents the results of the data obtained from the structured questionnaires which were disseminated to the research respondents who included architects, quantity surveyors, engineers, quantity surveyors, construction project managers and construction managers. The analysis of the collected data and interpretation of the results were obtained from the questionnaire study and they served as the basis of the quantitative data collection. A hundred and fifty respondents took part in the survey. After filtering and cleaning the data, a hundred and twenty of the questionnaires were completely filled in, hence this number was used for the analysis.

7.2 SECTION A: BIOGRAPHICAL DATA RESULTS

This section discusses the profile of the respondents regarding their educational qualification, profession, years of experience in the construction industry, and type of organization they work for. These profiles are considered relevant to the study.

7.2.1 Distribution of sample according to educational qualification

Findings relating to respondents' educational qualification revealed that 15.8 per cent had a post-matric diploma or certificate, 29.2 per cent had a bachelor's degree and 28.2 per cent had an honour's degree. The master's degree holders amounted to 19.2 per cent, and 7.5 per cent had a doctorate. This is illustrated in Figure 7.1.

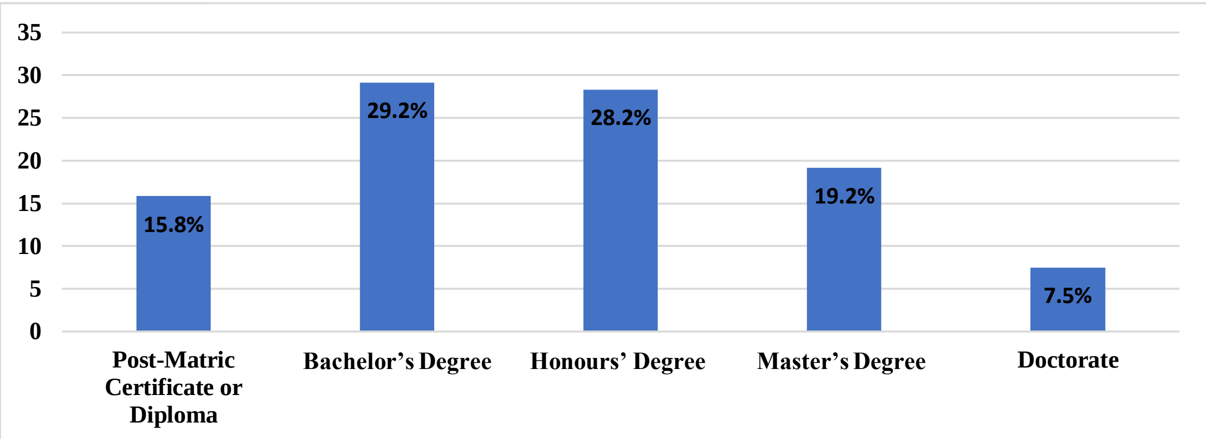

Figure 7. 1: Respondents' educational qualifications

7.2.2 Distribution of sample according to the profession

The result from the analysis showed that 12.5 per cent of the respondents were architects and 43.3 per cent were quantity surveyors. The engineers numbered 20.8 per cent, construction managers 12.5 per cent and 10.8 per cent were construction project managers (see Figure 7.2).

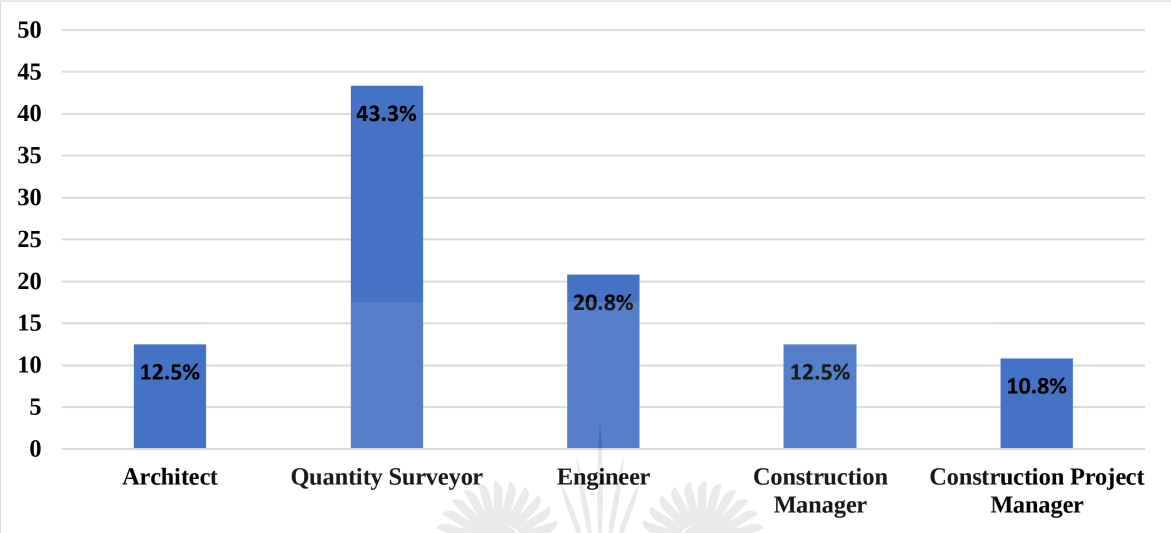

Figure 7. 2: Respondents' Profession

7.2.3 Distribution of sample years of experience in the construction industry

Figure 7.3 presents the years of experience of the respondents. At least fifty per cent (50%) of the respondents have in the range of five years' experience; 17.5 per cent have between six to ten years of work experience, and those that had between eleven to fifteen years numbered 10. 8 per cent. There is 10 per cent of the respondents with between sixteen to twenty years of work experience, and 11.7 per cent had more than twenty years of work experience in the construction industry. The years of experience of respondents were sufficient to provide useful responses to achieve the purpose of the study since above 50 per cent of the respondents had work experience of five years to more than 20 years.

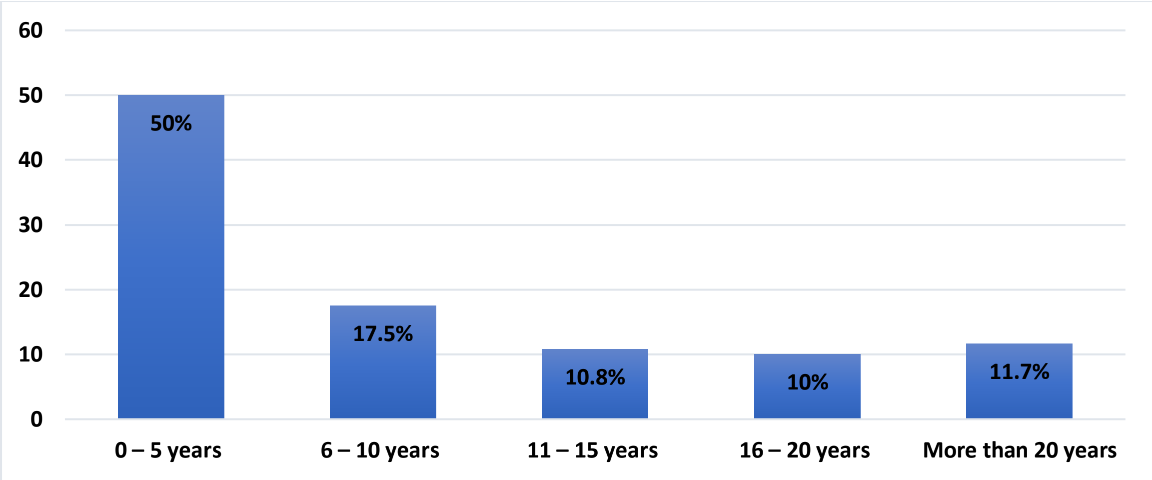

Figure 7. 3: Respondents' years of experience

7.2.4 Distribution of sample type of organization worked for

Figure 7.4 revealed three types of organization where the respondents work. A total of 44.2 % work in consultancies, 39.2 per cent work as contractors and 16.7% work in Government parastatals.

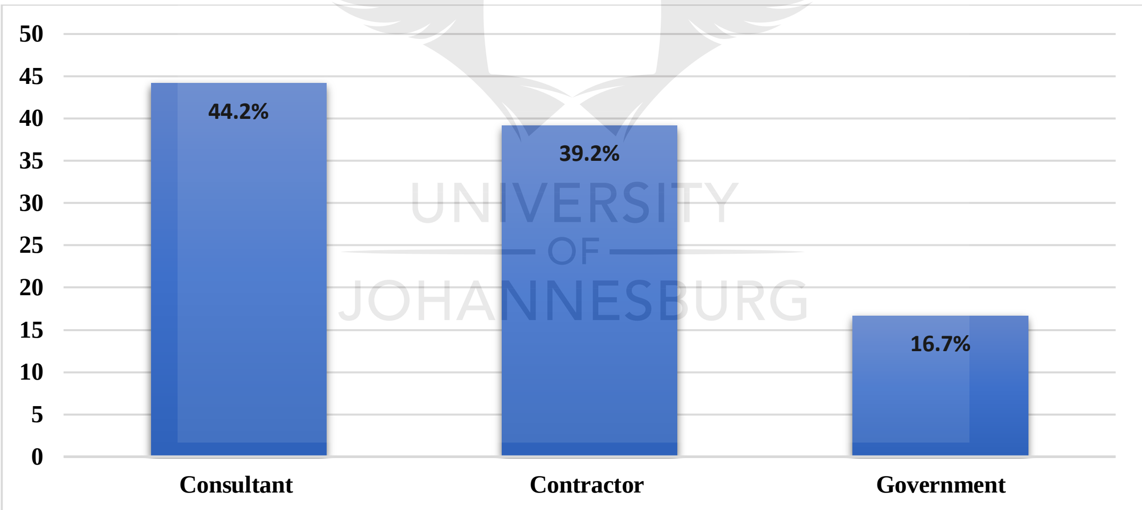

Figure 7. 4: Type of organization worked for

7.3 SECTION B: RESULTS FROM GROUP MEAN COMPARISON AND NON-PARAMETRIC ANALYSIS ON AWARENESS OF ICT TOOLS

This section discusses the compare mean and the non-parametric test on the level of awareness of ICT tools. The compare mean presented the individual mean item score (MIS or $\bar{x}$) and the rank (R) of each ICT tool against their ranking from professionals, while the non-parametric analysis presented the result of testing whether there are differences in the opinions of professionals on the levels of their awareness of ICT tool usage.

7.3.1 Compare Means on Awareness Level of ICT tools in the South African Construction Industry

Table 7.1. presents the compared group mean of awareness of ICT tools. Tools with MIS from 3.00 and above are considered strong. From the table, it is seen that the tool 'Architects' are most aware of is the 'Simulation-based tool' with MIS of 4.67. This group of respondents ranked 'Administrative tools' (MIS=4.47) second; 'Design/Estimation tools' third (MIS=4.40); 'Convergence Network' (MIS=3.47) fourth; 'Modelling tool' (MIS=3.20) fifth; 'Big-data predictive tool' (MIS=2.80) sixth; 'Virtualization' seventh with MIS of 2.73; 'Computer-based' (MIS=2.47) eighth, while 'Web-based' and 'Robotics' both ranked ninth with MIS of 2.33 and 2.33 respectively.

The table also indicates that 'Quantity Surveyors' ranked the awareness of 'Design/Estimation tool' as the highest (MIS=4.46); 'Convergence network' ranked second (MIS=4.12); 'Simulation-based tools' ranked third (MIS=3.98); 'Administrative tools' ranked fourth (MIS=3.29); 'Modelling-based tools' is ranked fifth (MIS=3.25); sixth is 'Big-data' with MIS of 2.94; seventh is 'Web-based ICT' with MIS of 2.54, eighth is 'Virtualization-based' (MIS=2.48); 'Computer-based' ranked ninth with MIS of 2.13, while the least ranked by this group of respondent is the 'Robotics, Sensors' with MIS of 2.02

'Engineers' ranked the awareness of 'Simulation-based tools' as the highest (MIS=4.92); 'Design/Estimation' ranked second (MIS=4.68); 'Convergence network' ranked third (MIS=4.60); 'Modelling' ranked fourth (MIS=3.64); 'Administrative tools' ranked fifth (MIS=3.36), and 'Big-data' ranked sixth with MIS of 3.24. The least ranked factors are 'Computer-based', 'Robotics', 'Virtualization', and 'Web-based tools' with MIS of 2.88, 2.80, 2.60, and 2.56 respectively.

The table also shows the ranking of awareness of ICT tools by the 'Construction Manager'. Ranked first is 'Design/Estimation' (MIS=4.80); 'Convergence network' ranked second (MIS=4.73); ranked third is 'Simulation-based tools' with MIS=4.53; 'Modelling-based' tools ranked fourth (MIS=3.47); 'Big Data' ranked fifth with MIS of 3.27, sixth-ranked is 'Web-based' (MIS=3.20), 'Computer-based' ICT tools ranked seventh with MIS of 3.13; ranked eight is ‘Administrative tool’ (MIS=3.07). The least ranked ICT tools are ‘Robotics’ ranked ninth (MIS=2.80), and the tenth is ‘Virtualization’ with MIS=2.73.

The last respondents, ‘Construction Project Managers’ ranked the awareness of ‘Simulation-based’ first with MIS of 4.23; second is ‘Design/Estimation’ with MIS of 4.08; ranked third is ‘Convergence network’ (MIS=4.00); ‘Administrative tools’ ranked fifth with MIS of 3.38; ‘Modeling-based tools’ also ranked fifth with MIS of 3.31; ‘Web-based tools’ ranked sixth with MIS of 3.23; ‘Computer-based tools’ and ‘Robotics’ both ranked seventh with MIS of 3.00. The least ranked tools are ‘Computer-based’ and ‘Robotics’ with MIS of 2.31 and 2.23 respectively.

Also, the table presents the Kruskal-Wallis H test to ascertain whether there is a significant difference in the opinion of professionals on their level of awareness of ICT tools. A p-value (sig) greater than 0.05 shows that there is a statistical difference in the opinions of respondents, and vice versa. The table indicates that there is a statistical difference in the opinions of professionals on all tools except ‘Design/Estimation’ (p-value =.000); ‘Simulation-based tools’ (sig =.008); and ‘Convergence network’ (p-value =.005). Therefore, there is no statistical difference in the opinion of respondents as to the use of these three tools.

Table 7. 1: Compare means on the level of awareness

	General			Architect		QS		Engineers		CM		CPM	
ICT Tools	Mean ($\bar{x}$)	Chi Square	Sig	$\bar{x}$	Rank (R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)
Convergence network	4.38	4.567	.335	3.47	4	4.12	2	4.60	3	4.73	2	4.00	3
Design/Estimation	3.92	22.385	.000	4.40	3	4.46	1	4.68	2	4.80	1	4.08	2
Administrative tools	3.81	9.479	.050	4.47	2	3.29	4	3.36	5	3.07	8	3.38	4
Simulation-based tools	3.33	13.790	.008	4.67	1	3.98	3	4.92	1	4.53	3	4.23	1
Computer-based ICT tools	2.86	1.694	.792	2.47	8	2.13	9	2.88	7	3.13	7	3.00	7
Web-based ICT applications	2.69	6.370	.173	2.33	9	2.54	7	2.56	10	3.20	6	3.23	6
Robotics, sensors, RFID, BMS, GIS	2.39	7.752	.101	2.33	9	2.02	10	2.80	8	2.80	9	3.00	7
Virtualization-based tools	2.23	1.846	.764	2.73	7	2.48	8	2.60	9	2.73	10	2.23	9
Big-data predictive tool	2.06	14.781	.005	2.80	6	2.94	6	3.24	6	3.27	5	2.31	8
Modelling-based tools	2.06	12.884	.012	3.20	5	3.25	5	3.64	4	3.47	4	3.31	5

7.3.2 Factor analysis on awareness of ICT tools

The factors on awareness of ICT tools usage were subjected to principal component analysis (PCA) using the SPSS version 25 software. Prior to performing the PCA, the suitability of data for factor analysis was assessed. It presented the results from KMO and Bartlett's test, anti-image matrices, commonalities for the data selected, total variance explained, the scree plot and the pattern matrix for the grouping on level of awareness of ICT tools. Table 7.1 presents the labels used for awareness of ICT tool usage.

Table 7. 2: Labels for awareness of ICT tools

Label	Factors
B5.1	Convergence network (internet, e-mail, video data)
B5.2	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS, CCS)
B5.3	Administrative tools (e.g. Microsoft Suites, Primavera)
B5.4	Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality
B5.5	Computer-based ICT tools
B5.6	Web-based ICT applications
B5.7	Robotics, sensors, RFID, BMS, GIS (industry 4.0 elements)
B5.8	Virtualization-based ICT applications
B5.9	Big Data – Predictive tool (e.g. ML algorithms)
B5.10	Modelling Based tools e.g. Multivate regression

7.3.2.1 Correlation matrix

Table 7.3 presents the correlation matrix. Inspection of the correlation matrix revealed the presence of co-efficient of 0.6 and above which was suitable for factor analysis

Table 7. 3: Correlation matrix for awareness of ICT tool usage

Correlation	B5.1	B5.2	B5.3	B5.4	B5.5	B5.6	B5.7	B5.8	B5.9	B5.10
B5.1	**1.000**	0.592	.070	.311	.159	.063	.240	.270	.344	.406
B5.2	0.592	**1.000**	.113	.191	.055	-.054	.073	.101	.133	.119
B5.3	0.070	0.113	**1.000**	.379	.520	.392	.483	.580	.389	.385
B5.4	0.311	0.191	.379	**1.000**	.279	.175	.371	.383	.432	.473
B5.5	0.159	0.055	.520	.279	**1.000**	.581	.695	.562	.506	.453
B5.6	0.063	-.054	.392	.175	.581	**1.000**	.550	.553	.367	.377
B5.7	0.240	0.073	.483	.371	.695	.550	**1.000**	.679	.509	.528
B5.8	0.270	0.101	.580	.383	.562	.553	.679	**1.000**	.666	.555
B5.9	0.344	0.133	.389	.432	.506	.367	.509	.666	**1.000**	.818
B5.10	0.406	.119	.385	.473	.453	.377	.528	.555	.818	**1.000**

7.3.2.2 KMO and Bartlett's test on challenges to ICT usage

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is a degree of whether the distribution of values is adequate for proceeding with factor analysis. A measure of < 0.5 is not acceptable, > 0.5 is miserable, > 0.6 is mediocre, >0.7 is fair, >0.8 is commendable and 0.9 is marvelous. Bartlett’s test of sphericity (‘Sig’) is a measure of the multivariate normality of the set of distributions (Pallant, 2016:190) which does not produce an identity matrix (Garson, 2012:39). Table 7.4 presents the results of the KMO and Bartlett's test of sphericity challenges to ICT tool usage. Pallant (2016:187) stated that the KMO value should be 0.6 or above and Bartlett's test of sphericity should be statistically significant at $p < 0.05$. The table showed a KMO sampling adequacy of 0.755 and Bartlett's test of sphericity at a p-value of 0.000. Therefore, factor analysis is appropriate for the set of data.

Table 7. 4: KMO and Bartlett's test on awareness of ICT tools

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.773
Bartlett's Test of Sphericity	Approx. Chi-Square	608.738
	df	45
	Sig.	0.000

7.3.2.3 Communalities table

Table 7.5 shows the various items after extraction and should contain values above 0.3. The values as seen from the table all consists of items greater than 0.3.

Table 7. 5: Communalities table on awareness of ICT tools

	Initial	Extraction
Administrative tools (e.g. Microsoft Suites, Primavera)	1.000	.765
Convergence network (Internet, e-mail, video data)	1.000	.661
Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality	1.000	.481
Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1.000	.404
Big-data predictive tool (e.g. ML algorithms)	1.000	.655
Robotics, sensors, RFID, BMS, GIS (Industry 4.0 elements)	1.000	.576
Modelling-based tools e.g. Multivate regression	1.000	.689
Virtualization-based ICT applications	1.000	.722
Web-based ICT tools	1.000	.660
Computer-based ICT tools	1.000	.648

7.3.2.4 Total variance explained

Using a principal component analysis extraction method, Table 7.6 shows the number of ICT tools' awareness factors and their respective eigenvalues. The latent root or Kaiser's criterion on awareness to ICT usage and factors with eigenvalues greater than 1.0 were employed. Hence, two factors with eigenvalues exceeding 1 were retained (4.627 and 1.632). They have a percentage of variance 46.268 and 62.587. respectively. Their cumulative percentage is 62.587 which highlights their significance above the other factors on awareness of ICT tool usage.

Table 7. 6: Total variance explained on awareness of ICT tool usage

Component		Initial Eigenvalues		Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**4.627**	46.268	46.268	4.627	**46.268**	46.268
2	**1.632**	16.319	62.587	1.632	**16.319**	**62.587**
3	.890	8.897	71.484			
4	.766	7.661	79.145			
5	.542	5.418	84.563			
6	.446	4.456	89.019			
7	.392	3.924	92.942			
8	.321	3.206	96.149			
9	.265	2.645	98.794			

7.5.2.5 Scree plot

Scree plot is subjective to the researcher's judgment. According to Figure 7.5, the scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, two factors which are retained on the steep slope were retained as seen in figure 7.5.

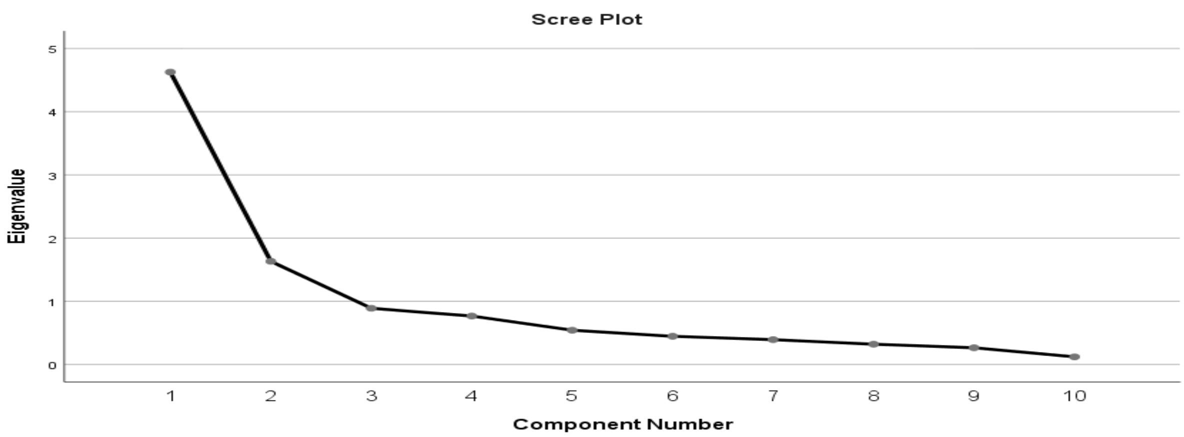

Figure 7. 5: Scree plot on awareness of ICT tools

7.5.2.6 Pattern matrix

Table 7.7 further interpreted the result from the scree plot using the oblimin method of rotation. It grouped the factors into two components. Component 1 is named "Advanced technological tools", and Component 2 is maned "Day-to-day ICT tools".

Component 1- Advanced technological Tools: The eight extracted factors for component 1 were virtualization-based tools (83.6%), Modelling-based tools (83.2%), Big-data tools (82.5%), Robotics/Industry 4.0 elements (76.7%), Web-based tools (70.8%), Simulation-based tools (70.2); Computer-based tools (67.4%), and Design/Estimation (42.8%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 46.268% of the variance (refer to Table 7.6)

Component 2- Day-to-day ICT tools: The two extracted factors for component 2 were Administrative tools (85.6%) and Convergence Network (83%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 62.587% of the variance (refer to Table 7.6)

Table 7. 7: Pattern matrix on awareness of ICT tools

	Component	
	1	2
Virtualization-based ICT applications	**0.836**	
Modelling-based tools e.g. Multivate regression	**0.832**	
Big Data – Predictive tool (e.g. ML algorithms Big-data predictive tool (e.g. ML algorithms))	**0.825**	
Robotics, Sensors, RFID, BMS, GIS (Industry 4.0 elements)	**0.767**	
Web-based ICT applications	**0.708**	
Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality	**0.702**	
Computer-based ICT tools	**0.674**	
Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	**0.428**	
Administrative tools (e.g. Microsoft Suites, Primavera)		**0.856**
Convergence network (Internet, e-mail, video data)		**0.830**

7.4 SECTION C: RESULTS FROM GROUP MEAN COMPARISON AND NON-PARAMETRIC ANALYSIS ON ICT TOOLS USED AT STAGES OF CONSTRUCTION WORK

7.4.1 Compare Means on ICT tools used at the planning stage

Table 7.8. presented the compared group mean of ICT tool usage at the planning stage. From the table, it is seen that the tool 'Architects' are most aware of is the ' Design/Estimation' with MIS of 4.47. These group of respondents ranked 'Simulation-based tools' (MIS=4.13) second; 'Administrative tools' were ranked third (MIS=3.80); 'Convergence Network' (MIS=3.53) fourth; 'Modelling tool' (MIS=3.13) fifth; 'Web-based tool' (MIS=2.27), and 'Virtualization based sixth (MIS=2.27); 'Big data' seventh with MIS of 2.13; 'Computer-based' (MIS=1.67) eighth, while 'Robotics' was ranked ninth with MIS of 1.53.

The table also revealed that 'Quantity Surveyors' ranked the usage of 'Design/Estimation tool' first (MIS=4.27) in the planning stage; 'Convergence network' ranked second (MIS=3.77); 'Simulation-based tools' ranked third (MIS=3.50); 'Modelling' ranked fourth (MIS=3.10); 'Big data' is fifth (MIS=2.29); sixth is 'Administrative tool' with MIS of 2.25; seventh is 'Robotics' with MIS of 1.83, eighth is 'Virtualization-based' (MIS=1.85), 'Computer-based' ranked ninth with MIS of 1.71, while the least ranked by this group of respondents is the 'Web-based ICT application' with MIS of 1.63

'Engineers' ranked the usage of 'Design/Estimation tools' during the planning stage as the first (MIS=4.40); 'Simulation-based' ranked second (MIS=4.36); 'Convergence network' ranked third (MIS=4.00); 'Modelling' ranked fourth (MIS=3.84); 'Big data' ranked fifth (MIS=3.56); 'Virtualization-based' ranked sixth with MIS of 3.36; 'Administrative tool' ranked seventh (MIS=3.40); and 'Robotics' was ranked eighth with MIS of 3.04. The least ranked factors are 'Computer-based', and 'Web-based tools' with MIS of 2.72, and 2.28 respectively.

The table also showed the ranking of usage of ICT tools at the planning stage by the 'Construction Managers'. Ranked first is 'Design/Estimation' (MIS=4.67); 'Convergence network' and 'Simulation-based' ranked second (MIS=4.13); while 'Modelling-based' tools ranked third (MIS=3.40). The least ranked factors are 'Big data'; 'Administrative tools'; 'Web-based'; 'Virtualization'; 'Robotics'; and 'Computer-based'. They have MIS of 2.80, 2.73, 2.67, 2.60, 2.53, and 213 respectively.

The last respondents, 'Construction Project Managers', ranked 'Design/Estimation' first (MIS=4.38) for use in the design stage. Ranked second is 'Simulation-based' with MIS of 4.23; ranked third is 'Convergence network' (MIS=3.54); 'Modelling-based' ranked (MIS of 3.46) fourth; 'Administrative tools' ranked fifth with MIS of 3.31; and 'Big data' ranked sixth with MIS of 3.15. The least ranked tools are 'Robotics'; 'Virtualization'; 'Computer-based' and 'Web-based' with MIS of 2.69, 2.62, 2.54, and 2.38 respectively.

Lastly, the table presents the Kruskal-Wallis H test to ascertain whether there is a significant difference in the opinion of professionals on ICT tools used at the planning stage. A p-value (sig.) greater than 0.05 shows that there is a statistical difference in the opinions of respondents, and vice versa. The table also revealed that there is no statistical difference in the opinion of respondents as to the use of five tools 'Simulation-based' tools (p-value=0.01); 'Web-based ICT tools (p-value=.000); Virtualization based' (p-value=.001); 'Big data' (p-value=.002), and 'modelling based tool' (p-value =0.000).

Table 7. 8: Compare means on the ICT tools used at the planning stage

	General			**Architect**		**QS**		**Engineers**		**CM**		**CPM**	
ICT Tools	Mean ($\bar{x}$)	Chi Square	Sig	$\bar{x}$	Rank (R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)
Convergence network	4.38	1.855	.762	3.53	4	3.77	2	4.00	3	4.13	2	3.54	3
Design/Estimation	3.92	12.937	.012	4.47	1	4.27	1	4.40	1	4.67	1	4.38	2
Administrative tools	3.81	9.479	.050	3.80	3	2.25	6	3.40	7	2.73	6	3.31	4
Computer-based ICT tools	3.33	19.354	.001	4.13	2	3.50	3	4.36	2	4.13	3	4.23	1
Simulation-based ICT tools	2.86	4.457	.348	1.67	8	1.71	9	2.72	9	2.13	10	2.54	7
Web-based ICT applications	2.69	22.014	.000	2.27	6	1.63	10	2.28	10	2.67	7	2.38	6
Virtualization based	2.39	10.945	.027	1.53	9	1.83	7	3.04	8	2.53	9	2.69	7
Modelling Based tools	2.23	18.828	.001	2.27	6	1.85	8	3.36	6	2.60	8	2.62	9
Robotics	2.06	16.554	.002	2.13	7	2.29	5	3.56	5	2.80	5	3.15	8
Big Data-Predictive tools	2.06	20.224	.000	3.13	5	3.10	4	3.84	4	3.40	4	3.46	5

7.4.2 Factor analysis for ICT tools used at the planning stage of construction in South Africa

The results from the EFA for ICT tools used at the planning stage of construction activities in South Africa are depicted in Tables 7.10 to 7.14, and Figure 7.6. Table 7.9 presents the labels of these factors. Prior to performing the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed the presence of coefficients of above 0.3 as presented in Table 7.10. The Kaizer-Meyer-Olkin (KMO) measure of sampling adequacy achieved a high value of 0.765 (Table 7.11); the Bartlett test of sphericity was also statistically significant at a p-value of 0.000, thereby supporting the factorability of the commonalities Table (Table 7. 12)

Table 7. 9: Labels for factor on ICT tools for planning Stage

Label	ICT tools
C6.1.1	Convergence network (Internet, e-mail, video data)
C6.2.1	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)
C6.3.1	Administrative tools (e.g. Microsoft Suites, Primavera)
C6.4.1	Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality
C6.5.1	Computer-based ICT tools
C6.6.1	Web-based ICT applications
C6.7.1	Robotics, sensors, RFID, BMS, GIS (industry 4.0 elements)
C6.8.1	Virtualization-based ICT applications
C6.9.1	Big Data – Predictive tool (e.g. ML algorithms) Big-data predictive tool (e.g. ML algorithms)
C6.10.1	Modelling-based tools e.g. Multivate regression

Table 7. 10: Correlation matrix for ICT tools used at the planning stage.

	C6.1.1	C6.2.1	C6.3.1	C6.4.1	C6.5.1	C6.6.1	C6.7.1	C6.8.1	C6.9.1	C6.10.1
C6.1.1	**1.000**	.350	.220	.340	.078	.033	.101	.208	.205	.361
C6.2.1	.350	**1.000**	.140	.383	.134	.056	.140	.071	-.033	.073
C6.3.1	.220	.140	**1.000**	.375	.457	.473	.433	.672	.381	.408
C6.4.1	.340	.383	.375	**1.000**	.234	.216	.310	.370	.495	.479
C6.5.1	.078	.134	.457	.234	**1.000**	.591	.804	.628	.341	.411
C6.6.1	.033	.056	.473	.216	.591	**1.000**	.544	.504	.410	.372
C6.7.1	.101	.140	.433	.310	.804	.544	**1.000**	.671	.493	.378
C6.8.1	.208	.071	.672	.370	.628	.504	.671	**1.000**	.558	.460
C6.9.1	.205	-.033	.381	.495	.341	.410	.493	.558	**1.000**	.705
C6.10.1	.361	.073	.408	.479	.411	.372	.378	.460	.705	**1.000**

Table 7. 11: KMO for ICT tools used at the planning stage

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.765
Bartlett's Test of Sphericity	Approx. Chi-Square	588.792
	df	45
	Sig.	0.000

Table 7. 12: Communalities table for ICT tools at the planning stage

	Initial	Extraction
Administrative tools (e.g. Microsoft Suites, Primavera)	1.000	.599
Convergence network (Internet, email, video data)	1.000	.842
Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality	1.000	.522
Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1.000	.639
Big Data – Predictive tool (e.g. ML algorithms) Big-data predictive tool	1.000	.804
Robotics, sensors, RFID, BMS, GIS	1.000	.600
Modelling-based tools e.g. Multivate regression	1.000	.771
Virtualization-based ICT applications	1.000	.724
Web-based ICT applications	1.000	.820
Computer-based ICT tools	1.000	.769

Using a principal component analysis extraction method, Table 7.13 shows the number of ICT tools at the planning stage and their respective eigenvalues. The latent root or Kaiser's criterion tools at the planning stage, factors with eigenvalues greater than 1.0 was employed. Hence, three components on ICT tools used at the planning stage with eigenvalues exceeding 1 were retained (4.458, 1.544, and 1.089). Thus, the final statistics of the principal component analysis and the components extracted accounted for approximately 71% of the total cumulative variance. The factor analysis also presented the scree plot in Figure 7.6. The scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, five components were retained on the steep slope.

Table 7. 13: Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.458	44.576	44.576	4.458	44.576	44.576
2	1.544	15.436	60.012	1.544	15.436	60.012
3	1.089	10.885	70.897	1.089	10.885	70.897
4	.694	6.936	77.832			
5	.643	6.430	84.263			
6	.531	5.311	89.574			
7	.366	3.662	93.236			
8	.336	3.365	96.601			
9	.212	2.118	98.719			
10	.128	1.281	100.000			

Figure 7.6 shows the scree plot of ICT tools used at the planning stage as they clustered into components.

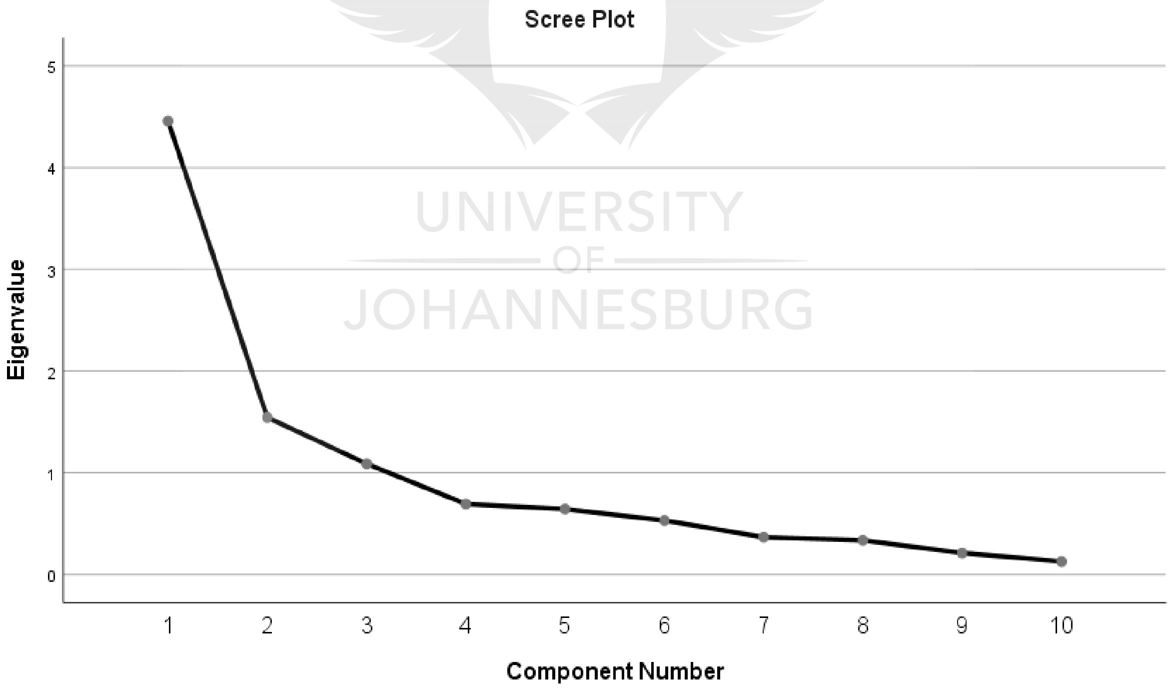

Figure 7. 6: Scree plot for tools at the planning stage

Based on an examination of the inherent relationships among the variables under each component, the following interpretation was made: **component 1 (F1**) was named **Industry 4.0- inclined ICT tools** and it has five factors loaded into it; **component (F2**) was named

Intermediate ICT tools and it has two factors loaded into it, and **component 3 (F3)** was named **Basic ICT tools** with three loaded factors. These names were derived from the components using the variables with the highest loading factor.

Table 7. 14: Pattern matrix for tools used at the planning stage

	Component		
	1	**2**	**3**
Big Data – Predictive tool (e.g. ML algorithms) Big-data predictive tool	**.934**		
Modelling-based tools e.g. Multivate regression	**.879**		
Robotics, sensors, RFID, BMS, GIS	**.768**		
Virtualization-based ICT applications	**.719**		
Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality	**.582**		
Convergence network (Internet, email, video data)		**.923**	
Administrative tools (e.g. Microsoft Suites, Primavera)		**.627**	
Web-based ICT applications			**-.827**
Computer-based ICT tools			**-.809**
Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)			**-.522**

Component 1 - Industry 4.0-inclined ICT tools: The five extracted factors for component 1 were Big data predictive tool) (93.4%), Modelling-based tools (87.9%), Robotics (82.5%), Robotics/Industry 4.0 elements (76.8%), Virtualization-based ICT applications (71.9%), and Simulation-based tools (58.2). The number in brackets indicates the respective factor loadings. This cluster accounted for 44.576% of the variance (refer to Table 7.13).

Component 2 - Intermediate ICT tools: The two extracted factors for component 2 were convergence networks (92.3%) and Web-based ICT applications (62.7%). The number in bracket represents the respective factor loadings. This cluster accounted for 60.012% of the variance (refer to Table 7.13).

Component 3 - Basic ICT tools: The three extracted factors for component 3 were web-based ICT applications (-82.7%), computer-based ICT tools (-80.9%), and design/estimation (-52.2). The numbers having negative factor loading value imply that the variables loaded in the opposite direction.

7.4.3 Compare means on ICT tools used at the design Stage

Table 7.15. presented the compared group mean of ICT tools used at the design stage. Tools with MIS from 3.00 and above are considered strong. At the design stage, 'Architects' ranked 'Computer-based tools' first (MIS=4.67); 'Design/Estimation' and 'Administrative tools' both ranked second with MIS of 4.33; ranked third is 'Convergence network' (MIS= 3.80) and 'Big-data tools' ranked fourth with MIS of 3.27. The least used tools by architects at the design stage are 'Modelling based tools'; 'Robotics'; 'Web-based tools'; 'Simulation-based'; and 'Virtualization' with MIS of 2.53, 2.13, 2.00, 1.80, and 1.67 respectively.

The table also revealed that 'Quantity Surveyors' ranked the usage of 'Design/Estimation tool' first (MIS=4.02) in the design stage; 'Convergence network' ranked second (MIS=3.81); 'Computer-based tools' ranked third (MIS=3.58) and 'Big data' ranked fourth (MIS=3.02). The least ranked tools used at the design stage by quantity surveyors are 'Administrative tools'; 'Robotics'; 'Modelling-based tools'; 'Virtualization-based'; 'Simulation-based'; 'Web-based tools' which ranked fifth, sixth, seventh, eighth (both virtualization base tools and simulation-based) and ninth respectively. Their MIS is 2.48, 2.25, 1.96, 1.69, and 1.56 respectively.

'Engineers' ranked the usage of 'Computer-based tools' during the design stage as the first (MIS=4.76); 'Convergence-network' ranked second (MIS=4.40); 'Design/Estimation' ranked third (MIS=4.24); 'Big data' ranked fourth (MIS=4.12); 'Robotics' ranked fifth (MIS=3.80); 'Administrative tools' ranked sixth with MIS of 3.68; 'Modelling-based tools' ranked seventh (MIS=3.32), and 'Virtualization' ranked eighth with MIS of 328. The least ranked factors are 'Simulation-based', and 'Web-based tools' with MIS of 2.56, and 2.52 respectively.

The table also showed the ranking of usage of ICT tools at the design stage by the 'Construction Manager'. Ranked first is 'Design/Estimation' (MIS=4.73); 'Computer-based' ranked second (MIS=4.33); 'Convergence network' ranked third (MIS=4.00); and 'Big data' tools ranked fourth (MIS=3.60). The least ranked factors are 'Robotics' (MIS=2.93); 'Web-based' (MIS=2.80); 'Simulation-based tool' (MIS=2.40); 'Administrative tools' (MIS=2.53); 'Virtualization' (MIS= 2.53); and 'Modelling-based' (MIS=2.53).

Lastly, 'Construction Project Managers' ranked 'Computer-based ' first (MIS=4.00) for use in the design stage. Ranked second is 'Design/Estimation' with MIS of 3.92; the ranked third is 'Big-data' (MIS=3.54); and 'Convergence network ranked (MIS of 3.23) fourth. 'Administrative tools' (MIS=2.92); 'Robotics' (MIS=2.92); 'Simulation-based tools'

(MIS=2.62); 'Modelling-based'(MIS=2.62); 'Virtualization-based' (MIS=2.54); and 'Web-based' (MIS=2.38) ranked last.

In addition, the Kruskal-Wallis H test ascertains whether there is a significant difference in the opinion of professionals on ICT tools used at the design stage. A p-value (sig.) greater than 0.05 shows that there is a statistical difference in the opinions of respondents, and vice versa.There is no statistical difference in the opinions of respondents on all tools except 'Convergence network' (sig.=.407); 'Administrative tools' (sig.=.069),; and 'Computer-based tools with sig. value of .034.

Table 7. 15: Compare means on ICT tools at the design stage

	General			Architect		QS		Engineers		CM		CPM	
ICT Tools	Mean ($\bar{x}$)	Chi Square	Sig	$\bar{x}$	Rank (R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)
Convergence network	4.23	3.996	.407	3.80	3	3.81	2	4.40	2	4.00	3	3.23	4
Design/Estimation	4.09	24.817	.000	4.33	2	4.02	1	4.24	3	4.73	1	3.92	2
Administrative tools	3.92	8.694	.069	4.33	2	2.48	5	3.68	6	2.53	8	2.92	5
Computer-based ICT tools	3.35	25.904	.000	4.67	1	3.58	3	4.76	1	4.33	2	4.00	1
Simulation-based ICT tools	3.03	10.445	.034	1.80	8	1.69	8	2.56	9	2.40	7	2.62	6
Web-based ICT applications	2.67	28.544	.000	2.00	7	1.56	9	2.52	10	2.80	6	2.38	8
Virtualization-based	2.40	14.485	.006	1.67	9	1.69	8	3.28	8	2.53	8	2.54	7
Modelling -based tools	2.23	16.501	.002	2.53	5	1.96	7	3.32	7	2.33	8	2.62	6
Robotics	2.08	15.962	.003	2.13	6	2.25	6	3.80	5	2.93	5	2.92	5
Big Data-Predictive tools	2.06	23.187	.000	3.27	4	3.02	4	4.12	4	3.60	4	3.54	3

7.4.4 Factor analysis for ICT tools used at the design stage of construction in South Africa

Table 7.16 presents the labels of ICT tools used at the design stage. The results from the EFA for ICT tools used at the design stage of construction activities in South Africa are depicted in Tables 7.17 to 7.23, and Figure 7.7. Prior to performing the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed the presence of coefficients of above 0.3 as presented in Table 7.17. The Kaizer-Meyer-Olkin (KMO) measure of sampling adequacy achieved a high value of 0.782 (Table 7.18). The Bartlett test of sphericity was also statistically significant at a p-value of 0.000, thereby supporting the factorability of the commonalities Table (Table 7.19)

Table 7. 16: Labels for ICT tools used at the design stage

Label	Factors
C6.1.2	Convergence network
C6.2.2	Design/Estimation
C6.3.2	Administrative tools
C6.4.2	Simulation-based tools
C6.5.2	Computer-based ICT tools
C6.6.2	Web-based ICT applications
C6.7.2	Robotics
C6.8.2	Virtualization -based
C6.9.2	Big Data – Predictive tool Big-data predictive tool
C6.10.2	Modelling-based tools

Table 7. 17: Correction matrix for ICT tools used at the design stage

	C6.1.2	**C6.2.2**	**C6.3.2**	**C6.4.2**	**C6.5.2**	**C6.6.2**	**C6.7.2**	**C6.8.2**	**C6.9.2**	**C6.10.2**
C6.1.2	**1.000**	.404	.318	.401	.073	.140	.264	.245	.311	.375
C6.2.2	.404	**1.000**	.225	.451	-.030	.055	.171	-.026	-.050	.164
C6.3.2	.318	.225	**1.000**	.461	.434	.500	.469	.696	.358	.454
C6.4.2	.401	.451	.461	**1.000**	.186	.215	.361	.345	.444	.453
C6.5.2	.073	-.030	.434	.186	**1.000**	.580	.680	.610	.329	.324
C6.6.2	.140	.055	.500	.215	.580	**1.000**	.687	.585	.476	.379
C6.7.2	.264	.171	.469	.361	.680	.687	**1.000**	.661	.538	.496
C6.8.2	.245	-.026	.696	.345	.610	.585	.661	**1.000**	.516	.459
C6.9.2	.311	-.050	.358	.444	.329	.476	.538	.516	**1.000**	.725
C6.10.2	.375	.164	.454	.453	.324	.379	.496	.459	.725	**1.000**

Table 7. 18: KMO for ICT tools at the design stage

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.782
Bartlett's Test of Sphericity	Approx. Chi-Square	615.197
	df	45
	Sig.	.000

Table 7. 19: Communalities table for ICT tools at the design stage

	Initial	Extraction
Administrative tools	1.000	.570
Convergence network	1.000	.616
Simulation-based tools	1.000	.561
Design/Estimation	1.000	.647
Big Data – Predictive tool Big-data predictive tool	1.000	.653
Robotics	1.000	.652
Modelling-based tools	1.000	.726
Virtualization-based ICT applications	1.000	.735
Web-based ICT applications	1.000	.536
Computer-based ICT tools	1.000	.564

Using a principal component analysis extraction method, Table 7.20 shows the number of ICT tools at the design stage and their respective eigenvalues. The latent root or Kaiser's criterion tools at the design stage, factors with eigenvalues greater than 1.0 was employed. Hence, two components on ICT tools used at the design stage with eigenvalues exceeding 1 were retained (4.599 and 1.662). Therefore, the final statistics of the principal component analysis and the components extracted accounted for approximately 63% of the total cumulative variance. The factor analysis also presented the scree plot in Figure 7.7. The scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, two components were retained on the steep slope.

Table 7. 20: Total variance for ICT tools at the design stage

Component		Initial Eigenvalues		Extraction Sums of Squared Loadings			
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4.599	45.986	45.986	4.599	45.986	45.986	4.367
2	1.662	16.623	62.608	1.662	16.623	62.608	2.458
3	.993	9.934	72.543				
4	.659	6.589	79.132				
5	.608	6.084	85.215				
6	.451	4.510	89.726				
7	.397	3.965	93.691				
8	.276	2.759	96.450				
9	.189	1.887	98.337				
10	.166	1.663	100.000				

Figure 7.7 shows the scree plot of ICT tools used at the design stage as they clustered into components.

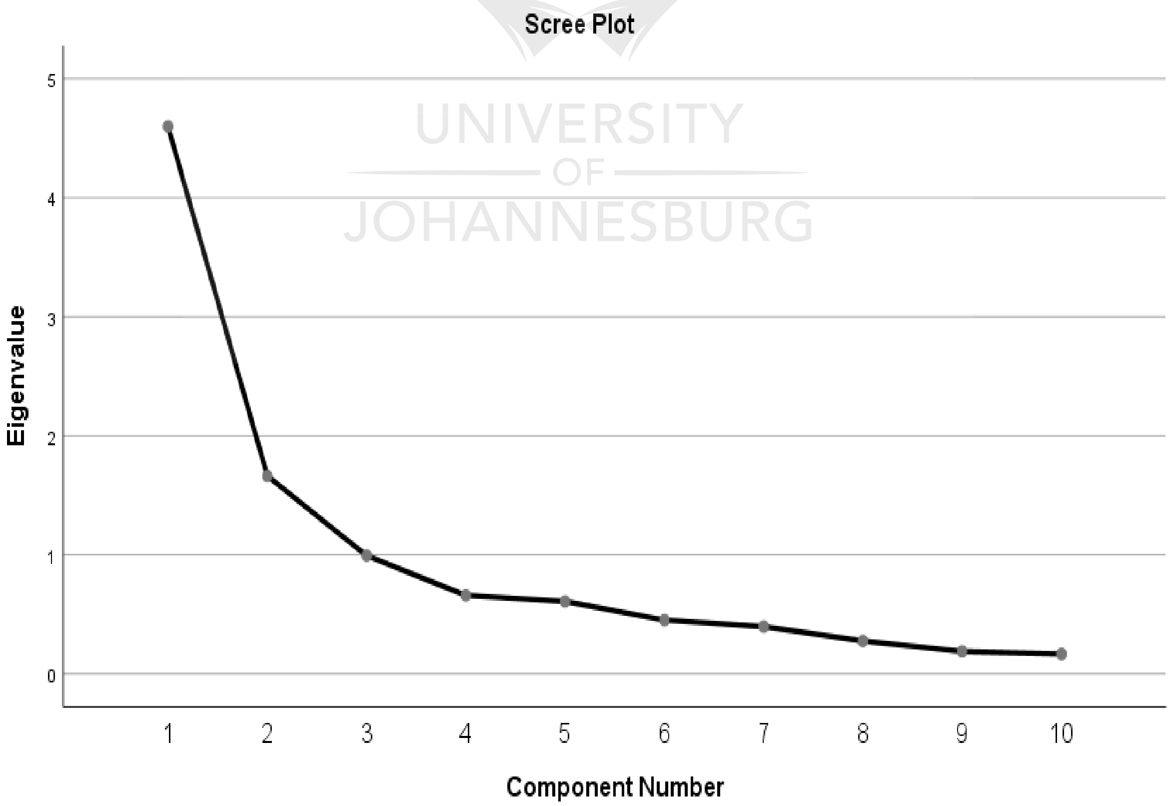

Figure 7. 7: Scree plot for ICT tools at the design stage

Based on an examination of the inherent relationships among the variables under each component, the following interpretation was made: **component 1 (F1**) was named **Advanced ICT tools**: it has seven factors loaded into it and **component (F2**) was named **Intermediate tools**, with three factors loaded into it. These names were derived from the components using the variables with the highest loading factor.

Component 1 - Advanced ICT tools: The seven extracted factors for component 1 were Virtualization-based ICT applications (86.4%), Modelling-based tools (83.8%), Big-Data (83.6%), Robotics/Industry 4.0 elements (83.1%), Web-based ICT applications (65.9%), Simulation-based tools (58.2), and Computer-based tools (55.5%). The number in brackets indicates the respective factor loadings. This cluster accounted for 46% of the variance (refer to Table 7.20).

Component 2 - Intermediate tools: The three extracted factors for component 2 were Convergence network (81.3%), Administrative tools (73.0), and Design/Estimation (70.9). The number in brackets indicates the respective factor loadings. This cluster accounted for 63% of the variance (refer to Table 7.20).

Table 7. 21: Pattern matrix for ICT tools at the design stage

	Component	
	1	**2**
Virtualization-based ICT applications	**.864**	
Modelling-based tools	**.838**	
Big Data – Predictive tool Big-data predictive tool	**.836**	
Robotics	**.831**	
Web-based ICT applications	**.659**	
Simulation-based tools	**.628**	
Computer-based ICT tools	**.555**	
Convergence network		**.813**
Administrative tools		**.730**
Design/Estimation		**.709**

7.4.5 Compare means on ICT tools used at the construction Stage

Table 7.22 presented the compared group mean of ICT tools used at the construction stage. Tools with MIS from 3.00 and above are considered strong. At the construction stage, 'Architects' used 'Computer-based' tools most with MIS of 4.53; 'Administrative tools' ranked second (MIS=4.47); 'Convergence Network' and 'Design/Estimation tools' both ranked third (MIS=3.80), while 'Big data' (MIS=3.27) ranked fourth. 'Robotics' (MIS=2.53) were ranked fifth; 'Web-based tool' and 'Modelling-based' both ranked sixth (MIS=2.13); 'Simulation-based' ranked seventh (MIS=1.80); and 'Virtualization-based' ranked eighth with MIS of 1.67.

The table also revealed that 'Quantity Surveyors' ranked the usage of 'Administrative tool' first (MIS=3.96) in the construction stage; 'Convergence network' was ranked second (MIS=3.81); 'Computer-based' was ranked third (MIS=3.48); 'Big data' was ranked fourth (MIS=2.96); 'Design/Estimation' was fifth (MIS=2.37); sixth was 'Modelling based' with MIS of 2.25; seventh was 'Robotics' with MIS of 1.88; eighth was 'Web-based' (MIS=1.69), 'Virtualization' ranked ninth with MIS of 1.65, while the least ranked by this group of respondent was the 'Simulation-based' with MIS of 1.63.

'Engineers' ranked the usage of 'Computer-based' during the construction stage as the first (MIS=4.28); 'Administrative tools' ranked second (MIS=3.81); 'Big-data' ranked third (MIS=3.64); 'Convergence network' ranked fourth (MIS=3.60); 'Modelling-based' ranked fifth (MIS=3.36); 'Robotics' ranked sixth with MIS of 3.16; 'Virtualization- based' ranked seventh (MIS=2.68); 'Design/Estimation' ranked eighth with MIS of 2.60, and ninth-ranked is 'Web-based tool' with MIS of 2.48. The least ranked factor is 'Simulation-based' with MIS of 2.32.

The table also showed the ranking of usage of ICT tools at the construction stage by the 'Construction Manager'. Ranked first is 'Administrative-tool' (MIS=4.60); 'Convergence network' ranked second (MIS=4.33); 'Computer-based' tool ranked third (MIS=3.67); ranked fourth is 'Big-data' with MIS of 3.40; ranked fifth is 'Web-based' (MIS= 2.53); 'Modelling-based' ranked sixth (MIS=2.47); while 'Simulation-based', 'Virtualization-based', and 'Robotics' ranked seventh (MIS=2.27); and 'Design/Estimation' ranked eighth with MIS of 1.87.

‘Construction Project Managers’ ranked both ‘Convergence network’ and ‘Design/Estimation’ first (MIS=4.08) for use in the construction stage. Ranked second is ‘Computer-based’ with MIS of 4.00; ranked third is ‘Big data’ (MIS=3.23); ‘Design/Estimation’ (MIS of 2.92) ranked fourth; ‘Simulation-based’ and ‘ Modelling-based’ ranked fifth with MIS of 2.62; ‘Robotics’ ranked sixth with MIS of 2.62 along with ‘Virtualization’ and ‘Web-based’ ICT tools with MIS of 2.23, and 1.92 respectively.

Lastly, the table presents the Kruskal-Wallis H test on to ascertain whether there is a significant difference in the opinions of professionals on their ranking of ICT tools used at the construction stage. A p-value (sig.) greater than 0.05 shows that there is a statistical difference in opinion of respondents, and vice versa.

Table 7. 22: Compare means on ICT tools at the construction stage

	General			Architect		QS		Engineers		CM		CPM	
ICT Tools	Mean ($\bar{x}$)	Chi Square	Sig	$\bar{x}$	Rank (R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)	$\bar{x}$	(R)
Convergence network	4.18	4.032	.402	3.80	3	3.81	2	3.60	4	4.33	2	4.08	1
Design/Estimation	3.86	4.453	.348	4.47	2	3.96	1	4.08	2	4.60	1	4.08	1
Administrative tools	3.86	18.468	.001	3.80	3	2.37	5	2.60	8	1.87	8	2.92	4
Computer-based ICT tools	3.17	12.625	.013	4.53	1	3.48	3	4.28	1	3.67	3	4.00	2
Simulation-based ICT tools	2.61	14.533	.006	1.80	7	1.63	10	2.32	10	2.27	7	2.62	5
Web-based ICT applications	2.50	6.926	.140	2.13	6	1.69	8	2.48	9	2.53	5	1.92	8
Virtualization-based	2.27	9.815	.044	1.67	8	1.65	9	2.68	7	2.27	7	2.23	7
Modelling-based tools	2.03	12.561	.014	2.53	5	1.88	7	3.16	6	2.27	7	2.38	6
Robotics	2.02	12.335	.015	2.13	6	2.25	6	3.36	5	2.47	6	2.62	5
Big Data-Predictive tools	1.97	3.737	.443	3.27	4	2.96	4	3.64	3	3.40	4	3.23	3

7.4.6 Factor analysis for ICT tools used at the construction stage in South Africa

Table 7.23 presents the labels of ICT tools used at the design stage. The results from the EFA for ICT tools used at the design stage of construction activities in South Africa are depicted in Tables 7.24 to 7.30, and Figure 7.8. Prior to performing the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed the presence of coefficients of above 0.3 as presented in Table 7.24. The Kaizer-Meyer-Olkin (KMO) measure of sampling adequacy achieved a high value of 0.765 (Table 7.25); the Bartlett test of sphericity was also statistically significant at a p-value of 0.000, thereby supporting the factorability of the commonalities Table (Table 7.26).

Table 7. 23: Labels for ICT tools used at the construction stage

Label	Factors
C6.1.3	Convergence network (Internet, e-mail, video data)
C6.2.3	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)
C6.3.3	Administrative tools (e.g. Microsoft Suites, Primavera)
C6.4.3	Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality
C6.5.3	Computer-based ICT tools
C6.6.3	Web-based ICT applications
C6.7.3	Robotics, sensors, RFID, BMS, GIS (Industry 4.0 elements)
C6.8.3	Virtualization-based ICT applications
C6.9.3	Big Data – Predictive tool (e.g. ML algorithms) Big-data predictive tool (e.g. ML algorithms)
C6.10.3	Modelling-based tools e.g. Multivate regression

Table 7. 24: Correlation matrix for ICT tools used at the construction stage

	C6.1.3	**C6.2.3**	**C6.3.3**	**C6.4.3**	**C6.5.3**	**C6.6.3**	**C6.7.3**	**C6.8.3**	**C6.9.3**	**C6.10.3**
C6.1.3	**1.000**	.500	.270	.288	.168	.044	.118	.274	.335	.373
C6.2.3	.500	**1.000**	.142	.304	.031	.014	.062	.076	.037	.118
C6.3.3	.270	.142	**1.000**	.393	.501	.454	.412	.562	.362	.440
C6.4.3	.288	.304	.393	**1.000**	.175	.150	.271	.142	.462	.445
C6.5.3	.168	.031	.501	.175	**1.000**	.704	.743	.551	.276	.363
C6.6.3	.044	.014	.454	.150	.704	**1.000**	.653	.544	.291	.369
C6.7.3	.118	.062	.412	.271	.743	.653	**1.000**	.514	.462	.433
C6.8.3	.274	.076	.562	.142	.551	.544	.514	**1.000**	.485	.482
C6.9.3	.335	.037	.362	.462	.276	.291	.462	.485	**1.000**	.794
C6.10.3	.373	.118	.440	.445	.363	.369	.433	.482	.794	**1.000**

Table 7. 25: KMO for ICT tools used at the construction stage

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.765
Bartlett's Test of Sphericity	Approx. Chi-Square	586.735
	df	45
	Sig.	.000

Table 7. 26: Communalities for ICT tools use at the construction stage

	Initial	Extraction
Administrative tools (e.g. Microsoft Suites, Primavera)	1.000	.679
Convergence network (Internet, email, video data)	1.000	.823
Simulation-based tools e.g. BIM; Mixed, Augmented and Virtual Reality	1.000	.526
Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1.000	.527
Big Data – Predictive tool (e.g. ML algorithms) Big-data predictive tool	1.000	.814
Robotics, sensors, RFID, BMS, GIS	1.000	.758
Modelling-based tools e.g. Multivate regression	1.000	.712
Virtualization-based ICT applications	1.000	.606
Web-based ICT applications	1.000	.871
Computer-based ICT tools	1.000	.817

Using a principal component analysis extraction method, Table 7.27 shows the number of ICT tools at the construction stage and their respective eigenvalues. The latent root or Kaiser's criterion tools at the construction stage, factors with eigenvalues greater than 1.0 was employed. Hence, three components on ICT tools used at the construction stage with eigenvalues exceeding 1 were retained (4.326, 1.711 and 1.095). Therefore, the final statistics of the principal component analysis and the components extracted accounted for approximately 71% of the total cumulative variance. The factor analysis also presented the scree plot in Figure 7.8. The scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, two components were retained on the steep slope.

Table 7. 27: Total variance explained for ICT tools at the construction stage

Component		Initial Eigenvalues		Extraction Sums of Squared Loadings			
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4.326	43.263	43.263	4.326	43.263	43.263	3.747
2	1.711	17.110	60.373	1.711	17.110	60.373	1.837
3	1.095	10.954	71.327	1.095	10.954	71.327	3.070
4	.767	7.670	78.997				
5	.650	6.505	85.501				
6	.430	4.300	89.801				
7	.343	3.434	93.235				
8	.303	3.029	96.264				
9	.226	2.257	98.521				
10	.148	1.479	100.000				

Figure 7.8 shows the scree plot of ICT tools used at the construction stage as they clustered into components.

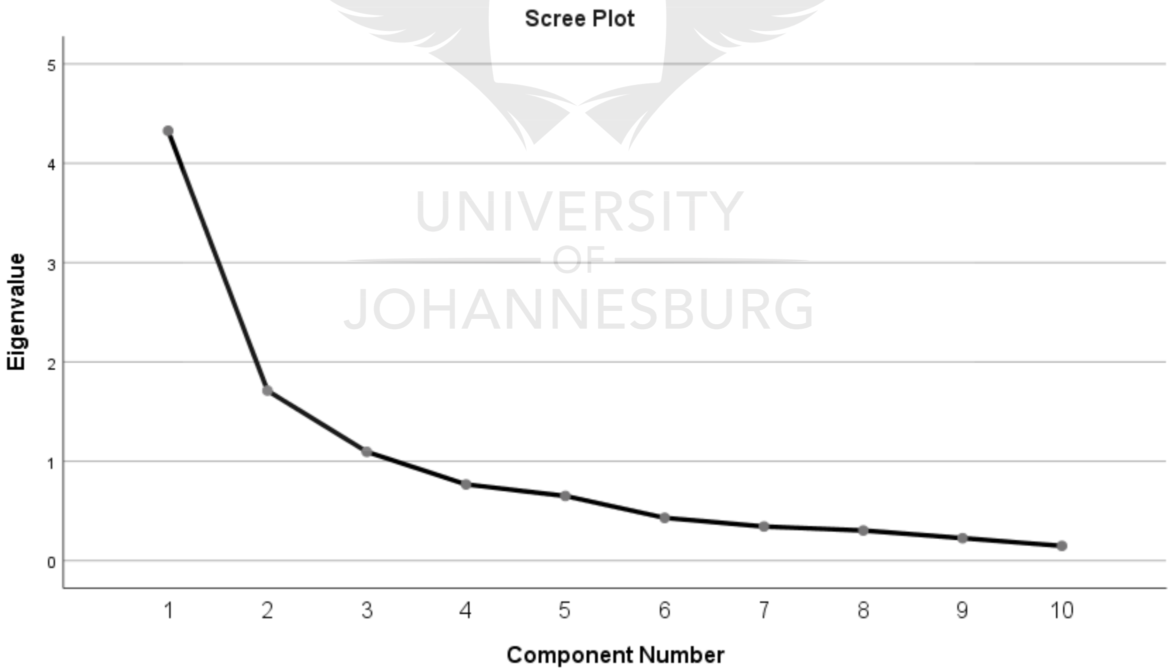

Figure 7. 8: Scree plot for ICT tools used at the construction stage

Based on an examination of the inherent relationships among the variables under each component, the following interpretation was made: **component 1 (F1**) was named **Industry 4.0-inclined tools**; it has five factors loaded into it. **Component (F2**) was named **Basic ICT**

tools and it has two factors loaded into it, while **Component (F3)** was named **Intermediate ICT** tools, with three loaded values. Negative loaded values show that the factors loaded in the opposite direction. This does not annul it, however. These names were derived from the components using the variables with the highest loading factor.

Component 1- Industry 4.0-inclined ICT tools: The five extracted factors for component 1 were Big-data predictive tools (84.6%), Robotics (90.9%), Modelling-based tools (80.2%), Simulation-based (67.1%), and Convergence network (55.7%). The number in brackets indicates the respective factor loadings. This cluster accounted for 43% of the variance (refer to Table 7.27).

Component 2- Basic ICT tools: The two extracted factors for components 2 were Convergence network (94%) and Administrative tools (72.9%). The number in brackets indicates the respective factor loadings. This cluster accounted for 17% of the variance (refer to Table 7.27).

Component 3- Intermediate ICT tools: The three extracted factors for components 2 were Web-based ICT applications(-93.9%), Computer-based ICT tools (84.4%), and Design/Estimation (61.6%). The number in brackets indicates the respective factor loadings. This cluster accounted for 11% of the variance (refer to Table 7.27).

Table 7. 28: Pattern matrix for ICT tools used at the construction stage

	Component		
	1	**2**	**3**
Big Data – Predictive tool Big-data predictive tool	**.946**		
Robotics	**.909**		
Modelling-based tools	**.802**		
Virtualization-based ICT applications	**.671**		
Simulation-based tools	**.557**		
Convergence network		**.940**	
Administrative tools		**.729**	
Web-based ICT applications			**-.939**
Computer-based ICT tools			**-.844**
Design/Estimation			**-.616**

7.5 SECTION D: RESULTS FROM DESCRIPTIVE AND INFERENTIAL ANALYSIS ON CHALLENGES TO ICT TOOLS USAGE

This section discusses the descriptive and inferential analysis of the third objective. The descriptive analysis presented the mean item score ($\overline{x}$) or MIS, standard deviation (σX) or SD, and the rankings of the factors in each objective of the study, while the inferential analysis presented the exploratory factor analysis of the objectives.

7.5.1 Mean item score on challenges to ICT tool usage in the South African Construction industry

Table 7.9 presents the respondents' ranking of their opinions on the challenges to the use of ICT tools for construction in South Africa. Respondents were requested to indicate the extent to which each of the identified tools is used at the construction stage, using a five-point scale: 1 = To no extent, 2 = Small extent, 3 = Moderate extent, 4 = Large extent, and 5 = Very large extent. 'High cost of purchase of ICT tools' was ranked highest (MIS = 4.01; SD = 1.000). The second-ranked challenge is the 'cost of training staff' with MIS of 3.92 and SD of .975; 'Costly upgrade of tools' is ranked third (MIS = 3.90, SD = .965); ranked fourth is 'High cost of installation' (MIS =3.84; SD =1.085); ranked fifth is 'Hesitation to adopt ICT tools among users' (MIS = 3.83; SD =.967), 'Lack of technical skills' ranked sixth (MIS = 3.64; SD =1.083), 'Inadequate support from government (e.g through policies)' ranked seventh (MIS 3.59, SD = 1.149), 'Organization process change' and 'Insufficient research and development of ICT in construction, both ranked eighth (MIS = 3.58, SD= 1.050) and (MIS= 3.58, SD=1.018) respectively. The ninth-ranked challenge is ' Lack of confidence in using new technologies' (MIS 3.57; SD 1.193); ranked tenth is 'Management problems in a firm' (MIS = 3.56; SD= .924); ranked eleventh is 'Unclear communication within staff' (MIS=3.35; SD=1.058); ranked twelfth is 'Insecurity of data transfer and transmission' (MIS=3.30; SD=1.066); 'Legal and standardization issues' ranked thirteenth (MIS=3.21; SD= 1.020); 'Difficulty of use' ranked fourteenth (MIS= 3.13, SD=1.020); 'Difficulty in evaluating the benefits of ICT use' ranked fifteenth (MIS= 3.02; SD= 1.012); 'Cultural barrier' ranked sixteenth (MIS =3.92;SD= 1.310); and 'Short life cycle of ICT inventions' ranked seventeenth (MIS=2.92; SD=1.022).

Table 7. 29: Descriptive statistics for challenges to ICT tool usage

	Mean	Std. Deviation	Rank
A high cost of purchase of ICT tools	4.01	1.000	1
Cost of training staff	3.92	.975	2
Costly upgrade of tools	3.90	.965	3
The high cost of installation	3.84	1.085	4
Hesitation to adopt ICT tools among users	3.83	.967	5
Lack of technical skills	3.64	1.083	6
Inadequate of support from the government (e.g. through Policies)	3.59	1.149	7
Organization process changes	3.58	1.050	8
Insufficient research and development (R& D) in Information technology in the construction industry	3.58	1.018	8
Lack of confidence in using new technologies	3.57	1.193	9
Management problems in a firm	3.56	.924	10
Unclear communication within the staff	3.35	1.058	11
The insecurity of data transfers and transmission	3.30	1.066	12
Legal and standardization issues	3.21	1.020	13
Difficulty of use	3.13	1.020	14
Difficulty in evaluating the benefits of ICT use	3.02	1.012	15
Cultural barrier	2.93	1.310	16
The short life cycle of ICT inventions	2.92	1.022	17

7.5.2 Factor analysis for challenges to ICT tools used in the South African construction industry

Table 7.30 presents the labels on challenges to effective use of ICT tools. The results from the EFA for challenges to using ICT tools for construction activities in South Africa are presented in Tables 7.31 to 7.37, and Figure 7.9. Prior to performing the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed the presence of coefficients of above 0.3 as presented in Table 7.31. The Kaizer-Meyer-Olkin (KMO) measure of sampling adequacy achieved a high value of 0.755 (Table 7.32) while the Bartlett test of sphericity was also statistically significant at a p-value of 0.000, thereby supporting the factorability of the correlation matrix (Table 7.33).

Table 7. 30: Labels on challenges to ICT tool usage

Label	Challenges
D7.1	The high cost of purchase of ICT tools
D7.2	Cost of training staff
D7.3	Costly upgrade of tools
D7.4	The high cost of installation
D7.5	Hesitation to adopt ICT tools among users
D7.6	Lack of technical skills
D7.7	Inadequate of support from the government (e.g. through policies)
D7.8	Organization process changes
D7.9	Insufficient research and development (R& D) in information technology in the construction industry
D7.10	Lack of confidence in using new technologies
D7.11	Management problems in a firm
D7.12	Unclear communication within the staff
D7.13	The insecurity of data transfers and transmission
D7.14	Legal and standardization issues
D7.15	Difficulty of use
D7.16	Difficulty in evaluating the benefits of ICT use
D7.17	Cultural barrier
D7.18	The short life cycle of ICT inventions

Table 7. 31: Correlation matrix on challenges to ICT usage

	D7.1	D7.2	D7.3	D7.4	D7.5	D7.6	D7.7	D7.8	D7.9	D7.10	D7.11	D7.12	D7.13	D7.14	D7.15	D7.16	D7.17	D7.18
D7.1	**1.000**	.387	.444	.258	.285	.168	.174	.148	.103	.206	.322	.241	.159	.074	-.038	.332	.285	.049
D7.2	.387	**1.000**	.767	.359	.182	.180	.325	.219	.509	.203	.295	.406	.137	.078	.013	.345	.544	.316
D7.3	.444	.767	**1.000**	.459	.234	.038	.304	.251	.536	.176	.340	.416	.101	.162	.117	.372	.723	.382
D7.4	.258	.359	.459	**1.000**	.466	.009	.288	.345	.453	.289	.278	.420	.183	.183	.211	.330	.567	.536
D7.5	.285	.182	.234	.466	**1.000**	.151	-.016	.252	.163	.268	.349	.182	.249	.072	.104	.266	.117	.378
D7.6	.168	.180	.038	.009	.151	**1.000**	.597	.335	.153	.213	.351	.296	.296	.215	.329	.361	.144	.129
D7.7	.174	.325	.304	.288	-.016	.597	**1.000**	.510	.390	.128	.320	.429	.213	.152	.181	.269	.420	.136
D7.8	.148	.219	.251	.345	.252	.335	.510	**1.000**	.590	.288	.460	.469	.487	.385	.487	.390	.294	.441
D7.9	.103	.509	.536	.453	.163	.153	.390	.590	**1.000**	.453	.383	.576	.250	.226	.248	.467	.631	.483
D7.10	.206	.203	.176	.289	.268	.213	.128	.288	.453	**1.000**	.293	.407	.341	.351	.279	.457	.289	.406
D7.11	.322	.295	.340	.278	.349	.351	.320	.460	.383	.293	**1.000**	.609	.613	.379	.522	.391	.335	.356
D7.12	.241	.406	.416	.420	.182	.296	.429	.469	.576	.407	.609	**1.000**	.568	.432	.418	.614	.445	.511
D7.13	.159	.137	.101	.183	.249	.296	.213	.487	.250	.341	.613	.568	**1.000**	.615	.587	.441	.174	.432
D7.14	.074	.078	.162	.183	.072	.215	.152	.385	.226	.351	.379	.432	.615	**1.000**	.592	.476	.228	.305
D7.15	-.038	.013	.117	.211	.104	.329	.181	.487	.248	.279	.522	.418	.587	.592	**1.000**	.377	.261	.571
D7.16	.332	.345	.372	.330	.266	.361	.269	.390	.467	.457	.391	.614	.441	.476	.377	**1.000**	.490	.476
D7.17	.285	.544	.723	.567	.117	.144	.420	.294	.631	.289	.335	.445	.174	.228	.261	.490	**1.000**	.480
D7.18	.049	.316	.382	.536	.378	.129	.136	.441	.483	.406	.356	.511	.432	.305	.571	.476	.480	**1.000**

Table 7. 32: KMO and Bartlett's Test on challenges to ICT tool usage

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.755
Bartlett's Test of Sphericity	Approx. Chi-Square	1267.335
	df	153
	Sig.	.000

Table 7. 33: Communalities for challenges to ICT use

	Initial	Extraction
The short life cycle of ICT inventions	1.000	.776
The high cost of purchase of ICT tools	1.000	.717
Costly upgrade of tools	1.000	.824
Management problems in a firm	1.000	.704
Difficulty in evaluating the benefits of ICT use	1.000	.875
Legal and standardization issues	1.000	.756
Inadequate of support from the government (e.g. through policies)	1.000	.861
Hesitation to adopt ICT tools among users	1.000	.663
Cost of training staff	1.000	.735
The insecurity of data transfers and transmission	1.000	.371
Cultural barrier	1.000	.616
Lack of technical skills	1.000	.662
Lack of confidence in using new technologies	1.000	.744
Insufficient research and development (R& D) in Information technology in the construction industry	1.000	.705
Unclear communication within the staff	1.000	.714
Difficulty of use	1.000	.589
The high cost of installation	1.000	.764
Organization process changes	1.000	.745
Extraction Method: Principal Component Analysis.		

Using a principal component analysis extraction method, Table 7.34 shows the number of challenges to ICT use and their respective eigenvalues. The latent root or Kaiser's criterion on challenges to ICT usage, factors with eigenvalues greater than 1.0 was employed. Hence, five factors on 'Challenge to ICT tool use' with eigenvalues exceeding 1 were retained (6.789, 2.277, 1.483, 1.253 and 1.024). They have a percentage of variance 37.715, 12.621, 8.238, 6.962, and 5.691. respectively. Their cumulative percentage is 71.227 which highlights their significance from the other factors on challenges to ICT usage. Thus, the final statistics of the principal component analysis and the components extracted accounted for approximately 71% of the total cumulative variance.

Table 7. 34: Total variance explained for challenges to ICT tool usage

Component		Initial Eigenvalues		Extraction Sums of Squared Loadings			
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.789	37.715	37.715	6.789	37.715	37.715	4.884
2	2.272	12.621	50.336	2.272	12.621	50.336	4.589
3	1.483	8.238	58.574	1.483	8.238	58.574	3.197
4	1.253	6.962	65.535	1.253	6.962	65.535	1.299
5	1.024	5.691	71.227	1.024	5.691	71.227	3.138
6	.879	4.885	76.112				
7	.696	3.869	79.981				
8	.624	3.469	83.449				
9	.535	2.972	86.421				
10	.501	2.784	89.205				
11	.466	2.589	91.794				
12	.404	2.245	94.039				
13	.290	1.611	95.650				
14	.226	1.254	96.904				
15	.190	1.054	97.958				
16	.152	.844	98.802				
17	.114	.633	99.435				
18	.102	.565	100.000				

The factor analysis also presented the scree plot in Figure 7.9. The scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, five components were retained on the steep slope were.

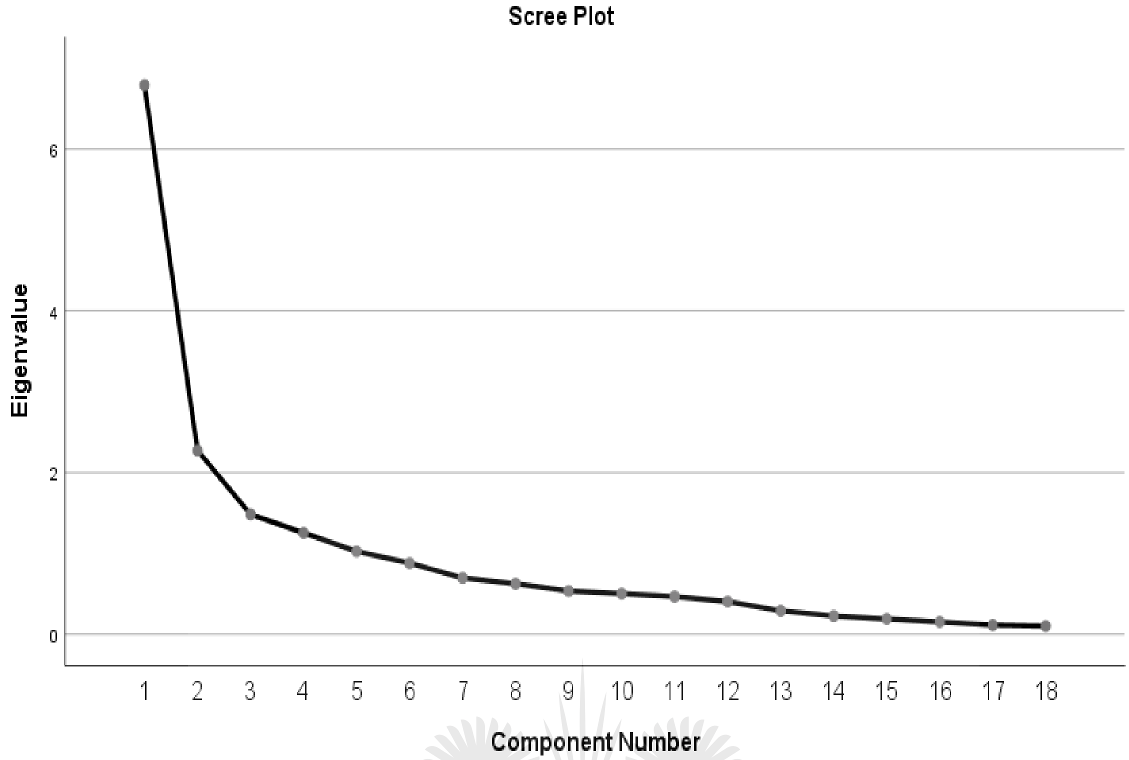

Figure 7. 9: Scree plot on challenges to ICT use

Table 7.22 shows the pattern matrix as they clustered into components. Based on an examination of the inherent relationships among the variables under each component, the following interpretation was made: **component 1 (F1**) was named **people-related problems:** it has seven factors loaded into it; **component (F2)** was named **Cost-related problems**: it has four factors loaded into it**; component 3 (F3)** was named **Standardization problems** with three loaded factors**, and Component 4 (F4)** was named **Management-inclined problems** with three loaded factors as well. The fifth component had values which loaded into other factors. The values were also lower; therefore, the component was eliminated. These names were derived from the components using the variables with the highest loading factor.

Component 1 (F1) - people-related factors: The seven extracted factors for component 1 were Lack of confidence in using new technologies (90.5%), Unclear communication within the staff (83.2%), Difficulty of Use (75.8%), Lack of technical skills (55.6%), Cultural barrier (52.7%), The insecurity of data transfers and transmission (5.25%), and Costly upgrade of tools

(43%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 37.72% of the variance (refer to Table 7.34)

Component 2 (F2) - Cost-related problems: The four extracted factors for component 2 were a costly upgrade of tools (89%), The high cost of installation (83.1%), The high cost of purchase of ICT tools (80%), and Cost of training staff (64.4%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 50.34% of the variance (refer to Table 7.34)

Table 7. 35: Pattern matrix on challenges to ICT use

	Component			
	1	**2**	**3**	**4**
Insufficient research and development (R& D) in information technology in the construction industry	**.905**			
Lack of confidence in using new technologies	**.832**			
Unclear communication within the staff	**.758**			
Difficulty of use	**.556**			
Lack of technical skills	**.527**			
Cultural barrier	**.525**			
The insecurity of data transfers and transmission	**.436**			
Costly upgrade of tools		**.890**		
The high cost of installation		**.831**		
The high cost of purchase of ICT tools		**.800**		
Cost of training staff		**.644**		
Inadequate of support from the government (e.g. through policies)			**.889**	
Legal and standardization issues			**.840**	
Hesitation to adopt ICT tools among users			**.513**	
Difficulty in evaluating the benefits of ICT use				**.961**
Management problems in a firm				**.612**
Organization process changes				**.443**

Component 3 (F3) - Standardization problems: The three extracted factors for component three are Inadequate support from the government (88.9%), Legal and standardization issues (84%), and Hesitation to adopt ICT tools among users (51.3%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 58.58% of the variance (refer to Table 7.34)

Component 3 (F4) - Standardization problems: The three extracted factors for component four were Difficulty in evaluating the benefits of ICT use (96.1), Management problems in a firm (61.2%), and Organization process changes (44.3%). This cluster accounted for 71.23% of the variance (refer to Table 7.34).

7.6 SECTION E: RESULTS FROM DESCRIPTIVE AND INFERENTIAL ANALYSIS ON MEASURES TO ENSURE EFFECTIVE USE TO ICT TOOLS

This section discusses the descriptive and inferential analysis of the fourth objective. The descriptive analysis presented the mean item score ($\overline{x}$) or MIS, standard deviation (σX) or SD, and the ranking of the factors in each objective of the study, while the Inferential analysis presented the exploratory factor analysis of the objective.

7.6.1 Mean item score on measures to ensure effective use of ICT tools in the South African construction industry

Table 7.36 presents the respondents' rankings of their opinions on the measures to ensure effective use of ICT tools for construction in South Africa. Respondents were requested to indicate the extent to which each of the identified tools is used at the construction stage, using a five-point scale: 1 = To no extent, 2 = Small extent, 3 = Moderate extent, 4 = Large extent, and 5 = Very large extent. 'Positive attitude towards technology' was ranked the highest (MIS = 4.17; SD = .941). The second-ranked challenge is the 'Proper education of users' with MIS of 4.13 and SD of .762; 'Supportive decision from top management' is ranked third (MIS = 4.05, SD = .754); ranked fourth is 'Propensity towards innovation' (MIS =3.99; SD =.957); ranked fifth is 'Allocating firm's resources for ICT' (MIS = 3.95; SD =.849), 'Professional experience of users' ranked sixth (MIS = 3.93; SD =.817), 'Understanding tools compatibility factors' ranked seventh (MIS 3.92, SD = .856); 'Client's request for ICT use' ranked eighth (MIS 3.88; SD=.949); 'Development of team knowledge for ICT' and 'Positive change movement', both ranked ninth (MIS = 3.84, SD=1.012) and (MIS= 3.58, SD=.996) respectively. 'End-user's involvement' and 'Understanding capability of the configuration of tools' jointly ranked tenth (MIS= 3.74, SD=.957) and (MIS= 3.74; and SD=1.008); 'Understanding complexity factors of tools' ranked eleventh (MIS= 3.71 and SD= .873); 'Knowing the cost' ranked twelfth (MIS 3.69; SD= 1.011); 'Clear communication of ICT objectives' (MIS=3.68; SD= .917), and 'Encourage expansion of organization' (MIS= 3.68; SD=.945) both ranked thirteenth; 'Supportive government involvement' ranked fourteenth (MIS= 3.67; SD= 1.155); 'Checking out relative advantage of the tool' ranked fifteenth (MIS 3.6; SD=.946), while the least ranked factor is 'Outsourcing' with MIS of 3.37 and SD of 1.092.

Table 7. 36: Descriptive statistics for measures to effective tool use

	Mean	Std. Deviation	Rank
Positive attitude towards technology	4.17	.941	1
Proper education for users	4.13	.762	2
Supportive decision from top management	4.05	.754	3
Propensity towards innovation	3.99	.957	4
Allocating firm's resources for ICT	3.95	.849	5
Professional experience of users	3.93	.817	6
Understanding the tools' compatibility factors	3.92	.856	7
Client's request for ICT usage	3.88	.949	8
Development of team knowledge for ICT	3.84	1.012	9
Positive change management	3.84	.996	10
End user involvement	3.74	.957	11
Understanding the capability of the configuration of tools	3.74	1.008	12
Understanding complexity factors of tools	3.71	.873	13
Knowing the cost implications	3.69	1.011	14
Clear communication of ICT objectives	3.68	.917	15
Encourage expansion of organizations	3.68	.945	16
Supportive government involvement (e.g. through policies)	3.67	1.155	17
Checking out the relative advantage of the tool	3.61	.946	18
Outsourcing	3.37	1.092	19

7.6.2 Factor analysis for measures to ensure effective ICT tools used in the South African construction industry

Table 7.37 presents the labels of factors to ensure effective ICT use. The results from the EFA for measures to ensure effective ICT tool usage for construction activities in South Africa are presented in Tables 7.38 to 7.44 and Figure 7.10. Prior to performing the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed the presence of coefficients of above 0.3 as presented in Table 7.38. For the KMO, Table 7.39 showed a sampling adequacy value of .893 and Bartlett's test of sphericity was also statistically significant at a p-value of 0.000, thereby supporting the factorability of the correlation matrix. The communalities after extraction are also presented in Table 7.40. It contains values above 0.3.

Table 7. 37: Labels for the factors used as measures

Label	Measures
E8.1	Positive attitude towards technology
E8.2	Proper education for users
E8.3	Supportive decision from top management
E8.4	Propensity towards innovation
E8.5	Allocating firm's resources for ICT
E8.6	Professional experience of users
E8.7	Understanding the tools' compatibility factors
E8.8	Client's request for ICT usage
E8.9	Development of team knowledge for ICT
E8.10	Positive change management
E8.11	End-user involvement
E8.12	The understanding capability of the configuration of tools
E8.13	Understanding complexity factors of tools
E8.14	Knowing the cost implications
E8.15	Clear communication of ICT objectives
E8.16	Encourage expansion of organizations
E8.17	Supportive government involvement (e.g. through policies)
E8.18	Checking out the relative advantage of the tool
E.8.19	Outsourcing

Table 7. 38: Correlation matrix measures to ensure ICT use

	E8.1	**E8.2**	**E8.3**	**E8.4**	**E8.5**	**E8.6**	**E8.7**	**E8.8**	**E8.9**	**E8.10**	**E8.11**	**E8.12**	**E8.13**	**E8.14**	**E8.15**	**E8.16**	**E8.17**	**E8.18**	**E8.19**
E8.1	**1.000**	.725	.546	.571	.523	.357	.559	.581	.617	.527	.425	.469	.657	.303	.534	.504	.514	.523	.472
E8.2	.725	**1.000**	.507	.687	.560	.396	.523	.590	.627	.658	.434	.351	.583	.421	.388	.565	.631	.497	.561
E8.3	.546	.507	**1.000**	.631	.603	.483	.663	.594	.494	.338	.411	.338	.460	.182	.521	.357	.473	.362	.405
E8.4	.571	.687	.631	**1.000**	.609	.461	.571	.656	.673	.666	.341	.122	.435	.321	.448	.517	.615	.417	.533
E8.5	.523	.560	.603	.609	**1.000**	.634	.708	.601	.628	.589	.555	.243	.448	.268	.514	.425	.603	.410	.497
E8.6	.357	.396	.483	.461	.634	**1.000**	.627	.472	.483	.479	.322	.195	.343	.197	.443	.193	.383	.219	.315
E8.7	.559	.523	.663	.571	.708	.627	**1.000**	.692	.688	.580	.558	.307	.489	.174	.552	.451	.603	.375	.402
E8.8	.581	.590	.594	.656	.601	.472	.692	**1.000**	.712	.494	.413	.378	.530	.124	.428	.475	.493	.353	.332
E8.9	.617	.627	.494	.673	.628	.483	.688	.712	**1.000**	.766	.535	.189	.557	.418	.472	.570	.675	.598	.531
E8.10	.527	.658	.338	.666	.589	.479	.580	.494	.766	**1.000**	.535	.107	.453	.484	.429	.562	.750	.573	.597
E8.11	.425	.434	.411	.341	.555	.322	.558	.413	.535	.535	**1.000**	.326	.460	.392	.487	.428	.529	.540	.403
E8.12	.469	.351	.338	.122	.243	.195	.307	.378	.189	.107	.326	**1.000**	.612	-.028	.408	.290	.163	.170	.207
E8.13	.657	.583	.460	.435	.448	.343	.489	.530	.557	.453	.460	.612	**1.000**	.349	.557	.715	.556	.429	.530
E8.14	.303	.421	.182	.321	.268	.197	.174	.124	.418	.484	.392	-.028	.349	**1.000**	.310	.409	.494	.507	.464
E8.15	.534	.388	.521	.448	.514	.443	.552	.428	.472	.429	.487	.408	.557	.310	**1.000**	.626	.543	.438	.479
E8.16	.504	.565	.357	.517	.425	.193	.451	.475	.570	.562	.428	.290	.715	.409	.626	**1.000**	.667	.502	.560
E8.17	.514	.631	.473	.615	.603	.383	.603	.493	.675	.750	.529	.163	.556	.494	.543	.667	**1.000**	.576	.630
E8.18	.523	.497	.362	.417	.410	.219	.375	.353	.598	.573	.540	.170	.429	.507	.438	.502	.576	**1.000**	.379
E8.19	.472	.561	.405	.533	.497	.315	.402	.332	.531	.597	.403	.207	.530	.464	.479	.560	.630	.379	**1.000**

Table 7. 39: KMO and Bartlett's test for the measure to ensure effective ICT use

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.893
Bartlett's Test of Sphericity	Approx. Chi-Square	1711.193
	df	171
	Sig.	.000

Table 7. 40: Communalities on effective measures

	Initial	**Extraction**
Checking out the relative advantage of the tool	1.000	.661
Understanding complexity factors of tools	1.000	.641
The supportive decision from top management	1.000	.635
Understanding the tools' compatibility factors	1.000	.684
Proper education for users	1.000	.723
Professional experience of users	1.000	.614
Positive attitude towards technology	1.000	.780
Propensity towards innovation	1.000	.696
Encourage expansion of organizations	1.000	.754
Understanding the capability of the configuration of tools	1.000	.782
Allocating firm's resources for ICT	1.000	.457
Client's request for ICT usage	1.000	.821
End-user involvement	1.000	.803
Outsourcing	1.000	.652
Clear communication of ICT objectives	1.000	.557
Positive change management	1.000	.694
Development of team knowledge for ICT	1.000	.748
Knowing the cost implications	1.000	.572
Supportive government involvement (e.g. through policies)	1.000	.556

Using PCA, the total variance explained is also presented in Table 7.41. The latent root or Kaiser's criterion with eigenvalues greater than 1.0 was used. Three factors with eigenvalues exceeding 1 were retained (9.775, 1.651, and 1.403). They have a percentage of variance 51.447, 60.139, and 67.524 respectively. Their cumulative percentage is 67.524 which highlights their importance above the other factors.

Table 7. 41: Total variance explained for the measure to effective ICT use

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	9.775	51.447	51.447	9.775	51.447	51.447	7.744
2	1.651	8.692	60.139	1.651	8.692	60.139	7.007
3	1.403	7.386	67.524	1.403	7.386	67.524	4.406
4	.913	4.805	72.330				
5	.774	4.072	76.401				
6	.651	3.427	79.829				
7	.612	3.219	83.048				
8	.518	2.727	85.775				
9	.431	2.266	88.041				
10	.339	1.785	89.826				
11	.326	1.718	91.544				
12	.312	1.641	93.185				
13	.297	1.565	94.750				
14	.248	1.307	96.057				
15	.211	1.109	97.167				
16	.179	.941	98.107				
17	.142	.747	98.854				
18	.122	.641	99.495				
19	.096	.505	100.000				

The factor analysis also presented the scree plot in Figure 7.10. The scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, only three factors which are retained on the steep slope were retained.

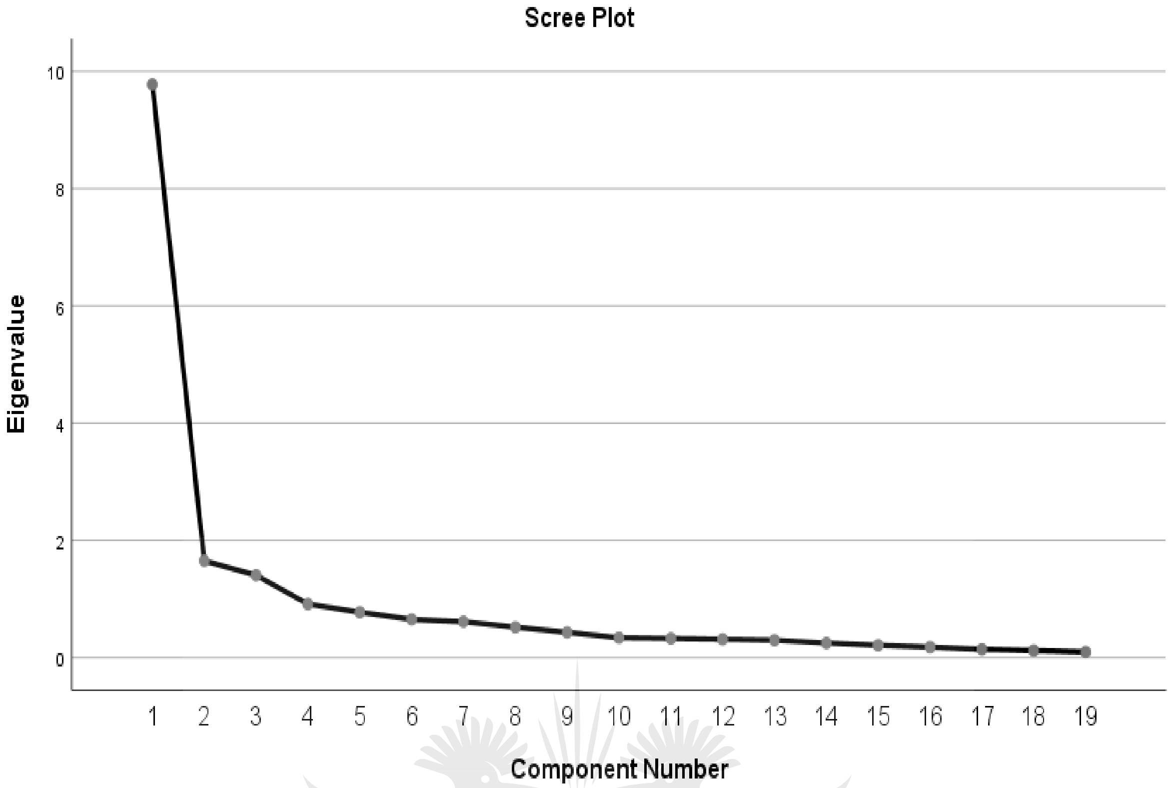

Figure 7. 10: Scree plot on measures to ensure effective ICT use

Table 7.42 shows the pattern matrix as they clustered into three groups. Using Obilim rotation, these groups were labelled **as Component 1/F1 (User-oriented factors) with** seven factors**, Component 2/ F2 (ICT knowledge factors)** of seven factors, and **Component 3/F3 (End-user factors)** of five factors.

Component 1/F1 ((ICT knowledge factors) The seven extracted factors for component 1 were Professional experience of users (87.2%), Positive attitude towards technology (84%), Proper education of users (78.8%), Propensity towards innovation (74%), The supportive decision from top management (71.8%), Understanding the tools' compatibility factors (67%), and Encourage expansion of organizations (55.4%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 52% of the variance (refer to Table 7.41)

Component 2/F2 (Users-oriented factors): The seven extracted factors for component 2 were Outsourcing (70.3%), Knowing the cost implications (71.1%), Development of team knowledge for ICT (66.9%), The understanding capability of the configuration of tools

(66.6%), Allocating firm's resources for ICT (41.2%), Supportive government involvement (63.2%), and Understanding complexity factors of tools (45.3%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 8.7% of the variance (refer to Table 7.41)

Component 3/F3 (End-users factors): The five extracted factors for component 2 were Client's request for ICT usage (94.4%), End-user involvement (68.9%), Checking out the relative advantage of the tool (46.4%), Clear communication of ICT objectives (44%), and Positive change movement (39.8%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 7.3% of the variance (refer to Table 7.41)

Table 7. 42: Pattern matrix on the measures to ensure effective ICT use

	Component		
	1	**2**	**3**
Professional experience of users	**.872**		
Positive attitude towards technology	**.840**		
Proper education for users	**.788**		
Propensity towards innovation	**.740**		
The supportive decision from top management	**.718**		
Understanding the tools' compatibility factors	**.670**		
Encourage expansion of organizations	**.554**		
Outsourcing		**-.903**	
Knowing the cost implications		**-.711**	
Development of team knowledge for ICT		**-.669**	
The understanding capability of the configuration of tools		**-.660**	
Allocating firm's resources for ICT		**-.412**	
Supportive government involvement (e.g. through policies)		**-.630**	
Understanding complexity factors of tools		**-.453**	
Client's request for ICT usage			**.944**
End-user involvement			**.698**
Checking out the relative advantage of the tool			**.460**
Clear communication of ICT objectives			**.440**
Positive Change Movement			**.398**

7.7 SECTION F: RESULTS FROM DESCRIPTIVE AND INFERENTIAL ANALYSIS ON THE BENEFITS OF EFFECTIVE ICT TOOL USAGE FOR CONSTRUCTION IN SOUTH AFRICA

This section discusses the descriptive and inferential analysis of the fifth objective. The descriptive analysis presented the mean item score ($\overline{x}$) or MIS, standard deviation (σX) or SD, and the ranking of the factors in each objective of the study, while the Inferential analysis presented the exploratory factor analysis of the objective.

7.7.1 Mean item score on benefits from the effective use of ICT tools in the South African construction industry

Table 7.43 presents the respondents' rankings of their opinions on the benefits of effective use of ICT tools for construction in South Africa. Respondents were requested to indicate the extent to which each of the identified tools is used at the construction stage, using a five-point scale: 1 = To no extent, 2 = Small extent, 3 = Moderate extent, 4 = Large extent, and 5 = Very large extent. The highest-ranked factor is 'Time-saving' with MIS of 4.29 and SD of .814. 'Improved communication during construction work' ranked second (MIS 4.25; SD= .781); 'Improves task efficiency' (MIS= 4.23; SD= .864) and 'Improves productivity' both ranked third (MIS =4.23, SD= .835); 'Enhanced decision making in firms' ranked fifth with MIS =4.17 and SD =.827; 'Enriches shared knowledge' ranked sixth with MIS 4.13 and SD .751; 'Reduced wastage of resources' (MIS= 4.12; SD= .894) and 'Enabled innovation' (MIS=412; SD=.918) both ranked seventh. 'Enabled team coordination' (MIS= 4.12; SD=.874) ranked eighth; 'Offers immediate connectivity' ranked ninth (MIS= 4.06; SD=.892); 'Simplified task' ranked tenth with MIS (4.05) and SD (.969); ranked eleventh is 'Improved the status of the construction industry at large' (MIS= 4.01 and SD= 1.057); 'Improved return on investment' ranked twelveth with MIS of 4.00 and SD of .979; 'Allows timely collection of data' ranked thirteenth with MIS 3.99 and SD .884, and the least ranked factor is 'Improved company turnover' with MIS (3.95) and SD (1.003).

Table 7. 43: Descriptive statistics on benefits of ICT tools

Benefits	Mean	Std. Deviation	Rank
Time saving	4.29	.834	1
Improved communication during construction work	4.27	.796	2
Improved competitive edge	4.26	.865	3
Improved productivity	4.23	.807	4
Improves task efficiency	4.23	.874	4
Enhanced decision-making in firms	4.21	.809	5
Enabled innovation	4.17	.901	6
Enhanced team coordination	4.12	.862	7
Enriches shared knowledge	4.12	.758	7
Reduced wastage of resources	4.09	.917	8
Offers immediate connectivity	4.03	.978	9
Simplified tasks	4.03	.970	9
Improved the status of the construction industry at large	3.98	1.085	10
Improved return on investment	3.98	.979	10
Allows timely collection of data	3.98	.930	10
Reduction in transaction cost	3.95	.906	11
Improved company turnover	3.94	1.007	12
Improved international competitiveness of the construction industry	3.91	1.085	13
Reduced stress and fatigue	3.88	1.086	14
The streamlined knowledge generation process of firms	3.77	.914	15

7.7.2 Factor analysis on the benefits of ICT tools used in the South African construction industry

Table 7.44 presents the labels of factors for this objective. The results from the EFA benefits of effective ICT tool usage for construction activities in South Africa are presented in Tables 7.45 to 7.4.9 and Figure 7.11. Prior to performing the PCA, the suitability of the data for factor analysis was assessed. Inspection of the correlation matrix revealed the presence of coefficients of above 0.3 as presented in Table 7.45. For the KMO, table 7.46 showed a sampling adequacy value of .856 and Bartlett's test of sphericity was also statistically significant at a p-value of 0.000, thereby supporting the factorability of the correlation matrix. The communalities after extraction are also presented in Table 7.47. It contains values above 0.3.

Table 7. 44: Labelling for benefits of ICT tool use

Label	Benefits
F9.1	Time-saving
F9.2	Improved communication during construction work
F9.3	Improved competitive edge
F9.4	Improved productivity
F9.5	Improves task efficiency
F9.6	Enhanced decision making in firms
F9.7	Enabled innovation
F9.8	Enhanced team coordination
F9.9	Enriches shared knowledge
F9.10	Reduced wastage of resources
F9.11	Offers immediate connectivity
F9.12	Simplified tasks
F9.13	Improved the status of the construction industry at large
F9.14	Improved return on investment
F9.15	Allows timely collection of data
F9.16	Reduction in transaction cost
F9.17	Improved company turnover
F9.18	Improved international competitiveness of the construction industry
F9.19	Reduced stress and fatigue
F9.20	The streamlined knowledge generation process of firms

Table 7. 45: Correlation matrix on the benefits of ICT use

	F9.1	F9.2	F9.3	F9.4	F9.5	F9.6	F9.7	F9.8	F9.9	F9.10	F9.11	F9.12	F9.13	F9.14	F9.15	F9.16	F9.17	F9.18	F9.19	F9.20
F9.1	**1.000**	.788	.619	.364	.599	.496	.483	.487	.409	.312	.475	.575	.512	.462	.447	.504	.486	.359	.445	.537
F9.2	.788	**1.000**	.648	.340	.620	.503	.464	.487	.267	.163	.299	.596	.514	.402	.395	.293	.368	.134	.365	.328
F9.3	.619	.648	**1.000**	.419	.613	.579	.504	.380	.354	.279	.467	.558	.402	.425	.543	.374	.334	.221	.398	.322
F9.4	.364	.340	.419	**1.000**	.556	.564	.531	.598	.463	.423	.504	.459	.476	.477	.607	.518	.529	.558	.629	.586
F9.5	.599	.620	.613	.556	**1.000**	.711	.545	.682	.503	.280	.441	.705	.619	.642	.633	.427	.470	.433	.564	.556
F9.6	.496	.503	.579	.564	.711	**1.000**	.546	.534	.415	.371	.367	.583	.539	.482	.616	.546	.484	.332	.528	.494
F9.7	.483	.464	.504	.531	.545	.546	**1.000**	.551	.422	.527	.550	.548	.627	.615	.621	.634	.571	.583	.499	.610
F9.8	.487	.487	.380	.598	.682	.534	.551	**1.000**	.531	.476	.543	.552	.568	.460	.530	.472	.511	.491	.608	.447
F9.9	.409	.267	.354	.463	.503	.415	.422	.531	**1.000**	.612	.418	.588	.398	.518	.526	.357	.411	.507	.440	.452
F9.10	.312	.163	.279	.423	.280	.371	.527	.476	.612	**1.000**	.540	.510	.238	.381	.530	.518	.432	.477	.380	.404
F9.11	.475	.299	.467	.504	.441	.367	.550	.543	.418	.540	**1.000**	.495	.483	.408	.466	.595	.573	.555	.446	.522
F9.12	.575	.596	.558	.459	.705	.583	.548	.552	.588	.510	.495	**1.000**	.545	.572	.641	.334	.354	.374	.499	.404
F9.13	.512	.514	.402	.476	.619	.539	.627	.568	.398	.238	.483	.545	**1.000**	.643	.597	.541	.640	.461	.438	.486
F9.14	.462	.402	.425	.477	.642	.482	.615	.460	.518	.381	.408	.572	.643	**1.000**	.709	.525	.586	.505	.470	.681
F9.15	.447	.395	.543	.607	.633	.616	.621	.530	.526	.530	.466	.641	.597	.709	**1.000**	.663	.599	.541	.553	.601
F9.16	.504	.293	.374	.518	.427	.546	.634	.472	.357	.518	.595	.334	.541	.525	.663	**1.000**	.866	.674	.547	.738
F9.17	.486	.368	.334	.529	.470	.484	.571	.511	.411	.432	.573	.354	.640	.586	.599	.866	**1.000**	.740	.632	.747
F9.18	.359	.134	.221	.558	.433	.332	.583	.491	.507	.477	.555	.374	.461	.505	.541	.674	.740	**1.000**	.711	.717
F9.19	.445	.365	.398	.629	.564	.528	.499	.608	.440	.380	.446	.499	.438	.470	.553	.547	.632	.711	**1.000**	.694
F9.20	.537	.328	.322	.586	.556	.494	.610	.447	.452	.404	.522	.404	.486	.681	.601	.738	.747	.717	.694	**1.000**

Table 7. 46: KMO and Bartlett's test on the benefits of ICT use

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.856
Bartlett's Test of Sphericity	Approx. Chi-Square	2100.008
	Df	190
	Sig.	.000

Table 7. 47: Communalities table on the benefits of ICT usage

	Initial	Extraction
Allows timely collection of data	1.000	.677
Improves task efficiency	1.000	.817
Offers immediate connectivity	1.000	.648
Reduction in transaction cost	1.000	.554
Time-saving	1.000	.757
Enhanced decision making in firms	1.000	.599
Enriches shared knowledge	1.000	.621
Improved productivity	1.000	.596
Improved competitive edge	1.000	.711
Enabled innovation	1.000	.758
The streamlined knowledge generation process of firms	1.000	.519
Improved communication during construction work	1.000	.785
Reduced wastage of resources	1.000	.614
Simplified tasks	1.000	.578
Enhanced team coordination	1.000	.673
Improved the status of the construction industry at large	1.000	.801
Improved international competitiveness of the construction industry	1.000	.852
Improved return on investment	1.000	.792
Improved company turnover	1.000	.600
Reduced stress and fatigue	1.000	.781

Using PCA, the total variance explained is also presented in Table 7.48. The latent root or Kaiser's criterion with eigenvalues greater than 1.0 was used. Three factors with eigenvalues exceeding 1 were retained (10.667, 1.906, and 1.160). They have a percentage of the variance of 53.336, 9.529, and 5.798 respectively. Their cumulative percentage is 68.663% which highlights their importance from the other factors.

Table 7. 48: Total variance of the benefits of using ICT tools

Component		Initial Eigenvalues		Extraction Sums of Squared Loadings			
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	10.667	53.336	53.336	10.667	53.336	53.336	8.630
2	1.906	9.529	62.865	1.906	9.529	62.865	7.368
3	1.160	5.798	68.663	1.160	5.798	68.663	6.048
4	.885	4.425	73.088				
5	.805	4.023	77.110				
6	.695	3.475	80.585				
7	.650	3.252	83.837				
8	.506	2.530	86.366				
9	.432	2.162	88.528				
10	.384	1.919	90.447				
11	.353	1.763	92.210				
12	.342	1.708	93.919				
13	.311	1.555	95.474				
14	.223	1.117	96.591				
15	.184	.920	97.511				
16	.152	.760	98.271				
17	.123	.613	98.884				
18	.103	.516	99.400				
19	.070	.348	99.749				
20	.050	.251	100.000				

The factor analysis also presented the scree plot in Figure 7.11. The scree plot revealed the larger factors that have eigenvalues > 1 on the steep side of the slope while the factors with eigenvalue < 1 were on the lower part of the plot. Therefore, only three factors which are retained on the steep slope were retained.

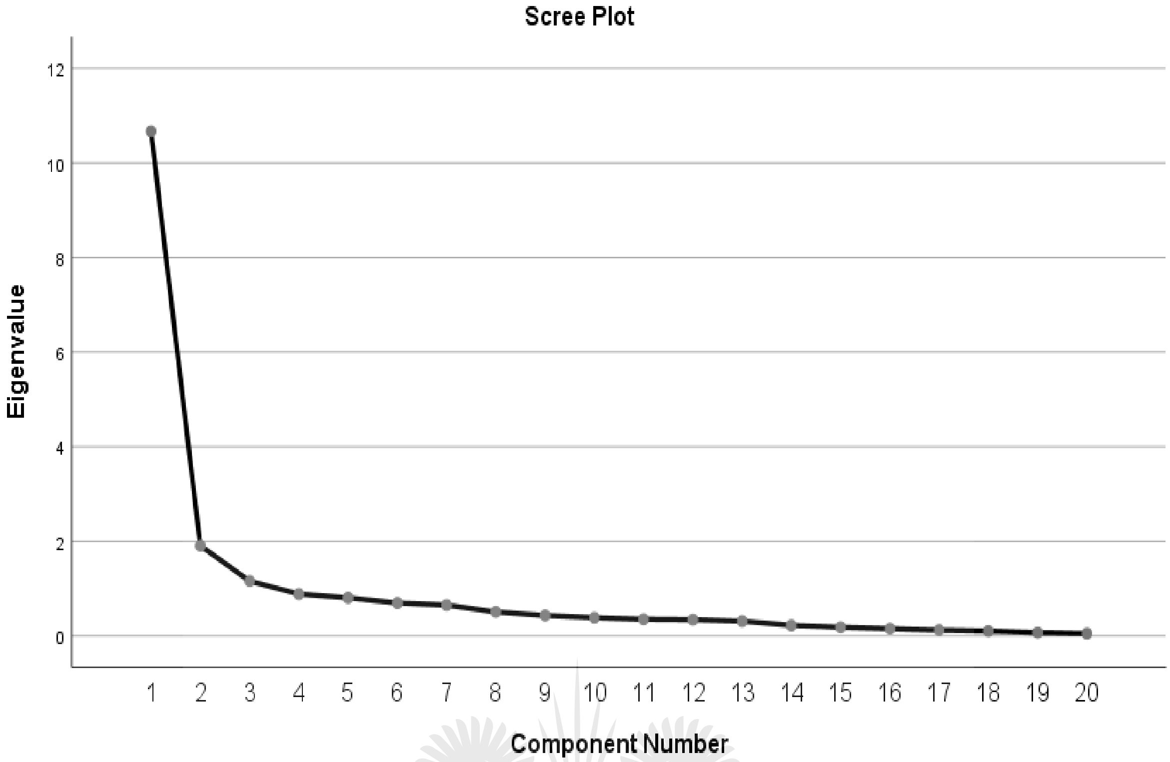

Figure 7. 11: Scree plot on the benefits of ICT use

Table 7.49 depicts the pattern matrix as they clustered into three groups. Using Obilim rotation, these groups were labelled as **F1/Component 1 (Construction industry at large improved), F2/ Component 2 (Saves time), and F3/ Component 4 (Enterprise at advantage).** The grouping had ten factors, seven factors and three factors respectively.

Component 1/ F1 (Construction industry at large improved): The ten factors that loaded into component 1 were Improved international competitiveness of the construction industry (96.8%), Improved the status of the construction industry at large (92.3%), Reduced stress and fatigue (87.7%), Improved return on investment (86.3%), Improved company turnover (61.3%), Enriches shared knowledge (47.8%), Simplified tasks (45.7%), Reduction in transaction cost (44.0%), Streamlined knowledge generation process of firms (42.8%), and Enhanced team coordination (40.0%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 53.34% of the variance (refer to Table 7.48)

<u>Component 2/ F2 (Saves time):</u> The seven factors that loaded into component 2 were Improves task efficiency (97.9%), Offers immediate connectivity (79.2%), Allows timely collection of data (74.4%), Time-saving (70.9%), Improved communication during construction work (61.2%), Enhanced decision making in firms (57.5%), and Reduced wastage of resources (48.3%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 9.5% of the variance (refer to Table 7.48)

<u>Component 3/ F3 (Enterprise at advantage</u>): The three factors that loaded into component 3 were Enabled innovation (85.4%), Improved competitive edge (79.6%), and Improved productivity (40.1%). The number in parenthesis indicates the respective factor loadings. This cluster accounted for 5.8% of the variance (refer to Table 7.48)

Table 7. 49: Pattern matrix on the benefits of ICT tools

	Component		
	1	**2**	**3**
Improved international competitiveness of the construction industry	**.968**		
Improved the status of the construction industry at large	**.923**		
Reduced stress and fatigue	**.877**		
Improved return on investment	**.863**		
Improved company turnover	**.613**		
Enriches shared knowledge	**.478**		
Simplified tasks	**.457**		
Reduction in transaction cost	**.440**		
The streamlined knowledge generation process of firms	**.428**		
Enhanced team coordination	**.400**		
Improves task efficiency		**.979**	
Offers immediate connectivity		**.792**	
Allows timely collection of data		**.744**	
Time-saving		**.709**	
Improved communication during construction work		**.612**	
Enhanced decision making in firms		**.575**	
Reduced wastage of resources		**.483**	
Enabled innovation			**.854**
Improved competitive edge			**.796**
Improved productivity			**.401**

7.8 SUMMARY OF CLUSTER FACTOR GROUPINGS FROM FACTOR ANALYSIS

Table 7.50 presents the summary of cluster factor groupings on the challenges to ICT tool usage, the measures to be adopted to ensure effective usage of ICT tools, and the benefits derived from the effective use of ICT tools for construction activities in South Africa.

Table 7. 50: Summary of Cluster grouping

Objectives	Cluster Grouping	Label
Awareness	Advanced technological tools	F1
	Day-to-day ICT tools	F2
ICT tools at the Planning stage	Industry 4.0-inclined ICT tools	F1
	Intermediate ICT tools	F2
	Basic ICT tools	F3
ICT tools at the Design stage	Advanced ICT tools	F1
	Intermediate ICT tools	F2
ICT tools at the Construction Stage	Industry 4.0-inclined ICT tools	F1
	Basic ICT tools	F2
	Intermediate ICT tools	F3
Challenges	People-related problems	F1
	Cost-related problems	F2
	Standardization problems	F3
	Management-inclined problems	F4
Measures	Users-oriented factors	F1
	ICT knowledge	F2
	End-users	F3
Benefits	Construction industry improved	F1
	Saves time	F2
	Enterprise at advantage	F3

7.9 TEST OF RELIABILITY

This section presents the reliability of the data collection instrument, in this case, the Cronbach's alpha value. Cronbach's alpha value of a minimum of .7 is accepted. Table 7.51 presents the Cronbach's alpha value derived from each objective.

Table 7. 51: Test of reliability

Objectives	Cronbach's alpha
Awareness of ICT tool	.857
ICT tools at the stages of construction work	
Planning Stage	.841
Design Stage	.854
Construction Stage	.841
Challenges to the use of ICT tools for Construction work	.895
Measures to ensure effective use of ICT tools for construction work	.942
Benefits of effective use of ICT tools for construction work	.952

7.10 CONCLUSION

This chapter revealed and analysed the data obtained from the structured questionnaire sent out to construction professionals in the Gauteng Province of South Africa. The analysed data were displayed using graphs and tables for easy interpretation. The next chapter will discuss the findings from the research analysis in relation to the stated research questions and the research objectives that were formulated in the first chapter of this dissertation. This is done to find out/determine whether the research objectives have been met.

CHAPTER EIGHT

DISCUSSION OF FINDINGS

8.1 INTRODUCTION

This chapter discusses the findings of this research study in relation to the stated research questions. In the discussions of findings, the extant literature examined is taking into consideration. This is to ascertain whether the stated research questions have been answered from the findings in the previous chapter (Chapter Seven). The results in this chapter are presented in relation to the research questions that guided this study, and the relevant data required.

8.2 BACKGROUND INFORMATION

This section of the questionnaire discussed the respondents' background information on their educational qualification, type of profession, years of experience in the construction industry, and the type of construction organization in which they work.

8.2.1 Background information results

Findings relating to respondents' educational qualification revealed that 15.8 per cent had a post-matric certificate or diploma, 29.2 per cent had a bachelor's degree, 28.2 per cent had an honour's degree, the master's degree holders numbered 19.2 per cent, and 7.5 per cent had a doctorate. As regards professions, 12.5 per cent of the respondents were architects, 43.3 per cent were quantity surveyors, engineers numbered 20.8 per cent, construction managers made up 12.5 per cent and 10.8 per cent were construction project managers.

Findings on the years of experience revealed that 50 per cent of the respondents have in the range of five years' experience, 17.5 per cent have between six to ten years of work experience, and those that had between eleven to fifteen years numbered 10. 8 per cent. There is 10 per cent of the respondents who have between sixteen to twenty years of experience, and 11.7 per cent have had more than twenty years of work experience in the construction industry. The years of experience of respondents were sufficient to provide useful responses to achieve the purpose of the study since more than 50 per cent of the respondents had work experience ranging from five years to more than 20 years. Lastly, the background information of respondents revealed three types of the organization where the respondents work: 44.2 % worked in consultancies, 39.2 per cent work as contractors and 16.7% work in Government parastatals.

8.3 RESEARCH QUESTION 1

What is the level of awareness of ICT tools used in the South African construction industry?

8.3.1 Level of awareness of ICT tool usage among construction stakeholders in South Africa

Engineers, CMs, and architects indicated that they are most aware of simulation-based tools (MIS of 4.92, 4.67, and 4.23 respectively), while CPMs and QSs revealed that they are most aware of design/estimation ICT tools (MIS of 4.80 and 4.46 respectively).

Based on the ICT tools of which professionals are aware, engineers, architects and CMs ranked design/estimation tools second (MIS of 4.68, 447 and 4.08), while CMs and QSs ranked convergence network tools as second, with MIS of 4.73 and 4.12 respectively.

Engineers, CMs, CPMs and QSs ranked the awareness of convergence networks third (MIS of 4.60, 4.53, 4.00 and 3.98 respectively), while architects ranked the awareness of design/estimation tools (MIS= 4.40) third

Architects ranked the awareness of administrative tools (MIS=3.47) fourth. Likewise, CPMs and QSs ranked the awareness of administrative tools fourth (MIS of 3.38 and 3.29), while engineers and CMs ranked the awareness of modelling-based tools fourth (MIS of 3.64 and 3.47).

CPMs, QSs and architects ranked their awareness of modelling-based tools fifth (MIS of 3.31, 3.25 and 3.20), engineers ranked their awareness of administrative tools (MIS of 3.36), and CMs ranked their awareness of modelling data tools fifth as well. The summary of the various tools of which the different professionals are aware is presented in Table 8.1

Simulation-based tools include radio frequency identification (RFID), building information modelling (BIM), virtual reality (VR), mixed reality (MR), and augmented reality (AR). Architectural, engineering and construction (AEC) professionals use simulation-based tools to explore and coordinate various construction processes (Xie, Shi and Issa, 2011:291). This is consistent with the findings of Weinstock and Stathopoulos (2006:55) that simulation-based tools are increasingly used by the AEC construction professionals for the construction design processes. In addition, simulation-based tools are the first tools of choice of AEC professionals as the core of their professional decision-making is executed with these tools (Naboni, 2013:3). Also, recent advances in construction work make a simulation-tools key to sustainable construction practices from the perspective of architects.

Professionals such as QSs and CPMs are more inclined to use design and estimation-based tools. The core function of the QS profession is estimation, architects are renowned for design, while a CPM could either be a QS or an architect. This would imply that design/estimation tools will be the construction ICT tool with which these professionals would be most familiar. This is consistent with the findings of Ann and Ahamad (2016:3) that QSs are highly aware of design/estimation tools. Similarly, in recent times the discussion of design/estimation tools is based on BIM, this being a platform whereby various ICT tools are used in combination. However, Stanley and Thurnell (2014:106) disagreed, contending that the usage of BIM for estimation is low compared to the use of the platform by other construction stakeholders.

A convergence network refers to the use of telephone, video and data communication. It involves using a platform such as email, video data, and the Internet. This is consistent with the findings of Azhar *et al.* (2016:2) that the rapid advancement of technology through computer continues to harness change and innovation in the construction industry. This view is also consistent with the findings of Oyedele *et al*. (2019:2), namely that administrative tools include the use of Microsoft Excel, Microsoft Project Office, Primavera, PriMus KRONO, and the like. Therefore, professionals who are more inclined to perform administrative tasks would use these tools (Nourbakhsh *et al.*, 2012:15). Modelling and big-data tools are those of which professionals in South Africa are the least aware. This is consistent with the findings of Mtya and Windapo (2019:215) that the South African construction industry is slow to employ tools such as BIM, and big data.

Lastly, the comparison of the ICT awareness regarding professionals revealed that there is a statistical difference in the opinion of professionals on all tools except 'Design/Estimation'(p-value =.000); 'Simulation-based tools'(sig=.008) and 'Convergence network' (p-value =.005). Therefore, there is no statistical difference in the opinion of respondents as to the use of these three tools.

8.3.2 Implication of findings

The theoretical review is consistent with the empirical findings of this research study. The awareness of various ICT tools used for construction activities in South Africa differs according to professions. Professionals involved with the design processes such as architects, engineers, and CPMs are more aware of simulation-based tools than other professionals. This is because the core of these professions is built on simulation-based tools. For the costing-inclined tools, QSs and CMs are more aware of design/estimation tools since the activities of their professions revolve around costing. This implies that professionals are mostly aware of ICT tools which are inclined to their profession. Subsequently, professionals are also aware of administrative tools and convergence network tools. Professionals such as architects are more aware of administrative tools than other professionals, while QSs and CPMs are more aware of convergence network tools than other professionals.

8.4 RESEARCH QUESTION 2

What are the ICT tools used at the various stages of construction activities in South Africa? The findings discussed ICT tools used in the planning stage, design stage and construction stage.

8.4.1 ICT tools used at the planning stage (PROCSA stages 0, 1 and 2)

All professionals ranked the use of design/estimation tools first in the planning stage of construction work. This is consistent with the findings of Silverio *et al.* (2017:90) that the strategic definition stage, which is part of the planning stage, involves the use of tools that used for cost reduction and design (Payne *et al.*, 2015:264). Kozlovska, Mackova, and Spisakova (2016:712) added that aspects of the construction planning stage incorporate time, cost, quality, project team selection, and building site planning by using design/estimation tools. Forcada *et al.* (2007:145) also agreed that key construction professionals use the design/ estimation and simulation-based ICT tools most at the planning stage of construction.

CPMs, engineers, and CMs have the use of the convergence network in common. Findings from this study revealed that convergence network ICT tools are ranked third among the tools used for the construction planning stage. This study revealed that CPMs, engineers, and CMs are more in tune with the use of convergence network ICT-based tool at the planning stage than other professionals. This agrees with PROCSA (2012:25) that at the planning stage, activities such as project initiation and land acquisition are carried out by the required team, which necessitates the use of convergence-network tools. This is also in agreement with RIBA and Sinclair (2013:8). This is also similar to the use of administrative tools by CPMs and engineers at the planning stage. Lastly, modelling tools such as BIM are used for project database creation, database update and digital site analysis (Chen and Tang, 2019:121), just as in the case of virtualization-based tools. Therefore, this study revealed that professionals such as engineers, CPMs, architects, CMs, and QSs use these tools more than other professionals at the design stage since a platform like BIM incorporates the core of activities of these professionals carried out at the planning stage.

Lastly, there is no statistical difference in the opinion of professionals in the use of simulation-based tools, web-based tools, virtualization-based tools, big data, or modelling tools at the planning stage. Regarding the use of the other tools, professionals have different opinions on their use at the planning stage of construction work in South Africa.

8.4.2 Implication of findings

The theoretical review is in line with the empirical findings of this research study. Professionals use ICT tools differently at the planning stage, while design/estimation and simulation tools are mostly used by all professionals at the planning stage of a construction process. Other tools are used differently by various professionals. Convergence network ICT tools dominated as the tool used by construction project managers, engineers, and CMs than other professionals in the planning stage. This implies that the group of CPMs, enginers, and CMs use convergence network tools more than the other tools, and more than other professionals in the planning stage. Overall, it is the third ICT tool used by professionals at the planning stage. Engineers, CPMs, CMs, QSs, and architects use the modelling-based ICT tools more than other professionals in the planning stage of construction work. Administrative tools are mostly used by CPMs than other professionals. These tools are the most used tools used by professionals at the planning stage. Engineers dominate the use of big-data tools, virtualization-based and administrative tools more than other professionals, yet these tools are the least used for construction planning since the level of awareness is low compared to other tools.

8.4.3 ICT tools used at the design stage (PROCSA stages 3 and 4)

In the design stage, engineers, architects, and CPMs indicated that a computer-based ICT tool is the first tool they would use in the design stage of construction work in South Africa while construction managers and quantity surveyors used to design/estimation tools first among other tools. This agrees with RIBA and Sinclair (2013:19) that professionals like architects, engineers and other professionals involved in building services are involved in the design stage of construction. The study of Adwan and Al-Soufi (2018:281) pointed out that computer-based ICT tools are used across various construction professions. This finding is also consistent with Evia (2010:452) that computer-based tools are used where a decision on safety and enhanced construction is made. Adwan and Al-Soufi (2018:284) agree as well that design/estimation tools are also used for operations which concern costing in the design stage of construction work.

Administrative tools are mostly used by architects in the design stage while they are also one of the tools by engineers for construction activities in the design stage. This finding is consistent with RIBA and Sinclair (2013:18) that one of the core objectives of the design stage involves administrative tasks such as updating proposals for the design process. Convergence network is another tool professionals such as engineers, CPMs and QSs would employ when the design process of construction begins. This agrees with the views of Adwan and Al-Soufi (2018:283) that the Internet, mobile, wireless and tracking-based ICT tools are the convergence network-based tools used for the design process. Leem and Kim (2013:1475) also agree that integrating the convergence of voice, data, Internet, and telecommunication tools are useful for construction activities in the design stage.

Bigdata-inclined tools are also used in the design stage by CPMs. This agrees with the studies of Bilal *et al.* (2016:500). In the same way, modelling-based tools are used mainly by engineers, CMs, architects, and QSs for the design process. BIM, an example of a modelling-based tool, is used for activities in the design stage (Chen and Tang, 2019:121). Simulation and virtualization-based tools (Tian and Lei, 2019:5) are also used to predict the energy performance of building projects while they are still in the design stage. In terms of robotics for the design process, this study determined that only engineers use this tool; this is because the construction industry is slow to innovate (Khoshnevis, 2004:5), unlike the manufacturing sector. Lundeen *et al.* (2019:24), however, pointed out that the construction industry can leverage using big data, modelling-based tools such as BIM to improve the design process. The summary of the various tools that the different professionals use in the design stage is given in Table 8.3. Lastly, the comparison of the responses of professionals on tools used at the design stage showed that they have the same opinion on the use of all tools except convergence network, administrative tools, and computer-based tools. Therefore, professionals respond to the use of these three tools differently when used at the design stage for construction work in South Africa.

8.4.4 Implication of findings

The theoretical review agrees with the empirical findings of this research study. Professionals use ICT tools differently at the design stage. Computer-based tools and design/estimation-based tools are mostly used at the design stage. The professionals who used them most are engineers, architects, CPMs, CMs, and QSs. These sets of professionals use these tools more than other professionals would use them in the design stage. Regarding administrative tools used for the design stage of construction, architects use these tools more than other professionals. Engineers, architects, CMs and QSs use the convergence network ICT and modelling tools more than other professionals at the design stage. Computer-based tools are mostly used by QSs and CMs. CPMs employ the use of big data ICT-based tools more than other professionals, and engineers use robotics and virtualization-based tools more than other professionals in the construction design stage. In addition, computer-based tools, design/estimation tools, administrative tools, and convergence networks are the top tools used by professionals in the design stage of construction activities in South Africa. However, high-end ICT tools such as robotics, BIM, and virtualization tools are not used that much for design process since only engineers use them minimally at the moment.

8.4.5 ICT tools used at the construction stage (PROCSA stage 5)

All professionals use computer-based ICT at the construction stage. RIBA and Sinclair (2013:23) indicate that at the construction stage, the project is executed by professionals as it was stated in the construction programme. Froese (2010:531) agrees with this that computer-based tools are used as an integration of tools that have project information by professionals at the design stage. This integration implies that computer-based tools work along with administrative tools, convergence network and other tools used for the construction process. This study also showed that architects and engineers would use the computer-based tools at the construction stage more than other professionals. Administrative tools are also used most by construction managers, CPMs, and QSs, engineers, and architects. At the construction stage, core administrative tasks are necessary for the process to be executed successfully. RIBA and Sinclair (2013:7) support the view that at the construction stage, professionals execute administrative activities such as site inspection (since project construction is ongoing) and review the progress of work done.

Convergence networks are used mostly by construction managers, architects, and engineers. Previous studies agree convergence tools like the Internet, mobile, data, voice, and telecommunication networks (Leem and Kim, 2013:1475; Adwan and Al-Soufi, 2018:279) are used for the construction stage. Architects and engineers use the design/estimation tools more than other professionals in the construction stage. In terms of big data and robotics for the construction process, this study finds that only engineers use these tools. This is because the construction industry is slow to innovate (Khoshnevis, 2004:5), unlike the manufacturing sector. Lundeen *et al.* (2019:24), however, pointed out that the construction industry can leverage using big data and modelling-based tools such as BIM to improve the activities at the construction stage. Lastly, the comparison of the opinion of professionals and ICT tools used at the construction stage revealed that they do not have the same views regarding the use of the various ICT tools except the administrative tools and computer-based tools. Therefore, they only have an agreement on the use of administrative tools and computer-based ICT tools for construction work in South Africa. The summary of the various tools that the different professionals use at the construction stage is presented in Table 8.4

8.4.6 Implication of findings

The theoretical review aligns with the empirical findings of this research study. Professionals use ICT tools differently at the construction stage. Computer-based and administrative tools are mostly used for the construction stage. They are mostly used by all professionals in the South African construction industry at the construction stage of projects. Computer-based tools are used mainly by CPMs, QSs and construction managers more than other professionals would use them. Architects and QSs use the design/estimation based tools more than other professionals for projects at the construction stage. Engineers use big data-inclined ICT tools, modelling-based tools, and robotics more than other professionals for construction. The implication of these findings would mean that computer-based tools, administrative tools, convergence networks, and design/estimation-based tools are the tools mostly used by professionals at the construction stage.

8.5 RESEARCH QUESTION 3

What are the challenges facing the use of ICT tools for construction work in South Africa?

8.5.1 Findings

From the factor analysis, four factors emerged and they are discussed as follows:

Cluster Factor 1 – People-related problems

This grouping had a total of seven factors which were 'Insufficient research and development (R& D) in information technology' in the construction industry (.905); 'Lack of confidence in using new technologies' (.832); 'Unclear communication within the staff' (.758); 'Difficulty of use' (.556), 'Lack of technical skills' (.527); 'Cultural barrier' (.525); and ' the insecurity of data transfers and transmission' (.436). These loaded items all relate to people-related problems encountered in the use of ICT tools.

People-related problems are the category of challenges caused by people or the user of ICT tools (Lam, Wong and Tse, 2010:36; Soja, 2011:192). People are intimidated by new technology, having low confidence in the technology (Perera *et al.*, 2017:312) since it appears that their technical skills are not sufficient for the new innovations (Hayes and Zulu, 2017:499). The technical skill required to use modern ICT to construction is still missing in the context of developing countries. This is because unlike developed countries, developing countries such as South Africa do not have enough knowledge of ICT as enabled by research compared to the developed economies (Soja and Cunha, 2015:323). This implies that the advances to ICT will be slow compared to developed parts of the world. This serves as a potential barrier to the application of ICT tools. This then necessitates the need to have sufficient research and development (Hosseini *et al.*, 2017:4) in the use of ICT tools which also enhances collaboration and ease of data transfer (Alkalbani *et al.*, 2013:66) for the construction project in developing countries.

Effective communication is necessary to enhance the successful use of ICT since construction work is a collaborative process (Ahuja, Yang, and Shankar, 2009:323). However, due to the fragmented nature of construction activities, barriers such as unclear communication hinder the application of ICT tools in a country such as South Africa (Berenger and Agumba, 2016:1729). Unclear communication problems can also be as a result of the cultural barrier (Alaghbandrad *et al.*, 2017:280). These findings are consistent with previous studies by Van Reijswoud, (2009:13) and Oesterreich and Teuteberg (2016:136). Therefore, there is a need to overcome these barriers to ICT use in the construction industry.

Cluster Factor 2 – Cost-related problems

The four extracted items loaded onto cluster factor 2 were 'Costly upgrade of tools' (.890); 'The high cost of the installation' (.831); 'The high cost of purchase of ICT tools' (.800); and 'Cost of training staff' (.644). Cost-related factors described the barriers to the effective use of ICT application arising from the financial implications of such tools (Sardroud, 2014:56). The high cost of purchasing ICT tools can also be described as the investment cost incurred on the tool. Love, Irani, and Edwards (2004:521) and Eadie and Perera (2016:23) agree that enterprises are posed with the challenge of attaching investment cost to ICT tools. In addition, the cost of purchase of such tools and the cost of installation of these tools are also expensive: for example, 3D-printers for construction activities (Attaran, 2017:677). This accounts for the notion of uncertainty in the return of such investment. Using BIM an ICT tool as an example, a company is posed with the challenge of evaluating the return on its investment (Walasek and Barszcz, 2017:1230). Another cost-related factor has to do with the cost of training staff or personnel on the use of ICT tools. Since innovations are dependant on the users, enterprises have to incur expenses to train the personnel on the use of complex or simple ICT tools. This is consistent with the studies of Alkalbani *et al.* (2013:66) and Oesterreich and Teuteberg (2016:136). Cost-related problems affecting ICT are therefore crucial challenges to ICT adoption which require strategic measures.

Cluster Factor 3 - Standardization problems

This grouping had three factors which were 'Inadequate of support from the government (e.g. through policies)' (.889); Legal and standardization issues' (.840) and 'Hesitation to adopt ICT tools among users' (.513). Standardisation problems are those which emanate from external sources regarding the use of ICT tools. These external sources in this context refer to the government and end-users such as the client of a constriction project. Alaghbandrad *et al.* (2017:281) agree that ICT standardization issues are a barrier to its effective use for construction activities. Standards are required to give direction to the communication emanating from ICT tools like the Internet of Things (IoT) and the user or environment (Bandyopadhyay and Sen, 2011:59). A tool like BIM has legal problems regarding the use of the model (Gustavsson and Samuelson, 2012:527). The absence of the appropriate legal and standardization for the ICT tool is a barrier to its effective use. The main influencer of standardization and legal procedures for ICT tools is the government. Inadequate support from the government hinders the effective use of ICT tools (Watson, Boudreau and Chen, 2010:26) since it is a key influencer of its use in the same way users can influence ICT tool usage. Hence, there should be proper standardization and legal measures regarding ICT use in the construction industry.

Cluster Factor 4 - Management inclined-problems

The three extracted items loaded onto cluster factor 4 were 'Difficulty in evaluating the benefits of ICT use' (.961); 'Management problems in a firm' (.612), and 'Organization process changes' (.443). Management-inclined problems are those emanating from the top decisionmakers of an enterprise. The difficulty in measuring the benefits of ICT use poses problems to its effective use. This agrees with Borut and Jaklič (2010:87) that there is a difficulty in measuring the benefit from ICT use since the direct and indirect effects are not visible. This can also emanate from another barrier where there is a management problem in the enterprise. A management problem is a people-problem which affects the overall performance of an enterprise, especially when an organization process changes. This supports the findings of Ahuja *et al.* (2010: 164) that all factors affecting ICT tools are interrelated: a negative influence by the management of an enterprise causes problems regarding its use and vice versa. It is therefore imperative that management problems should be overcome.

8.5.2 Implication of findings

The theoretical review is consistent with the empirical findings of this research study. It is apparent from the empirical findings which revealed that respondents consider that people-related problems mostly affect ICT use in the construction industry. These problems include insufficient research and development on ICT, lack of confidence in using new technology, unclear communication in the construction process, users encountering difficulty in the use, lack of technical skill to use the tools, cultural barrier, and insecurity of data transfer as supported by evidence from past studies. Some of these people-related problems are peculiar to the developing nations. For example, research and development in ICT usage are low compared to the developed counterparts. This implies that the subject of innovation in developing still needs thorough scholarly and industry attention.

Cost-related problems are a subject of core attention. In developing countries, the construction industry is saturated by SMEs. As an implication, the enterprises in this category are limited in size and manpower. Therefore, they are also limited by cost in handling ICT innovations. The cost of purchase of such tools, the cost of installation of the tools, the cost of training staff, and the cost of the upgrading of such tools are all subjects of concern. This also applies to the developed countries where there are SMEs too. However, the difference between developed and developing countries is that there are better platforms in the developed countries to handle the issue of financing innovation. Costly upgrading of tools is a major hindrance to ICT tools since ICT tools usually have a short life span between the time its use commences and the time a newer and improved invention is on the market. This is because the workplace keeps evolving; this calls for a complementary innovation. Therefore, an upgrade will be necessary. Standardization and legal issues have a long-term and short-term effect on ICT tools for construction activities. The complex nature of some ICTs such as BIM calls a for a need to have adequate standardization and a legal platform. Government policies need to support the use of ICT tools both on the individual level and the firm level. The implication of management-inclined problems is felt in the decision making of ICT use or purchase in a firm or enterprise. A supportive decision from the management level will have a positive effect on an ICT tool, and the other way round.

8.6 RESEARCH QUESTION 4

What are the measures to ensure the effective use of ICT tools in the South African construction industry?

8.6.1 Findings

From the factor analysis, three factors emerged, and they are discussed as follows:

Cluster Factor 1 – User-oriented factors

This grouping had a total of seven factors which were 'Professional experience of users'(.872); 'Positive attitude towards technology' (.840); 'Proper education for users' (.788); 'The propensity towards innovation' (.740); 'The supportive decision from top Management' (.718); 'Understanding the tools' compatibility factors'(.670), and 'Encourage expansion of organizations' (.554). A measure to ensure effective use of ICT tool emanates from the user of such a tool, hence the label 'User-oriented' factors. A propensity toward innovation can be driven by computer innovation self-efficacy. This is supported by the findings of Son, Lee, and Kim (2015:92). This self-confidence in using computer-oriented tools is also largely dependent on the proper education of users, their professional experience, as well as their attitude towards technology. Proper education of users has a positive way of driving the effective use of ICT tools in the same way as their professional experience (Taylor, 2015:281). This will enhance an understanding of the compatibility factor of ICT tools which can facilitate its use as well (Son, Lee, and Kim, 2015:92). A supportive decision from the management of an enterprise will encourage ICT users in that organization. It creates a conducive environment that encourages capacity building through the acquisition of more knowledge, skill, education and professional experience that will enhance ICT use (Dang and Le-Hoai, 2019:515). This will, in turn, encourage expansions of the firm through a competitive edge (Massa and Testa, 2009:129). Most industries in the construction sector of developing nations like South Africa are SMEs, hence an expansion is beneficial to the enterprise and construction industry at large.

Cluster Factor 2 ICT knowledge

The seven extracted items loaded onto cluster factor 4 were 'Outsourcing' (-.903); 'Knowing the cost implications' (-.711); 'Development of team knowledge for ICT' (-.669); 'The understanding capability of the configuration of tools' (-.660); 'Allocating firm's resources for ICT' (-.412); 'Supportive government involvement (e.g. through policies)' (-.630), and 'Understanding the complexity factors of tools' (-.453). Development of team knowledge on ICT is crucial to its adoption. This then propels the need for understanding the way knowledge is managed among the team in an organization. Innovative measures on knowledge management system and knowledge management capacity (Santoro *et al.*, 2017:347) are pivotal to this end.

Thereafter, knowing the cost implication of ICT tools will lead to a decision on how to allocate a firm's resources (Aigbavboa, Thwala and Lesito, 2015:46). This also informs a decision on outsourcing (Ashrafi and Murtaza, 2008:125) or not as the capability of the configuration of the tool (Underwood and Khosrowshahi, 2012:31) has been ascertained. Lastly, supportive government involvement is a driver to ICT use in the construction industry. This is consistent with the findings of Oni (2013:22) that the government should provide a platform for construction professional bodies and policy-makers to enhance technologically-driven innovation in the construction industry. These factors will serve as measures to ensure the effective use of ICT tools in the construction industry.

Cluster Factor 3 End-users

This grouping had a total of five factors which were 'Client's request for ICT usage' (.944); 'End-user involvement' (.698); 'Checking out the relative advantage of the tool' (.460); 'Clear communication of ICT objectives' (.440), and 'Positive change movement' (.398**).** An end-user of an ICT tool has an effect on its adoption, even in the construction process spheres. The findings of Christiansson *et al.* (2011:321) agreed that end-users can drive the effective use of ICT tools even in the design stage (Christiansson, Svidt and Pedersen, 2010:105) especially since they are the core reason for using an ICT tool in the first place. This also makes the determining of the relative advantage of ICT tool important both for the end-user, the construction team, and the construction process. This is in line with the findings of Kannabiran and Dharmalingam (2012:187) that being aware of the relative advantage of ICT tool in terms of investment to yield ratio is crucial to its adoption. Knowledge of the long-term and short-term benefits to be derived from this tool is vital. The process of clear communication is also another driver of ICT use in the construction industry. Clear communication is the basis of any construction instruction (Hosseini *et al.*, 2019:118). It has an impact on the success and productivity achieved in a project.

8.6.2 Implication of findings

The theoretical review is consistent with the empirical findings of this research study. It is clear from the empirical findings which revealed that respondents consider that user-oriented factors are a measure to promote effective use of ICT in the construction industry. These measures include the professional experience of construction ICT users, their positive attitude towards technology, their education, their propensity towards innovation, supportive decisions from top management, understanding the tools' compatibility factors and encouraging the expansion of organizations. The implication of these findings is that when the measures are employed in tandem, several barriers to ICT use in the construction industry will be overcome. This then leads to achieving the benefits from ICT tools as they were originally intended. Also, when there is an adequate knowledge of ICT on an individual level, team level and end-user level, communication will be effective. Ths support of the government will also help to overcome some challenges to ICT use which might be difficult to overcome by the SMEs which saturated the construction industry of developing countries like South Africa.

8.7 RESEARCH QUESTION 5

What are the benefits of effective ICT tool usage in the South African construction industry?

8.7.1 Findings

From the factor analysis, three factors emerged, and they are discussed as follows:

Cluster Factor 1 – Construction industry improved

This grouping had a total of seven factors which were 'Improved international competitiveness of the construction industry' (.968); 'Improved the status of the construction industry at large' (.923); 'Reduced stress and fatigue' (.877); 'Improved return on investment' (.863); 'Improved company turnover' (.613); 'Enriched shared knowledge' (.478); 'Simplified tasks' (.457); 'Reduction in transaction cost' (.440); 'The streamlined knowledge generation process of firms' (.428); and 'Enhanced team coordination' (.400). This cluster factor is named 'Construction industry improved'. It described benefits for the construction industry at large.

Information and communication technology tools usage is beneficial to the construction industry by improving its international competitiveness. Giotopoulos *et al.* (2017:60) agreed that the use of ICT infrastructure increases the construction industry competitiveness. Particularly for the SMEs, ICT use for the construction industry is an indication of the wellness of the construction industry. Therefore, improved return on investment, company turnover and reduction in transaction cost are inevitable.

Traditional construction activity is known to be tedious and stressful. This study revealed that the use of ICT tools for construction activities reduces stress and fatigue. However, Kajewski (2010:38) contends that construction workers become stressed when trained for ICT use. Nam (2014:1035) also added that ICT use leads to job stress. Therefore, the effect of ICT use on the construction work and the construction workers deserves careful scrutiny.

ICT tool usage enriches shared knowledge. It also streamlines the knowledge generation process of an enterprise. Liu, Wang, and Zhang (2017:8) support the view that the use of ICT tools such as BIM in the construction enhances knowledge sharing. It creates a simpler form for knowledge sharing. This leads to enhanced team coordination (Ariff *et al.*, 2011:1). Therefore, these benefits on an organizational level are a result of the effective use of ICT tools in the construction industry.

Cluster Factor 2 – Productivity-related

This grouping had a total of seven factors which were 'Improves task efficiency' (.979); 'Offers immediate connectivity'(.792);'Allows timely collection of data'(.744);'Time-saving' (.709); 'Improved communication during construction work'(.612); 'Enhanced decision making in firms'(.575); and 'Reduced wastage of resources'(.483). This label addresses productivity as it relates to other benefits from effective ICT use. They include time management and communication. Time is one of the valuable assets for construction activities. Construction work seeks to achieve value for money, cost, and time while considering sustainability. ICT tools allow a timely collection of data (Akinbile and Oni, 2016:164). This saves time spent on achieving a construction task while also improving task efficiency (Hamada *et al.*, 2016:76). Therefore, resources are well maximized for the construction process. Another productivity-related benefit of ICT use comes through improved communication. Hasan *et al.* (2018:320) support the view that ICT tools enhance the communication process which in turn improves the productivity of the construction process. Decision making is also enhanced when there is better communication through ICT tools.

Cluster Factor 3 – Enterprise at an advantage

This grouping had a total of three seven factors which were 'Enabled innovation' (.854); 'Improved competitive edge' (.796), and 'Improved productivity'(.401). Construction enterprises are a reflection of the construction industry. Another advantage of using ICT is seen on an organizational level. It is evident that productivity influenced by innovation leads to the competitiveness of the enterprise. ICT tools enhance the innovativeness of an enterprise. The findings of Santoro *et al.* (2017:347) support the view that ICT use in an organization improves knowledge sharing which also leads to the enterprise innovativeness. This brings about improved productivity. A direct relationship exists between the productivity of an enterprise, its innovativeness and competitiveness (Giotopoulos *et al.*, 2017:60). A highly innovative enterprise will achieve higher productivity and competitive advantage.

8.7.2 Implication of findings

The theoretical review is consistent with the empirical findings of this research study. Improvement of the construction industry productivity is a key benefit of the ICT tool. These benefits are seen first on an enterprise level. It then reflects the construction industry at large. The use of ICT would imply improved innovation that leads to better productivity and competitive advantage. Productivity is measured when a task is more efficiently handled than it was before ICT tools were employed. Connectivity and communication become easier in the construction process. This leads to maximizing time since the decision-making process is streamlined. The status of the South African construction industry in the international sphere will be improved. Although staff training on ICT use could lead to stress, it is a temporary challenge. The construction workers will enjoy the benefit in the long run. The South African construction industry can be used to mirror other developing construction nations. Therefore, ICT tools improve the construction industry, its productivity, and the SMEs which saturate it.

8.8 CONCLUSION

The data obtained from the questionnaire answered by the respondents regarding the level of awareness of ICT tools used in the construction industry; the ICT tools used at the planning, design and construction stages; the challenges regarding the use of ICT tools for construction work; the measures to ensure effective use of ICT tools for construction activities in South Africa, and the benefits derived from the effective use of ICT tools for construction activities in South Africa were presented and discussed in relation to the study. The findings which emerged from the data provided the answers to the research questions of the study. The next chapter discusses the conclusions and recommendations of this research in relation to the research objectives of the study.

CHAPTER NINE

CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

9.1 INTRODUCTION

This study reviewed the ICT tools used for construction activities in South Africa. In this chapter, the conclusions and recommendations of the research study are presented and discussed in relation to the stated objectives of this study. In achieving this purpose, the specific objectives of the study were:

i. to evaluate the level of awareness of ICT application among construction stakeholders;
ii. to examine ICT applications used at the different stages of construction projects in the South African construction industry;
iii. to assess the challenges facing the effective application of ICT for construction projects in the South African construction industry;
iv. to address the measures for ensuring the effective application of ICT for construction projects in the South African construction industry; and
v. to determine the benefits in the effective application of ICT for construction projects in the South African construction industry

9.2 RESEARCH OBJECTIVE ONE

The first research objective was to evaluate the level of awareness of ICT application among construction stakeholders.

Evidence from the literature evaluate ICT tools such as the convergence network (Internet, e-mail, video data), design/estimation (e.g. AutoCAD; 3D &4D BIM, WInQS), administrative tools (e.g. Microsoft Suites, Primavera), simulation-based tools (e.g. BIM; mixed, augmented and virtual reality), computer-based ICT tools, web-based ICT applications, robotics, sensors, RFID, BMS, GIS (Industry 4.0 elements), virtualization-based ICT applications, big-data – predictive tools (e.g. ML algorithms), and modelling-based tools e.g. Multivate regression. The level of awareness of professionals about these tools differ. Some tools are better known by these professionals than others. This can be traced to the fact that some tools are more profession-specific or professionally inclined than others. It contributes to the body of knowledge by making known the level of awareness of construction professionals of ICT use for construction purposes.

The questionnaire survey results obtained from the randomly selected respondents revealed that simulation-based tools and design/estimation tools are the tools of which construction professionals are most aware. The engineers, architects and CMs are mostly aware of simulation-based tools since their professions revolve around the use of such tools, while CPMs and QSs are mostly aware of design/ estimation tools. The next level of awareness of the professionals relates to the convergence network tools. Engineers, CMs, QSs, and CPMs are more aware of these tools than other professionals. The next level of tools professionals are aware of are the administrative tools and modelling-based tools. Lastly, only engineers are very much aware of big data ICT-inclined tools in the South African construction industry. Therefore, from both the reviewed body of literature and the findings from the structured questionnaire, the first research objective was well achieved.

9.3 RESEARCH OBJECTIVE TWO

The second objective of the current study was to examine ICT applications used at the different stages of construction projects in the South African construction industry.

The studies from literature revealed that in the planning stage of construction work, ICT tools such as convergence network (Internet, e-mail, video data), design/estimation (e.g. AutoCAD; 3D &4D BIM, WInQS), administrative tools (e.g. Microsoft Suites, Primavera), simulation-based tools (e.g. BIM, mixed, augmented and virtual reality), computer-based ICT tools, web-based ICT applications, robotics, sensors, RFID, BMS, GIS (Industry 4.0 elements), virtualization-based ICT applications, big data predictive tools (e.g. ML algorithms), and modelling-based tools e.g. Multivate regression, are used. However, professionals would use them differently. Some tools are more prioritized than others based on the core of the profession and the influence of such a tool at the planning stage.

The survey results obtained from the respondents revealed that at the planning stage, all professionals believed that the use of design/ estimation tools comes first. The next tool for the planning stage is the simulation-based tool. These design/estimation and simulation-based tools are the only tools according to this study that are used across all professions in the planning stage. The next tool used in the planning stage is the convergence network. CPMs, engineers and CMs use it more than other professionals. Modelling-based tools are the next type of tools used in the planning stage. They are used more by engineers, CPMs, CMs and

QSs. Administrative tools and big data tools are used more by CPMs and engineers than other professions. Lastly, in the South African constriction industry, only engineers use virtualization-based tools for construction processes at the planning stage.

Also, at the design stage, the results from respondents showed that in the South African construction industry, computer-based tools and design/estimation tools are the most frequently used tools. They are used more by engineers, architects and CPMs than other professionals at this stage of construction. The next tools used at the design stage are administrative tools and convergence network tools. They are mostly used by architects, and engineers and QSs respectively. Big-data tools are also used at the design stage, but mostly by CPMs. Engineers use more modelling-based tools, robotics and virtualization-based tools at the design stage than any other professionals. Therefore, this part of the research objective was achieved in the current study since the theoretical and empirical evidence is in tandem with each other for the planning stage of construction work.

Lastly, at the construction stage, computer-based tools and administrative tools are the most widely used tools. They are used more by architects, engineers, CMs, QSs and CPMs than any others. In the construction stage as well, the convergence network tools are used more by CMs and architects than other professionals. In the South African construction industry, engineers would use big-data tools, robotics and modelling-based tools more frequently than other professionals. Therefore, the research objective was achieved in the current study since the theoretical and empirical evidence is in line with each other for the planning stage of construction work. This contributes to the body of knowledge by providing the various ICT tools used by construction professionals at the planning, design, and construction stages of construction activities in South Africa.

9.4 RESEARCH OBJECTIVE THREE

The third objective of the current study was to address the challenges facing the effective application of ICT for construction projects in the South African construction industry.

Literature revealed that the challenges to ICT use include problems such as hesitation to adopt ICT (e.g. BIM adoption), high cost of implementation, organizational process changes, a need for enhanced skills/ staff training, knowledge management, acceptance by the workforce, lack of standard (software incompatibility problem) and reliable construction team, a higher requirement for computing required, data security and data protection, enhancement of existing communication networks, regulatory compliance (e.g. for RFID technology or BIM), and legal and contractual uncertainty, among others.

From the survey results obtained from the respondents, it was observed the people-related factors, cost-related problems, standardization problems, and management-inclined problems are the core challenges to ICT use in the South African construction industry. People-related problems include insufficient research and development on ICT applications, the users' lack of confidence in the use of new technologies, unclear communication of the ICT usage, users' difficulty in using the tools since they lack the right technical skills, cultural barriers, and the problem of insecurity of data transfer. Cost-related challenges include the cost of purchase, installation, and upgrade of ICT tools. The cost of training staff on the use of ICT tool is also a factor.

Standardization and legal problems include inadequate support from the government through policies. Management-oriented problems relate to the difficulty in evaluating the benefits of investing in ICT tools, top management of enterprises posing problems, and difficult organizational processes. All these challenges affect ICT usage in the South African construction industry since it is an industry saturated by SMEs.

Therefore, the research objective was achieved in the current study since the theoretical background is supported by the evidence mentioned. This contributes to the body of knowledge on ICT tool usage in the South African construction industry by addressing the challenges posed to its effective use.

9.5 RESEARCH OBJECTIVE FOUR

The fourth objective was to address the measures for ensuring the effective application of ICT for construction projects in the South African construction industry.

Evidence from the literature revealed that measures to ensure the effective use of ICT tools in the construction industry involve people, processes and technology. From the questionnaire survey obtained from respondents, it was revealed that measures to ensure the adequate use of ICT tools for construction processes involve users. User-oriented factors include the professional experience of construction ICT users, their positive attitude towards technology, their proper education, a supportive decision from the core management in the enterprise, an understanding of the tool's compatibility factors, and an encouragement for enterprise expansion. Another measure is having knowledge of ICT through outsourcing, knowing the cost implication of the tool, development of team knowledge, understanding the capability of the configuration of the tool, allocating firm's resources, and supportive government involvement. Lastly, end-users involvement through client's request for ICT use, checking out the relative advantage of such a tool, clear communication of ICT objectives, and a generally positive change movement will ensure effective use of ICT tools in the South African constriction industry.

Therefore, the research objective was achieved in the current study since the theoretical background is supported by the evidence discussed. This contributes to the body of knowledge on ICT tool usage in the South African construction industry by addressing the measured to ensure its effective use in the construction industry.

9.6 RESEARCH OBJECTIVE FIVE

The last objective of the current study was to determine the benefits of the effective application of ICT for construction projects in the South African construction industry

The literature revealed that there are numerous benefits to innovation. For the construction industry, the benefits are seen first on an organizational level, then the construction industry at large. From the questionnaire survey obtained from respondents, the benefits to ICT tool usage include improving the construction industry, its productivity and the enterprises involved. Improved international competitiveness, the elevated status of the construction industry, improved return on investment, improved turnover, enhanced knowledge sharing, simplified construction tasks, reduction in transaction cost, streamlined knowledge and enhanced team coordination are the numerous benefits to the construction industry. Productivity-related benefits from ICT usage include improved task efficiency, immediate connectivity, timely collection of data, enriched decision making, and reduction in wastage of resources. Lastly, enterprise benefits from ICT are through enabled innovation, improved productivity and improved competitive edge. Therefore, it can be concluded that the research objective was achieved from both the reviewed literature and the structured questionnaire.

9.7 GENERAL RESEARCH CONCLUSIONS

The main purpose of the study was to address the ICT tool usage in the South African construction industry, especially tools used at the planning, design and construction stages. This research study achieved its objectives through the data collected as well as the methodology used for the study. The following conclusions were obtained from the research:

i. The construction process in South Africa is evolving. This is owing to new trends in ICT tools and the present age of the fourth industrial revolution which increases the need for adequate preparation by construction professionals in terms of their awareness and skill reparation. Re-skilling is necessary.

ii. The traditional skills that construction professionals need to be augmented with the skills required for the present age ICT demand for the construction industry. Therefore, re-skilling is necessary.

iii. The stages of construction work require adequate use of modern ICT tools. A construction process is logical. It starts from inception to planning, design and construction, to the final use. Construction professionals use tools differently at these stages. Therefore, the ICT tools for these stages must be adequately employed to overcome the challenges posed at each stage of the construction process.

iv. The challenges to the effective use of ICT tools in the South African construction industry are people-, cost-, standardization-, and management-related. However, there are measures to overcome these challenges.

v. ICT users, knowledge of ICT tools and end-users play adequate roles in ensuring the effective use of ICT tools. Numerous benefits ensue from the use of such drivers.

vi. The benefits from the effective use of ICT tools are seen on an enterprise level, the productivity of the construction sector, and the general output of the construction industry.

vii. The Government is a key player on the subject of ICT use in the construction industry. Policies and legislation have an effect on the standardization and legal procedures to ICT use in the construction industry.

9.8 LIMITATION OF THE STUDY

There were a few limitations experienced during the execution of this research study. Firstly, the researcher was able to collect data from construction professionals based only in the

Gauteng Province of South Africa. Also, the study did not discuss the closeout stage (6) of construction work according to the PROCSA plan.

9.9 RECOMMENDATIONS

Overall, the findings of this study revealed the level of awareness of construction professionals on ICT usage in the South African construction industry. It discussed the ICT tools used at the planning, design and construction stages. In addition, it identified the challenges posed to the use of ICT tools for construction activities in South Africa. It also addressed the drivers that can ensure the effective use of ICT tools while discussing the benefits emanating from its effective use as well. Therefore, the following are recommended:

9.9.1 Construction industry: The construction industry can employ approaches that can reinforce ICT use in the construction industry. It is recommended that:

i. Research and academia should develop appropriate tools to evaluate the benefits of using innovations in the construction industry. This will explore the uncertainty of return on investment

ii. Appreciating the benefits of adopting ICT tools is also necessary

iii. Strengthening the measures influencing ICT tool usage is important

iv. Reducing the factors that have a negative effect on ICT tool utilization in the construction industry is vital

9.9.2 Construction enterprise: This addresses the issues that construction enterprises can put in place to encourage effective ICT use.

I. There should be a platform which encourages change management in enterprises seeking ICT tools as the core tool for successful project delivery.

II. Also, organizations should consider appropriate and effective instruments for staff training on innovations.

III. Training should be done to build construction workers' confidence in the use of new technologies.

IV. Enterprises should revise their success in evaluating criteria for using ICT tools.

9.9.3 The ICT tools: Some recommendations are made which concern the ICT applications used in the construction industry. These include the following:

I. ICT tools should be further reinforced and merged into the stages of the construction process.

II. The appropriate decision should be made as to which tool is best suited for a construction stage. For example, the analytical hierarchy process (AHP) is a technique that can be used.

9.9.4 The Government of South Africa: Some recommendations are made for the government as regards ICT use in the construction industry of South Africa:

I. Policies should be drafted which will support SMEs in the construction industry to use ICT tools.

II. Standardization and legal procedures should be considered which will facilitate the use of ICT. They should address issues such as compatibility and ownership.

III. ICT applications are generally costly; therefore there should be government intervention to reduce costs so that SMEs can conveniently purchase ICT tools.

IV. The government should increase support for academic institutions that conduct research on new inventions for the construction industry.

9.10 RECOMMENDATIONS FOR FUTURE RESEARCH

This study further recommends the following as areas for further research:

i. Further studies should be done/conducted to determine the factors influencing the use of an ICT tool or group of ICT tools by a construction enterprise. A platform such as the UML use case diagram can be used to describe the relationship between cost, planning, and a process. This is necessary since the estimation for a tool is done from the planning stage of construction work. Lastly, for any construction process, cost-effective ICT applications are necessary for project success.

ii. Future studies may also be conducted to address ICT tools used at the other stages of construction work.

iii. Lastly, alternative methodologies may be considered for conducting future research. For example, utilising other analysing methods such as an artificial neural network (ANN), hedonic regression, or logistic regression can be used to predict the factors influencing the choice of an ICT tool.

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APPENDIX 1: COVER LETTER

University of Johannesburg

Department of Construction Management and Quantity Surveying

Doornfontein, 2028

2016

TO WHOM IT MAY CONCERN

Dear Sir/Madam

<u>LETTER OF INVITATION FOR RESEARCH SURVEY</u>

The Department of Construction Management and Quantity Surveying at the University of Johannesburg, South Africa is undertaking a research project on the following topic: AN EVALUATION **OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN SOUTH AFRICAN CONSTRUCTION INDUSTRY.**

To this end, we kindly request that you complete the following short questionnaire. Answering this questionnaire will take approximately 15 minutes.

Please do not enter your name or contact details on the questionnaire. It remains anonymous. Information provided by you remains confidential and will be kept at the Department.

Should you wish to know the findings of the research, you are welcome to contact Tawakalitu Odubiyi at +27604274461 or at kalitutawa@gmail.com. The Department will gladly send you a summary of the results. Please answer the questions truthfully.

Thank you in advance

Tawakalitu Odubiyi

APPENDIX 2: QUESTIONNAIRE

QUESTIONNAIRE ON AN EVALUATION OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN SOUTH AFRICAN CONSTRUCTION INDUSTRY

INSTRUCTIONS:

PLEASE ANSWER THE FOLLOWING QUESTIONS BY CROSSING (X) ON THE RELEVANT BLOCK OR WRITING DOWN YOUR ANSWER IN THE SPACE PROVIDED.

EXAMPLE of how to complete this questionnaire:

Your highest educational qualification? If it is Post-Matric Certificate or Diploma certificate:

Matric Certificate (Grade 12)	1
Post-Matric Certificate or Diploma	2 (X)

SECTION A: BACKGROUND INFORMATION

This section of the questionnaire refers to the background or biographical information. Although we are aware of the sensitivity of the questions in this section, the information will allow us to compare groups of respondents. Once again, we assure you that your response will remain anonymous. Your cooperation is appreciated

1. Your highest educational qualification:

Matric Certificate (Grade 12)	1
Post-Matric Certificate or Diploma	2
Bachelor's Degree	3
Honours' Degree	4
Master's Degree	5
Doctorate	6

2. Your profession:

Architect	1
Quantity Surveyor	2
Engineer	3

Construction Manager	4
Construction Project Manager	5

3. Years of experience in the construction industry:

0 – 5 years	1
6 – 10 years	2
11 – 15 years	3
16 – 20 years	4
More than 20 years	5

4. For which of the following do you currently work?

Consultant	1
Contractor	2
Government	3

<u>SECTION B: AWARENESS OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) TOOLS IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY</u>

This section of the questionnaire investigates the level of awareness of ICT tool usage in the South African construction industry

5. Kindly indicate your level of awareness of ICT tool usage in the South African construction industry.

	AWARENESS OF ICT TOOL USAGE IN THE INDUSTRY	Not Aware	Slightly Aware	Somewhat Aware	Moderately Aware	Very Aware
AW01	Administrative tools (e.g. Microsoft Suites, Primavera)	1	2	3	4	5
AW02	Convergence network (Internet, e-mail, video data)	1	2	3	4	5
AW03	Simulation-based tools e.g. BIM; mixed, augmented and virtual reality	1	2	3	4	5
AW04	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1	2	3	4	5
AW05	Big data – Predictive tool (e.g. ML algorithms)	1	2	3	4	5
AW06	Robotics, sensors, RFID, BMS, GIS (industry 4.0 elements)	1	2	3	4	5
AW07	Modelling -based tools e.g. Multivate regression	1	2	3	4	5
AW08	Virtualization -based ICT applications	1	2	3	4	5
AW09	Web-based ICT applications	1	2	3	4	5
AW10	Computer-based ICT tools	1	2	3	4	5

SECTION C: THE INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) TOOLS USED AT VARIOUS STAGES OF CONSTRUCTION ACTIVITIES IN SOUTH AFRICA

This section of the questionnaire investigates what ICT tools are used by the **Professional Client/Consultants Service Agreement Committee (PROCSA) template for stages of construction work**

PROCSA **Stages 0, 1, and 2 are** grouped as **the planning stage**.

PROCSA **stages 3 and 4 are** also grouped **as the design stage,**

And**,** the **construction stage is the PROCSA stage 5.**

6. Based on your experience in the industry, rate the use of ICT tools relevant to each PROCSA stage of construction work.

		Planning Stage (PROCSA stages 0,1 &2)				
	ICT TOOLS	Never Use	Almost Never	Occasionally Use	Almost every time	Every time
TL01	Administrative tools (e.g. Microsoft Suites, Primavera)	1	2	3	4	5
TL02	Convergence network (Internet, e-mail, video data)	1	2	3	4	5
TL03	Simulation based tools e.g. BIM; mixed, augmented and virtual reality	1	2	3	4	5
TL04	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1	2	3	4	5
TL05	Big data – Predictive tool (e.g. ML algorithms)	1	2	3	4	5
TL06	Robotics, sensors, RFID, BMS, GIS	1	2	3	4	5
TL07	Modelling-based tools e.g. Multivate regression	1	2	3	4	5
TL08	Virtualization-based ICT applications	1	2	3	4	5
TL09	Web-based -ICT applications	1	2	3	4	5

		Design stage (PROCSA stage 3 &4)				
	ICT TOOLS	Never Use	Almost Never	Occasionally Use	Almost every time	Every time
TL01	Administrative tools (e.g. Microsoft Suites, Primavera)	1	2	3	4	5
TL02	Convergence network (Internet, e-mail, video data)	1	2	3	4	5
TL03	Simulation based tools e.g. BIM; mixed, augmented and virtual reality	1	2	3	4	5
TL04	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1	2	3	4	5
TL05	Big data – Predictive tool (e.g. ML algorithms)	1	2	3	4	5
TL06	Robotics, sensors, RFID, BMS, GIS	1	2	3	4	5
TL07	Modelling-based tools e.g. Multivate regression	1	2	3	4	5
TL08	Virtualization-based ICT applications	1	2	3	4	5
TL09	Web-based -ICT applications	1	2	3	4	5

		Construction stage (PROCSA Stage 5)				
	ICT TOOLS	Never Use	Almost Never	Occasionally Use	Almost every time	Every time
TL01	Administrative tools (e.g. Microsoft Suites, Primavera)	1	2	3	4	5
TL02	Convergence network (Internet, e-mail, video data)	1	2	3	4	5
TL03	Simulation based tools e.g. BIM; mixed, augmented and virtual reality	1	2	3	4	5
TL04	Design/Estimation (e.g. AutoCAD; 3D &4D BIM, WInQS)	1	2	3	4	5
TL05	Big data – Predictive tool (e.g. ML algorithms)	1	2	3	4	5
TL06	Robotics, sensors, RFID, BMS, GIS	1	2	3	4	5
TL07	Modelling-based tools e.g. Multivate regression	1	2	3	4	5
TL08	Virtualization-based ICT applications	1	2	3	4	5
TL09	Web-based -ICT applications	1	2	3	4	5

TL10	Computer-based ICT tools	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

SECTION D: THE CHALLENGES FACING THE USE OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) TOOLS FOR CONSTRUCTION WORK

This section of the questionnaire identifies the challenges encountered in the use of ICT tools for construction work in South Africa.

7. To what extent are/could the following be challenges for ICT tool usage in the South African construction industry?

	CHALLENGES TO THE USE OF ICT TOOLS	To no extent	Small extent	Moderate extent	Large extent	Very large extent
CL01	Short life-cycle of ICT inventions	1	2	3	4	5
CL02	High cost of purchase of ICT tools	1	2	3	4	5
CL03	Costly upgrade of tools	1	2	3	4	5
CL04	Management problems in a firm	1	2	3	4	5
CL05	Difficulty in evaluating the benefits of ICT use	1	2	3	4	5
CL06	Legal and standardization issues	1	2	3	4	5
CL07	Inadequate of support from government (e.g. through Policies)	1	2	3	4	5
CL08	Hesitation to adopt ICT tools among users	1	2	3	4	5
CL09	Cost of training staff	1	2	3	4	5
CL10	Insecurity of data transfers and transmission	1	2	3	4	5
CL11	Cultural barrier	1	2	3	4	5
CL12	Lack of technical skills	1	2	3	4	5
CL13	Lack of confidence in using new technologies	1	2	3	4	5
CL14	Insufficient research and development (R& D) in Information technology in construction industry	1	2	3	4	5
CL15	Unclear communication within staff	1	2	3	4	5
CL16	Difficulty of use	1	2	3	4	5
CL17	High cost of installation	1	2	3	4	5
CL18	Organization process changes	1	2	3	4	5

SECTION E: THE MEASURES TO ENSURE EFFECTIVE USE OF ICT TOOLS IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

This section of the questionnaire identifies the measures to ensure effective use of ICT tools for construction work in South Africa.

8. To what extent are/could the following be measure for effective ICT tool usage in the South African construction industry?

	MEASURES TO ENSURE EFFECTIVE APPLICATION OF ICT	To no extent	Small extent	Moderate extent	Large extent	Very large extent
ME01	Checking out the relative advantage of the tool	1	2	3	4	5
ME02	Understanding complexity factors of tools	1	2	3	4	5
ME03	Supportive decision from top management	1	2	3	4	5
ME04	Understanding the tools' compatibility factors	1	2	3	4	5
ME05	Proper education for users	1	2	3	4	5
ME06	Professional experience of users	1	2	3	4	5
ME07	Positive attitude towards technology	1	2	3	4	5
ME08	Propensity towards innovation	1	2	3	4	5
ME09	Encourage expansion of organizations	1	2	3	4	5
ME10	Understanding capability of configuration of tools	1	2	3	4	5
ME11	Allocating firm's resources for ICT	1	2	3	4	5
ME12	Client's request for ICT usage	1	2	3	4	5
ME13	End user involvement	1	2	3	4	5
ME14	Outsourcing	1	2	3	4	5
ME15	Clear communication of ICT objectives	1	2	3	4	5
ME16	Positive change management	1	2	3	4	5
ME17	Development of team knowledge for ICT	1	2	3	4	5
ME18	Knowing the cost implications	1	2	3	4	5
ME19	Supportive government involvement (e.g. through policies)	1	2	3	4	5

SECTION F: THE BENEFITS OF EFFECTIVE ICT TOOL USAGE IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

This section of the questionnaire identifies the benefits of ICT tools used for construction work in South Africa.

9. To what extent are/could the following benefit from effective ICT tool usage for construction activities in South African construction?

	BENEFITS OF EFFECTIVE ICT USAGE	To no extent	Small extent	Moderate extent	Large extent	Very large extent
BT01	Allows timely collection of data	1	2	3	4	5
BT02	Improves task efficiency	1	2	3	4	5
BT03	Offers immediate connectivity	1	2	3	4	5
BT04	Reduction in transaction cost	1	2	3	4	5
BT05	Time saving	1	2	3	4	5
BT06	Enhanced decision making in firms	1	2	3	4	5
BT07	Enriches shared knowledge	1	2	3	4	5
BT08	Improved productivity	1	2	3	4	5
BT09	Improved competitive edge	1	2	3	4	5
BT10	Enabled innovation	1	2	3	4	5
BT11	Streamlined knowledge generation process of firms	1	2	3	4	5
BT12	Improved communication during construction work	1	2	3	4	5
BT13	Reduced wastage of resources	1	2	3	4	5
BT14	Simplified tasks	1	2	3	4	5
BT15	Enhanced team coordination	1	2	3	4	5
BT16	Improved the status of the construction industry at large	1	2	3	4	5
BT17	Improved international competitiveness of the construction industry	1	2	3	4	5
BT18	Improved return on investment	1	2	3	4	5
BT19	Improved company turnover	1	2	3	4	5
BT20	Reduced stress and fatigue	1	2	3	4	5

Thank you for your cooperation in completing this questionnaire.