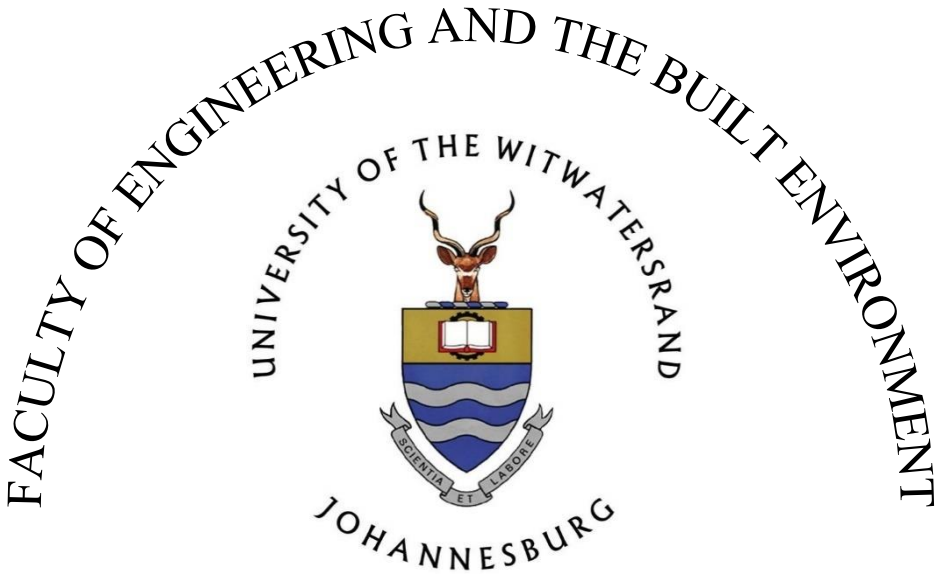
ADDRESSING SKILLS SHORTAGES IN THE SOUTH AFRICAN RESIDENTIAL CONSTRUCTION INDUSTRY THROUGH AUTOMATION – A CASE OF GAUTENG REGION



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DECLARATION

I hereby declare that the project work entitled, “Addressing the Skills Shortage in the South African Construction Industry Through Automation”, submitted to the University of Witwatersrand is a record of an original work done by the author under the supervision of Ehsan Saghatforoush in partial fulfilment of the requirements for the degree of Master of Science in Building (Project Management).

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ABSTRACT

The construction industry remains a cornerstone and plays a leading in many national and global economies and contributes up to 10% of GDP in developed countries and more than 25 % in developing countries. In South Africa since 2008, the industry has been contributing an average of 9% of the total employment in both formal and informal sectors and around 9% towards the GDP. Despite playing such a significant role in the nation's economy, researches have shown that the industry is crippled with many challenges which amongst others include shortages of skilled personnel to do the work. The construction industry which oftentimes is used as a measure of a country's level of development, however, over the years it has failed to deliver as per expectations owing to these skills shortages. Previous researches on construction skills shortage have focused on education and training as a remedy but this has failed to yield the desired solutions as the skills shortages are still being felt despite heavy investments in education and training. A more radical approach is thus needed to overcome these challenges. This study is therefore conducted to evaluate the potential use of robotics, automation and artificial intelligence in addressing skills shortages in the South African construction industry.

In order to evaluate the potential use of automation and artificial intelligence in addressing skills shortages, there was a need to establish the records of the current skills shortage and the benefits of automation in overcoming such skills shortages. For this, meta-synthesis of existing literature was used for global skills shortages and the advantages of construction automation. To narrow down the issue of skills shortages specifically to the South African construction industry, five interviews were contacted to identify the enablers and threats for using construction automation in the country as well as the extent to which the use of such automation can affect the perceived labour intensive construction industry.

Results from this study shows that, despite the construction industry playing a significant role in many economies globally, there are damning results when it comes to skills shortage. With the advent of the 4th Industrial Revolution, the use of automation and artificial intelligence in the construction industry is the next big thing. The research concluded that, although cconstruction automation and robotic technologies can be adopted and used, there should be compensation of the benefits accruing from the use of automation and artificial intelligence to offset the possibility of high levels of unemployment.

Keywords: ***Construction Automation, Skill, Skills Shortages, Integration, Artificial Intelligence, Scarce Skills***

DEDICATION

To my source of encouragement and happiness, my children; Panashe Bradley, Bright Munashe and Bethel Ruvarashe. Mommy loves you and always remember that, “Education is the foundation upon which we build a bright future.”

LIST OF PUBLICATIONS

Conference Paper:

Takawira, M. & Saghatforoush E. (2018). *An Evaluation of the Need to Address Skills Shortages in the South African Construction Industry through Automation*. 10th Construction Industry Development Board (CIDB), Post Graduate Conference: Towards a better Route to Enhanced Productivity, Performance and Transformation of Construction. Port Elizabeth, South Africa, 25-27 February 2018.

Journal Articles:

The following articles are expected to be published from this research:

1. An evaluation of the threats and enablers for the adoption of construction automation techniques in developing countries.
2. How and to what extend can automation address skills shortages in the South African construction industry?
3. Comparison of different automation tools available in addressing construction skills shortages.

TABLE OF CONTENTS

DECLARATION ..... **i**
ACKNOWLEDGEMENTS ..... **ii**
ABSTRACT ..... **iii**
DEDICATION ..... **iv**
LIST OF PUBLICATIONS ..... **v**
TABLE OF CONTENTS ..... **vi**
LIST OF FIGURES ..... **ix**
LIST OF TABLES ..... **x**
LIST OF ACRONYMS ..... **xi**
CHAPTER ONE: INTRODUCTION **1**
1.0 BACKGROUND **1**
1.1 STATEMENT OF THE PROBLEM 5
1.2 JUSTIFICATION OF THE RESEARCH 6
1.3 AIM OF THE STUDY 9
1.3.1 OBJECTIVES OF THE STUDY 9
1.4 RESEARCH QUESTION 10
1.4.1 RESEARCH SUB-QUESTIONS 10
1.5 SCOPE OF THE STUDY 10
1.6 LIMITATIONS OF THE STUDY 11
1.7 SIGNIFICANCE OF THE STUDY 12
1.8 ETHICS IN RESEARCH STUDY 13
1.9 RESEARCH OVERVIEW 13
1.10 SUMMARY 14
CHAPTER 2: LITERATURE REVIEW **15**
2.0 INTRODUCTION **15**
2.1 THE OVERVIEW OF THE GLOBAL CONSTRUCTION INDUSTRY 15
2.2 DEFINITION OF TERMS 21
2.3 THE SOUTH AFRICAN CONSTRUCTION INDUSTRY 22
2.4 CHALLENGES FACED IN SOUTH AFFRICAN CONSTRUCTION INDUSTRY 23
2.4.1 BACKGROUND TO THE CURRENT SKILLS SHORTAGES 24
2.4.2 CHALLENGES IN ENSURING ADEQUATE SKILLS SUPPLY 25
2.4.3 CAUSES OF SKILLS SHORTAGES IN THE CONSTRUCTION INDUSTRY 34
2.4.4 THE EFFECTS OF SKILLS SHORTAGES 38
2.5 IMPLEMENTATION OF AUTOMATION IN OTHER INDUSTRIES 40

2.6 CONSTRUCTION AUTOMATION 42
2.6.1 BACKGROUND TO CONSTRUCTION ROBOTICS AND AUTOMATION 43
2.6.2 APPLICATION OF CONSTRUCTION AUTOMATION 45
2.6.3 TYPES OF AUTOMATION TECHNOLOGIES THAT CAN BE USED IN THE CONSTRUCTION INDUSTRY 48
2.6.4 AREAS OF AUTOMATION 52
2.7 REASONS FOR AUTOMATING CONSTRUCTION OPERATIONS 53
2.7.1 BARRIERS TO AUTOMATION IN THE CONSTRUCTION INDUSTRY 55
2.8 REASERCH GAP 57
2.9 SUMMARY 59
CHAPTER 3: RESEARCH METHODOLOGY **60**
3.0 INTRODUCTION **60**
3.1 RESEARCH TYPE **64**
3.2 EPISTEMOLOGY 64
3.3 RESEARCH PHILOSOPHY 65
3.4 RESEARCH APPROACH 66
3.5 RESEARCH METHOD 68
3.5.1 CASE STUDY 68
3.6 RESEARCH CHOICE 69
3.7 TIME HORIZONS 70
3.8 RESEARCH TECHNIQUES AND PROCEDURES 71
3.8.1 DATA COLLECTION METHODS 71
3.8.2 DATA ANALYSIS – QUALITATIVE VERSUS QUANTITATIVE 76
3.8.4 AREA OF STUDY AND TARGET POPULATION 78
3.8.5 RELIABILITY AND VALIDITY 78
3.8.6 ETHICAL CONSIDERATIONS 80
3.9 SOFTWARE 81
3.10 LIMITATIONS OF THE METHODOLOGY 81
3.11 SUMMARY OF THE RESEARCH METHODOLOGY 82
3.12 SUMMARY 83
CHAPTER 4: DATA PRESENTATION & ANALYSIS **84**
4.0 INTRODUCTION **84**
4.1 DATA ANALYSIS – META-SYNTHESIS 84
4.1.1 SKILLS SHORTAGES IN THE CONSTRUCTION INDUSTRY 84
4.1.2 BENEFITS OF AUTOMATION IN THE CONSTRUCTION INDUSTRY 91

4.2 DATA ANALYSIS – INTERVIEWS 102
4.2.1 RESPONSE RATE AND GENERAL INFORMATION 102
4.2.2 UNDERSTANDING OF CONSTRUCTION AUTOMATION 104
4.2.3 ENABLERS FOR USING CONSTRUCTION AUTOMATION 105
4.2.4 THREATS FOR AUTOMATION 108
4.2.5 AUTOMATION AND SKILLS SHORTAGES 108
4.4 THE POTENTIAL OF AUTOMATION TO ADDRESS SKILLS SHORTAGES. 111
4.5 SUMMARY 114
CHAPTER 5: DISCUSSIONS **115**
5.0 INTRODUCTION **115**
5.1 DISCUSSION OF RESULTS 115
5.1.1 WHAT ARE THE SKILLS SHORTAGES CURRENTLY EXPERIENCED IN THE CONSTRUCTION INDUSTRY? 115
5.1.2 WHAT ARE THE BENEFITS OF USING AUTOMATION IN THE CONSTRUCTION INDUSTRY? 117
5.1.3 WHAT ARE THE ENABLERS AND THREATS FOR USING AUTOMATION IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY? 119
5.1.4 HOW AND TO WHAT EXTEND CAN AUTOMATION ADDRESS SKILLS SHORTAGE IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY? 121
CHAPTER 6: CONCLUSION & RECOMMENDATIONS **126**
6.1 CONCLUSION 126
6.2 RECOMMENDATIONS 128
6.3 CONTRIBUTIONS TO ACADEMICS AND PRACTITIONERS 130
6.4 AREAS OF FURTHER RESEARCH 131
REFERENCES **133**
APPENDIX A: ARTICLES READ FOR SKILLS SHORTAGES META-SYNTHESIS **147**
APPENDIX B: ARTICLES READ FOR ADVANTAGES OF AUTOMATION META-SYNTHESIS **150**
APPENDIX C: INTERVIEW QUESTIONS **154**
APPENDIX D: INTERVIEW GUIDE / PROTOCOL **157**
APPENDIX E: NVIVO – CONSTRUCTION SKILLS SHORTAGES **162**
APPENDIX F: NVIVO – ADVANTAGES OF CONSTRUCTION AUTOMATION **165**
APPENDIX G: ETHICAL CLEARANCE **169**

LIST OF FIGURES

Figure 2.1: Distribution of the Availability of Labour

Figure 2.2: Global Construction Industry Skills Shortage Trends

Figure 2.3: Quality Maths and Science Subjects

Figure 2.4: Quality of the education system

Figure 2.5: An example of infrastructure and industry development

Figure 2.6: The Relevance of Digital Technologies in the Engineering and Construction Industry Value Chain

Figure 2.7: Relationship between Design Automation Techniques

Figure 2.8: Illustration of the Economic Comparative Analysis of Using Automation

Figure 3.1: Research Design according to Saunders *et al*., (2016).

Figure 3.2: Research Design According to Crotty

Figure 3.3: An All-Inclusive Research Design

Figure 3.4: Research Approach

LIST OF TABLES

Table 2.1: Proportion of students attaining basic literacy in mathematics and science from beginning of primary to end of secondary schooling (PISA Scale) (OECD 2010.)
Table 2.2: Causes of Construction Skills Shortages from Previous Researches
Table 2.3: Historical Development of Technologies Related to Construction Automation
Table 2.4: Application of Artificial Intelligence during Pre-construction Phase
Table 2.5: Application of Artificial Intelligence during Construction Phase
Table 2.6: The Impact of Digital Technology on Engineering and Construction Projects

Table 3.1: Research Choices and the Respective Data Collection and Analysis Method
Table 3.2: Methods to Be Used to Gather Relevant Information

Table 4.1: Databases used in the search for construction skills shortage
Table 4.2: Keywords used in the search for skills shortage
Table 4.3: STARLITE principles applied to the literature search
Table 4.4: CASP evaluation method for skills shortage
Table 4.5: Identified construction skills in short supply
Table 4.6: Databases used in the search for advantages of construction automation
Table 4.7: Keywords used in the search for advantages automation
Table 4.8: STARLITE principles applied to the literature search
Table 4.9: CASP evaluation method for advantages of construction automation
Table 4.10: Identified advantages of construction automation
Table 4.11: Impact of digital technology on Engineering and Construction projects
Table 4.12: Response rate for interviews and questionnairs
Table 4.13: Percentage distribution of interviews and questionnairs
Table 4.14: Drivers for Construction automation

LIST OF ACRONYMS

3D	3 Dimensional
AI	Artificial Intelligence
ATM	Automated Teller Machine
BIM	Building Information Modelling
BRT	Business Round Table
CA	Construction Automation
CETA	Construction Education Training Authority
CIDB	Construction Industry Development Board
ILO	International Labour Organisation
RAC	Robotics and Automation in Construction
RICS	Royal Institute of Chartered Surveyors
TVET	Technical and Vocational Education and Training
CITB	Construction Industry Training Board
DHET	Department of Higher Education and Tertiary
DoL	Department of Labour
DPW	Department of Public Works
EPWP	Expanded Public Works Programme
FMB	Federation of Masters Builders
GDP	Gross Domestic Product
IT	Information Technology
JIPSA	Joint Initiative on Priority Skills Acquisition
MBSA	Masters Builders South Africa
MTSFW	Mid Term Strategic Frame Work
NDP	National Development Plan
NSA	National Skills Authority
PwC	Price Water Copper
R&D	Research and Development
RAC	Robotics and Automation in Construction
RICS	Royal Institution of Chartered Surveyors
SA	South Africa
SAFCEC	South African Forum of Civil Engineering Contractors

SAM	Semi Automated Machine
SETA	Sector Education Training Authority
StatsSA	Statistics South Africa
STEM	Science Technical English Mathematics
TBM	Tunnel Boring Machine
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USA	United States of America
WEF	World Economic Forum

CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND

The South African (SA) construction industry can be categorised into three sub-divisions and these are civil engineering, building construction and materials manufacturing sector. The civil engineering involves the construction of structures for use by the public like roads, bridges, dams and any other structures excluding buildings, while the building sub-sector involves erection, completion and renovation of buildings and related structures. Lastly, the materials manufacturing sector encompasses the manufacturing of materials for use in both the civil engineering and building sectors (Carroll, 2016) According to the CIDB, most of the works in the civil engineering are commissioned by the public sector, which accounts of 80% of the works (Cottle, 2014). When it comes to economic growth contributions, the construction industry is a major contributor of global economies. The construction industry in developed countries contributes about 10% while it contributes more than 25% in developing countries economic growth (Human, 2013; Kim *et al.*, 2015). This is just to build on what International Labour Organisation (ILO, 2001) had observed. The ILO acknowledges that there is indeed a correlation between construction industry and level of economic growth in a country. This is so because the construction industry is used as a measure of a country's level of economic growth. Thus, for developing countries to experience economic growth there is a need for the government to invest in fixed capital formation.

According to StatsSA, (2013), the South African construction industry contributed 3.5% of the national Gross Domestic Product (GDP) in 2013. Year on year, the construction industry grew by 3.1% since 2011 compared with the real GDP which grew by 2.5 % over the same period (SA Government, 2012). The South African government has thus declared the construction industry as a strategic national asset and over the years the government has committed itself to revive the industry. This saw the launch of the Strategic Plan (2015-2020) by the Department of Public Works (DPW) with the aim of transforming the image and operations of the construction industry (DPW, 2015), with a total of R845 billion has been committed by the government towards reviving the infrastructure industry in the country.

However, notwithstanding the significance of this industry, the world's economic growth is limited due challenges that are faced by the construction industry globally and SA is not an exception. Hussin *et al.*, (2013) attribute many of the challenges that cripple the construction

industry to its fragmented and complex nature. Similarly, Abrey & Smallwood, (2014) echo that the construction industry has been embroiled with both poor productivity and risky working conditions due to these challenges faced. Some of the challenges being faced include, high accidents and fatality rates on construction sites, poor quality of work, the difficulty in the management of construction sites and retaining of skilled workforce (CIDB, 2001; Ding *et al.*, 2014). More so, acute skilled labour shortage has been identified to be one the challenges faced that have had the potential of slowing down economic growth which continue to plague the construction industry (Amrop, 2012; APEC, 2014). The authors agree that the problem of shortages of skills within the construction industry has been an on-going one. This, according to the ILO (2001), is due to the failure of the building sector to attract and retain skilled artisans supply, (Makhene & Thwala, 2009; Engineering News, 2014).

In May 2004, SA won the bid to host the prestigious FIFA World Cup in 2010 (SA Government, 2004). In order to meet up with the demands of hosting such a prestigious event the South African government in 2005 announced a massive government spending on infrastructure projects ranging from the upgrade of soccer stadiums and associated services for the successful hosting of the FIFA World Cup. It is during this time when general skills shortage in the construction were identified and highlighted as a hindrance to this government initiative (SA Government, 2005). In 2006, construction of the Gautrain Rapid Rail Link project which had been on the table since 2000 also started ahead of 2010 FIFA Wold Cup, further straining the skills pool in the country. By 2007, the government and the industry acknowledged that the issue of skills shortages in the industry was posing a threat on the successfully delivery of the projects (Singh, 2007).

The issue of construction skill shortages, however, is not only a South African phenomenon; its effects are being felt around the globe (Healy *et al.,* 2015). This was highlighted by the report by Grant Thornton International (2012), which shows that globally, the average shortfall of skilled workers is 39% with higher figures of 60% recorded for Malaysia and Singapore. In the United States, the problem of construction skilled labour shortage has been an on-going one for more than three decades from the time it was first predicted (ILO, 2001). This was according to the Business Round Table (BRT, 1983) Report, where shortage of skilled labour was listed as one of the main challenges faced by the US construction industry then. Today, the US National Association of Home Builders (2017) highlighted that 82% of construction companies consider shortage of skilled workers as their main problem in delivering quality

construction projects on time. To highlight this further, the number of unfilled positions in 2018 rose by more than 33% to 243 000 as compared to 2017 (Construction Executive, 2018). RICS accordingly, believes that the UK is already at the grip of its worst skills shortage in twenty years (JLT Speciality, 2017). A report by KPMG and the London Chamber of Commerce and Industry highlighted that the construction industry is faced with a major skills shortage which may endanger the rolling out and delivery of the government's infrastructure projects due to lack of sufficient skilled workers to deliver the projects (KPMG, 2014). From the results of a survey carried out by the Federation of Masters Builders (FMB), skills shortages in the UK construction industry has hit a record high with Brexit (FMB, 2017) and the market outlook is far from improving.

In Australia skills shortages, has been attributed to the long term down turn in the construction industry after the 2009 recession which saw many specialty trade workers having to switch industries and professional workers migrating (Construction Business Owner, 2015). More so, in Japan, 83% of the employers recorded difficulties in filling positions according to the Manpower Group (2016). Japan has since revised its immigration laws to allow for more specialised foreigners to come and work in the country as a measure of addressing skills shortages faced in the country's construction industry. With the high levels of skills shortages in the construction industry and the situation being far from improving, it begs the question that; "*who will build the new homes, and other infrastructure projects that governments are rolling out."*

In response to skills shortages, previous researches on skills shortage have been focusing on education and training of the workforce and adjusting immigration laws to allow for more skilled people in the country (ILO 2001; CIDB, 2009; Ntuli, 2013; Windapo, 2016)**.** It is evident though that these solutions have not managed to completely combat the problem. Despite heavy investment in education and training in the construction industry over the past years, this intervention has failed to yield the desired solutions as the skills shortages are still being felt to date (Makhane and Thwala, 2009). Previously, scholars in the field of construction skills shortages advocated for the establishment of training programmes as a means of permanently solving this dilemma (Muya *et al.*,2003), but this option is rarely being fully utilised by those in authority, and again people cannot be forced matched into training institutions to consider a career in the construction industry. These shortfalls of education and training as a means of solving construction skills shortages have left room to try construction

automation (CA) and robotics. This is because, automation and robotics applications presents opportunities to solve issues like skills shortages, poor productivity and risks associated with the construction industry (Kim *et al.,* 2015).

Technological development plays an integral part in the construction industry in averting some of the woes that are faced in the construction industry, by helping the industry realise the goals of enhanced design, procurement, construction and maintenance of the finished project (Harris, 2017). Commenting on the benefits of automation and robotics in other industries, Peterson (2016) echoes that the process of applying the same technologies in the field of CA will greatly benefit the outcome and performance of the industry. But for robots and automation which has been the crux of development and transforming all other sectors save for the construction industry (Ding *et al.,* 2014; Kumar *et al.,* 2016). When compared to other industries, like manufacturing, aerospace and automobile, the level of automation in construction industry is by far less. CA is concerned with the application of ideologies of industrial robotics to the construction sector, from building construction, civil engineering and in the prefabrication of construction modules (Khare, 2016). This however may be attributed to the inappropriateness of the current available automation and engineering technology for the efficient and effective production of large scale construction products (Ding *et al.,* 2014). The South African construction industry is thus failing to reap the full benefits of associated with automation and integration of the works in the form of design software, data and analytics, 3D scanning and mobile solutions (Harris, 2017).

In order to address the complex task of planning and managing the design and construction process, many processes have been automated (Nof, 2009). Similarly, Selvakumaran (2016) acknowledged that, using automation as well as artificial intelligence (AI) to undertake routine functions could help free up the supply of skilled labour for more creative tasks. Despite continuous reports of skills shortages, firms continue to assign human labour on time consuming tasks which possibly can be automated (Tyler, 2017). As a result, the limited resources can be used to control and steer the algorithmic optimisation set up of the machines. The US Department for Education and Employment (DfEE, 2000), suggested that the evolution of convectional construction methods and processes, is redefining the skills which will be required in the industry to cope up with such changes and the industry should be geared for such changes to control the shortage of skilled labour.

Traditionally, the construction industry which had been viewed as technologically stagnant when compared with other industries (Zhai, 2010; WEF, 2017), but in recent years it has become the most researched area in the field of service robotics (Malaguer & Abderrahim, 2008). The unstructured nature of the construction work environment makes it difficult for the introduction of Robotics and Automation in Construction (RAC) (Akshatha *et al.,* 2017; Balaguer & Abderrahim, 2008). This is because work in the construction industry involves the interaction of numerous independent parties (architects, builders, suppliers etc.) and generally the handling and placement of heavy objects with a high degree of tolerances. This results in low levels of standardization and efforts should therefore be made to boost automation levels and streamline the construction processes to improve productivity and empower employees (Balaguer & Abderrahim, 2008).

Of importance to note from the available literature is that, robotics and automation can indeed be a solution to the current public construction skills woes in SA and beyond (Schoeman *et al.,* 2017). At this juncture however, it is imperative to take a closer look at the pros and cons of such mechanism in the construction sector. This is because, although there has been much talk about the education and training in the construction industry there is scant research especially in the South African context with regards to the suitability and advantages that may accrue due to the automation of construction processes.

1.1 STATEMENT OF THE PROBLEM

The SA construction industry is faced with skills crises which is evident either in terms of quantified skills shortages or the deterioration in the quality of work (Rust & Koen, 2011; Mbeki, 2014; Windapo, 2016). This construction industry skills shortages have resulted in inequitable delivery of infrastructure among South African communities (Sorinolu, 2014; Windapo, 2016; Oke *et al.,* 2018) and is the main constraint hampering economic growth (Makhene & Thwala, 2009; Tshele, 2014; Manpower Group, 2016). In the Development Indicators Report, (2012), the presidency revealed a worrisome shortage of skills particularly in the construction and engineering sectors and it is a major concern given the need to roll out massive infrastructure programmes (SA Government, 2012). During the 2010/11 financial year, the National Treasury reported that only 68% of the government capital budget was utilised, ramping up the government's ability to implement the R3.2 trillion infrastructure projects a huge challenge. Burmeister of Amrop (2012) was once quoted saying "*We simply do not have the right kinds of skills to meet the specific demands of new huge infrastructure*

projects." Skills shortages challenge and the need to increase the industry's low productivity are thus some of the factors compelling and driving the construction firms to invest in AI, machines and in certain instances automate the production lines (ILO, 2001; WEF, 2016; McKinsey, 2017). Results from McKinsey Report (2017) proved that construction firms can increase productivity by up to 50% through the adoption of AI and real-time data analysis.

This research is therefore carried out with the purpose of investigating the degree to which automation and AI can help bridge the skills shortage in the South African construction industry using Gauteng Province as the study area.

1.2 JUSTIFICATION OF THE RESEARCH

On the global outlook, the construction industry is one of the leading industries with a combined annual market capitalization in excess of USD10 trillion (Gerbert *et al*., 2016). But despite its tremendous potential, many firms in the construction industry are struggling to reach full capacity owing to the shortage of skilled workers and very low productivity growth (McKinsey 2017). The current wave of skills shortages have been on-going for long (Construction Round Table, 1983, Latham Report, 1994) and have had the effect of constraining the production capacity of the industry. In SA, the construction industry continues to experience such skills shortages to date (Rust & Koen, 2011; Mbeki 2014; Tshele & Agumba, 2014; Windapo, 2016) mainly due to skills mismatch. This is despite the high unemployment rate of around 27.7% which is reported to be in the in the country (CIDB, 2017). As it is, the country faces the dichotomy of high unemployment rate especially among the unskilled and semi-skilled, while at the same time a high vacancy rate for the highly skilled people (Amrop, 2012).

In any nation, the construction plays an integral part in the economic growth and remains the main contributor in the economy. The first industry to be established by humans, it continues to shape our daily lives in a unique way (WEF, 2016). All other industries tend to rely on the construction industry for the provision and maintenance of accommodation, plants and infrastructure and it is the construction industry that determines where and how almost everyone works, lives and plays.

In SA, the construction industry contributes and facilitates socio-economic development and economic growth (DoL, 2008; Rust & Koen, 2011) and recently, there has been an increasing load on infrastructure due to urbanisation and the ageing infrastructure. Emphasis is on the

industry to face these challenges with innovative solutions (Rust & Koen, 2011; Infrastructure News, 2014). The construction industry helps in improving the quality in the life of local citizens through the provision of socio-economic infrastructure like hospitals, schools, roads and other basic facilities. Despite this important role played by the construction industry, it remains crippled with many challenges which among others include, acute shortages of skilled labour (Faltinsky & Tokunova, 2018). This is against the prevalence of a high unemployment rate among the youths (StatsSA, 2018). Many stakeholders in the construction industry are experiencing severe skill shortages (Oke *et al.*,2018) and previous research has shown that the construction industry is infiltrated with an aging population with few new young entrants into the labour market (Windapo, 2016). The shortages of skilled labour have resulted in increase in construction costs and time overruns poor quality of work and high accidents rate (Windapo, 2016). In the UK alone, over £90 billion is lost annually due to skills shortages (US Chamber of Commerce, 2017) and the National Institute of Standards and Technology reported that, $15.8 billion goes to waste every year due to a lack of proper information management systems (Aranda-Mena & Wakefield, 2014). Back home in Africa, the issue of skills shortages has been at the centre stage of many discussions and forums as failure to tackle the issue has resulted in the failed implementation of many government initiatives on socio-economic developments (Nyatsumba, 2017). To keep up with spiralling socio-economic demands, the world of construction and engineering is forever changing with the demand for infrastructure driven by rising population and rapid urbanisation.

Other challenges faced in the construction industry include, slow adoption to technological changes, issues of efficiency, safety, cost overruns and construction delays (Edge 2018; Faltinsky & Tokunova, 2018). Overall, the use and implementation of AI and CA within the construction industry remains relatively nascent. Digitalisation in the construction industry should therefore be seen as a medium through which many challenges faced in the industry can be decisively improved (Koutsogiannis, 2018). These challenges include among others, boosting productivity, minimising delays and reworks on construction projects, improving safety and accelerating the building lifecycle.

The construction industry is also faced with constant late information and design changes, several skilled people leaving the industry and collusion by both contractors and consultancy (Manpower Group, 2016). The most driving forces to the current construction industry skills shortages is the preconceived idea of poor working conditions, that construction work needs

hands-on experience and there is no use of technology which most youths are fond of (Human, 2013). This makes it difficult either for the industry to attract new recruits among the youths or for the youths to consider the construction industry as a career choice.

In his speech during the Investors' Summit in Germany in October 2018, President Cyril Ramaphosa noted with worrisome how skills shortages experienced in the country are derailing economic progress. The country needs to develop a rich skills pipeline to guarantee proper maintenance and timeous upgrades of existing infrastructure while at the same time avoiding further deterioration of essential services across the country. Several conferences, government and captains of the industry have in the past voiced their concerns on the ever increase in difficulties when looking to fill skilled positions in the construction sector. Every year the government is committed to invest in infrastructural development projects to boost the socio-economic wellbeing of its citizens but this initiative is met with a crunch when it comes to the availability of skilled people for the implementation of such projects.

As recommendations from previous researches, huge investments have been made into the educational system in order to try and address this phenomenon. Joint Initiative on Priority Skills Acquisition (JIPSA) together with the National Skills Authority (NSA) were established to try and look into the skills supply pipeline, but still the issue of skills shortages remains a huge challenge for the delivery of infrastructure projects. It is against this background that this research is being conducted to establish whether or not CA can be used in addressing construction skills shortages and to remain viable. To overcome the stiff competition in the industry, anticipation is for companies and organisations to overcome such challenges. With increased urbanisation across the world, many key infrastructural projects that are being implemented end up competing for a shrinking skills pool with fears that the shortage of skills will further delay projects implementation and delivery even in major markets (Amrop, 2012). In order to grow and overcome skills shortages, it is important to research and come up with resolutions to the causes of construction skills shortages. Failure of which will result in the failed implementation and delivery of government's infrastructure projects including the NDP and Vision 2030.

Various reports indicate that productivity in the construction industry have remained stagnant or even decreased (Bock, 2015) over the years when compared with the manufacturing industry where productivity have grown by over 1500% since the inception of robots and automation in

the production line (Holt *et al.,* 2015; Tyler, 2017). The construction industry has vast of potential to correct this perception, while at the same time improving on productivity and efficiency courtesy of digitalisation, innovative technologies and new construction techniques (WEF, 2016). Should the construction industry continue to lag behind in digital adoption, the industry risks continued marginalisation and losing new relent to other sectors of the economy (CITB 2018).

The idea behind robotics and automation technology is to make construction safer, faster and cheaper hence promoting technology that is aimed at increasing productivity is vital for the health of the construction industry. This is evident from the increase in R&D in the area of CA recently and has led to the augmented reality, drones, 3D scanning, BIM, autonomous equipment and advanced building materials emerging. Through the adoption and exploiting these innovations, companies that digitalise and streamline their activities will tend to boost productivity and enhance quality and safety of their working environments and curb the effects of skills shortages. However, for this dream to become a reality, it requires commitment and concerted efforts by the industry and the government as the regulatory body. Ironically, the adoption and use of technology may help address most of the issues faced in the construction industry. BIM, Visual Reality, Project Management software or mobile devices may be integrated in the scheduling and planning of the construction processes as well as communication and collaboration which can lead to increased productivity and safe working environment.

1.3 AIM OF THE STUDY

While the country is faced with construction skills shortages high levels of unemployment are also recorded. The government's policy on EPWP as a tool to create employment and the promises of automation and AI on the other hand to augment skills shortages, grow the economy and reduce unemployment seems to clash. In most developed countries, automation and AI is gaining momentum in the construction industry and their economies are growing with very low unemployment rates. **The aim of this research is therefore to investigate the potential of adopting automation in addressing skills shortage in the South African construction industry.**

1.3.1 OBJECTIVES OF THE STUDY

- To establish the current skills shortage records in the construction industry

- To identify the benefits of automation in overcoming construction skills shortage
- To identify the enablers and threats for using automation in the South African construction industry.
- To show the extent to which automation can be used to address skills shortages in the South African construction industry.

1.4 RESEARCH QUESTION

To what extend can automation be used to augment skills shortage being experienced in the South African construction industry?

1.4.1 RESEARCH SUB-QUESTIONS

In assessing how automation can be used to augment construction skills shortages in South Africa, we need to consider current skills shortages that are being experienced, how future jobs are going to be affected as well as the effects of displacement and retrenchment brought about by automation. The following research sub-questions were been developed to help in answering the main research question:

1. What are the skills shortages currently experienced in the construction industry?
2. What are the benefits of automation in the construction industry?
3. What are the enablers and threats for using automation in the South African construction industry?
4. How and to what extend can automation address skills shortage in the South African construction industry?

1.5 SCOPE OF THE STUDY

Construction Automation has two branches namely, the soft and hard, with soft automation utilised mainly during the design phase of the project controlled by computers and with the ability to be reprogrammed, while hard automation, on the other hand involves the use of robots and /or machines designed to perform specific and or repetitive tasks. Notwithstanding the benefits of hard automation, the uneconomic nature of hard automation and the clash it posses with the government polices of employment creation, this research will be focused on both hard and soft automation and encourage skills training to alleviate skilled labour shortages in the construction industry. With global reports of skills shortages being experienced in the industry, it is important to research on the effects of the utilization of both soft and hard

automation on these shortages. Apart from the above challenges, there is a huge gap between Research and Development in automation at learning institutions and the actual site requirements which is difficult to overcome (Singh *et al.,* 2017).

Although skills shortages are being experienced across the country, this study will be focused on the Gauteng Region as it is the most populous and fast growing of the nine provinces that make up SA (Stats SA, 2016). The selection of Gauteng Province is also because not only is it the home of economic hub of SA, it is highly urbanised, and the country's most popular city, Johannesburg and the administrative Capital City of Pretoria are also found within this region (DoL, 2012; StatsSA, 2016). According to Silverman (2007), a population to a study is a group of people who are of particular interest with at least one characteristic in common. It is from this population that the researcher generalised the results as the whole population was thought to have significant traits in common (Saunders *et al.,* 2009). The author further highlighted that, though it may be possible to collect data from the whole populace, this can only be so for a research population is of a manageable number.

1.6 LIMITATIONS OF THE STUDY

Nevertheless, the results of this research must be interpreted with caution and a number of limitations which the researcher encountered when carrying out this research should be borne in mind. Limitations of the study relates to the design or methodology characteristics that influenced the interpretation of the findings from the research. During the research process, the researcher encountered some limitation which might have influences quality of this research. These limitations have impacted on the quality of the research findings as well as the ability of to answer the research questions. These limitations arise from the methodology that was used or issues to do with the researcher. Because the area of construction automation is still in elementary stages, very few studies have been conducted and it was very difficult to compare the results of using automation to address skills shortages in the South African construction industry. Most of the studies exists in theory and not in practical and results from the manufacturing and automobile industry for example were used as the basis the potential positive impact of automation and AI on construction skills shortages. Although automation is the future everywhere, this study did not seek to establish the skills set that are consummate with automation and AI.

As this research was exploratory in nature, the research aim and objectives of the study area were left broad. This was to lay the groundwork for more complete researches in future. The choice of interviews to collect data also has a limiting factor on the results. Although the respondents were approached via snowball sampling from those who have been engaged in projects in developed countries before where automation and AI are at more advanced stages than it is in South Africa. The use of very few participants also limited the researcher's access to data. Theoretical data from meta-synthesis and five research participants was used to generalise the results of the whole study. Time constraints also affected the quality of the results of this study. Due to the limited time frame to carry out and submit the research, a cross-sectional research was conducted, instead of a more informed longitudinal research. Since the transition from the current set up to a more automated state of the industry, a longitudinal research over a longer period of time could have helped in making an informed decision on the use of AI and automation in addressing skills shortages in the South African construction industry.

1.7 SIGNIFICANCE OF THE STUDY

Previous researches conducted with regards to addressing skills shortage in SA focused on education and training and other various ways to retain the aging workforce (ILO, 2001; CIDB, 2009; Ntuli, 2013; Windapo, 2016). Implementation of results from these previous studies has failed to address skills shortage at grass root level with the proposed solutions from these researchers and policy makers having little impact on addressing the concern of skills shortage (Chan *et al.,* 2007). This is despite the industry's efforts through programmes to improve recruitment and training and retention alleviating skills shortages (Pappas 2004).This is so because the proposed policies seem to be disconnected from the realities experienced within the industry. The president, Cyril Ramaphosa during his State of the Nation Address (SONA) 2019, reiterated that, in line with the Framework for Skills for a changing World the school curricula is being revised to respond to the emerging technologies, robotics and AI. It is at the backbone of these concerns that this research is conducted.

In the absence of such a study, it is extremely difficult for the government agencies, the private sector and academics alike to accurately and effectively analyse the benefits that accrue due to the implementation of automation within the construction industry in SA. This research will contribute to the limited literature with regards to CA in SA and as such it can be used as an eye opener and reference to those who seek to research further into the subject.

This research is thus formulated: -

- To promote awareness in the use of construction automation.
- With the aim for the construction industry to embrace the full benefits promised by automation as has been reported in other sectors.
- To encourage the use of technology and robots especially for those tasks that are less. appealing and dangerous for human labour in order to free up labour for other tasks.
- Raise awareness on new skills demanded as a result of the Fourth Industrial Revolution.

1.8 ETHICS IN RESEARCH STUDY

While carrying out this research, the endeavour is to apply procedures for ethics as laid down by the University of the Witwatersrand. Complete, voluntary participation for all respondents will be ensured, by seeking informed consent for the participants and discussing the risks and procedures (if any).

This study further guarantees the confidentiality of all the participants and strict principle of anonymity during the gathering and analysis of all data collected.

The author sought official ethical clearance from the University of the Witwatersrand prior to undertaking the research to avoid unexpected ethical problems that could arise from administering the research, particularly with regards to data collection. This allowed for the fortification of rights of both the author and participants. The ethical clearance certificate is attached to this research.

1.9 RESEARCH OVERVIEW

Chapter One: Introduction

The first chapter introduced the research project that seeks to address skills shortage in the construction industry using automation. In carrying out this research, the researcher sought to understand why the construction industry in SA is always faced by skills shortage, current effort in addressing such shortages and what else can be done to ensure that the issue is permanently addressed. This information will contribute to the existing body of knowledge and or can be expanded in future.

Chapter Two: Literature Review

The second chapter exploits the literature review, body of literature on what other researchers have written about CA and skills shortages.

Chapter Three: Research Methodology

In chapter three, the various methods that the researcher used in gathering field data are discussed.

Chapter Four: Data Presentation, Analysis and Discussions

Chapter four is the record of the evidence and data gathered from the field. The evidence is the record of what actually is happening in the field of CA and any possible areas of improvements. Research findings are compared with the findings in the literature as detailed in Chapter Two with some suggestions are put forward during the discussions. The chapter ends with the summary of the results and discussions.

Chapter Five: Conclusion and Recommendations

As the closing chapter, chapter five presents conclusions of the research and recommendations for further studies. Areas uncovered in the study are highlighted and proposed for further studies.

1.10 SUMMARY

This chapter introduces the topic and the study area, the aim and the objectives of the study pertaining skills shortages in the construction industry. The chapter gave an overview of the research questions that informed the study. The research questions assisted shaping the direction of the study on what data needs to be collected. The research question and sub-questions have been developed to help meet the aim and objectives of the research. Section 1.5 describes the scope of the study followed by the limitations in section 1.6. The significance of this study in contributing to the body of knowledge is described in section 1.7 and the ethical considerations that are taken into account when contacting this study. The last section of this chapter seeks to present the structure of this research. And in the following chapters, by answering the research questions, an attempt will be made to reconcile the differences between theory and practice on skills shortages. The following chapter will examine thoroughly the issue surrounding skills shortages and construction automation.

CHAPTER 2: LITERATURE REVIEW

2.0 INTRODUCTION

Saunders *et al.,* (2016) defined literature review as the detailed and justified analysis including commentary on the merits and faults of literature within the area of study. It is a process of conducting surveys on previously published material (Copper *et al.,* 2009). Of importance to note is that, literature review in not based primarily on establishing any new facts of findings on the study area, but it is based on the extracting information related to the study area from publications that contains primary information, the information which will then be digested, sifted, classified, simplified and synthesised. The purpose of literature review is for the researcher to demonstrate his/her familiarity with the existing body of knowledge (Saunders *et al.,* 2016). The main aim reviewing the literature is to help with a clear understanding of the nature and meaning of the research problem that has been identified earlier (De Vos *et al.,* 2005). In this section, various literatures read on skills shortages particularly in the construction industry, automation, robotics and integration of construction works will be outlined. Causes and effects of skills shortages will be highlighted as well as measures to address such shortages. The section also analyses the level of automation use in the construction industry and the extent to which automation is being used in helping in bridging the skills shortage gap.

2.1 THE OVERVIEW OF THE GLOBAL CONSTRUCTION INDUSTRY

The construction industry is the backbone of many global economies, society and the environment and its core business evolves around engineering and buildings. Approximately 100 million people are employed in the construction industry globally and it generates in excess of US$10 trillion in annual revenue which translates to 6% of the global GDP (WEF, 2018). Construction activities encompasses transport and civil infrastructure, social infrastructure, housing and commercial real estates. Construction affects every area of society and is an integral party and society in general cannot function without built assets. The present construction industry is faced many challenges (Nof, 2009; WEF, 2016) because of its fragmented and complex nature. Conventional project delivery strategies such as fast-track, parallel execution of the design and construction further increase the complexity of the industry. With many new infrastructure projects expected to be rolled out on a large scale globally, the organisation's size and its potential global reach is now starting to matter. With the large scale of the projects comes complexity in winning and acquiring new contracts as many global

players in the industry have to navigate through tough political, commercial, regulatory and governance environments, in order to secure contracts.

Research studies have shown that, the management of design and construction in modern Architectural Engineering and Construction (AEC) projects is now more challenging because of the complexity nature of the projects (Senthilkumar, 2010; Kiprotich, 2014), with some of the problems posed by new construction projects requiring to be addressed through innovative solutions (Son *et al.*, 2010). In order to address these complex tasks of planning and managing the design and construction, many processes have been automated (Nof, 2009; Senthilkumar, 2010). Robotics, automation and AI have the potential to hurl the construction industry by merely capturing every human experience from design to project delivery. But for this to happen there is need to change the mind-set of all stakeholders involved in projects and those in decision making position (Wisskirchen *et al.*, 2017). Despite the influence of IT in all other industries, the construction industry is the slower adopter of it (Department of Science and Technology, 2014; Holt *et al.*, 2015; KPMG, 2016; WEF, 2016).

Results from previous studies have shown that the construction industry is very hesitant in its move towards the application of robotics and automation technologies in its operations. This resulted undoubtedly in the industry employing very lower level of technology than any other industry and the levels of Research and Development in the use automation is very low and this have resulted in high unnecessary construction costs (Son *et al.*,2010). The reason for this slow adoption maybe because, currently much of the commercially available AI and machine learning applications are focused in the manufacturing industries where the operational domain is similar, conducted indoors and in highly structured environments. The complexity of projects and unstructured nature of the construction work environment makes it difficult for the implementation of RAC (Akshatha *et al.*, 2017; Balaguer & Abderrahim, 2008). This leaves the construction industry heavily dependent on manual labour which most of the times is not readily available.

This brought us to the issue of skills shortages which is another challenge faced in the construction industry that has threatened the successful delivery of many projects. Around the globe, construction companies over the years have been scrambling with right skilled personnel to fill job openings (BRT, 1983; WEF, 2018), despite high levels of unemployment recorded worldwide. This is as a result of the construction industry globally failing to attract and retain

new skills to replace the aging workforce and due to the industry's failure to adapt to new technological changes (ILO, 2001; Mukora, 2008; Tshele & Agumba, 2014; Windapo, 2016).

The issue of construction industry skills shortages is not a new phenomenon, but it has been a recurring problem. In the UK construction industry, it has been an issue for more than 30 years (Dainty *et al.*, 2005; CIOB 2009) and the concern remains that the industry is incapacitated to successfully deliver the projected growth in the medium term (Chan *et al.*, 2007). The Public Sector and Education UK, also acknowledges that the industry is faced with skills shortages which could de-rail construction output targets and they proposed a solution through harnessing the changes in technological environment and for the industry to be part of the disruptive change (Faithful Gould, 2016). A report by the CITB, (2016) suggested that to cope up with the demand for skilled construction labour in the UK, the industry needs to fill 232 000 new skilled positions. This is despite the fact that 400 000 skilled workers who will be reaching their retiring age in the next decade will need replacement as well. In a separate report released by the Recruitment and Employment Confederation (REC), the skills shortages in the construction were described as "*critical*" (REC, 2016). The UK's ageing construction workers is in dire need of skilled workers to keep up with the demands for the government's housing and infrastructural projects.

RICS predicted that, in the run up to 2019, lack of skills would impact at least 27 000 construction projects annually (Agency Central, 2015). Although many firms are faced with shortage of skilled workers, on the contrary, they continue to deploy scarce human labour on tasks that can easily be managed and completed using technology (Tyler, 2017). Of the firms surveyed by RICS, 66% confirmed that already they have been forced to turn down work citing lack of staff and this situation could be set to grow over the next five years if no action is taken now (FMB, 2015). Results from the Construction and Infrastructure Market Survey conducted by RICS for the first quarter of 2018 shows that 60% of the respondents cited skills shortage as a major constraint to growth during the last quarter of 2017 with only 12% of the respondents being confident that the government will meet its target on increasing housing units mainly due to skills shortage in the construction industry (RICS, 2018). These statistics are worrisome for the successful implementation of the government's housing projects among other developments. The FMB reinforced the findings of the RICS survey ranking bricklayers, carpenters and joiners, plasterers and floorers as the most affected trades (FMB, 2018).

Given the current levels of redundancies, the ageing population of construction workers and the number of new recruits, the issue of skills shortages is far from being solved. The continuation of construction skills shortages have the potential to undermine the broader economic growth (Murchadha and Murphy, 2018) as it is the biggest single obstacle holding back construction output (PwC 2018). With many European countries recovering from the global economic crisis and flooded with projects, skills shortages is the number one factor that is holding back projects for months before they can be implemented (Deloitte, 2018). Most companies have resorted to training, salary increases or technological innovation because if these shortages are not addressed or other means of increasing productivity, it could result in substantial economic regression. And to curb on skills shortages, top European companies are now taking a leap step in understanding the benefits of using technology and innovation in their line of business.

Healy *et al.,* (2015) and Tsuruta *et al.,* (2018), both concurred that skills shortage is one major problem being experienced in many different economies globally. Since the construction industry is labour intensive, skills shortages has become one crucial risk hindering construction projects from being sustainable (Mohd-Rahim *et al.,* 2016). Construction industry being cyclic in nature, the image of the construction industry is a contributing factor to the current shortages. In New Zealand, the construction industry is in desperate need of artisans, engineers and builders to address and meet up with the demands of the industry (Engineering News, 2018), with the figures ranging between 50 000 and 60 000 qualified artisans required in the next five years to satisfy the expected growth. These high figures are against a meagre 11 500 applicants received on average for artisan training programs.

In Australia, skills shortages have been attributed to the down turn in the construction industry after the 2009 recession which saw many specialty trade workers having to switch industries and professional workers migrating (Construction Business Owner, 2015). The increase in new projects has worsened the situation in recent years. The Bureau of Resources and Energy Economics (BREE) reported that, there are currently 98 projects in the advanced stages of developments putting fierce competition on employers when trying to find skilled workers (BREE, 2012). Elsewhere in the European Union labour markets, every member state is faced with the challenges of shortage of skilled workers with relevant qualifications or willing to take up certain occupations (IOM, 2012). These shortages are exacerbated by the deepening demographic crisis and skills mismatch.

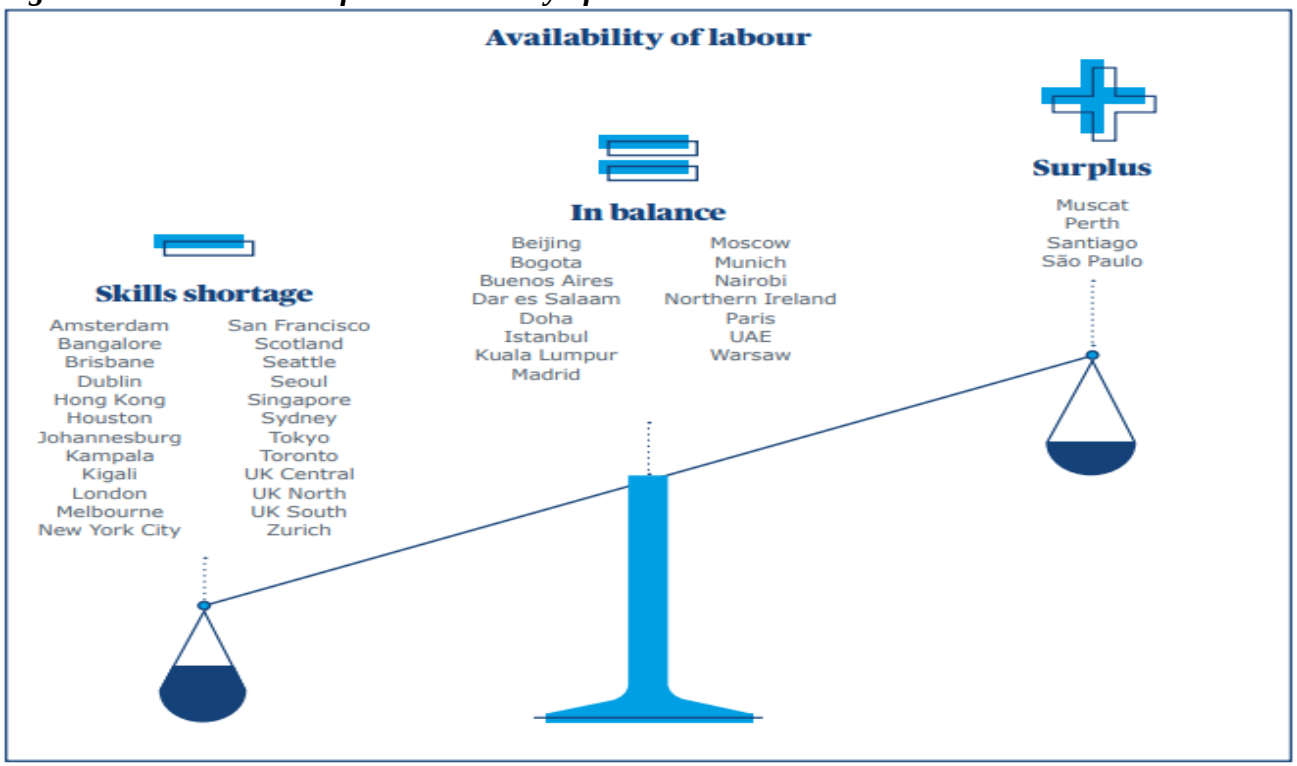
Although the construction industry plays a significant role in shaping the US economy (Sunder 2012), over the last two decades, the industry has endured skilled labour shortages in varying characteristics and intensity and the issue continues to persist (Pappas 2004). A study by Pat Galagan, (2010) showed that, 79% of the organisations surveyed confirmed to be experiencing serious skills shortages due to the sharp difference in the needs of the business and the nature of the graduates that are released into the market. Where the industry requires the workforce to be more knowledgeable about the work, team work and more use of technology, the graduates only have the theoretical knowhow without the relevant practical experience of what is expected of them at work. This tend to suggest a serious mismatch between the current workforce and industry requirements proving that the school curriculum and tertiary institutions are out of touch with the reality and requirements of the industry (Mateus *et al.*. 2014).

Japan is leading in the application of automation technology for its construction industry to address challenges such as skilled labour shortages, productivity, quality, safety and high construction cost (Ding *et al.,* 2014; Tsuruta *et al.,* 2018; Pan *et al.,* 2018). Evidence from its construction industry performance points out that, the use and adoption of new and advanced technologies like CA could possibly improve on the quality, safety and productivity in the construction industry (Tejankar, 2015).

From the global overview of the construction industry, it is obvious that many countries in the world are faced with skilled labour shortages and that the key to the construction industry's woes might be laying in ability to adopt digitalisation and AI. With the level of complexity in most new projects, many are relying on fusing AI in the form of digital sensors, intelligent machines, mobile devices and new software applications in the form of BIM (WEF, 2016).

In summary, Figure 2.1 shows that many markets globally struggle when it comes to skilled labour shortages than those that are in the balance or surplus of skills supply. This goes to show that the issue of skills shortages is a serious problem that needs urgent attention.

Figure 2.1: Distribution of the Availability of Labour

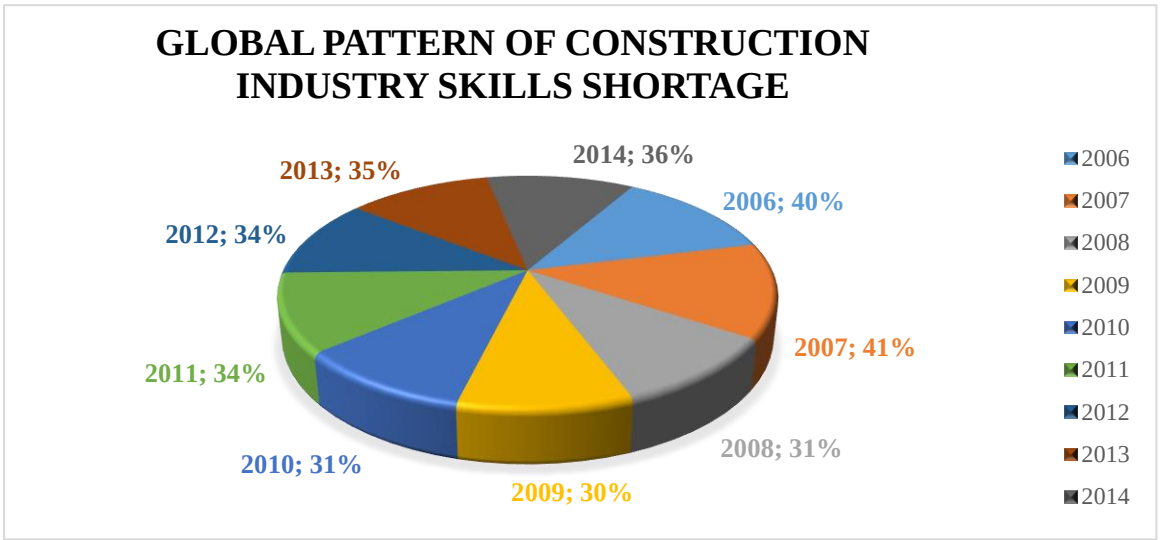


Source: Gerbert et al., (2016)

The issue of skills shortages is an on-going issue with no permanent solution in place for at least in the near future.

Figure 2.2 below chronicles the trends in records of construction industry skills shortages between 2006 and 2013.

Figure 2.2: Global Construction Industry Skills Shortage Trends



Source: Author's Illustrion as adopted from the Department of Labour, (2016).

2.2 DEFINITION OF TERMS

Construction Automation (CA) – Yaghoubi, 2013 defined CA as use of mechanical and electronic means in construction to automate a process or control in order to reduce human involvement, time or effort at the same time maintaining or improving on quality. Similarly, Joshi & Shah (2010) defined automation as a "*technique, method or system of operating or controlling a process by automatic means using electric devices, use of control systems and information technologies reducing the human intervention to a minimum*". It involves a range of innovative technologies, AI, advanced machineries and the internet of things in speeding and efficiently completing tasks (Mahbub, 2012).

Integration – entails the close working together of the construction professionals (Contractors, Architects, Engineers and Quantity Surveyors) during the design and or construction phase. Integration uses automation technologies at all construction stages from conceptual design (in the form of CAD), scheduling, estimating and project management through various software's right to the use of fully on-site automated machines (Sadique & Mahesh, 2016).

Artificial Intelligence – can be defined as the use of machines, electronic devices and computer software in construction work sequencing to boost productivity by reducing the duration and laborious work and increase safety on construction sites (Joshi & Shah, 2010).

Skill – it is a personal trait which can add value to an individual. A skill can be improved through education, training and development although it not the same as educational qualification or a training certificate but oftentimes qualifications and certificates are used as approximate indicators of personal skills. In its broader sense, a skill can be equated to personal competence. (Edge, 2018).

Skills Shortages - is the insufficient supply of proper qualified workers who will be willing to work under current market conditions and or at the prevailing wages (Windapo, 2016). There is said to be skills shortages when an employer fails for find workers with the desired competences from the labour market. Of importance is to differentiate this situation from vacant positions that are hard to fill because of poor working. (Edge, 2018). Where there is a misalignment between the organisations' objectives and its employees, there exists a skills gap. Skills gap often termed skills deficiency is as a result of the differences between the desired skills level and the actual skills possessed by employees within an organisation (Silva, 2018).

To close this skills gap, organisations need to provide the necessary training, recruit externally or modify its objectives to meet the quality of its skills pool (Edge, 2018).

Scarce Skills – are those professions where there is a dearth of trained and experienced workers either currently or expected for the future, because such skilled people are not available or those available do not meet the employment criteria (DHET, 2014). To differentiate '*scarce*' from '*critical skills'*, the CIDB defined '*scarce skills'* as referring to skills that are in short supply but can be overcome through short-term targeted training (such as many artisan skills) and *'critical skills*' as referring to high-level skills within certain occupations where short term training is not possible (CIDB, 2007).

2.3 THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

Having looked at the global outlook of the construction industry and the definition of key terms, attention is shifted to the study area which is the SA construction industry. Even though the government hails considers the construction sector as part of the country's economic fibre, it is threatened with major delivery challenges (SA Government, 2013). Since 2008, the SA construction industry has been contributing around 9% yearly towards GDP and in total employment for both formal and informal (CIDB, 2015). As with the global markets, the construction industry in SA is also experiencing shortages of skilled labour due to the ageing workforce, the cyclic nature of the industry and technological advancement. Between 2010 and 2014, the number of jobs in the construction industry grew by nearly 200 000 but most of these jobs were contract and on temporary basis (DHET 2016). Locally many considers working in the construction industry as a sign of low social standing and it lacks in attractiveness due to its physical demands (Human, 2013; Windapo, 2016). Construction work can be dangerous and messy leading to poor working conditions for certain construction trades and high fatality rates (Okoye, 2018). In 2016, the construction industry had the third highest fatality rate after fishing and transport sectors (StatsSA, 2016). This is so because as the construction site is full of activities and hives, construction workers are prone to hazards and accidents. StatsSA (2016) further breaks down the figures to say 14% of construction site fatalities are caused by falls from elevated heights. Many accidents on construction sites occur when scaffolding has not been erected properly, ladders are incorrectly fastened or workers slip and fall.

While in most cases skilled workers need practical experience instead of just supervisory experience, today's youth are not fond of physically demanding work and would rather work

with computers than doing field work (Mukora, 2008). With skills shortages, come cost overruns for infrastructure projects and corporate capital spending plans, and while vision 2030 is in full swing rising number of job opportunities, the number of suitable candidates for certain trades in the construction industry aren't rising as envisaged (Hilling, 2016).

During the draft of the Government Gazette Notice 380 of 2014, the Department of Higher Education and Training (DHET) in conjunction with the Joint Initiative on Priority Skills Acquisition (JIPSA) identified five priority areas that needed immediate attention. Of these five areas, three were linked to the construction and infrastructural development (Government Gazette, 2014). This goes to show the government's efforts in delivering quality infrastructure projects amidst high skills shortages. The following were identified as areas of high priority;

- High-level, world-class engineering and planning skills for the network industries, namely transport, communications, water and energy
- City, urban and regional planning and engineering skills
- Artisanal and technical skills, with priority attention to infrastructure development, housing and energy, and in other areas identified as being in strong demand in the labour market
- Management and planning skills in education and health
- Mathematics, science and language competence in public schooling.

After looking at the general outlook of the SA construction industry, there is a need to narrow down and examine exactly what challenges are faced in the industry, the background to the challenges and their effects in the delivery of construction projects.

2.4 CHALLENGES FACED IN SOUTH AFFRICAN CONSTRUCTION INDUSTRY

Despite the role played by the construction industry in fulfilling the economic growth and infrastructure development, the industry is faced with many challenges like slow adoption to changes, efficiency, safety, cost overruns and delays but skills shortages have proved to be the most challenging (Edge, 2018; Windapo, 2016; Tshele & Agumba, 2014). Other challenges faced include constant late information and design changes, several skilled people leaving the industry and collusion by both contractors and consultants. Construction managers, supervisors, skilled trades and engineers are rated among the most difficult to fill positions for companies (Manpower Group, 2016) and to remain viable in the industry, the anticipation is

for companies or organisations to overcome such challenges. It is unfortunate that, with many signalling the dawn of the 4th Industrial Revolution, the country is not failing to produce and meet demand for engineers, artisans or technicians who can help deliver on the NDP's much anticipated R845 billion strategic infrastructure projects (Amrop, 2012). Against this setback, the country has no other alternative but to aggressively launch a skills development programme to match with the need for proper maintenance and upgrades of existing structures while at the same time avoiding further deterioration of vital services across the country. The physical capital and financial commitment is not a challenge in reviving the economy and promoting economic growth, it is the human capita that has proved a challenge as it is not easy to accelerate training for engineers and artisans that do the work.

2.4.1 BACKGROUND TO THE CURRENT SKILLS SHORTAGES

With the country winning the bid in 2004 to host the prestigious FIFA World Cup in 2010 (SA Government, 2004), in 2005 the government announced huge infrastructure spending programme (CIDB & DPW, 2007) which also included the construction and provision of infrastructure to host the 2010 FIFA World Cup. In 2006, the Gautrain Rapid Link project also commenced which had been on the drawing tables for more than a decade. At that time, the planning committee highlighted the general construction skills shortage. This was to necessitate the timely interventions by the responsible authority to guarantee the timely delivery of these infrastructure development programme (SA Government, 2005). In response to the need for timeous delivery of the 2010 FIFA World Cup Projects, the CIDB together with the NDPW commissioned a commission of enquiry enumerate the current construction industry skills base at that time. The commission was also tasked to project the required skills to meet the demand for the timely delivery of the FIFA World Cup Projects and to identify where shortages existed and come up with proposals to address the existing skills gap (CIDB, 2007).

Skills shortages at that time was considered so as serious as it has the potential of sabotaging the Accelerated and Shared Growth for SA (ASGSA) initiative (Business Day 2006). The same sentiments were echoed by the Harvard Group (2008) which was appointed by the National Treasury whose findings concluded that skills shortages were limiting economic growth prospects in the country (National Treasury, 2008). Kraak, (2008) also acknowledged shortage of skills as the main obstruction to the socio-economic growth and development in any

economy. The Deputy President then, Mlambo-Ngcuka who was driving this ASGSA concurred to this saying, *'Government's R372m infrastructure investment between now and 2009 is expected to stretch the country's skills pool to the limit'*. With the Expanded Public Works Programme (EPWP)'s strong focus on traditional construction methods, this further stretched the demand for qualified supervisors and managers (CIDB, 2007). Fast tracking the issue of skills shortage to the current situation, Shava & Maramura (2017) portrayed the skills shortage challenge as so dire that the SA private and public sectors are on the brink of collapsing due to the shortage of relevant skills for the job.

A new ministry, the Department of Higher Education and Training was established in 2009 to address skills shortage and so was CETA to address skills shortage particularly in the construction industry. In order to meet the National Development Plan (NDP), the government prioritised apprenticeship programmes as well as the Technical and Vocational Education and Training (TVET) in a bid to meet the demand for skilled workers. The TVET, however are not producing enough of the minimum skilled candidates required to do the job (Dialogue, 2017). Some construction companies among them, Aveng, WBHO, Murray and Roberts, Group Five, Basil Read, Raubex and Stefanutti Stocks have joined hands with to the government initiatives of developing artisan skills in the construction industry (SAFCEC, 2016). The development and retraining of key technical skills cannot be over emphasised where the country need to meet up with the demand for new infrastructure as well upgrading the existing services.

2.4.2 CHALLENGES IN ENSURING ADEQUATE SKILLS SUPPLY

The skills supply pipe line for construction and engineering professional have been beleaguered with many challenges which have negatively affected efficiency and quality of construction projects (Tshele & Agumba, 2014). The dwindling in the skills supply pipeline is due to the fact that, to be considered for enrolment in construction and engineering programmes at institutes of higher learning, learners require higher grades mathematics and science whose pass grades are also on the downward spiral. As such, the main challenge is on restoring a skills supply pipeline that is capable of producing a kind of skills required by the construction and engineering sectors (DPW & CIDB, 2007).

To exacerbate on the issue of maths and science grades in 2004, only 3% of the matriculates could enrol for construction and engineering at DHET (CIDB, 2007). Such low figures affect the pipeline supply for skills much needed in the construction industry. One of the barriers to

the implementation of CA in SA is institutional, the quality of science and mathematics grades at basic education level means that few matriculates are enrolling for construction and engineering at tertiary institutions. The field of automation requires higher grades in these two subjects for the development and proper implementation of construction robotics (Yaghoubi, 2013).

In 2010 SA, ranked was placed on the 17th position of the G20 countries on the average literacy of students in Mathematics and Science subjects (Table 2.1 below). With this quality of pass rate, basic education department is not preparing youths for the development and implementation of CA.

Table 2.1: Percentage of Students who attain Maths and Science on a PISA Scale

	Country	**%**
1	Japan	96.7
2	Republic of Korea	96.2
3	Canada	94.8
4	Australia	93.8
5	China	93.5
6	United Kingdom	92.9
7	France	92.6
8	India	92.2
9	USA	91.8
10	Germany	90.6
11	Russian Federation	88.4
12	Italy	87.5
13	Turkey	58.2
14	Argentina	49.2
15	Mexico	48.9
16	Indonesia	46.7
***17**	**South Africa**	**35.3**
18	Brazil	33.8
19	Saudi Arabia	33.1

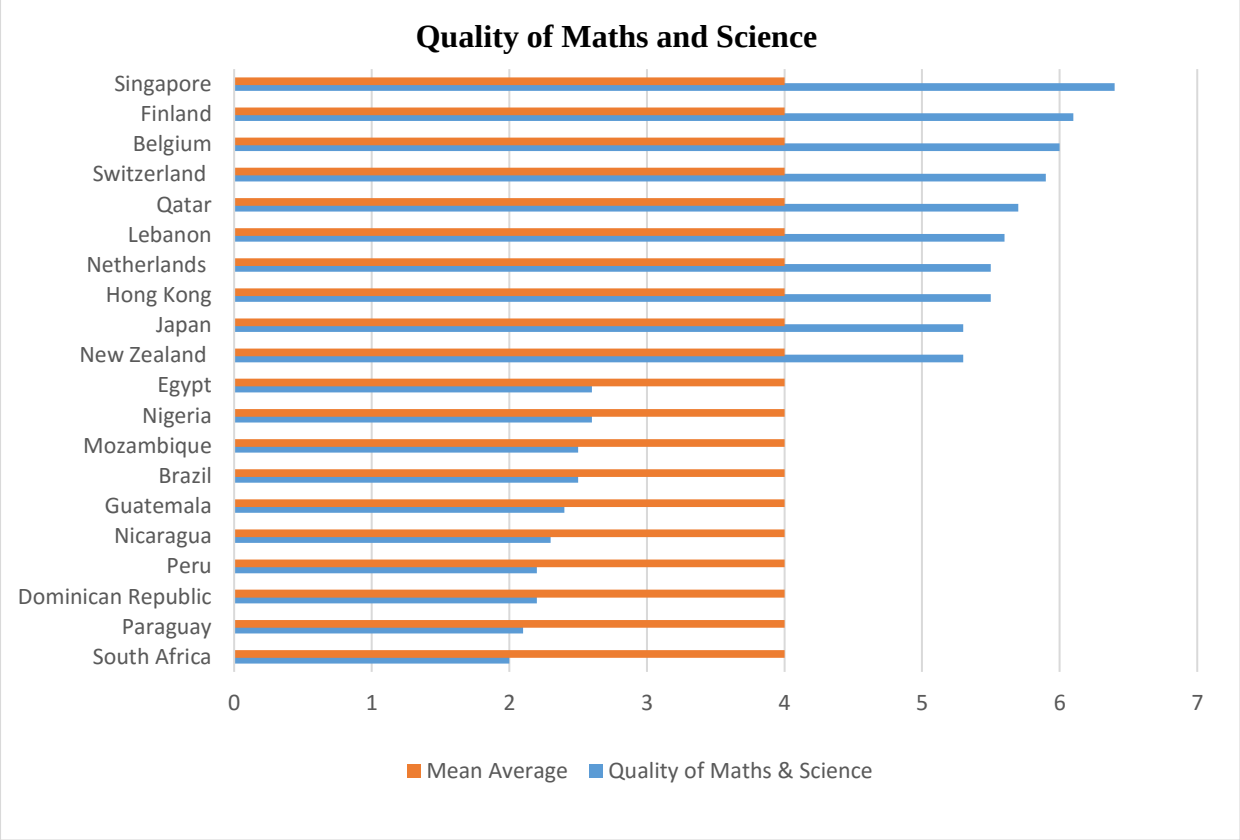
Source: OECD 2010

A new breed of workers is needed with a string academic background and special training on robotics, engineering and controlling if we are to realise the dream of robotics on most construction sites, but this is something our education system is currently failing to address to adequately curb skills shortages in the construction industry. But with the average performance of South African students in the STEM subjects on the PISA scale, this reality will be far from being realised. This performance contributes to the on-going skills shortages being experienced

in the country especially for the construction industry. The country's poor performance in STEM subjects has seen very few students graduating in the engineering field, skills which are much needed to drive the construction industry forward.

The poor quality of the education system in South African is further reflected by the country's general performance in the in the quality of Maths and Science education. In a separate survey carried out by WEF in 2016, SA ranked last on the 139 countries that were surveyed on quality of Maths and Science education. This performance is as a result of the overall poor quality of education system which seems not to be improving. This poor performance in STEM coupled by the poor quality of the education system has adversely affected the skills supply in the engineering field and the construction industry was not spared (refer to Figure 2.2 below on the quality of Maths and Science).

Figure 2.2: Quality Maths and Science Subjects

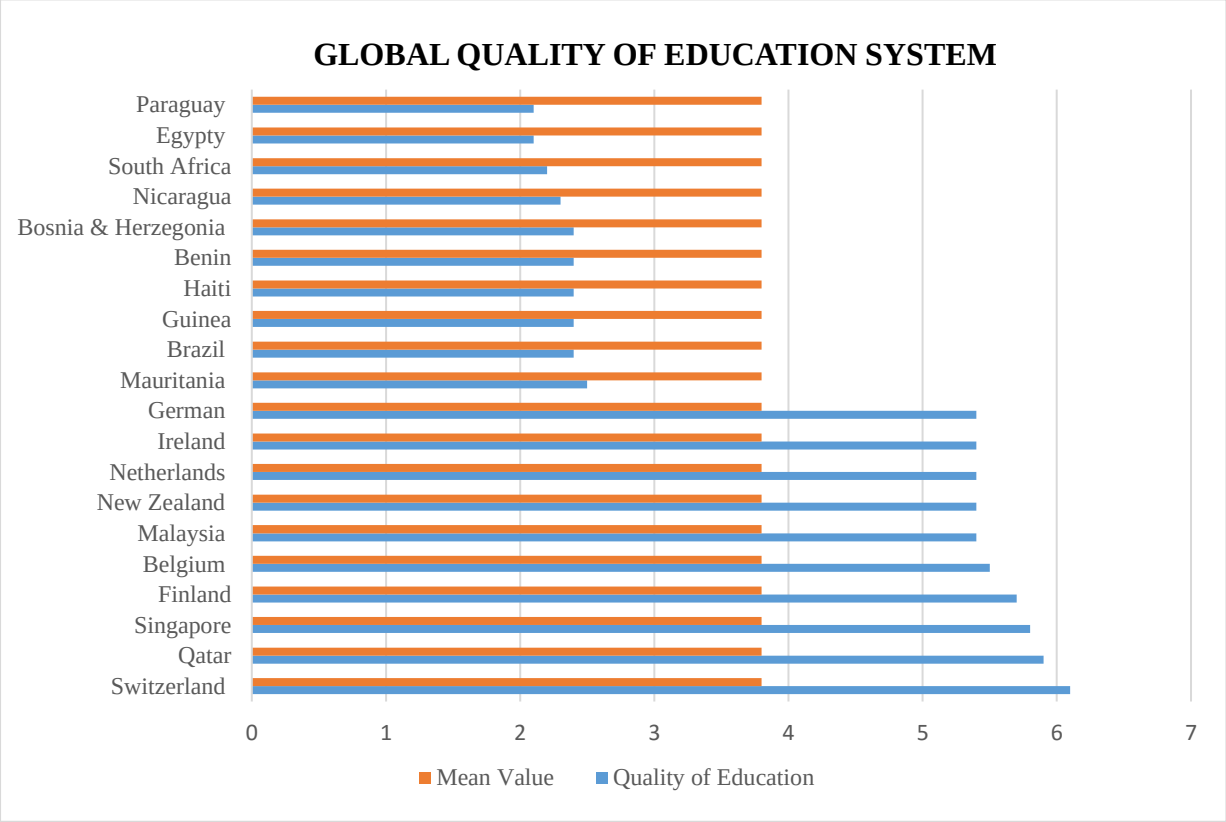


Source: WEF: Global Information Technology Report 2016

The poor quality of the SA education system contributes immensely to the poor quality of Maths and Science subjects. Figure 2.3 below shows the global quality of SA education system, where globally, the country was ranked third from last on the quality of the education and it's

no doubt that the country was ranked last when it comes to its performance on the Maths and Science subjects.

Figure 2.3: Quality of the Education System



Source: WEF: Global Information Technology Report 2016

Of the 139 countries that were for the survey, SA was again third from bottom on the quality of education (WEF, 2016) with its performance way below the mean average of 3.8.

From the Figures 2.2 and 2.3 above, SA ranks third from last in the mathematics and Science literacy rate among the G20 nations and this is a signal of an educational system that is not preparing society for further learning and productivity work (ILO, 2010; DHET & LMIP, 2016). With science literacy increasingly considered as a measure of economic growth necessary for finding solutions to complex social and environmental problems (PISA, 2015), the situation remains dire with the results of a survey carried out by WEF in 2016 where SA was ranked last among the 139 countries that were surveyed on the quality of Maths and Science education. Further to exacerbate the situation, the quality of education in the country has remained poor. This poor quality of education is further exposed from the 2016 WEF survey where SA ranked last on the list of 139 countries that were surveyed. To further

demonstrate on the effects of the poor quality of the education system in 2011, only 9 193 of the 160 300 university graduates graduated in the engineering field a huge shortfall from the anticipated 15 000 engineering graduates per year if the country is to meet its engineering professional requirements (Engineering News SA, 2013).

And again in 2014, SA's maths and science was ranked last of the 148 economies surveyed by the WEF (Ramaila, 2014). Currently, the ratio of engineer to people is 1:2600 compared to the international norm where one engineer serves 40 people (Wits, 2017). The poor performance of the students on the Maths and Science subjects is a reflection of the poor quality of the education system in the country. The quality of the education in the country needs to be improved to meet the international standards, if the country is to produce more engineering graduates to help curb skills shortage currently being experienced in the country.

Due to the flaws in the quality of education system in the country and the poor performance of students in Maths and Science subjects, those responsible with the country's education system needs to address this problem from the root level. To address the skills shortage and restore the pipeline of skills shortages for the future in the construction industry, the CIDB proposed the following:

- Interventions by the Department of Basic Education to ensure an increase in the numbers for maths and science matriculates
- Involvement by DPW, industry and other professionals in marketing the industry and its attractiveness
- Improvement and matching the current training with industry requirements in terms of skills
- Install funding for learner ships and that experiential training be conducted for an adequate time period to meet qualifications criteria for artisans and improved skills development.

It is evident from the quality of education and that of maths and science in the country that there is still an acute shortage of engineering skills much needed for the development of sustainable construction in the country. Skills shortage is also attributed to the increased demand for highly skilled personnel around the world (Edge, 2018).

To overcome the challenge of skills shortage in the construction industry, focus should be directed on new training programmes to suit the industry requirements, internship and

mentoring of new entrants or importing such skills. The focus should not be to simply equip the entrants with the skills, but for them to gain the necessary practical experience in order to put their theory education into practice (Engineering News 2014). Most of the time, the available training programmes just enrol students for a period of time, after which they release them into the market where they are not absorbed to recruit another group for training without later absorbing them. Another challenge faced in the industry is the high proportion rate of an ageing workforce who would need replacement without compromising quality and performance of the industry.

In order to address the skills supply pipeline, the current education curriculum would need to be adjusted to ensure that graduates that are produced meet the world standards in terms of their performance (DPW & CIDB, 2007; Rasool & Botha, 2011). Records from DoL and DBE shows that, very few students enrol for training in qualifications that will help in addressing shortage of skills in the country (DoL, 2016; Basic Education 2018). Shortages of skilled labour which have been a hot potato issue in the country and beyond for some time now is being further compounded by the ever increasing demand for technical and digital skills due to technology evolving in the work place. The resistance by the construction industry when it comes to change is likely the root cause of slow adoption of technology (Windapo, 2016; WEF, 2016; Training Force, 2018), but regardless of this fundamental nature, institution of higher learning should be responsible to lead and drive the much needed change and improve the face of the construction industry through the adoption of technology (Holt *et al.*, 2015). To achieve this goal, there is need to expose learners studying towards construction related programmes to emerging technologies so that as the future advances and geared for Revolution 4.0, already there is a skills base capable of implementing such technologies in the construction industry.

With the 2010 Soccer World Cup fever gone, the proposed solution for restoring skills shortages as tabulated by the Public Works and the CIDB implemented, the government felt it was ready to spearhead the expansion and development of the country's infrastructure. In 2012, the first ever National Infrastructure Plan was developed by the Presidential Infrastructure Coordinating Commission (PICC). The plan identified 18 Strategic Integrated Projects (SIPs) (Government of SA, 2012) to be implemented but however, the initiative has been met with insufficient skills to meet the increased demand for skilled personnel needed to complete the projects efficiently. Shortage of skills was identified by the six different economic

infrastructure sectors as hampering the smooth implementation and execution of the national infrastructure (DPME & DBSA, 2012).

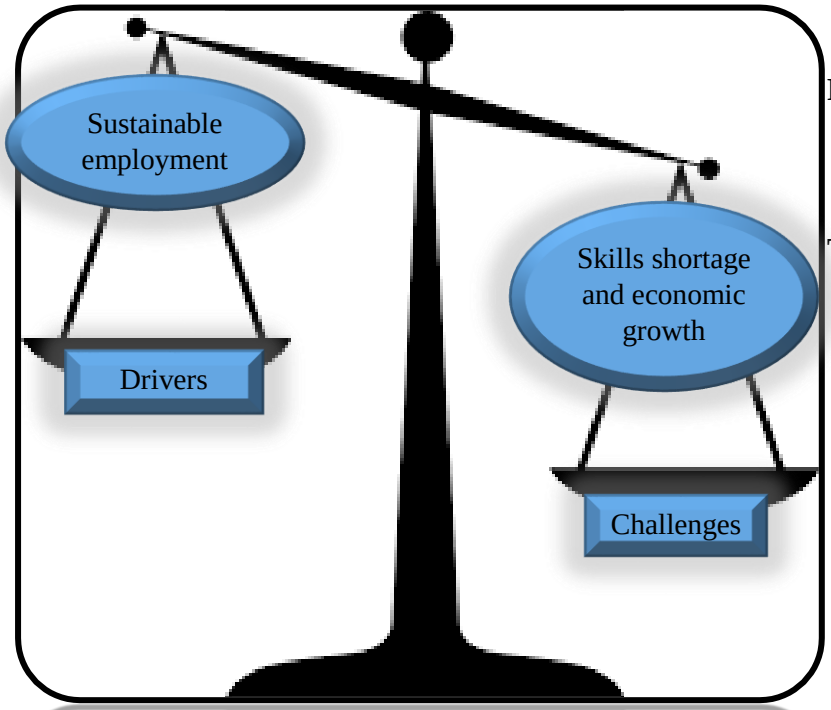
With the new SIP's in place, it was noted that the country did not have the desired quality of candidates and the right skills to deliver projects of that nature and magnitude. In 2013, Malusi Gigaba, then minister of Public Enterprise outlined challenges that are faced during the execution of construction projects as delays and commotions on sites, poor site management, time and cost overruns, skills and competences issues and lack of worker participation (SAPA, 2013). He further acknowledged that, the construction industry is faced with service delivery protests, and various indicators pointed to a severe scarcity of qualified tradesmen and supervisory staff which in turn impacted the demand for quality management, standard operating procedures and training. Of the 20 National Scarce Skills list (Government Gazette, 2014), 8 of them can be directly linked to the construction industry. The unattractiveness of the construction industry coupled with the recurring shortage of skills, places considerable pressure on businesses to deliver projects. During the Masters Builders South Africa (MBSA) annual conference held in 2017, Minister for Economic Development, Patel outlined some of the challenges faced in the construction industry as the reduction in infrastructure spending by state-owned enterprises, conspiracy between companies, corruption, project delays, cost overruns and a lack of transformation by the industry (MBSA, 2017).

As a result of these challenges, contracts are being poorly executed eroding profit margins and in most cases results in losses (Silva *et al.,* 2018). Jones, (2014), of the Artisan Training Institute, states that due to lack of skilled staff, projects end up in delays and the quality of the end product is often times compromised. He stated that if these problems are not addressed, they will further impact badly on the government's current Medium Term Expenditure Framework. Shortage of skills has also affected on the quality of even the low cost RDP houses for the poor with some of the beneficiaries opting to stay in their shacks than to move in poorly constructed houses (Engineering News SA, 2014). Poor quality of projects may result in reworking which on its own result in increased costs and delays the delivery of the final project (Silva *et al.,* 2018).

The growth of modular construction is on the rise and most construction companies around the globe are using the technique not only to reduce the time frame of the projects but also to enhance quality and life span of the structure (Bizconnect Standard Bank, 2017). This

according to McKinsey's report "*Imagining Construction's Digital Future*", construction companies that use Prefabricated, Prefinished Volumetric Construction (PPVC) report a 50% savings in staffing and time by using 3D and modular techniques which in turn increases the company's competitiveness (McKinsey, 2017). As a bonus, this new construction method reduces air and noise pollution as well as improving site safety. SA is on the blink of running out of skilled artisans in the near future. The skill base for construction managers, brick layers, carpenters, plumbers, electricians and painters is fast dwindling (Mathews, 2013). As a result, the country has experienced a shortage of about 46 000 artisans in the three years running to 2013, this was highlighted by the DHET at a Gala Dinner to launch the first ever National Artisan Development (Dialogue, 2017). Providing employees with skills required for today's job as well as those for the future is very strategic in the national growth and development of the G20 nations (ILO, 2010). To meet up with the demand for infrastructure development, there is need to strike a balance between sustainable employment and skills shortages and economic balance (Infrastructure Dialogue, 2017). It is one thing to create employment through infrastructure development, but if the country does not have the skills in its pool to execute those projects, unemployment will remain high and the economy will continue to deteriorate (Dialogue, 2017). Figure 2.4 highlights the challenge of creating sustainable employment in the economy and skills shortage and economic growth on the other end.

Figure 2.4: An Example of Infrastructure and Industry Development



Requirements
- Vision leadership
- Education and skills development
- Localisation

The right balance between:
- Labour intensity vs automation
- Maintenance vs newly built
- Metro vs rural
- Public vs private

Source: Infrastructure Dialogue (2017)

In SA, the construction industry is failing to attract new younger generation workforce (Engineering News, 2014), while at the same time the industry is faced with an ageing workforce who are nearing their retirement age. This is putting a stain on the skills supply because while few skilled workers are qualified to enter the market approximately 30% are leaving the industry annually (Mukora, 2008). Addressing the KPMG Global Construction Dialogue in Johannesburg, Minister Gigaba attributed construction skills shortages to the ageing artisans in the country with an average age of 55 years. This poses a danger on the skills transfer as possible mentors are getting older and older (SAPA, 2013). It is a fact that younger generations do not see some construction trades as attractive career path to take (Heaton, 2015). But when they see robotic machines now doing the job, the younger generation will begin to consider robotic construction as a good career and take pride in the profession.

Labour experts Adcorp (2014) on the other hand attributed SA's skills shortages to the migration of skilled workers, restrictive immigration laws for skilled foreigners and an education system that is not preparing for the future (Sharp, 2014). To point out on the dysfunctional of our education system, one may consider the high numbers of students graduating from tertiary institutions every year, and still wonder why the country is still grappling skills shortages. Drawing a conclusion from this, maybe these graduates do not possess the required skills that are highly sought after and only a few graduates possess the relevant skills in demand. To further elaborate on this, in her speech during 2017 MBSA annual conference, CETA CFO Ms Ndlovu, CFO highlighted poor quality of tertiary education and the absence of technical studies in the schooling system as some of the reasons for skills shortages.

To intricate on this, as of January 2014, 470 000 vacancies were open that requires to be filled by skilled people, while at the same time, despite these huge vacant jobs, the country simultaneously possesses a surplus of unemployed graduates estimated at 344 000 (Sharp, 2014). By 2016, the figure for unfilled positions has rose to 829 800 (Adcorp Employment Index, 2016). These graduates hold degrees, diplomas and certificates and they lack technical skills required to drive the economy forward. The high prevalence of poverty among the youths results in millions of them being unable to enrol for secondary, tertiary and or training creating a challenge when it comes to developing new skills and employment prospects (Manpower Group, 2016).

Although a pass mark in tertiary education is used by many as the gauge for employment prospects, 10% of graduates are failing to secure employment as their qualifications do not match with the open vacancies (mismatch of skills). With many graduating from tertiary institutions with arts, humanities, social sciences and mid-level professional graduates like teachers and nurses, employers and the job market seek to fill managers and high level professionals like engineers, doctors, lawyers and accountants. The construction industry continues to suffer because of lack of the right skills to meet up with the demand for new infrastructure projects in the labour market. This is depicted by the dichotomy of high unemployment rate among the unskilled and semi-skilled and high vacancy rates for the highly skilled (Amrop, 2012). The bulk of the students enrolled in tertiary institutions are taking subjects that support science and technology and engineering nor future oriented skills (WEF, 2016).

In SA, the major constraints to sustainable job creation lies on the structural mismatch between demand and supply of labour (DHET, 2016). This mismatch has favoured highly qualified and skilled workers forgetting the fact that most of the unemployed and those in the job market have low levels of skills. The Master Builders Association of Western Cape (MBAWC) in 2013 developed a Digital Video Disc (DVD) presentation for circulation in schools in the Western Cape to try and rectify this situation and promote the skilled artisan aspects of the construction industry as a viable career path. Children need to know what career opportunities are out there. And without many school leavers entering the construction sector, it is going to cause a problem in the delivery of construction projects. Without proper skills in their human resources pool, contractors continuously struggle to complete their projects timeous and successfully which impact their profit margins and quality of work done (Milford, 2016).

2.4.3 CAUSES OF SKILLS SHORTAGES IN THE CONSTRUCTION INDUSTRY

A skills shortage is said to exist where there are no enough people in the job market to meet up the demand (Richardson, 2007). Skills shortage exist as a result of ranging situations where an employer experience difficulties to fill-in an openings with the desired candidate who possesses the right skills for the job (Mkhonza & Letsoalo-Fuze, 2017). Simply put, genuine shortage of skills occurs when employers across the industry find it difficult to fill vacant posts because there are not enough job seekers in the market who have the right skills for the job. A typical example of genuine skill shortage will be where there is a high demand for QS's for

construction projects, but there are currently few QS's currently unemployed and looking for a job. Recruitment and retention difficulties contributes to the current wave of skills shortages. This is despite a good supply of individuals with the required skills, they opt not to work due to either the existing working conditions or they are not happy with the remuneration.

Although a slump in construction activities due to the global financial crisis alleviated skills shortages to some extent, a 2012 research showed that 74% of the companies surveyed were still having difficulties in filling engineering posts (Amrop, 2012). The country is grappling through a critical skills shortages in a number of key economic sectors, as a result of a serious mismatch between skills being demanded by an increasingly sophisticated economy and those in supply (Nyatsumba, 2017). This is mainly because of the failure by the industry to attract new labour into the market and at the same time experiencing an aging population (Mukora, 2008). Although many appreciates the positive contributions of the construction industry and recognise it as an important sector in the development of society, the widespread negative perception of construction jobs further exacerbates the talent gap (WEF, 2018). In the UK for example, just 11% of those surveyed considered work in the construction industry as "*exciting*".

The focus on skills shortage should not be on the quantity but on the quality of the skilled workforce as well the extent to which the skills shortages exist and the underlying causes of the shortages that exist (NCVER, 2001; Sutherland, 2010). Both the quality and quantity of education provided in most schools in the country lacks substance to the requirements of the industry (JIPSA2007; Breier & Erasmus, 2009). Breier & Erasmus, (2009) went on to blame skills shortages on the education system that is still suffering from years of neglect and dysfunctional from the Apartheid regime where majority of the black people were denied quality education and skills training. In most cases, skilled workers needs practical involvement in the work on ground, rather than theoretical or supervisory exposure. Today's millennials have no preference for "*dirty work*" and would rather work with computers (Mukora, 2008).

While blue-collar workers view construction jobs as being dirty and dangerous, many white collar workers think work in the construction industry lack innovation and is not challenging. To improve on productivity and job satisfaction, companies can adopt and resort to technologies like automated construction equipment, prefab components, sensor-equipped work gear and mobile collaboration tools (WEF, 2018). Currently the construction industry is going through rapid digital transformation technologies such as Building Information

Modelling (BIM), wireless sensing, big data and analytics, 3D printing, and autonomous equipment (WEF, 2016). These can be fused in the current curriculum to improve the attractiveness of the construction industry and help attract fresh blood who are so fond of working with computers.

There are certain challenges to the adoption of technology in the institutions of higher learning ranging from the economics and government policies, commercial concerns of IT vendors and strategic student concerns (Holt *et al.*, 2015). Despite challenges faced in implementing technology in the school curriculum, implementation of some construction technology in the education system sacrifices nothing and can be more efficient if used as an effective motivation for students in the construction disciplines. For robots to become more common sight on the work sites, a new breed of workers is needed, workers with a strong academic background and special training in areas of robotics, engineering and control (Yaghoubi, 2013). Something our education system is currently failing on.

Locally the construction industry is perceived to be a job of low social standing and lacks in attractiveness due to its physical demands (Windapo, 2016). This can be highlighted by the fact that, despite high unemployment rate in the country, the construction industry continues to experience skills shortages (Tshele & Agumba, 2014; CIDB, 2017) mainly due to skills mismatch (Amrop, 2012; Nyatsumba, 2017) and failure to attract enough youths in the industry. Results from Pocket World survey reveals youth unemployment in SA as the worst among all the country surveyed at a whopping 57.4%. Though this this did not match with StatsSA results of 52.4%, the harsh reality of SA's abysmal unemployment rate among the youths cannot be argued (SA Government, 2018). The disconnection between the youth's perception of construction and the reality of working in the industry is costing the industry much needed manpower. Instead of seeing it as diverse, innovative and exciting, youths focus on the stereotypical negative image that has been haunting the industry for years (Waters & McAlpine, 2016). During Infrastructure Dialogue (2017), the following were also highlighted as the reasons for skills shortages particularly in SA construction industry;

- Gaps in the training system – the country's education training system is not preparing the matriculates for skills training until after leaving high school. Although the level of education and training has shown some signs of improvement in the last decade, the pace of this improvement is not consummate with the level of investment in education and training by both the government and the private sector.

- Building the right skills: Apart from TVET colleges, there is a lack of formal training and the right skills training with necessary accreditation. There is a lack of industry knowledge or linkage in terms of awareness about the right skills that are required.
- Revolving door internships and learner-ships: Although there is a number of internship and skills training programmes in the workplace by the government and other large organisations, employment is not always the outcome. In the workplace, companies take in interns in order to fulfil certain requirements. The interns complete skills training but in many cases they are not permanently employed by the same company, either due to unavailability of permanent jobs or for cost reasons. After a year or less, these interns find themselves without a job with the reality being that over time, learnt skills are lost if not kept in practise. The same companies however might take in new interns and go through the same process (NYDA, 2014).
- Capacity building: Small Medium Enterprises (SMEs) which are a major growth segment for SA, envisaged to be a key employer going forward) often do not have the capacity.

Apart from the causes of skills shortages raised above, HIV/AIDS is also blamed for the shortage. According to Mail and Guardian (2008), half of the deaths recorded in SA are HIV/AIDS related increasing to 70% the cause of deaths among the age group of 15-49 years who should be filling up the skills gaps. HIV/AIDS is possessing an enormous socioeconomic development challenge in the country. The dysfunctional education system which is still recovering from decades of Apartheid era, an era that denied the majority of the black people from acquiring quality education and skills was cited also as a contributing factor to the current skills shortages (JIPSA, 2007).

This is not the first time a research is carried out on construction skills shortages. Many researches were carried out in the past on the causes and how best to address the revolving issue of skills shortages in the construction industry. Results of such results are presented in Table 2.2.

Table 2.2: Causes of Construction Skills Shortages from Previous Researches

Factors	**Previous Researches**
Ageing workforce	Chini *et al.,* (1999); Mahlberg *et al.,* (2013).
Change in skill requirements / new technology	Awe *et al.,* (2010); Chini *et al.,* (1999); Healy *et al.,* (2015); Lill (2009); Oseghale *et al.,* (2015); Salleh *et al.,* (2014).
Dissatisfaction with labour organization	Lill (2008); Oseghale *et al.,* (2015).
Economy change	Awe *et al.,* (2010); Chini *et al.,* (1999); Zaki *et al.,* (2012); Watson (2012).
Geographic location	Healy *et al.,*(2015
High education level	Hamid *et al.,* (2013); Salleh *et al.,* (2014).
Increase demand of craft workers	Watson (2012).
Lack of job security/high mobility/ poor treatment	Hamid *et al.,* (2013); Lill (2008); Oseghale *et al.,* (2015).
Low number of new entrants	Chini *et al.,* (1999); Healy *et al.,* (2015); Ismail & Yuliyusman (2014); Watson (2012).
Low wages/salary	Chini *et al.,* (1999); Ismail & Yuliyusman (2014); Salleh *et al.,* (2014); Zaki *et al.,* (2012).
Not meeting employer expectation	Awe *et al.,* (2010); Ismail & Yuliyusman (2014); Zaki *et al.,* (2012).
Poor education/training	Awe *et al.,*(2010); Chini *et al.,*(1999); Ismail & Yuliyusman (2014); Lill (2008); Oseghale *et al.,* (2015); Salleh *et al.,*(2014); Watson (2012).
Poor construction industry image	Chini *et al.,* (1999); Hamid *et al.,* (2013); Lill (2008); Oseghale *et al.,* (2015); Salleh *et al.,* (2014).
Poor site safety/working environment	Ismail & Yusliman (2014); Lill (2009); Oseghale *et al.,* (2015); Salleh *et al.,* (2014); Zaki *et al.,* (2012)
Skill workers migrate overseas	Hamid *et al.,* (2011); Lill (2008); Salleh *et al.,* (2014).
Unattractive job/lack of worker-oriented career path	Awe *et al.,* (2010); Hamid *et al.,* (2013); Healy *et al.,* (2015); Ismail & Yuliyusman (2014); Salleh *et al.,* (2014); Zaki *et al.,* (2012).

Source: Mohd-Rahim et al., (2016)

Knowing the effects skills shortage have will help to establish the magnitude of the problem and the need to address it. The next section of this research will demonstrate the effects skills shortages have on the construction industry before proposing solutions to address the issue.

2.4.4 THE EFFECTS OF SKILLS SHORTAGES

The report by Turner and Townsend, (2017) predicts that the global construction costs are expected to be up 4.3% in 2018 compared to 4.1% in 2017. This increase has been attributed

to the challenges faced by developers in securing relevant skills to deliver the projects. The survey identified that there was growing competition for labour and resources as the global markets are recapturing from the period of the global financial crisis and recession unlocking greater economic activities. With the growth in construction industry globally driven by India and China, key infrastructure projects find themselves competing for a diminishing skills pool amid fears that this shortage of skills have a negative impact of delaying projects in major markets (Amrop, 2012). After years of recession, there are now huge investments in infrastructure and real estate development creating a gap between the industry demand and the industry's building capacity, driving up the cost inflation (Turner &Townsend, 2017).

The shortage of the necessary skills slows down progress in the design, implementation and construction of the major mega projects and the maintenance of the existing infrastructure. With the announcement of FIFA World Cup, the construction industry in the country was in such a hype and there was a scramble for skilled labour to complete these projects ahead of time. During the construction of FIFA World Cup stadium in 2010, the issue of skills shortage had significant effects on the time delays and construction cost overruns (Baloyi & Bekker, 2011). The concern about skills shortages is evident in that, since the construction industry over the past years has been booming and therefore working to capacity and this is apart from the government's Vision 2030 projects (CIDB, 2007). This shortage of skilled labour has given rise to the increase in construction costs while at the same time negatively impacting on the quality of work. Experienced construction managers, engineers, supervisors and artisans are among the hardest hit trades and their shortage have threatened to slow down service delivery unless ameliorated delivery systems are introduced with supporting interventions to bridge the current gaps (CIDB, 2007; Manpower Group, 2014). Due to skills shortages, there was an average increase in wages of 9.5% across the construction increase in 2013 which was above the rate of inflation and increases seen in other industries (PwC, 2013). Skills shortage has also been a major contributing factor towards cost increases as the employers are willing to pay even more salaries to secure and attract labour (Rasool & Botha, 2011; Visser, 2016). The industry faces more work with fewer workers due to the unattractiveness of the construction industry to lure the younger generation (Zaki *et al.*, 2012; Healy, 2015). The cost increases associated with skills shortages are apparent either from the ineffectiveness of the workforce or the costs associated with reworks, productivity issues and particularly the risk for potential and subsequent claims (PwC, 2013), high incidents/accidents rate, increase in construction

costs, time overruns and poor quality of work. It is therefore important to look also at the measures of addressing the causes and challenges in ensuring adequate skills supply.

The issue of construction skills shortages have been persisting despite so many previous researches having been centred on education and training in addressing skills shortages. The failure of education and training to completely eradicate skills shortages have necessitated the need to carry out this research but this time with the aim of investigating the potential of using automation in addressing these shortages. Many agreed that the construction industry has been a slower adopter of technology when compared to other industries yet it can be a leading in digitalisation. At this point in time, it is perhaps of importance to look at how automation and AI have been successfully used in other industries.

2.5 IMPLEMENTATION OF AUTOMATION IN OTHER INDUSTRIES

While other sectors have successfully incorporated robotics and AI in transforming their productivity performance, the construction industry in comparison has progressed at a glacial pace. Having identified the construction industry as a slower adopter of CA, we will look at how automation is helping in some of those industries that are considered as drivers of automation technology.

In the banking sector, automation and AI have been used with success through the use of automated teller machines (ATM's) which has greatly reduced the need for bank visits to carry out transactions and or to get cash (Bindiya, 2012; Jegede, 2014). Automation has increased banking sector capacity and freed employees to focus on higher value work assignments. It can be safely said that with automation, productivity has greatly increased while at the same time cutting on costs and improving customer satisfaction (McKinsey, 2017). Bank tellers now render other customer service facilities. Employment in the banking industry has actually arose since the introduction of ATM's (Binuyo & Aregbeshola, 2014) against the general perception that automation creates unemployment. Robotics which is the synchronisation and combination of software, mechanical and electrical engineering aimed at the betterment of the lives of human labour at the risk of getting injured while performing tasks on site (Ruggiero *et al.*, 2016). Between 1970 and 2010, the number of bank tellers in the USA doubled from 300 000 to 600 000 (Bureau of Labour Statistics, 2016).

In the mining industry, the implementation of automation technology in underground mining operations promoted mining productivity and reduced operating expenses. Automation creates a safer working environment (Atlas Copco, 2017) and involves the use of in-vehicle assistance system (like collision detection) which is on the upsurge. Automation holds the key to more efficient mining industry as the global demand for mineral resources locked deep in the earth increases. Sensor based sorting which has been in use since the 1920's increase efficiency in separating valuable minerals from waste rock. Remote monitoring and control of equipment is used mainly during blasting, drilling and transportation (Calam, 2015). Automated machines used to perform these tasks are faster, more accurate and cover even more are in less time.

Automated systems in the medical industry, has been adopted and replaced medical processes like primary screening in radiography and electro cardiograph as well as the laboratory analysis of human cells, genes and tissues in the diagnosis of diseases and deoxyribonucleic acid (DNA) matching. The automated system is able to carry out these processes at a much greater speed and accuracy (Age Technologies; Fong *et al.,* 2011). Robots are also used for surgical operations with greater accuracy than when performed by a human surgeon, surgical cuts are becoming smaller compared to traditional open surgery, less pain, less risk of infection and less bleeding on the patient. Even more complicated operations are carried out by robotics which in the past were not possible.

The sporting industry, is also benefiting from an ever-growing arsenal of automated systems to increase its efficiency and capabilities. Examples of automation in the sporting industry includes the goal line technology, the retractable stadium roof (which opens and closes as the weather dictates), sports journalism and monitoring and data collection during the game (Corfield, 2016). In the communication industry, automated telephones, switchboards and answering machines have also replaced many telephone operators (Nof, 2009).

Having learnt of the benefits of the implementation of robotics and automation in other industries, application of same the same technologies in the field of CA will greatly benefit the construction industry (Peterson, 2016). Productivity in the manufacturing industry have grown by over 1500% since the inception of robots and automation in the production line (Holt *et al.,* 2015; Tyler, 2017) whereas in the construction industry, productivity have remained stagnant or even decreased (Bock, 2015). The following section will focus on the possibility of using

robotics, automation and AI in the construction and compare the benefits of it with the other industries.

2.6 CONSTRUCTION AUTOMATION

The application of robotics and automation has been the heart of many scientific researches and development for the last century and has contributed immensely in the development of other industries save for construction (Kumar *et al.,* (2016). Robotics and automation which has for many years been associated with the factories and manufacturing industries is now migrating to buildings and construction sites due to the rapid technological advancement which enable them to perform increasingly complex tasks (Frey & Osborne, 2013). Despite the influence of IT in all different sectors, the construction industry is however the slower adopter of it (Department of Science and Technology, 2014; WEF, 2016; KPMG, 2016), with the applicability of automation in the construction industry in real world construction projects very limited (Holt *et al.,* 2015). The general opinion is that despite being a poor innovator of technology, the construction industry is also a late adopter of new technology when it can be a source of innovation (Vaha *et al.,* 2013). The ever increasing use and dependence on computer technology, has made it compulsory for organisations to meet changing situations with globalisation in the construction industry to meet client demands (Bilau *et al.,* 2015). Previous studies widely credit the use of IT as overall being responsible for the increase in productivity levels in all other sectors and it is equally reasonable to assume the same for the construction industry. Recently Kumar *et al.,* (2016) echoed the same sentiments that applying the same technologies in the construction field as in other industries may also be beneficial for the outcome of the construction activities.

Of importance is to investigate ways in which the fusion of technology in the construction industry is likely to yield results and identify areas where automation and robotics can be more relevant (Mahbub, 2012). According to the 2016 Industrial Manufacturing Trends, 25% of the construction work will be carried out by robots within the next five years. This gave birth to Construction Robotics with the aim of advancing construction industry using robotics and automation (Construction Robotics, 2016). Unlike robots used in the manufacturing industry which perform routine tasks in a familiar environment, construction robots are designed to be mobile, manouver in the changing environment and be able to multitask (Oke *et al.,* 2018).

With high levels of skilled labour shortages being reported, smart technology is becoming more important as it allows for construction work to be streamlined thereby efficiently utilising the limited available labour on more important tasks. The construction industry failed to keep up with the new technology and was left legging behind while in the 1990's when the UK economy was booming and most industries become reliant on computers and computer technology to complete tasks (Coe & Jones, 2010). The ability of the construction industry to automate will be vital especially in working areas which threatens the presence of humans. For instance, robots can first be sent to underwater or extra-terrestrial environments to create habitats and await later human travellers. There is actually plenty of room for improvement in all process elements concerning robotics and automation (Ellatar, 2008).

Apart from the need to relive workers of dangerous work environments / ergonomics, automation and AI is also best be suited for work in remote areas in need of development but with limited numbers of engineers (Allianz, 2017). In a study conducted by United Nations Educational, Scientific and Cultural Organisation (UNESCO) it was estimated that at least 2.5 million new entrants in the field of engineering and technicians were required in Sub-Saharan Africa between 2010 and 2015 if the region was to attain the UN millennium development goals of improved access to clean water and sanitation. The region fell well short of this ambition and is still falling (Selvakumaran, 2016).

Due to the physical demands of work in the construction industry, the author tracked down the history of the use of robotics and automation in the construction industry to help easy handling of equipment and material on construction sites.

2.6.1 BACKGROUND TO CONSTRUCTION ROBOTICS AND AUTOMATION

History and contemporary records shows that there has been always some form and level of automated construction methods used in time immemorial from as early as 1100's. Table 2.3 below chronicles the historical development of CA from the early stages of industrial revolution to the latest trends in automated project control and decision support systems.

Humans have always relied on the use of machines especially for strenuous work or activities that pose health hazards. The use of machines is meant to speed up construction processes and to relieve people from ergonomics working positions. This is evident from Table 2.3 below.

Table 2.3: Historical Development of Technologies Related to Construction Automation

Period	Construction robotics and automation tools developed
1100s	Pulleys & levers
1400s	Cranes
1500s	Pile driver
1800s	Elevators, steam shovels, internal combustion engine, power tools, reinforced concrete
1900s	Slip-form construction
1910s	Gantt charts, work breakdown structures (WBS)
1920s	Dozers, engineering vehicles
1930s	Prefabrication, hydraulic power, concrete pumps
1950s	Project evaluation and review technique (PERT), computers
1960s	Time-lapse studies, critical path method (CPM)
1970s	Robotics, computer-aided design (CAD), discrete-event simulation
1980s	3-D CAD, 4-D CAD, mass production of personal computers, spread sheets, relational databases, geographic information systems (GIS), large-scale manipulators
1990s	Internet, intranets, extranets, personal digital assistants (PDAs), global positioning systems (GPS), barcodes, radiofrequency identification systems (RFID), wireless communications, remote sensing, precision laser radars (LADARS), enterprise resource planning (ERP), object-oriented programming (OOP), concurrent engineering, industry foundation classes (IFC), building information models (BIM), lean construction (LC)
2000s	Web-based project management, e-Work, parametric modelling, Wi-Fi, ultra-wide band (UWB) for tracking and positioning, machine vision, mixed augmented reality, nanotechnology

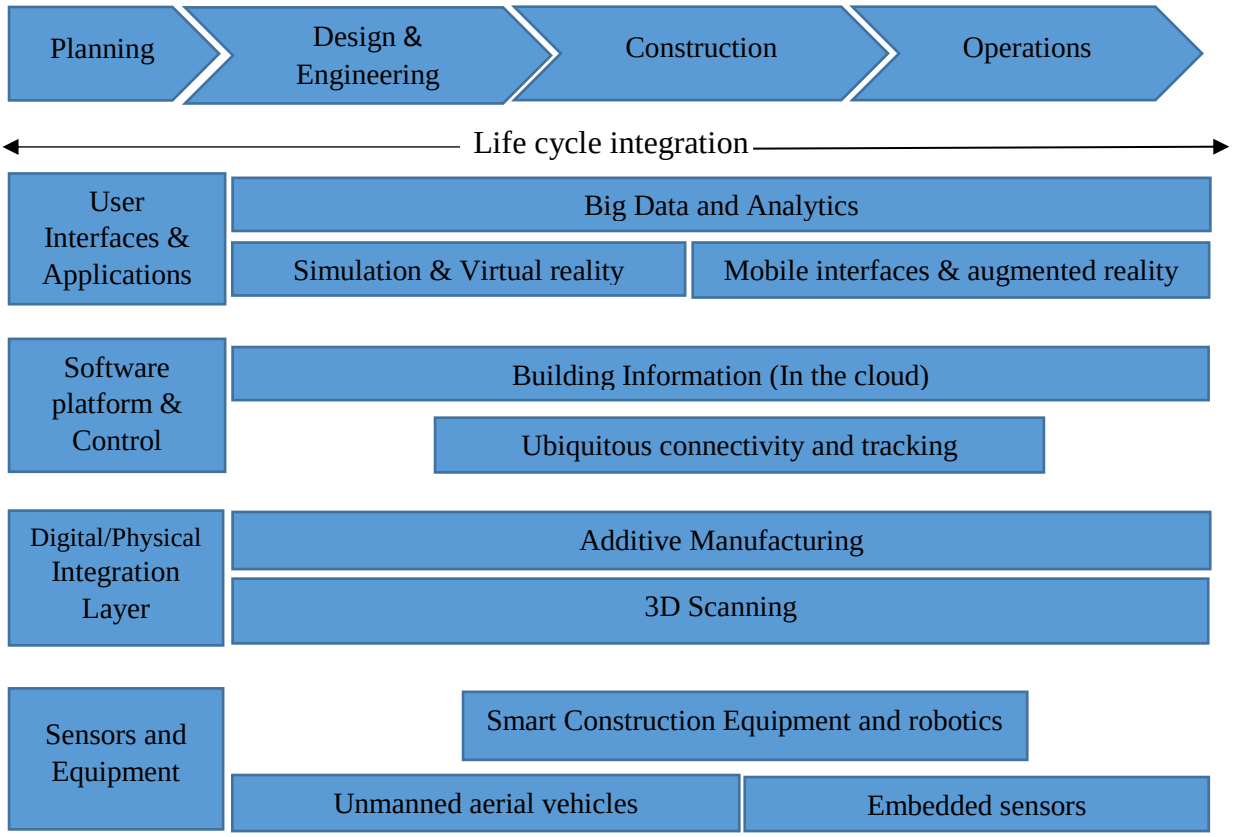
Source: Vaha et al., 2013

The development in traditional construction methods and processes started where site utilise crude tools to get the work done. From crude tools, construction sites started then to mechanise and incorporate machines in the production line. With the invention of computers, different software have been developed to aid construction design, planning and integration and lately with Revolution 4.0, the construction industry is gradually going digital (Osunsanmi *et al.*, 2018). The aim of these improvements is on enhancing construction project delivery and performance.

2.6.2 APPLICATION OF CONSTRUCTION AUTOMATION

Automation in the construction industry is very broad and encompasses all stages of construction from initial planning and design through the construction of structures, operation and maintenance until the disposal of the asset (Tejankar, 2015). To survive in today's competitive market, many firms are beginning to incorporate automated equipment, means and methods in their regular construction operations (Vaha *et al.*, 2013). Automation principles are applicable to building, civil and modular construction. The current vibe of industrialisation of building construction started around the 1960's in Japan with the advent of prefabricated houses made from wood and steel and the trend continued with Japan leading in the R&D of automated machine as a means of sustaining the industry when faced with skills shortages and pressure to provide decent accommodation to the citizens (Pan *et al*., 2018).

Fig. 2.5: Digital Technology in Engineering and Construction Industry Value Chain.



Source: Gerbert et al., 2016

Figure 2.5 depicts the integrated use of automation and robotic techniques in the life cycle of a project, from the planning right through to the operations and maintenance of the project. It shows the relevance of digital technology along the engineering and construction industry's

value chain. From the value chain above, the use of robots and automation is not only limited to the methods and processes of construction, but it can also be utilised during the planning and design of the project (Kim *et al.*, 2015).

As is depicted in Figure 2.5, CA has two main branches; soft and hard. Soft or programmable automation which includes the use of software designed to accommodate product configurations (Shakely, 2014). It encompasses the use tools such as Autodesk's Generative Design, Doxel, Artificial Neural Networks, Building Information Model (BIM) and Navis to manage and integrate the design and construction processes of projects. Soft automation also termed design automation (Sandberg *et al.*, 2016) is controlled by the use of computers and can be reprogrammed to adjust its operations for different products / projects.

To further explain the value chain above, the use of soft automation during the design, preconstruction and construction stages is explained below;

Digital Design - Assist with document control and integration as design progresses from sketches to construction documents. Table 2.4 below outlines the potential use of AI during the pre-construction phase and the accrued benefits from using it.

Table 2.4: Application of Artificial Intelligence during Pre-construction Phase

Estimating	**Construction relationship management**	**Market intelligence**	**Marketplace:**
Automate and improve the accuracy of bid estimates	Provide dashboard for business development pipeline	Gather and analyse information gathering from past projects and competitor performance	Create a platform for stakeholders to pre-qualify, evaluate and select partners

The recent developments in the field of design automation and its application during the design phase of a project has the ability to show the effect on cost, equipment availability, staff capabilities, project buildability and facilitate re-use of successful solutions instead of reinventing the wheel on every project. Design automation makes it easier to generate solutions whilst trying the "*what-if*" solutions which are more cost efficient than in real life (Sandberg *et al.*, 2016). All these trials are done while the project is still in design stage thereby eliminating the possibility of demolishing and redoing the work once the work started on site. Table 2.5 outlines the potential use of AI across the construction phase of the project.

Table 2.5: Application of Artificial Intelligence during Construction Phase

Design Management	**Scheduling**	**Materials Management**	**Field Productivity**	**Quality Control:**
Visualize drawings and 3-D models on site, on mobile platforms	Create, assign, and prioritize tasks in real time	Identify, track, and locate materials across the supply chain	Track crew deployment in real time for the effective staff management	Inspect remote sites through, drones, pictures and tags shared through app
Update blueprints in the field with mark-ups, annotations, and hyperlinks	Track progress online Immediately deliver work plan and schedule to all workers		Manage project staffing across skilled trades Track on-site productivity at a trade and worker level	Update and track live punch lists across projects to expedite project closure

There are cost benefits as outlined before that accrue from the application of AI and automated techniques. Table 2.6 shows the impact of the use of digital technology on the overall project costs and on construction time should digital technology be utilised right from the conceptional design phase of a project. With the increased demand on resources, complexity of projects and cost sensitive on the part of the clients, clients now look for value for their money. Robotics, AI, and the Internet of Things have the potential to reduce construction costs by up to 20 % for highway, 14 % for power plant and 12% for office building projects.

Table 2.6: The Impact of Digital Technology on Engineering and Construction Projects

	Office Buldings	**Highway construction**	**Power Plant construction**
Impact on total life cycle costs	-15%	-16%	-12%
Design and Engineering costs	0%	0%	-5%
Construction costs	-12%	-19%	-14%
Operation costs	-18%	-10%	-10%
Impact on construction time	-30%	-23%	-15%

Source: Gerbert *et al.,* ***(2016)***

Hard automation is the use of robots or machines that are designed to perform specific and repetitive tasks. Because hard automation is designed and customised for the specific task at hand, it is often uneconomical to use and most of the time flexible automation is used. (Shakely,

2014). This is a robot or machine that has been designed to alter the line of production to accommodate a variety of product mixes. It typically includes robotic arm capable of flexi movement with interchangeable heads that can multi-tasks. Hard robotics includes the use of machines, drones', sensors and Radio Frequency Identification (RFID) to automate various construction activities. While prefabrication and BIM occupy a large limelight when it comes to innovation in the building and construction industry, hard automation is mostly less discussed (Heaton, 2015). Machines for hard automation can be used for both off-site prefabrication and on-site construction activities. Traditionally limited to the soft automation, a new generation of robots have been developed which can move, learn and interact with people and other machines and have dexterity and flexibility.

2.6.3 TYPES OF AUTOMATION TECHNOLOGIES THAT CAN BE USED IN THE CONSTRUCTION INDUSTRY

For the understanding and implementation of CA, Bock & Linner, (2015) grouped new design, innovation management methodologies and enabling technologies as follows those that are robot-oriented design, robotic industrialization, construction robots, site automation and ambient robotics. As already highlighted, CA can be introduced at different levels of construction development (Gerbert *et al.*, 2016; McKinsey, 2017) and it can be broadly broken down into and implemented during the digital design, preconstruction and construction phases of a project depending with the availability of resources.

- Digital design automation
    a) BIM
    b) Master Models
    c) Simulation
- Construction automation:
    a) Surveying and Site inspection tools
    b) Positioning automation
    c) Site Monitoring
    d) Machine automation

2.6.3.1 Digital Design Automation

a) **Building Information Modelling (BIM)**

BIM can be defined as the digital representation of the physical and functional characteristics of a facility including quantities and properties of the building components and it uses different

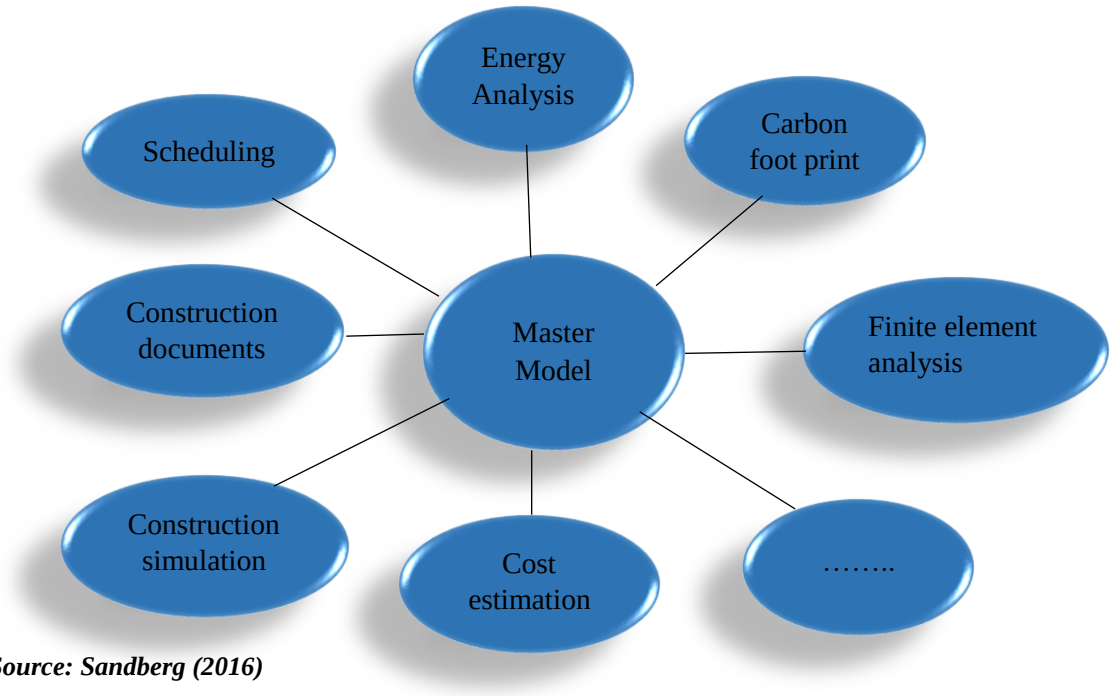
software in designing and presenting it (Khare, 2013; Vaha *et al.*, 2013). The idea behind the concept of BIM is to virtually present and complete the project and have all the aspects incorporated before physical construction begins (Holt *et al.,* 2015). The level of preplanning can extend to include the spatial coordination of all the materials, labour and construction sequencing and allows to virtualise the planning of how the building will be used and reused by the owner after construction. BIM has the main advantage of being manipulated to simulate different construction scenarios (material used and or construction methods) and select an optimal one out of them at predesign stage before any meaningful work starts on site (Faltinsky & Tokuvona, 2018). Because the construction process involves different stakeholders at different phases of the project life cycle, the premise of BIM is to allow collaboration by these stakeholders to insert, extract, update and modify information before the development of the physical project. It ensures that stakeholders can share project data at any stage of the project life cycle (Vaha *et al.,* 2013). They went on to say that, BIM has the capability of being used in exhibiting the whole building life cycle, including process of construction and facility operations and to take advantage of its information even when demolishing the structure at the end of the life cycle. If every member in the collaborating team has free access to the project information, every member of the team can better manage BIM and project delivery process to prevent any possibilities of reworks once physical construction commences.

b) **Master Model and Simulation**

Master model are aimed at building and coming up with a geometrical illustration used for CAD, computer aided manufacturing and computer aided engineering. With every change, the geometry illustration is automatically transmitted to all domain specific models (Sandberg *et al.,* 2016). Simulation on the other hand is defined as the art and science of developing and experimenting, evaluation and redesigning of construction projects with computer based representation of construction systems to understand their underlying behaviour (Bajpai *et al.,* 2015). As civil engineering projects involves a lot of money, labour and time, failure or delays in delivering the project can result in great losses. Simulation therefore assists in understating the implications on design and ideas before actual construction takes place (refer to figure 2.6).

Simulation provide tools to appraise the performance of construction projects under an alternative resource allocation and process planning by modelling the dynamic interaction between resources and processes (Sandberg *et al.,* 2016). It should be noted that these design automation techniques are interlinked and can be used in conjunction with each other.

Figure 2.6: Relationship between Design Automation Techniques



Source: Sandberg (2016)

2.6.3.2 Construction Automation

a) Surveying and Site Inspection Tools

With construction sites covering vast areas of land and buildings now shooting stories high into the sky, site inspection by foot can take days to complete. But with automation (drones), the same task can be done by one pilot in a few hours (Recode's Code, 2017). Site inspections are conducted to analyse safety precautions and site progress. Due to the time consuming and expenses in gathering survey data, very few companies would bother perform the exercise precisely. Data collection with drones on the other is a quick streamlined process and those firms that uses automated surveying equipment may end up carrying out multiple surveys to account for the changes that might be occurring on the site over time to effectively manage costs (Land Point). Tunnel Continuous Set out used in roads and train tunnels automatically performs the setting out. It integrates a scanning device to survey the excavation front and a laser projector that continuously displays the actual tunnel excavation against the planned tunnel section.

b) Positioning Automation

For centuries the tasks for the designing in the construction industry has been heavily relied on labour. Satellite positioning technology now enables the automation of the surveyor's tasks

resulting in increased productivity and reduced costs. One such technology is the use of Global Positioning System (GPS) a tool that aids CA (Nichols, 1996).

c) Site Monitoring

The monitoring of site activities is very crucial for many, because of the many participants involved in the construction industry. Stakeholders need to be constantly aware of the project status for real time decision making and planning ahead. Site monitoring can be done using Ultra Wide Band (Teizer & Sofer, 2007). Smart technologies are now designed to make construction sites more efficient and to streamline project schedules. The use of smart concrete sensors for example helps eliminate the need for time consuming procedures like lab tests and embrace real time temperature and maturity monitoring.

d) Machine Automation

Construction Robotics (USA) leaders in construction robotics have developed a range of robotic equipment for use in the construction industry. Under their trade name, they have developed the Semi-Automated Masonry (SAM). The machine is capable of laying three times as many as a bricklayer was developed in 2015 to leverage human jobs (Peters, 2015) and can lay between 800 and 1 200 bricks per day. In Australia a prototype machine Hadrian was designed by Fast Company. Hadrian is rumoured that it can build a house of 15 000 bricks in just two days. They also develop brick road paving machine (Tiger Stone). Tiger stone uses built-in sensors and is capable of staying on track. It can lay at least 400m^2 a day of stone paving compared to 100m^2 which can manually be laid. Remote controlled demolition is the robot that is used to carry out controlled demolition of structures with the operator at a safer distance. Architectural Navigation robot uses CAD drawings or BIM models to navigate a construction site completing layouts and measurement tasks.

In South African construction industry there is evidence that automation equipment is in use. The Robotic welder was launched in 2010 (Construction News, 2010), asphalt paving machine used in road construction, robotic painting, sheet metal bending, concrete handling machines, excavators and drilling machines. During the construction of the Gautrain Rapid Railway system, the Three Boom Jumbo Drilling Machine and the Tunnel Boring Machine (TBM), were used for the underground tunnel between Killarney and Rosebank. In the Lesotho Highlands Water Project (Katse Dam) a similar TBM was used and completed the 22km long tunnel 20 months ahead of schedule. The drilling machine was used for drilling blast holes for

explosives in dolomite area as directed by a survey laser beam on the exact spot where the drill hole was to be (Gautrain, 2007).

2.6.4 AREAS OF AUTOMATION

Automation in the construction industry can be used virtually in every construction, both civil works like roads and runways construction, structures and building construction, ports, tunnels, factories and industries, and it may be implemented at different construction stages be it at the design stage, for material handling, physical construction or during the maintenance phase of the project. With the digital journey at the centre stage of the construction industry and Revolution 4.0, applications within design automation are growing making the design and development process less time consuming and more organised. Technology available in the construction industry include BIM, connected jobsites and smart testing devices. When integrated within the design process, design automation applications may have positive design impact on cost, availability of equipment and staff and the buildability of the project (Sandberg *et al.*, 2016). Successful solutions may be reused rather than reinventing the wheel when working on a new project. Several solutions may also be generated with different trials. Integrated IT helps evaluate life cycle impact of early design decisions. With technology it is now possible for engineers and contractors to streamline the design and building processes, optimise project schedules and increase safety, sustainability and efficiency on sites.

Another area of automation deals with the prefabrication and mass production of building components. Automation can be used just like in the manufacturing industry. After mass production then comes automation for handling of building components. Material handling seeks to provide a smooth flow of machinery for handling thereby increasing productivity especially with high rise construction (Howe, 2000). With the use of offsite prefab manufacturing, building components are manufactured in factories away from the construction site and then transported to site where they will be lifted up and assembled on the building structure. During assembling, different automated techniques will be utilized in the process like automated guide vehicles (AGV) and robots.

Automation can also be applied on traditional building methods. This is despite the perceived idea that construction projects tend to be unique and prototypical. A closer look reveal that this uniqueness is only on the function, organisation, project and activity. But the basic level of construction process, process and motion are repetitive for every construction project and this

amenable the use of automation principles. The use of adaptive machinery capable of handling a variety of tasks rather than specialised machines may be the best idea (Howe, 2000).

2.7 REASONS FOR AUTOMATING CONSTRUCTION OPERATIONS

In order for the construction industry to meet up with the increased demand for infrastructure developments due to urbanisation, the industry needs to shift from the tradition construction methods to the modern ones to improve productivity and performance (Oke *et al.,* 2018). Stakeholders in the construction industry have been advocating for the adoption of the use of robotics and automation to meet the growing demand for populace, (Strukova & Liska, 2012). Construction Executive, (2018) and Bock *et al* (2012) reiterated the same in that if construction's power players are to choose to proceed responsibly, automation and digital technology in the construction industry will aid the skills shortages and rising labour costs by streamlining construction processes and empowering workers.

The adoption of robots and automation is aimed at the betterment of the lives of the human labour who, otherwise are at the risk of getting injured while working on site. And with the development of computer technology, robots can be used for more complex tasks (Kim *et al.,* 2015). From the Project Manager's view point, project success is achieved when the project performance indicators are at an optimum value. That is to say, when the project is completed within the project matrix; the lowest possible cost, highest quality standards and within time schedule (Ellator, 2008). The application of CA is aimed at raising building project performance, save the client on costs and preserving the environment.

When it comes to improving productivity and profits, automation technologies may be the last resort since there is little hope in reversing the long standing issue pf skills shortages in the construction industry. Fusion and combination of robotics and encouragement of the use of prefabrication may present opportunities for construction to boost in the next decade (Tyler, 2017). Although there are many reasons and push factors for the adoption of smart technology on construction projects, one of the reasons is to combat the effects of skills shortages (Geniebelt, 2018; Mahbub, 2008) as smart technology is aimed at making the work more efficient and streamline project schedules. With many of the sites still physically tracking down work, using paper trails, emails and phone calls to exchange and access information, this results in missed deadlines and overspending. This is according to the National Institute of Standards

and Technology (2018) which reported that the construction industry yearly wastes a staggering US$15.8 billion due to lack of efficient information management systems.

The main reasons for motivating for robotics and CA are improved productivity, quality and reliability, safety, enhancement of working conditions, savings in labour costs, standardisation of components, life cycle cost savings and simplification of the work force (Nof, 2009). He went on to state that, because construction projects are distinctive in nature as such implies periodic mobilisation of construction equipment, materials, supplies, personnel and all temporary facilities at the beginning of every construction project. Skilled labour shortages due to either economic fluctuations or geographical considerations make the adoption to project based means and techniques even more challenging. The possibility of automating construction processes to overcome this transition to project based demands. Offsite manufacturing and assembling helps overcome the difficulties in the delivery of supplies.

Stormer *et al.*, (2014) outlined the role of the business and the economy, politics and society, technology and innovation, resources and the environment and society and the individual as trends that are driving future jobs and skills. The high accident rate on construction sites calls for the need to move from the traditional construction methods. The construction industry in the country has the third highest on fatality rates after fishing and transport sectors (StatsSA, 2016), with many of these accidents being attributed to human error, risky work practice and interaction between humans with equipment, materials and tools, robotics and automation brings about safety in the workplace. This high figures of construction injuries and fatalities is an indication that the industry needs to adopt new alternative construction methods as a way to improve site safety. Some of these efforts advocate on the use of machines to complete repetitive tasks.

CA helps cut unnecessary construction costs while at the same time improving quality and productivity on construction sites. The use of digital technology in the construction industry should therefore be viewed as the cornerstone in the construction industry sector reforms to productivity, efficiency and quality of the end product (CITB, 2018). If correctly implemented, it can also help in attracting, retaining and inspiring younger generation to consider construction work as a career of choice. Different types of robotic equipment have been applied during the design and construction phases in an effort to improve quality, productivity and reduce costs and material waste on sites (Gatton & Kearney, 1989; Ellator, 2008).

In the last four decades, various indicators (growth, performance, defect rates and productivity levels) have all suggested that traditional construction methods have reached their limits (Bock, 2015; Folkesson & Lonnroos, 2018) and in order to overcome these limits, there is a need for the adoption of alternative construction methods for future projects, what the manufacturing and service industries have implemented with a record of success; automation in their production lines. Over the years, productivity in the construction industry has taken a nose dive compared with other sectors (Sadique & Mahesh, 2016), further indicating that these convectional construction methods have reached the limits. This decline in the productivity has been witnessed even in the developed countries (Bock, 2015; Sadiquel & Mahesh, 2016) and one way of addressing the issues faced in the construction industry is through increased automation and integration of the design, modelling and process control (Pandey *et al.*,2006).

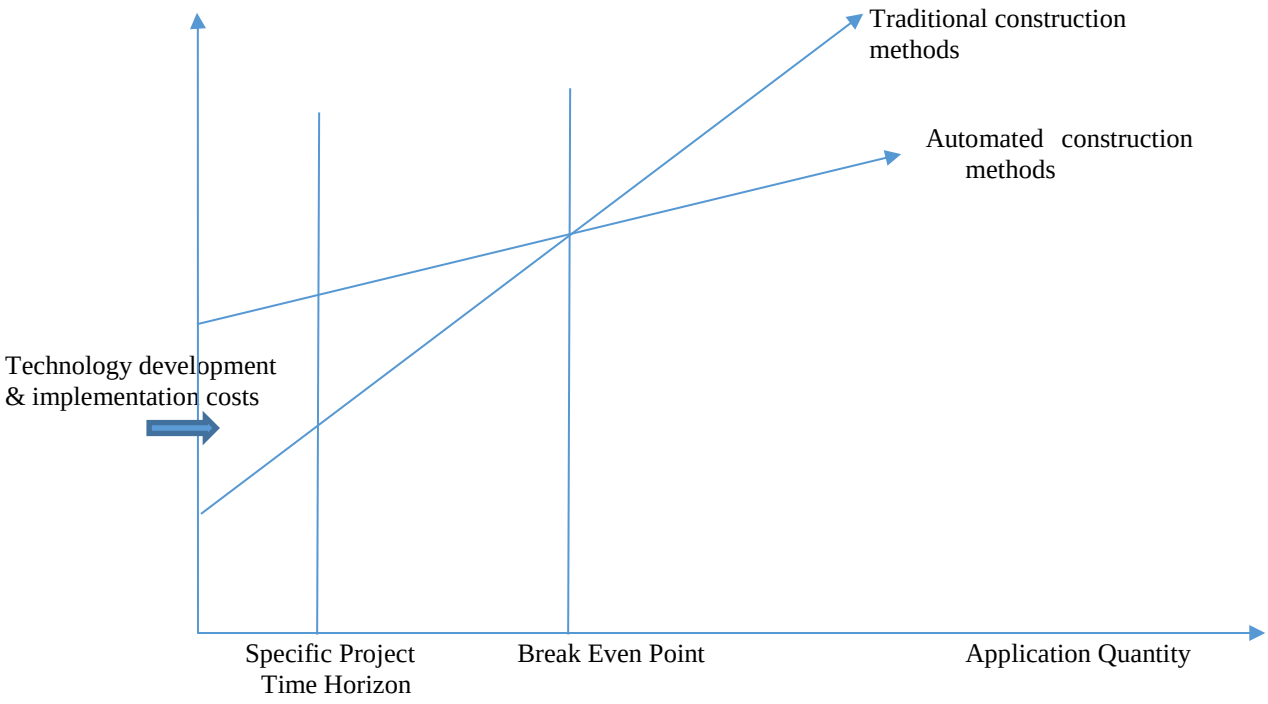
In a democratic country where labour has a voice and strikes being regular on construction sites with the potential of bringing work to a standstill (case of Medupi and Kusile Power Stations in 2011 and 2014), this tends to reduces the use of machines and automation on sites. Labour unions view these technologies as a way of getting rid of workers (Yaghoubi, 2013) increasing unemployment in the process. At the same time hiring more workers is not an option if a firm wants to maintain a profitable margin (Bizconnect Standard Bank, 2017). Although automation has many potentials, the SA construction industry tends to shy away from pursuing it. This is so because the workers now have a voice in the democratic SA and strikes are common on sites and once erupts, it may bring the activities on site to a standstill. There is a common perception that businesses should not opt for automation at the detrimental of the poor and unemployed. Rather than opting for automation, business and government should continue to seek creative solutions to solve the issues (Dialogue, 2017). EPWP with the support of the ILO promotes lour intensive construction as a way of continuously create employment among the unemployed youths. We have to employ people in order to skill them.

2.7.1 BARRIERS TO AUTOMATION IN THE CONSTRUCTION INDUSTRY

While advanced CA technology undoubtedly offers great potential and opportunities in the industry it has not been significantly accepted for use. Its full implementation remains a greatest challenge for engineers and management (Singh *et al.,* 2017). Despite the advantages and the benefits brought with the use of CA, automation remains lagging in the construction industry when compared with other sectors (Healy *et al.,* 2015). The construction industry remains

lagging technologically when compared with other industries. Unlike in the manufacturing industry where a product is intended for mass production, construction products (or structures) are usually once-off and unique (Vaha *et al.*, 2013). One of the primary challenges in the introduction of automation in the construction industry has to do with the cost and benefit analysis linked with a specific robotic application to suit each project (Ellator, 2008).Figure 2.7 illustrates this cost and benefit analysis of using robots.

Figure 2.7: Illustration of the Economic Comparative Analysis of Using Automation



Source: Author's illustration of the cost and benefit of automation

From the illustration in figure 2.7, due to the treatment of construction projects as distinct and separate profit centres, any investment made on the project in terms of R&D or plant has to be paid off within the life time of the construction period, that is to say any particular automated construction method is deemed commercially viable if its economic breakeven point lies within the time horizon of the project otherwise it will not be considered.

The technical and economic viability of the robotic application needs to be carefully evaluated. The technical viability being determined by the ergonomic evaluation of all the necessary procedures to be taken to complete a work task and by analysing the requirements if the work was to be done robot control and process monitoring. The economic viability is determined by the cost and benefit analysis of the development and implementation of the robots. Figure 2.7 above illustrates this cost and benefit analysis.

Some of the barriers for the full application of automation in the construction industry has to do with the resistance by the industry to adopt new technologies (Mahbub, 2008). Lack of support staff to manage new technology (Healy *et al.,* 2015). Hewit & Gambatese (2002) identified barriers to automation as within the design phase of the project. The barriers identified include the uniqueness of the construction industry and that the industry does not present the same set of problems across all sites. Mahbub (2012) sited high costs/financial obligations of securing and sustaining new technology, the fragment nature of the industry, difficulty in the use and understanding of the technology (lack of skills which can implement new technology). He noted that some of the technologies are not locally available and at times there is resistance by the workers and labour unions to adjust fearing loss of employment. This perception had been squashed. Previous studies have shown the positive correlation between automation and employment (International Federation of Robotics, 2017). Due to the increase use of computerisation, the overall labour demand increased by more than eleven million jobs between 1999 and 2010 in the European Union countries. This suggests that, the job-creating effect of robotics and computers overcompensated the job-destructing effect. While over 800 000 low skilled workers in the UK lost their jobs due to technology advancement, 3.5 million high-skilled new jobs were created and for countries with high robot density like Germany, Japan and Korea, have the lowest unemployment rates.

2.8 REASERCH GAP

The failure by the construction industry to embrace innovation quickly has resulted in stagnant productivity that is negatively affecting the economy, society and the environment. The main contributing factor to this is the on-going industry-wide shortage of qualified construction workers to meet up with the demands (WEF, 2018). This industry-wide skills shortage has challenged the implementation and management of construction projects which in turn has had an effect on the project triangle (cost, time and quality) of the end product. The skills shortage has also hindered the implementation of new digital technologies which could aid in improving productivity. There is need for stakeholders in the industry to cooperate and nurture talent through upskilling, attracting new talent to the industry and promoting new technologies (Vaha *et al.,* 2013; Oke *et al.,* 2018; WEF, 2018) in order to close the existing talent gap. In order to attract best recruits and be considered a career of choice, the industry needs to be equipped with the right skills and knowledge. But if the industry continues falling behind in its adoption of digital technology, the construction industry risks being marginalised and losing on new

generation of talent to other sectors of the economy who are fond of working with computers and new technology (CITB, 2018).

Previous researches had been carried out on the causes of skill shortages and the remedies in the construction industry (Mukora, 2008; Windapo, 2016; DoL, 2009; DHET, 2016) but still the suggested solution seem not to yield the desired results as the country is still faced with skills shortages. In 2010, the G20 leaders assured their support for vigorous training approaches to overcome challenges and fostering strong sustainable and balanced growth in each country and globally (ILO, 2010). One challenge faced with all G20 nations is to instantaneously implement education and training that is responsiveness to changes in skills requirements and as well as improving access to training and skills development. This is to respond to the many studies and commentaries that keep on pointing to a serious growing skills mismatch (World Bank 2018).

With the researches carried out suggesting the need for education and training to curb construction skills shortages, in 2000 CETA was established under the Skills Development Act 1998 and the SA government in 2009 established a new ministry of Higher Education and Training. And most of these researches suggest the need for training and apprentice as a solution to these skills shortages. While it is good for the government to be pushing for more apprenticeship programmes, this move is only but part of the solution to skills shortages (CITB, 2018). Despite these suggested solutions for the DHET and SETA skill shortages remain (Rasool & Botha, 2011). This is so for both the local market and in the global market. Perhaps it is time to shift the attention from education and training to provide the solution of the skills shortages and take a paradigm of machines and automation to augment the skills shortages.

With increased global competition on limited resources, businesses must keep up with trends when it comes to technological advancement and innovation. According to the Manufacturing, Engineering and Related Services SETA, shortage of skilled labour is the major contributing factor to the low levels of digitalisation of the construction industry, low levels of productivity and lack of competitiveness and high production costs in the country (Nyatsumba, 2017). He went on to say that businesses must be willing to invest in technologies that helps reduce on production costs and ensuring that they remain competitive both domestically and internationally. But again it's not just about investing in technology, the trick is on the alignment of technology to the desired performance (KPMG 2017). With up to 50% of the costs in construction attributed to labour related costs, skills shortage escalates the costs of

projects (Pistorious, 2017). This provides impetus for automation and mechanisation in the construction industry, which can also result in higher productivity. The importance of adopting automation technology is the need of today's infrastructure projects and construction firms to boost productivity levels and improve on quality of work (Tejankar, 2015). But this is not possible where an economy does not have enough trained personnel particularly when it comes to engineering professionals (Business Report, October 2017).

This is not the first time a research on construction skills shortages is carried out. Previous researches were centred on education and training, but it is clear that these proposed solutions are failing to effectively address the issue as skills shortages are still being experienced in the construction industry. This goes to show that, there is still a gap to be considered when it comes to addressing skills shortages in the construction and it is at the back bone of gap that this research is conducted to investigate the potential of using automation and AI to combat construction skills shortages.

2.9 SUMMARY

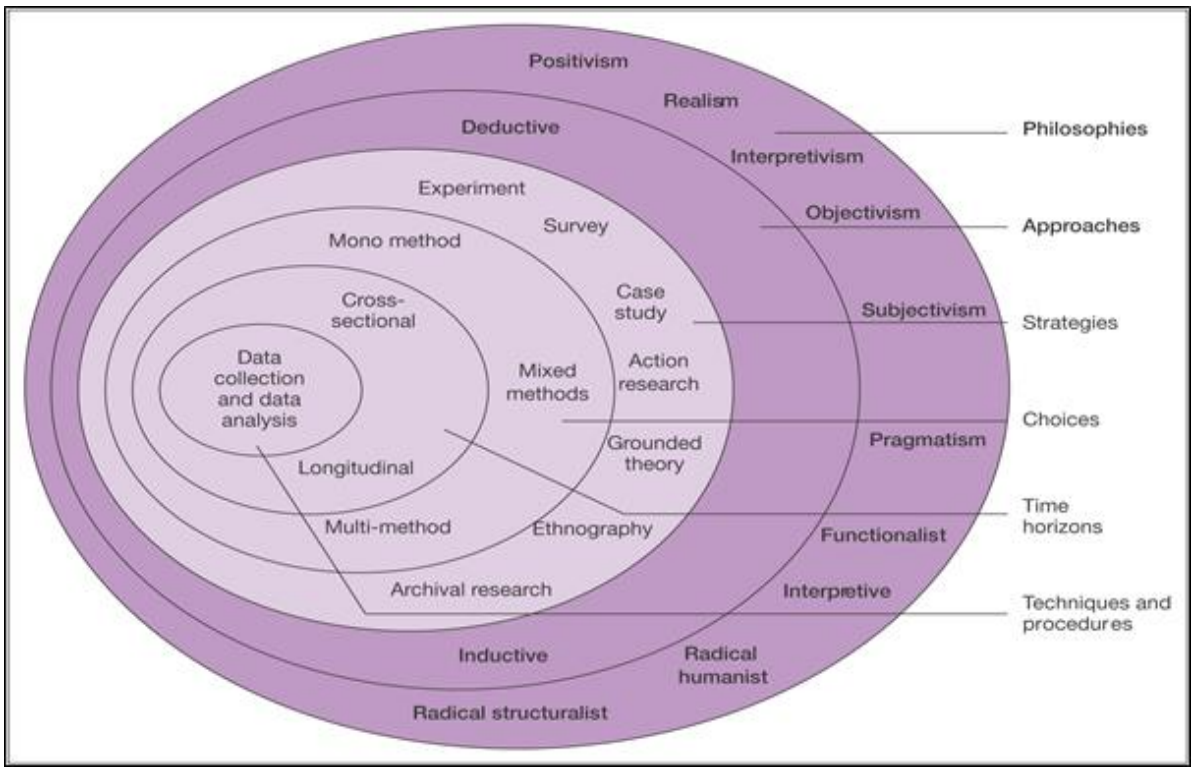
Preceding from chapter one Chapter Two provides an overview of various literature and documentations on global and local construction outlook with regards to skills shortages and the challenges faced in ensuring adequate skills supply. The chapter discuss the implementation of automation in other industries, the evolution and development of CA over the years. The chapter provides the appreciation and the potential use of construction automation and AI in curbing skills shortages. The gap between the body of knowledge and the aim of the study was identified which needed to be addressed in order to meet the objectives of this research. The following chapter outlines the methodology to that will be used to facilitate the answering of the research questions and closing the gap between the body of knowledge and the objectives of this study.

CHAPTER 3: RESEARCH METHODOLOGY

3.0 INTRODUCTION

The first chapter clearly set out the research questions and objectives, the previous chapter, chapter two critically evaluated both the empirical and theoretical literature in line with the set objectives. Subsequently, the third chapter highlights the adopted methodology that is intended at achieving the set objectives. According to Fisher (2010), research methodology entails the study of all methods, approaches and philosophies that the researcher may use to carry out the investigations. The main aim of the research methodology is to bridge the gap between research problem and the perceived solutions (Dadhe, 2016). Similarly, the research methodology aims at systematically solving the research problem and as such can be referred to as the structured process of conducting a research which encompasses the research design, data collection and data analysis (Kothari 2004; Saunders *et al.*, 2016). Research design has been defined by, Bryman & Bell, (2003), as a plan of activities to be undertaken by the researcher and determine the source and type of information to be selected based on the research questions and research purpose. To help describe the research design process, Saunders *et al.*, (2016) came up with "*the research onion*" which shows six stages of research design as shown in Figure 3.1.

Figure 3.1: Research Design according to Saunders et al., (2016).

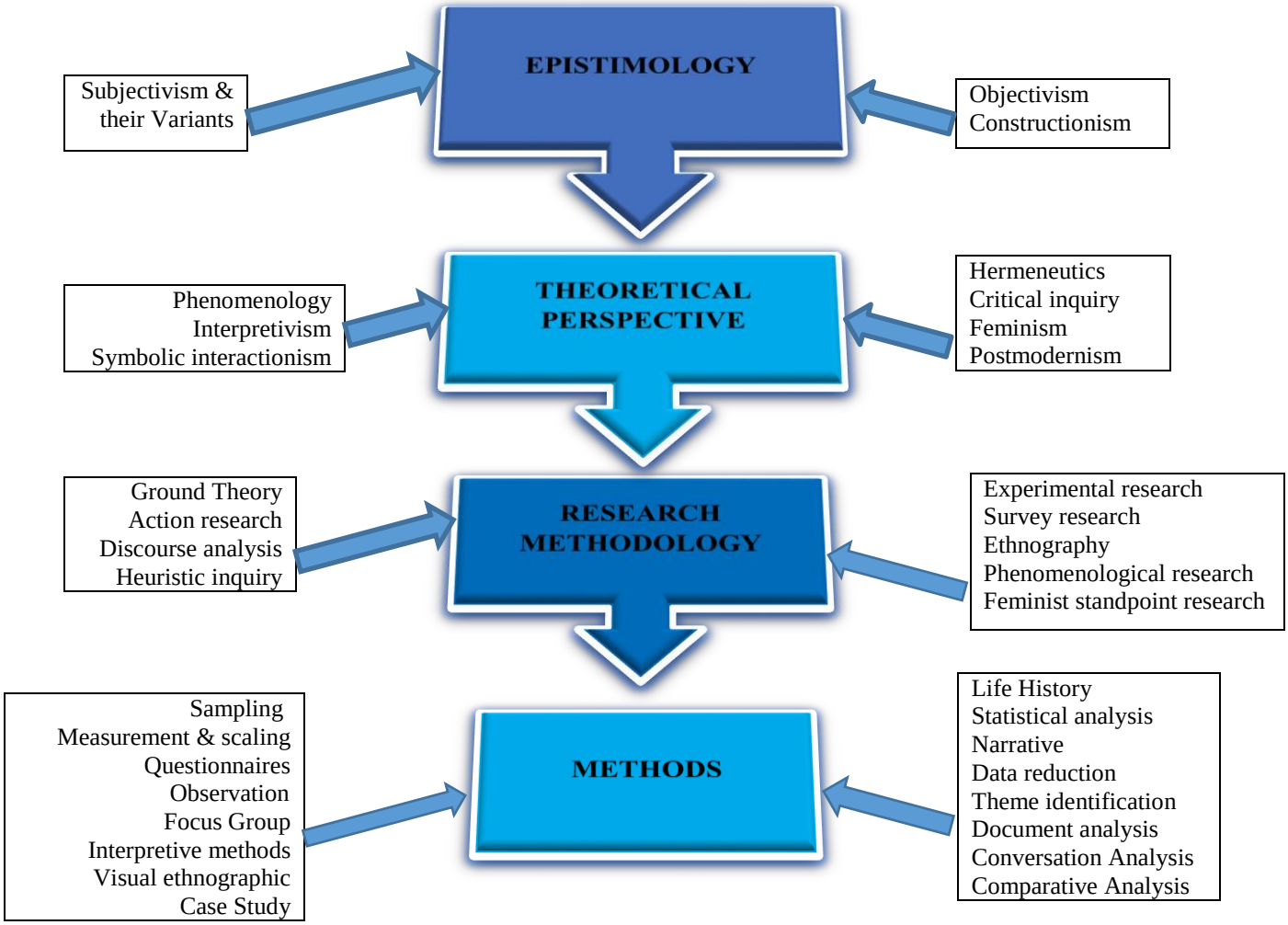


Source: Saunders et al., (2016)

In coming up with the research methodology, the researcher was guided by the principles as laid down by Saunders *et al.,* (2016)'s "*research onion*" as it considers most of the methodology aspects on a broader perspective. The *"research onion"* affords a summary of all the significant issues that have to be considered and reviewed prior to tackling any research.

Contrary to the views of Saunders *et al.*, (2016) on the research design process, Crotty, (2007) broke down the process into four main stages: Epistemology; Theoretical Perspective; Research Methodology and Research Methods. Figure 3.2 is the presentation of the research design according to Crotty, (2007).

Figure 3.2: Research Design According to Crotty



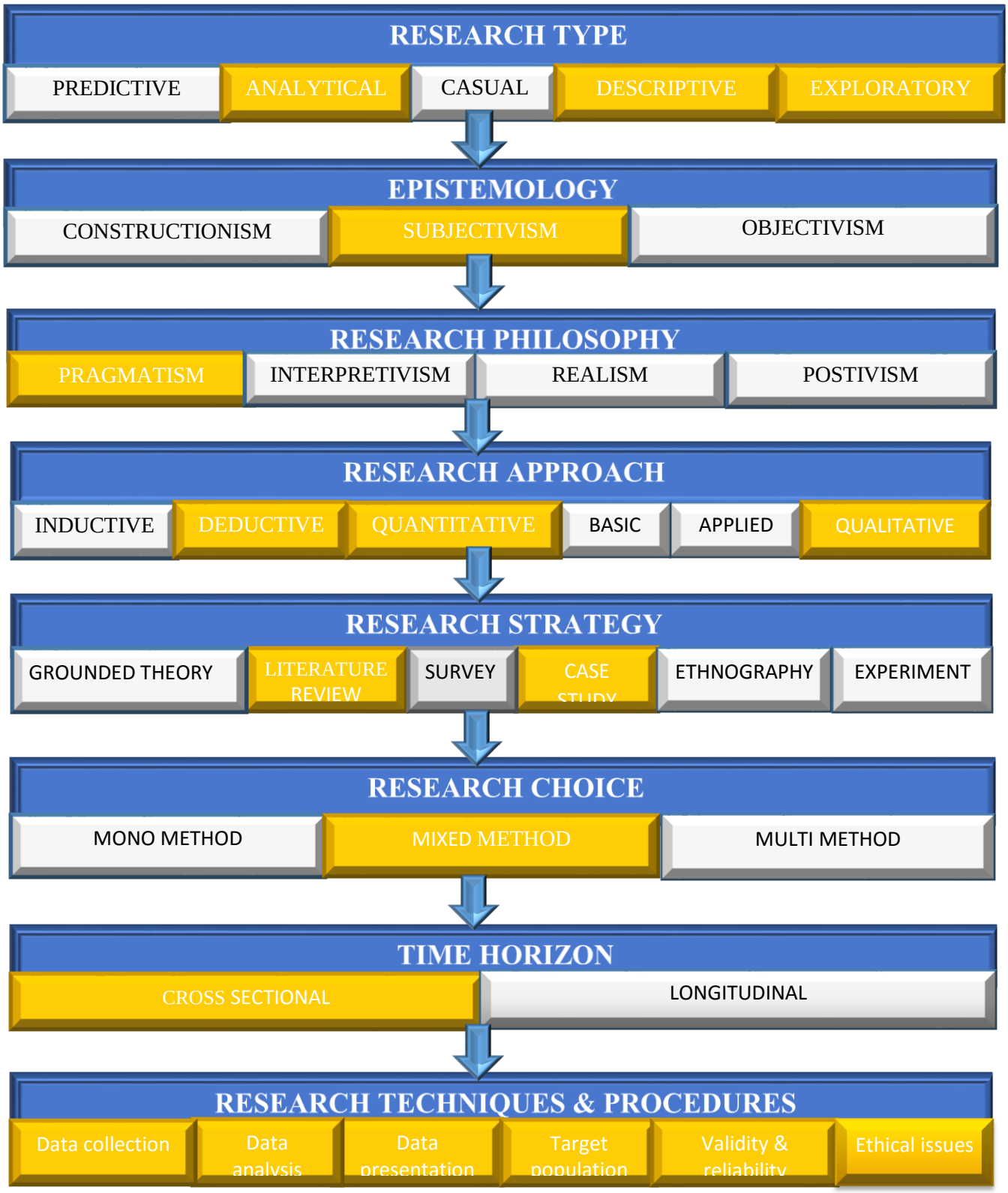
Source: Crotty (2007)

It is evident in Figures 3.1 and 3.2 that, different scholars do not agree on the names and/ or stages to be followed incoming up with the research design. This is evident as renowned authors seem to clash on the names and stages. A classic example would be, where Bogdan & Biklen, (2010) classified basic and applied research as research types, while Collins & Hussey, (2003) describes the same as research approaches and Kothari, (2004) gives exploratory and descriptive research as research types. Contention is also seen by some of the renowned authors on books that cover research, namely Saunders *et al.*, (2016) and Crotty, (2007). However to incorporate views of other authors, the researcher came up with an all-inclusive design by modifying the model by Saunders *et al.*, (2016) and came up with a model that encompasses the lacking aspects from the model like epistemology (Crotty, 2007); research types and additions to approaches (Collis & Hussey, 2003; Khotari, 2005).

In coming up with a research design best suited for addressing skills shortages in the South African construction industry, the researcher had to consider the views of other authors in her research design. The author thus put into perspective the different techniques used in the collection of data whilst discussing the shortcomings and delimitations of the selected methodology to support the chosen choices. The all-inclusive design approach was therefore adopted in order to increase reliability of the methodology and to increase assurance of achieving objectives of the study.

Figure 3.3 highlights the author's choice for research methodology for this study from the options available.

Figure 3.3: An All-Inclusive Research Design



Source: Author's illustration adapted from (Kothari, 2004; Saunders et al., 2016)

Legend:

Researcher's Selection

3.1 RESEARCH TYPE

The choice of the research largely depends on the objectives and how much information is known about the research problem and objectives set out. Exploratory research is carried out in studies where no or a limited number of previous researches exist on the study area (Collins & Hussey, 2003), with the aim of gaining an understanding of the underlying reasons and opinions and helps develop ideas for potential future research. It is the initial research which forms a basis for more conclusive future researches. Since there is a limited number of researches carried out before on CA as an alternative to skills shortages, the current disruption and displacement of the labour market in the wake of the Fourth Industrial Revolution has prompted the researcher to undertake this exploratory research on how the use of automation and AI to argument skills shortages. According to Kirby (2003), Descriptive Research uses qualitative data to assess, describe, interpret and record existing conditions. The purpose of a descriptive research for this study is to describe, explain and validate the current construction skills shortages, to identify *what* the current skills shortages are that exist while Analytical Research explains or suggests the occurrence of something by answering how or why it has happened. Analytical Research is usually done as an extension of Descriptive Research.

3.2 EPISTEMOLOGY

According to Creswell & Clark, (2011), the selection of the epistemology determines whether the research philosophies and approaches that will be selected by the researcher will help in adding value to the research problem. Epistemology was used to probe further into the skills shortages in the construction industry and the extent to which automation can be used in addressing such shortages. The dichotomy of South African construction industry is that, while the industry is faced with a high unemployment rate among the unskilled and semi-skilled, there is a high vacancy rates for the highly skilled at the same time (Amrop, 2012). The introduction of robots, machinery and AI in the construction industry may be faced with resistance from the workforce who might feel threatened.

The choice of epistemology for this research was thus subjectivism as it highlights that individuals tend to be influenced by the society that surrounds them and behave in a certain way (LeCompte, 2011), and before robots are brought on site, there is need to communicate it with the employees and assure the security of their employment. The author believes these are the societal factors that will influence the employees as highlighted by subjectivism. The choice

of subjectivism was found to be more appropriate in enriching this research. This is more so as objectivism analyses social essentials free of social actors and justifying factors to the causes of a problem (Locke, 2010).

3.3 RESEARCH PHILOSOPHY

The purpose of research philosophy is to transform things believed into things known: doxa to episteme. Research philosophy has been defined by Bryman (2012), as the set of values with regards to the quality of the reality under investigation and tends to directs the way in which to gather, analyze and use data about a certain phenomenon, and the choice of the philosophy is outlined by the type of knowledge being investigated (May, 2011). Of importance to note is that, philosophical disagreements are bound to happen in any research while developing a philosophy. Saunders *et al.,* (2016) pointed out five major philosophies that can be applied in a research as; positivism, critical realism, interpretivism, post modernism and pragmatism.

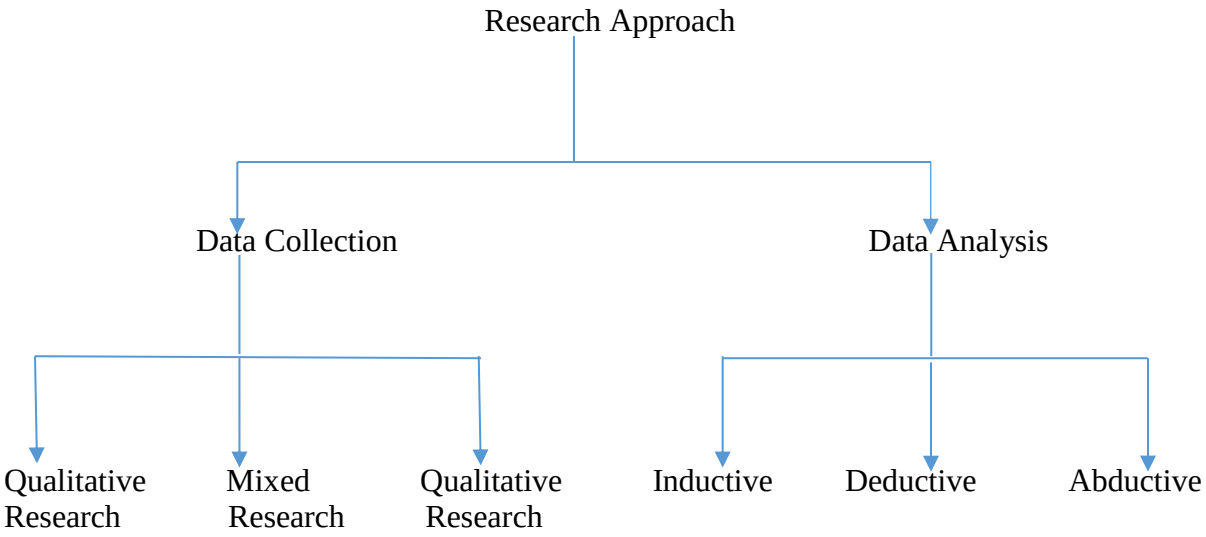
In line with seeking to develop an understanding into addressing the skills shortage in the SA construction industry, the author adopted the pragmatism philosophy. The choice of the pragmatic approach does not make it superior amongst the other philosophies and it is important to note that, most authors also caution against believing that one philosophy is better than the rest. They argue that each philosophy has its own strengths highlighting that the choice of a particular philosophy depends on the research questions (Gray, 2004; Dudovkiy, 2016; Saunders *et al.,* 2016). According to Creswell & Clark, (2011), the elements that give rise to the choice of pragmatism philosophy are problem centred, pluralistic, real world practice oriented and consequences of actions.

As every research starts with a problem with the aim of contributing towards practical solutions that inform the future, the choice of pragmatism indicates that concepts are relevant where they sustain action (Saunders *et al.,* 2016). The pragmatic view was adopted for this research to allow the use of both positivism and interpretivism for research questions suggesting different philosophical positions (Stern, 2004). More so, pragmatism philosophy allows the utilization of a mixed-method approach thereby improving the reliability of data and flexibility and the selection of subsequent methods as was highlighted by Morgan, (2007). The author cemented the importance of centering attention on the research problem in social research and applying pluralistic approaches to draw knowledge about the problem from.

3.4 RESEARCH APPROACH

Creswell & Clark, (2011), defined the research approach as a plan and procedures to be followed in the research and consists of the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation. The research approach is mainly influenced by the research problem and is essentially divided into data collection methods and data analysis methods. Figure below illustrates the research approach that was adopted for this research.

Figure 3.4: Research Approach



Source: Author's illustration

Data collection is the process of gathering and measuring information on variables of interest, in an established systematic fashion in order to answer the research questions, test hypotheses and evaluate outcomes. The aim of collecting data is to capture quality evidence that then translates to rich data analysis which allows for the building of a convincing and credible answer to the research questions posed (Kabir, 2016). The process of data collection starts with determining the kind of data required followed by the selection of the sample of the population from which data will be collected, and then decide on the instruments to be used to collect data from the sample.

The data collection process can be broadly categorised as either qualitative or quantitative. Qualitative Data is mostly non numerical and is in the form of words and sentences. Qualitative data is aimed at addressing the "*how*" and "*why*" questions and tend to use unstructured

methods of data collection like focus groups, group discussions and interviews to fully explore the topic. Quantitative data on the other hand is aimed at testing the objective theories by examining the relationship between the variables (Creswell & Clark 2011). The data is numerical in nature and can be mathematically computed and is aimed at addressing the "*what*" questions. It is suited best where there are assumptions about testing theories deductively, building in protections against bias, controlling for alternative explanations, and being able to generalize and replicate the findings. Data is normally collected through surveys and asking questions.

Mixed methods involves collecting both qualitative and quantitative data to provide a more complete understanding of a research problem than either approach alone. Mixed data collection methods capitalize on strengths and reduce weaknesses that stem from using either qualitative or quantitative data collection method. The researcher adopted a mixed research approach which implies the adoption of both quantitative and qualitative research methods. A mixed research approach has the following benefits; increasing reliability, bringing both objectivity and subjectivity to the research and easy and clear analysis of data and its presentation.

Data analysis for this research was analysed using the deductive approach. The deductive approach was adopted to argue about the knowledge of the perceived shortage of skills in the construction industry, and how, if possible automation can be used to address such shortages. With a deductive approach, it works from the top to down, looking at existing literature and testing hypotheses to add or contradict to a theory (Creswell & Clark, 2011). For this research a deductive approach was also considered suitable because of the research time constraints i.e. limited time frame to set up the study before going into data collection and analysis (Saunders *et al.,* 2016).

A deductive approach was found to be appropriate as it suits scenarios where the research project is concerned with probing whether the observed phenomena fit with expectations from previous researches (Wiles *et al.,* 2011). The perception of the workers on the introduction of robots and AI will also be considered as this perception influences the worker's integration on innovation (Straub, 2009). Traditionally, work in the construction industry is done manually. Advocating for the for the use of robots and AI might be met with resistance from the workers who might view automation as taking up their work because of the parallel of process of change

that exists when embracing new technology. The perception is that workers should have their concerns addressed before they can resist the use of new automation technology.

3.5 RESEARCH METHOD

The research strategy otherwise known as research design or method refers to the framework within which the researcher conducted the research to find definitive answers to the research questions (Abosede & Onanuga, 2016). Draper, (2004), opined that it is the overall plan of the implementation of the project in practice covering the sampling strategy, the methods of collecting data and its analysis, thus portraying it as the practical arrangement of answering the research questions. The research design serves as a structure and execution plan of the research as a way of maximising the validity of the research findings. Research design is thought to give directions from the inherent philosophical assumptions through to the data collection. In simpler terms, a research design is a plan of action to get from *here* to *there*. Where '*here*' refers to the original set of questions to be answered and '*there*' is some set of conclusions or answers (Yin, 2003). There are different research strategies as cited by Saunders *et al.*, (2009), and these include; surveys, experimental, case study, grounded theory, action research and ethnography. Although these strategies are associated with different research approaches, what matters is whether the adopted strategy is compatible with the research questions and the set objectives. After all these strategies do not exist in isolation and can be used in concurrence with others as they bear unique strengths and weaknesses.

Kothari (2004) branded a good research design as one that ensures efficiency in terms of time and cost; minimises bias and maximises validity and reliability of the data collected. Zhrabi (2013), opines that the validity and reliability of data can be ensured through mixed method research design, otherwise known as triangulation. This was achieved through comparing the results from literature review and results from the interviews conducted.

3.5.1 CASE STUDY

A case study is a presentation of an in-depth analysis of issues while trying to give a correlation among variables. According to Yin, (2013), case studies provide description and detail about particular cases which help to set the basis for future studies. Additionally, the case study approach gives a detailed and contextual analysis of any given phenomena regardless of its complexity answering the how and why questions in research (Gomm, 2012). The author

adopted the case study approach for this study, in particular a multiple case study approach for the following reasons;

- The qualitative approach, subjectivism epistemology and descriptive research suggest that case study research strategy is appropriate for these
- Time would not have allowed to look at all companies within the construction industry
- Not everyone in the construction industry uses automation

Although the case study approach is still yet to be universally accepted by researchers as a reliable, objective and legitimate, it is often difficult to generalise data collected from a specific case (Yin, 2013). But Gomm, (2012) in his defence for the adoption of case studies as a research method said that, since most scientific inquiries have to be replicated through multiple experiments, case studies too can be based on multiple cases of the same issue or phenomenon. In support of this views, Palakshappa, (2012) likened the adoption of case studies to the doctor's skills which are oftentimes built upon the knowledge of his interaction with many different individual cases. In support of the use of case studies, regardless of the limitations associated with it, LeCompte (2011) is of the opinion that generalisations inevitably changes over time, such that they become of only historical interest. Generalisation of the information in data collection and analysis is also slowly penetrating even in qualitative research and there are no absolutes and all "*truth*" is relative. In consideration of the limitations associated with the case study approach. Wolcott, (2009) recommends that triangulation of data collection tools should be used. Triangulation involves the use of different data collection methods within one study in order to increase the validity of the data collected and that the data is "*telling what one thinks it's telling.* To curb on the limitations on relying only on one data collection method, the author used different data collection methods like meta-synthesis and interviews to triangulate and build knowledge thereby overcoming the weaknesses of relying on case studies alone.

3.6 RESEARCH CHOICE

The research choice also referred to as the methodological choice determines the data collection techniques and data analysis procedure to be followed by the researcher. Table 3.1 below is a list of the choices available and the instances on which they will be applicable as suggested by Saunders *et al.,* (2016).

Table 3.1: Research Choices and the Respective Data Collection and Analysis Method

Research Choice	Method	Data Collection Technique	Data Analysis Procedure
Mono Method	Mono-method quantitative	Use of one quantitative technique e.g. questionnaire	Statistical Analysis
	Mono-method qualitative	Use of one qualitative technique e.g. in-depth interviews	Narrative analysis
Mixed Method	Mixed-method simple	Use of qualitative techniques and analysis followed by quantitative techniques and analysis	Narrative and Statistical analysis
	Mixed-method complex	Analyse qualitative data quantitatively	Statistical analysis
Multi method	Multi-method quantitative	Use of more than one quantitative technique e.g. questionnaire and observation	Statistical Analysis
	Multi-method qualitative	Use of more than one qualitative technique e.g. focus groups and in-depth interviews	Narrative, Discourse Analysis

Source: Author's Illustration, concepts adopted from Saunders et al., (2016)

The research choices outlined in the research onion include mono method, mixed-method research and multi-method (Saunders *et al.,* 2016). Mono method is the use of one research approach while mixed-method is when two or more research methods are used, i.e. when both qualitative and quantitative research methods are used in one research and according to Bryman, (2012) multi-method involves a wider selection of research methods.

3.7 TIME HORIZONS

Time horizons located in the second inner layer of the onion determines the time frame within which the researcher intents to complete the research project (Saunders *et al.,* 2016) and can either be cross-sectional and longitudinal (Bryman, 2012; Saunders *et al.,* 2016). The time horizon adopted is cross-sectional as the research is already established and data must be collected at a certain point in time (Saunders *et al.*, 2016). It shows a snapshot of the results i.e. this was the situation, concerning skills shortage at this point and time of the research.

3.8 RESEARCH TECHNIQUES AND PROCEDURES

3.8.1 DATA COLLECTION METHODS

These are also known as research instruments which are described as devices or techniques used to obtain standardised information from all subjects in the sample (Shajaham, 2005). The researcher used appropriate techniques to elicit the required information from the given sources which are based on two sets of data; primary and secondary data. In trying to answer the research questions highlighted in Chapter One of this research, both quantitative and qualitative research methods were used. For quantitative data collection, the researcher made use of the interviews as a means of primary data collection. For secondary data collection, meta-synthesis was used.

3.8.1.1 Primary Data Collection Methods / Meta-Synthesis

In analysing secondary data, the researcher used meta-synthesis where the synthesis of the literature on construction industry skills shortage was broadly categorised into two main streams; the quantitative nature of skills shortages and the qualitative nature of the skills gap. This approach was used to lay down a foundation regarding construction skills shortages and the benefits of construction automation. Before drawing the conclusion on the South African construction industry, the researcher feels the need to highlight the problem of skills shortage at a global level as well as the perceived advantages of automation and make a conclusion on their application to the South African context.

For qualitative research, meta-synthesis was used to synthesis the data collected. The process of meta-synthesis was carried out with the objective of integrating the results of a number of different previous qualitative researches that are interrelated (Walsh & Downe, 2005) and from those researches, select and appraise, summarise and categorise the evidence to address the research question (Chenail *et al.,* 2018). Meta-synthesis is carried out through a systematic statistical analysis of previous studies on the topic under review. In qualitative research (literature review), adopting a meta-synthesis approach was reliable for systematic search of resources as this process follows an intentional, logical and consistent approach to analysing data across different qualitative studies, and then compare and contrast the results of the different studies. One of the benefits of conducting a meta-synthesis is that at the end of it, data collected for a specific research is collectively viewed and then the research findings are integrated into a form that is easily accessible and understandable even by the layman.

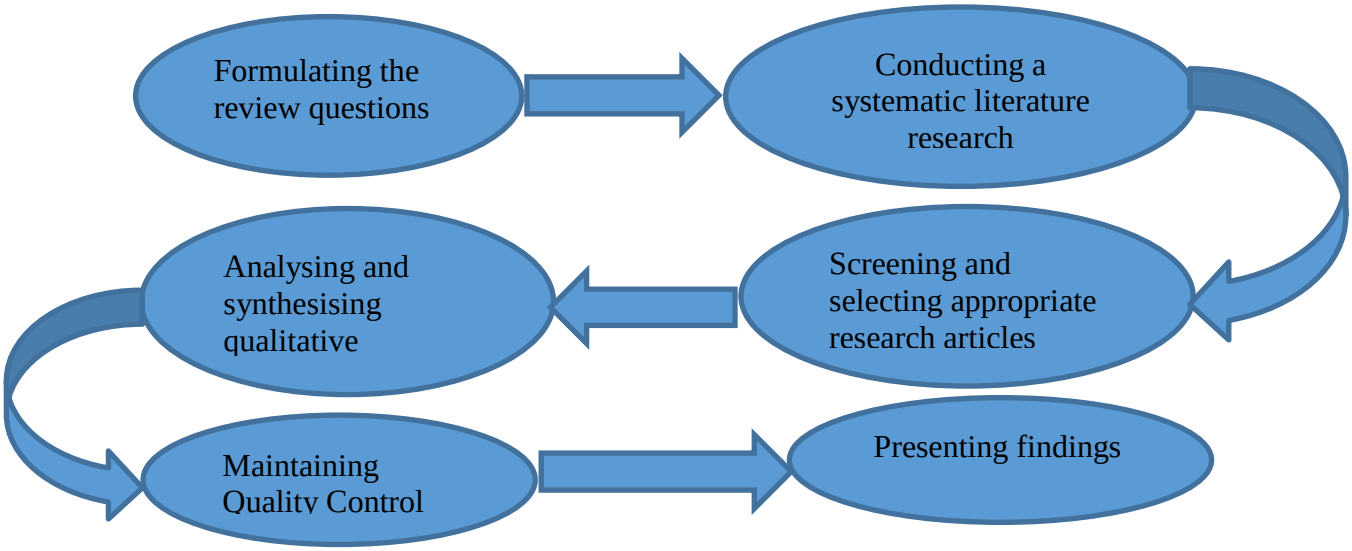
According to Erwin (2011), meta-synthesis is an analytical technique that builds on the qualitative results of the previous studies to gain a deeper understanding of the study area. He went on to say that, meta-synthesis involves rigorously going through qualitative data in order to synthesis the results of previous studies in order to generate a comprehensive meaning of the data through an interpretative process of the analysed data. In digging deeper in order to generate new knowledge about the phenomenon under study, the findings of the previous researches are considered in light of the sociocultural and disciplinary context in which the primary research was originally conducted (Peterson, 2009).

While conducting meta-synthesis for this research, the following sources of information were analysed; interpreted data, unanalysed quotes, field notes and documents (Finfgeld, 2003). Finfgeld, (2003) went on to describe the three types of meta-synthesis;

- Theory building which pushes the levels of theorising beyond that which can be achieved in a single study
- Theory explication which reconceptualise abstract phenomena
- Descriptive which comprehensively analyses a phenomena

The meta-synthesis process was formulated based on Sandelowski & Barroso, (2007)'s six step process of meta-synthesis for qualitative research and follows the following flow chart:

Figure 3.4: Meta-synthesis Flow Chart



1. ***Formulating the Review Questions***

The first step in carrying out a meta-synthesis research is to identify the research questions. The research questions though they may be broader, they will be redefined and narrowed down

in scope over the course of conducting the synthesis (Walsh & Downe, 2005). In adopting this process of meta-synthesis, the researcher identified two specific research questions and then used the available literature to select, appraise, summarise and combine qualitative evidence to try and address those research question.

- *What are the skills shortages currently experienced in the construction industry?*
- *What are the benefits of automation in the construction industry?*

2. Conducting a Systematic Literature Research

In this section, keywords were defined to guide the literature search. "*Skills shortages in the construction industry*" together with the "*benefits of construction automation*" were searched from studies that were conducted between 2 000 and now. This selection of the articles published after the year 2 000 was based on the views of McDonald, (2014) and Young, (2013) in that the nature, complexity and demands of projects have changed significantly over time and relying on outdated information published way back could potentially affect the validity of the information.

To clearly identify and set the parameters of the research question, the availability of further information required to probe the assessment related to the research questions and objectives of the study, four basic questions should be answered in order to establish the inclusion and exclusion criteria:

i. ***What***: To answer the "***what***" question, the researcher identify what the research is about. For this study, it is identifying the skills that are currently in short supply in the construction industry and the benefits of automation in the construction industry?
ii. ***Who***: populates the research population and for the purpose of this study, it is the text books, scientific articles and magazines and masters' and PHD thesis.
iii. ***When***: determines the research time period which will be considered by the researcher. This includes the studies carried out after 2000 due to the need to collect current data on the performance of the industry which can still be useful and applicable in the present day situation.
iv. ***How***: this is the data collection method. For this research, a systematic search is done for conducted studies available from different scholar articles and **the saturation point** is used to stop and limit more searches.

After formulating the research questions, the next step was to come up with the database for search where the following strategies were used as they maximise the number of potentially relevant articles retrieved and ensure the highest level of rigor (Lachal *et al.,* 2017).

- Using data base thesaurus term
- Using free text terms
- Using broad terms

The names of the desired databases used in this study are presented in **Table 4.1**.desired database, keywords were searched for the skills in short supply in the construction industry and were presented in **Table 4.2.** For the location of search papers, the researcher used the following to come with the number of articles to consider;

- Reference list checking
- Citation searching
- Hand searching through back issues of selected journals and author searching.

3. Screening and Selecting Appropriate Research Articles

The third step included the search and selection of appropriate articles. Due to the impossibility to consider all the articles found on the study area, some of the articles were removed from the search sources based on the inclusion and exclusion criteria as defined in **Step 2** of the meta-synthesis process above. This according to Alkins *et al.*,(2008), who asserted that the selection of the articles to be considered and used for meta-synthesis should follow a sample of quality criteria. Weeds, (2006) noted that those articles that contradict in terms of research content, quality and criteria through multi-stage evaluation should be purged from the final list of articles to be considered for the research. In order to narrow down on the literature search, *STARLITE* principles were used as proposed by Booth, (2006). The principles are tabled on **Table 4.3.**

4. *Analysing and Synthesising Qualitative Findings*

Data analysis starts with the categorisation and organisation of data searching for patterns, critical themes and meanings that can be generated from the data collected. In analysing data, the researcher made use of the Critical Appraisal Skills Programme (CASP).

5. Maintaining Quality Control

The purpose is to provide clear descriptions and explanations for the choices made. Established approaches to the synthesis of primary qualitative research studies were used like audit trails.

CASP was used to evaluate the quality of the primary qualitative research studies, as well both electronic and manual search strategies to locate all pertinent articles concerning the study area.

6. Presentation of Findings

After the CASP evaluation of the articles, data from the articles with the accepted scoring rate is presented in the form of tables and or chats for analysis.

3.8.1.2 Secondary Data Collection Methods

Shuttleworth, (2008), defines primary data as data that comes from first hand interaction with a knowledgeable person or from a witness of the experience under study. Primary data is collected solely for the purpose of the study under investigation and as such deemed to be precise, current, tailored and private. Bryman & Bell, (2011), opines that surveys are used for quantitative research, and involve sampling a representative portion of the whole population. Empirical data produced from the surveys is then analysed and recorded.

Interviews

Saunders *et al*., 2016 defined an interview as a discussion between two or more people for the purpose of establishing an understanding from asking brief and unambiguous questions to which the interviewee responds willingly. Apart from literature review they recommended the use of in-depth interviews as a way of collaborating data collected. Yin, (2003), divided interviews into three; open ended, focused and structured. According to Griffiths, (2004), the other reason for carrying out the interviews is to avoid relying on the researcher's pre-determined assumptions.

To fulfil the requirements of the study, in-depth information on enablers and threats to the adoption of CA in SA was required which was sought by engaging in interviews **(Appendix C: Interview Questions)**. Due to the difficulties in getting respondents knowledgeable about construction automation, the interviewer had scheduled seven semi-structured interviews. The interviews were scheduled for client organisation, multidisciplinary consulting, project managers, large and medium contracting firms to help achieve the aim of the study which is**: To investigate the potential of adopting automation in addressing skills shortage in the South African construction industry.**

- *What are the enablers and threats for using automation in the South African construction industry?*

- *How and to what extend can automation address skills shortage in the South African construction industry?*

Since the research is analytical, descriptive and explanatory in nature, interviews were deemed appropriate for the exploratory part with the respondents afforded a chance to clarify statements and this allowed a greater opportunity to probe these responses to achieve a better understanding of the interview questions. Participates for the interview were chosen and selected via snowballing.

While preparing for and conducting interviews, the researcher was guided by the interview protocol (**Appendix D: Interview Protocol**). Before conducting the interviews, an interview guide was pretested on three separate people other than the actual respondents to avoid dubious questioning and to minimise the risk of misunderstandings. The interview was conducted in English for easier analysis of the information given.

3.8.2 DATA ANALYSIS – QUALITATIVE VERSUS QUANTITATIVE

Data analysis entails the breakdown of information gathered, its display and drawing conclusions from it. From data breakdown summaries and clusters of the data collected are written. Data is then organised and assembled before conclusions are drawn deducing the meaning and noting regularities and patterns.

The selection between the quantitative and qualitative research approaches is based on the quality and type of the research questions of the study (Yin, 2013). The main aim of the research method to be used is to seek solutions to the questions posed in the objectives and the literature gathered. The need to select the best research method cannot be under estimated as the research method will help the researcher successfully answer the research questions or to test the hypothesis. Any blunder at the outset of a research may end up derailing even a promising study.

The author opted for a mixed approach for the research, to capitalise on the importance of both qualitative and quantitative approaches, allowing the researcher to capture and record both statistical and subjective data. Adopting a mixed data collection approach allows the adoption of both quantitative and qualitative research instruments for data collection. Both qualitative and quantitative data collection methods have their own limitations, hence using both approaches allowed for offset the limitations posed by each approach.

Primarily, qualitative research is associated with exploratory research type and is used in gaining an understanding to the fundamental reasons, opinions and motivations to provide insights into the research problem and often times helps develop ideas or hypothesis for potential quantitative research. It is useful where there is the need to reveal trends in thought and opinion and dig deeper into the problem. For this reason, NVivo software was used to analyse both quantitative and qualitative data collected. Selected articles for meta-synthesis were first analysed using CASP for the selection of articles while NVivo was used to further analyse data on the remaining articles. Data captured from interviews was first transcribed on a word document where analysis was conducted per interview question. Data was then captured on NVivo for grouping and coding starting with the descriptive followed by pattern coding.

A descriptive code is the provisional process between data collection and data analysis. A code is a word or short phrase that literally assigns a comprehensive, significant, essence-capturing, and/or suggestive characteristic for a portion of language-based or visual data collected (Saldana, 2013). It is important to ensure that not only sufficient data is collected, but sufficient quality data to work with that have been appropriately transcribed and formatted when determining what should be coded.

With pattern coding, descriptive data is arranged in a systematic order to make it part of the system, clarification to categorise it. It is simply a process that allows data to be separated and grouped to consolidate the meaning and explanation (Grbich, 2007). Data analysis is the searching of the patterns and ideas within the data. Pattern coding thus, is a way that enables the organisation and grouping of similar descriptive coded data into categories because of the shared similar characteristics.

3.8.3 DATA PRESENTATION

The researcher used a combination of tables, bar graphs and percentages for the presentation of collected data. The analysis of data involved the examination, classifying or tabulating the results of data collected (Yin, 2013). Before starting on the data analysis process, the researcher checked for flaws in the data collected like omissions in responding to research questions by the respondents (Bryman, 2008).The completeness of the data, its consistence with the instructions was checked from the responses accordingly and where gross omissions existed the information sheets were removed. After the presentation of data, quantitative and qualitative data analyses were used to analyse the data.

3.8.4 AREA OF STUDY AND TARGET POPULATION

This research was confined to the Gauteng Province as it is the most populous and fast growing province of the nine provinces that make up the whole of SA (Stats SA, 2016). Due to the selection of the Gautrain case study, Gauteng Province was also chosen because not only is it the home of economic hub of SA, but it is highly urbanised, and the country's most popular city, Johannesburg and the administrative Capital City of Pretoria are also found within this region (DoL, 2012; StatsSA, 2016). According to Silverman (2007), a population to a study can be defined as a collection of individuals that are of interest with at least one characteristic in common. It is from this population that the researcher generalised the results as the whole population was thought to have significant traits in common (Saunders *et al.,* 2009). The author further highlighted that, though it may be possible to collect data from the whole populace, this can only be so for a research population is of a manageable number. Since the population was large and given the time constraints of the research, there was need to sample the population. Although results from sampling the whole population would have created a higher degree for results to be generalised, sampling only a portion of the whole population increased the accuracy of the data.

3.8.5 RELIABILITY AND VALIDITY

Four tests are used to ascertain the quality of any empirical research; these are reliability, construct validity, internal validity and external validity.

Reliability is a measure of regularity and should a separate study be carried out, it should arrive at the same results (Somekh & Lewin, 2007). According to Myers, (2009), for one to test the reliability of a research, the findings and conclusions of one researcher should be reproduced by another researcher undertaking the same research. To achieve reliability, there must be sufficient and compelling evidence collected and analysed (Davies, 2007; Somekh & Lewin, 2007), with the aim of reducing biases and errors in a study (Yin, 2014).

a. Data Collection

To increase reliability in the data collected, meta-synthesis was run on existing literature both locally and internationally on construction skills shortages and the use of CA. This was followed by interviews that were later contacted to closely examine and monitor if there was any relationship in the data collected by these methods.

b. Research Study

For reliability of this study, the research procedure and findings are well documented for easy reference to steps that were followed for any investigator to follow and to arrive at the same results and conclusions hopefully.

Validity can either be construct, internal or external. Construct validity is the determination of the correct measuring instrument for the concepts being studied (Polit & Black, 2012). The qualities of the translation of an idea, behaviour or concept are discussed to establish the cause and effect of a function (Trochim, 2006). To guarantee and reinforce construct validity of this research, the findings were shared and discussed with the supervisor throughout the research to reduce the likelihood of reporting false findings and misinterpretation of information (Yin 2014). As already highlighted under research methods, data was collected from multiple sources, where findings could be triangulated to check if they point towards the same findings, thereby increasing the credibility of the research and eliminating bias.

To check for internal validity, casual relationships between variables were tested and to measure and control them using construct validity (Welman, *et al.*, 2005). External validity is a check whether the results of the research can be generalised or not (Bryman, 2008), i.e. the results of the research are applicable in other similar situations. Internal validity was maintained through the following;

1. Referencing previous studies

In an endeavour to increase construct validity, referencing of previous work was done to previous researches to distinguish the researcher's own work from previous ones.

2. Reduction of human error and instrumentation effects

As this research involved engaging with the respondents, there was an inherent human nature which is prone to errors. This inherent human nature could have affected validity on two aspects:

i. Errors in answering the questionnaire since this were done in the absence of the author. This was controlled for by putting in a section that asked the respondents to take their time and complete **ALL** of the questions **HONESTLY**. In addition, erroneous questionnaires were removed during capturing the results.
ii. Errors in uploading and taking results which was guarded for by rechecking entries.

3. Familiar environment

Questionnaires were given to the respondents for them to complete them in a familiar environment. Respondents were also assured of their anonymity and confidentiality of their responses. This reduced the Hawthorne effect whereby respondents change their usual conduct due to studies they are involved in (Welman *et al.,* 2005).

4. Pilot testing

The interview guide and questionnaires were tested on other people first before the real respondents in order to get a chance to correct questions which might have been ambiguous or misunderstood. This increased the criterion related validity.

For measuring and controlling external validity of this research, it is imperative to note that this study was conducted in the South African construction industry, Gauteng Region. As a result the findings of research cannot necessarily be expected to be applicable to other countries given the different conditions in the countries nor can they be expected to be generalised to other sectors or industries SA. Saunders *et al.,* (2007) defined generalisability as *"the extent to which the findings of a research study are applicable to other settings".* Another factor that affected the external validity of this research was the time constraint. This meant that the author was not in a position to conduct the survey on a bigger sample. This might have an effect on the external validity of this research.

3.8.6 ETHICAL CONSIDERATIONS

As already highlighted in the first chapter of this study, there are some ethical issues which the researcher had to consider. These include confidentiality, for example, of the respondents, informed approval, emotional safety, and complementarity (Oka & Shaw, 2000). To ensure that research ethics where observed, the following measures were adopted and the reasons thereof.

a) Ethical approval

The author sought official ethical clearance from the University of the Witwatersrand prior to undertaking the research to avoid unexpected ethical problems that could arise from administering the research, particularly with regards to data collection. This allowed for the fortification of rights of both the author and participants. The ethical clearance certificate is attached to this research **(Appendix G: Ethical Clearance)**

b) Informed consent of respondents

After obtaining the ethical clearance from the institution, a stipulation was made to notify all respondents about the research area for which their perceptions were being sought and to gain their approval before responding to the questionnaires or interviews.

c) Confidentiality of information

To promote confidence to answer honestly and protect individual information confidentiality was assured to all respondents in the cover note on the questionnaire and was further assured prior to the commencement of the interviews.

d) Anonymity of respondents

This was through the exclusion of the names of the respondents in the questionnaires and interviews and presentation of results. The respondents were assured of this in the cover note on the questionnaire and before the interviews. This was done to avoid prejudicing the respondents.

3.9 SOFTWARE

NVivo is a qualitative data analysis computer software package that is used when working with large amounts of data. Although it is mainly focused on qualitative data analysis, NVivo also supports and can be used by researchers using mixed methods and uses coding to properly manage data. Coding is used to break down and condense data into smaller units (Saldana, 2013). Coding is a systematic way of reducing data sets into smaller manageable units through the creation of classes and ideas originally from the data. Coding is the process of recognizing models and themes in your sources and classifying them into coding containers, called nodes. These can contain as many references (as much evidence) as you consider relevant and group information from different sources according to themes, subjects, concepts, empirical evidence and ideas.

3.10 LIMITATIONS OF THE METHODOLOGY

As with the majority of studies, the design of this study was subject to some limitations. Research work is subject to limitations in its methodology according to (Hair *et al.*, 2000), who further suggested measurement error, time pressures, financial limitations and sampling bias as common limitations to research;. To further highlight on these limitations, the limitations that were faced by the researcher while carrying out this research are discussed below;

- The first challenge faced by the researcher was understanding and choosing research design to adopt for research use since different scholars disagree on them. However, this was overcome by extensive reading to show what is widely held and to get guidance from previous studies.
- Accessibility was an issue for the researcher as organisations and some respondents treated divulging information suspiciously. Thus, winning the trust and confidence of the research participants was a challenging task that the researcher had to overcome. Assurance was made to the respondents that this study was purely for academic research and no one was going to be misquoted or implicated in any way.
- There may have been bias in data collected rendering applicability of research results to other organisations questionable. This is because firstly, the sample was limited to companies in the Gauteng Region only and secondly even for the companies in the region, not everyone was included in the study, but a sample which the researcher perceived to be a fair representation of the study area. The use of multiple methods countered this limitation as it increased generalizability of the data collected.

3.11 SUMMARY OF THE RESEARCH METHODOLOGY

Table 3.2 summarises the methods that were followed in gathering research information. This follows the illustration of the research design that was adopted by the researcher as adopted from Kothari, (2004) and Saunders *et al.*,2016) The research sub question together with the objective, the method of gathering and analysing data are clearly elaborated and the software that was used.

Table 3.2: Methods Used to Gather Relevant Information

Sub Question	Objective	Research Method	Data Collection Method	Data Analysis Method	Software Used
1 What are the skills shortage currently experienced in the construction industry?	To establish the current skills shortage records in the construction industry.	Literature Review	Meta-synthesis	Qualitative	NVivo
2 What are the benefits of automation in the construction industry	To identify the benefits automation has brought about in the construction industry	Literature Review	Meta-synthesis	Qualitative	NVivo
3 What are the enablers and threats for using automation in the SA construction industry?	To survey the extent to which automation can be implemented in the construction industry.	Case Study	Interviews	Quantitative	NVivo
4 How and to what extend can automation address skills shortage in the SA construction industry?	To show the potential of how automation can positively affect on the perceived labour intensive construction industry	Case Study	Interviews	Quantitative	NVivo

3.12 SUMMARY

This chapter focused on the research design and methodology that underpin this study. However, due to the contradictions in the names and stages to be followed during research design, the researcher had to consider the views of other authors in her research design to come up with an all-inclusive research design that was followed in this study. Exhaustive information regarding the mixed methods design for data collection and data analysis, origins, relevance to this study and their general characteristics, were explored in this chapter. The following chapters were built from the methodological propositions made in this chapter by utilizing the proposed data collection, presentation and analysis approaches to scrutinize the quantitative and qualitative data.

CHAPTER 4: DATA PRESENTATION & ANALYSIS

4.0 INTRODUCTION

This chapter discusses issues relating to data collection, analysis and discussions. It serves to analyse and present the research findings in order to answer the objectives that were set out in the first chapter of this research. The research main question was: *"Can automation be used in the construction industry to augment skills shortages being experienced in the South African construction industry".* Therefore the purpose of this study was to identify the skills shortage in the construction and how automation can be used if at all in addressing such skills shortages.

As already discussed in the previous chapter, data collection for this research was gathered from reviewing literature and interviews. Using literature, meta-synthesis is used to access the level and extent of the skills shortage as well as the benefits of automation in the construction industry globally. In an effort to narrow down this research to the South African context, interviews were conducted for the enablers and threats for using automation particularly in SA construction industry and the extent to which automation can be used in addressing skills shortages construction industry. As a measure to ensure the reliability and validity of the data collected, data cleaning was done and only what was deemed relevant to the objectives of this research was taken into consideration. The data collected was analysed and presented using tables, pie charts and bar graphs and the arithmetic mean as supported by Crawshaw & Chambers (2001).

4.1 DATA ANALYSIS – META-SYNTHESIS

Qualitative data analysis involves working with data collected, organising it and breaking it into small and manageable units, synthesising and searching for patterns, data coding with the aim of discovering patterns, concepts, themes and meanings.

4.1.1 SKILLS SHORTAGES IN THE CONSTRUCTION INDUSTRY

The process of searching and the selection of appropriate articles for inclusion is detailed in the six step meta-synthesis processes described below and summarised diagrammatically in Figure 4.1. Several scientific databases around the world were investigated for data collection on the skills shortages in the construction industry. This was done to show that the shortage of

skills is not only being experienced in South African, but it's a global phenomenon and also to show how skills shortages in SA relates globally.

The six step meta-synthesis process follows the following steps;

Step 1: Formulating the review questions

The first step in meta-synthesis was to formulate the research question. As stated earlier, the research question is: "*What are the skills shortage currently experienced in the construction industry?"* The extent of construction industry skills shortages is globally examined to highlight that the plight and effects of construction skills shortages are being experienced globally in many different markets.

Step 2: Conducting a systematic literature research

Key words were defined for *"skills shortages in the construction industry"*. After the defining the key words, parameters were set that would guide on the search and exclusion criteria. From the parameters set, only articles published from year 2000 to date were considered. The database for the search was then established based on; data base thesaurus, free text terms and using the broad base terms. Table 4.1 presents the names of the data bases used in this study.

Table 4.1: Databases Used in the Search for Construction Skills Shortages

Construction Skills Shortage
Emerald Insight
Springer Link
Science Direct
Research Gate
Google Scholar

From the data base, Table 4.2 below is the list of keywords that were used to search for skills shortages in the construction industry. Based on the relationship of the keywords, article title and abstract, sources were extracted from the database and a total of 41 792 sources were extracted from the database based on their relations to the keywords and investigating their title and abstract and their relationship with the research question.

Table 4.2: Keywords Used in the Search for Construction Skills Shortages

Keywords
Construction skills shortage
Scarce skills in construction industry
Skills shortage in the construction industry
Construction skills shortage in South Africa

Step 3:
Screening and selecting appropriate research articles

From the list of the databases, appropriate articles on the study area were searched and selected. Due to the need to consider current trends on skills shortage and the need to eliminate obsolete information on skills shortages, only articles published in the databases as highlighted in Table 4.1, either scientific journals, conference papers or surveys conducted by reliable institutions on construction skills shortages were considered theses between the years 2000 to date were considered. From a total of 41 792 articles that were retrieved from the data bases and due to the impossibility to consider all the articles found on the study area, some of the articles were removed from the search sources based on the inclusion and exclusion criteria and due to duplicate in publications. In order to further narrow down on the literature search, "*STARLITE*" principles were used as proposed by Booth, (2006). The principles are tabled on Table 4.3 below, only those articles that meet the "*STARLITE*" criteria were considered for inclusion and further considerations.

Table 4.3: STARLITE Principles Applied to the Literature Search

S	Sampling strategy	Comprehensive
T	Type of Study	Fully reported (any kind of qualitative study)
A	Approaches	Electronic and citation snowballing
R	Range of years	Fully reported 2000 until 2019
L	Limits	Language (English)
I	Inclusion and exclusions	Inclusion (qualitative method, specifically on skills shortage in the construction industry Exclusion (quantitative or mixed methods)
T	Terms used	Complete search strategy published in Online Supplemental Data
E	Electronic sources	Google scholar, Science Direct, Emerald Insight, Research Gate, Springer Link , ASEE, IAARC, JCME

Step 4: Analysing and synthesising qualitative findings

Data analysis starts with the categorisation and organisation of data searching for patterns, critical themes and meanings that can be generated from the data collected. In analysing data, the researcher made use of the constructivist ground theory.

Step 5: Maintaining Quality Control

When maintaining quality control, clear descriptions and choices made needs to be explained. Established approaches to the synthesis of primary qualitative research studies were used like audit trails. CASP and the grounded theory were both used in appraising quality of the primary qualitative research studies, as well both electronic and manual search strategies to locate all relevant articles pertaining the area under study.

In order to determine and screen the number of documents that would be considered for this study, CASP is used to narrow down the documents. This is the process of examining research evidence systematically in order to access its validity to the current research, the results of that research and its relevance before using it to inform a decision (Hill & Spittlehouse, 2003). The principal aim of CASP is to assess as to whether the articles selected address research questions and context is relevant to the study under review (Hannes 2011).

Table 4.4 outlines the articles that were subjected to CASP to come up with the articles that would be considered for this study.

Table 4.4: CASP Evaluation of Articles – Skills Shortages

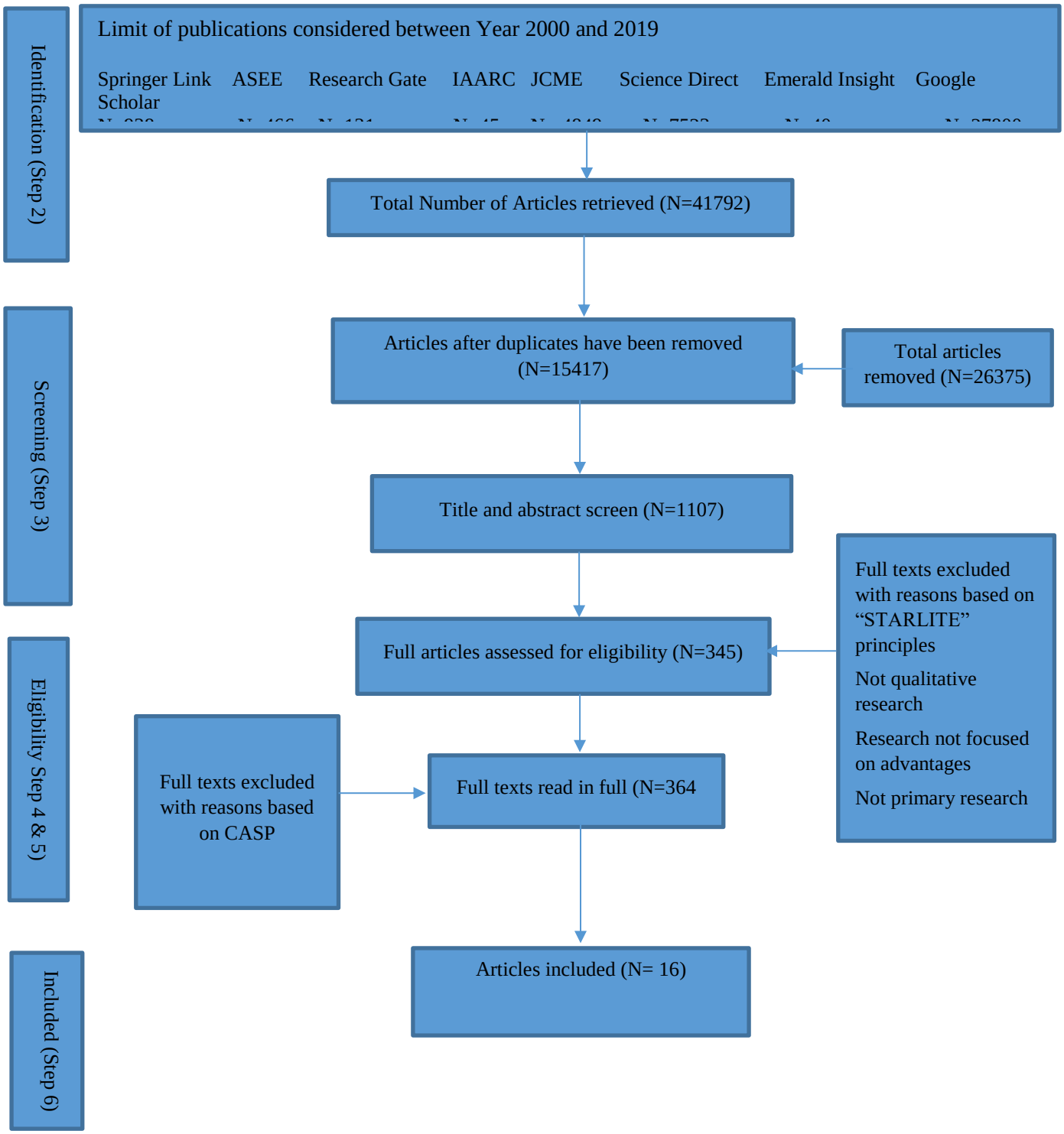
	Study is qualitative	Qualitative research is clearly justified	Research questions clearly stated	Study context is described	Sampling method is described and appropriate to the research question	Data collection method is described and appropriate to the research question	Ethical considerations taken into account	Data analysis is described and appropriate for the research question	Claims are supported by sufficient evidence	How valuable is the research	CASP Total Score (%)
Olsen & Tatum (2012	**10**	**9**	**8**	**10**	**9**	**9**	**8**	**9**	**9**	**9**	**90**
Oseghale et al.,(2015)	**9**	**9**	**10**	**9**	**9**	**8**	**9**	**9**	**8**	**9**	**89**
McGrath-Champ et al., (2006)	**10**	**9**	**8**	**9**	**9**	**8**	**8**	**9**	**9**	**9**	**88**
Gambin et al., (2016)	**9**	**8**	**9**	**9**	**9**	**8**	**9**	**8**	**9**	**9**	**87**
NCVER (2001)	**10**	**9**	**8**	**9**	**8**	**9**	**8**	**8**	**9**	**9**	**87**
IOM (2012)	**9**	**9**	**8**	**10**	**9**	**8**	**9**	**8**	**7**	**9**	**86**

CITB (2018)	**9**	**8**	**8**	**9**	**9**	**10**	**8**	**9**	**8**	**8**	**86**
Society of Chartered Surveyors Ireland (2018)	**9**	**9**	**8**	**9**	**8**	**8**	**9**	**8**	**9**	**9**	**86**
Silva (2018)	**9**	**9**	**8**	**9**	**8**	**8**	**8**	**8**	**9**	**9**	**85**
Li (2018)	**9**	**8**	**9**	**8**	**9**	**9**	**7**	**8**	**9**	**9**	**85**
Mkhonza & Letsoalo-Fuze (2017)	**9**	**9**	**8**	**9**	**7**	**9**	**8**	**9**	**8**	**9**	**85**
Hajela (2012)	**9**	**8**	**9**	**8**	**7**	**8**	**9**	**9**	**8**	**9**	**84**
Karimi (2017)	**9**	**9**	**8**	**7**	**9**	**8**	**8**	**8**	**9**	**9**	**84**
Mohd-Rahim et al., (2016)	**9**	**8**	**8**	**9**	**8**	**7**	**8**	**8**	**9**	**8**	**82**
APEC (2014).	**9**	**9**	**8**	**7**	**9**	**8**	**7**	**9**	**7**	**9**	**82**
Murchadha (2018)	**9**	**8**	**9**	**9**	**9**	**9**	**8**	**5**	**7**	**8**	**81**
Gambin et al., (2012)	8	8	7	8	6	8	8	7	8	8	76
BCI Economics (2011)	8	8	7	7	8	8	7	8	8	7	76
McKinsey (2017)	8	8	7	8	7	6	9	8	7	7	75
Turner & Townsend (2017)	9	8	5	8	7	8	7	8	8	7	75
Makhene & Twala (2009)	8	8	5	8	7	9	8	7	6	8	74
Windapo (2016)	8	8	7	9	6	7	8	8	7	6	74
KPMG (2017)	9	9	7	6	8	6	7	8	5	8	73
Healy et al., (2015)	8	7	6	8	4	7	8	8	8	9	73
Chang-Richards et al., (2015)	8	8	7	8	6	7	7	6	8	7	72
Building Sight (2018)	8	8	6	7	5	5	7	8	9	8	71
Mitra & Tan (2012)	8	7	8	7	8	7	6	7	7	6	71
Baloyi & Bekker (2011)	7	8	7	7	6	8	7	8	6	7	71
Campbell (2016)	8	5	7	6	8	9	5	7	7	8	70
Othman (2014)	5	7	8	8	5	6	7	8	7	7	68
Watson (2012)	7	7	8	5	7	8	7	6	7	6	68
Rasool & Botha (2011)	8	8	7	8	6	7	5	5	8	5	67
Skills Guernsey (2012)	8	7	8	6	8	7	5	4	7	5	65
Wang & Bhanugopan (2010)	6	5	7	5	7	8	7	5	7	5	62

After vetting and scoring the articles using CASP, articles were reduced from 34 to 16 for skills shortages and these were the final articles that were only considered further for this research. These 16 articles were found to be within the suitable scoring range of at least 80%.

Figure 4.1 below summarises the meta-synthesis process that is followed based on Sandelowski & Barroso, (2007)'s six step process of meta-synthesis for qualitative research.

Figure 4.1: Meta-synthesis flow chat – Construction Skills Shortages



Step 6: Presenting Findings

Results from synthesising literature on skills shortage in the in the broadly categorise the skills in short supply as Professionals and Artisans. Many authors reported Artisans as the most

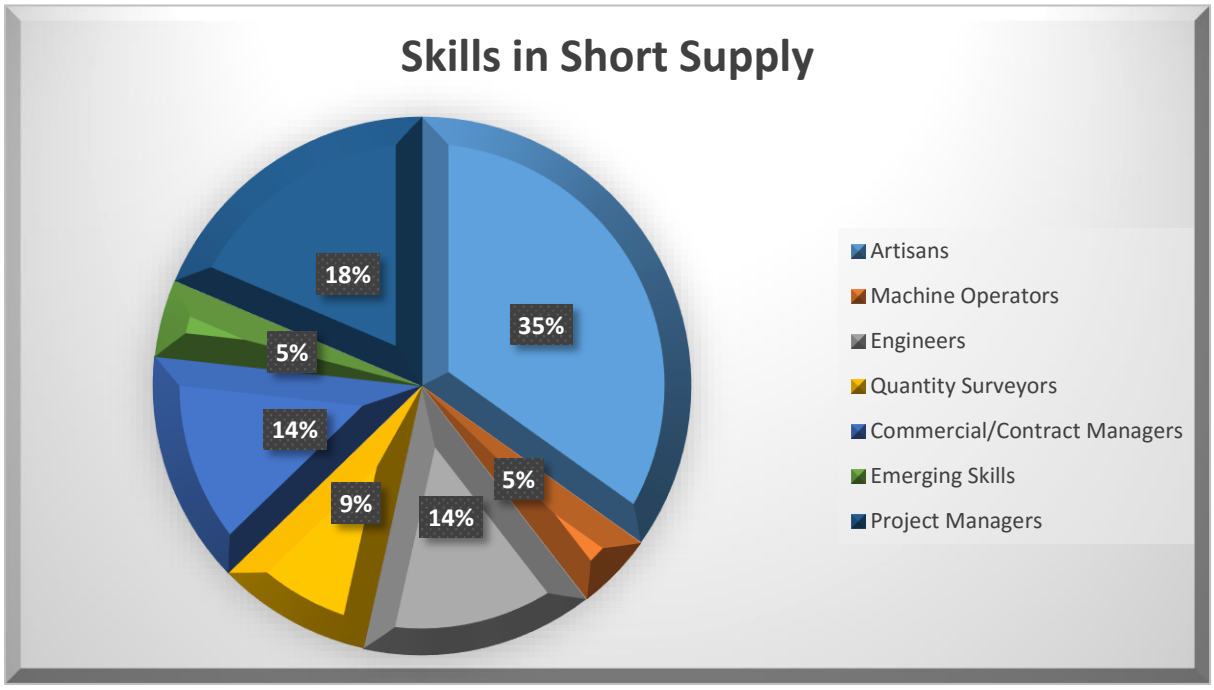
scarcest. This maybe because the bracket for artisans includes in itself so many professions like; Carpenters, Welders. Electricians, Brick layers, Plumbers and Roofers. Under the Professionals' category, Project Managers were recorded as the scarcest followed by a tie on Commercial / Contact Managers and Engineers. Quantity Surveyors and Emerging Skills were least scarce. Table 4.5 below summarises the list of the authors whose articles were considered for the research based on their CASP scoring.

Table 4.5: Identified Construction Skills in Short Supply

Resource	Code	Category
McGrath-Champ *et al.*, (2006); IOM, (2012); Oseghale et al., (2015); IOM, (2012); Hajela, (2012); Gambin et al., (2016); APEC, (2014); CITB, (2018)	Engineers; Civil, Design	**Professionals**
IOM (2012); Society for Chartered Surveyors Ireland, (2018); Oseghale et al., (2015); National Centre for Vocational Educational Research, (2001); Li, (2018); IOM, (2012); Hajela, (2012); Gambin et al., (2016); CITB, (2018)	Quantity Surveyors /Surveyors / Estimators	
IOM (2012); Society for Chartered Surveyors Ireland, (2018); Mkhonza & Letsoalo-Fuze, (2017); McGrath-Champ *et al.*, (2006); CITB, (2018)	Commercial / Contract Managers	
Oseghale et al., (2015); Gambin et al., (2016); CITB, (2018)	Architects	
McKinsey (2017); CITB (2018); CITB, (2018)	Emerging Skills	
Society for Chartered Surveyors Ireland, (2018); Olsen & Tatum, (2012); Murchadha, (2018); Li, (2018); Karimi, (2017); Gambin, et al., (2016); CITB, (2018)	Electricians	
McGrath-Champ *et al.*, (2006); IOM, (2012); Silva, (2018); Mkhonza & Letsoalo-Fuze, (2017); McGrath-Champ *et al.*, (2006); Li, (2018); Karimi, (2017); Hajela, (2012); Gambin et al., (2016)	Project Managers / Site Managers	
Silva (2018), Olsen & Tatum (2012); McGrath-Champ et al (2006) CITB (2018)	Machine Operators	**Artisans**
Silva, (2018); Mohd-Rahim *et al.*, (2016); Olsen & Tatum, (2012); IOM, (2012); Hajela, (2012); Gambin et al., (2016); CITB, (2018); APEC (2014); Li, (2018); Murchadha, (2018); National Centre for Vocational Educational Research, (2001); Oseghale et al., (2015); Society for Chartered Surveyors Ireland, (2018)	Artisans/Craftsmen (Carpenters, Welders. Brick layers, Plumbers, Painters and Roofers)	

From synthesis of the literature, skills in short supply were grouped and Figure 4.2 below was developed to illustrate the skills in short supply.

Figure 4.2: Skills in Short Supply from Literature Review



Contemporary records from previous researches shows that, many markets in the world struggle when trying to fill vacant positions for skilled workers especially in the construction industry and the issue has been going on for a number of years now. This correspond with the findings from literature review in Chapter Two where the shortage of skilled labour is reported in almost all the recent surveys carried out on the status of the construction industry. Skills shortages are recorded as posing a threat to the successful delivery of different infrastructure projects around the world.

On the global outlook, more and more markets continue to experience skills shortages than those in the balance or with surplus labour supply. This is against high unemployment rates that are also experienced in those markets. Results from **Table 4.5** above is a clear testimony of the dilemma faced in the construction industry globally.

4.1.2 BENEFITS OF AUTOMATION IN THE CONSTRUCTION INDUSTRY

As described in the previous chapter and highlighted on the first section of this chapter, the process of meta-synthesis was used to gather information on the benefits of automation in the construction industry and the results as follows; The process of searching and selection of

appropriate articles for inclusion is summarised in Figure 4.6 for the advantages of construction automation. Several scientific databases were investigated for data collection on the advantage of automation in the construction industry.

The six step meta-synthesis process

Step 1: Formulating the review questions

The first step in meta-synthesis is to formulate the research question. As stated earlier, the research question is: *"What are the benefits of automation in the construction industry*?" The benefits of CA are examined and recorded to highlight what benefits can be tapped into the South African construction industry through the adoption of automation.

Step 2: Conducting a systematic literature research

From the review question key words were defined for *"advantages of construction automation"*. After the defining key words, parameters were set that would guide in the search and exclusion criteria. From the parameters set, only articles published from year 2000 to date were considered. The database for the search was then established based on; data base thesaurus, fee text terms and using the broad base terms. The names of the desired databases used in this study are presented in **Table 4.7** below.

Table 4.7: Databases used in the search for advantages of construction automation

Databases used in the search for advantages of construction automation
Springer Link
Google Scholar
Science Direct
Research Gate
International Association for Automation and Robotics in Construction (IAARC)

Keywords were formulated to align with the search for advantages and benefits of automation in the construction industry. The key words that were used are presented in **Table 4.8**. 42 389 sources were extracted from the database based on their relations to the keywords and investigating their title and abstract and their relationship with the research question.

Table 4.8: Keywords used in the search for advantages automation

Keywords
Advantages of construction automation
Benefits of automation in the construction industry
Effects of automation in the construction industry

Step 3: Screening and selecting appropriate research articles

From the list of the databases, appropriate articles on the study area were searched and selected. Due to the need to consider current trends on benefits of CA and the need to eliminate obsolete information on benefits of construction automation, only articles published from the year 2000 to date and published in reliable scientific journals or conferences and theses were considered. A total of 42389 articles were retrieved from the data bases. Due to the impossibility to consider all the articles found on the study area, some of the articles were removed from the search sources based on the inclusion and exclusion criteria, and due to duplicate in publications. In coming up with the list of articles to be further considered for the research, the principles of "*STARLITE*" were applied in literature search. As depicted in the **Table 4.9** below, only those articles that meet the "*STARLITE*" criteria were considered for inclusion. The articles were reviewed to determine if they meet the inclusion criteria set prior to the beginning of the search.

Table 4.9: STARLITE principles applied to the literature search

S	Sampling strategy	Comprehensive
T	Type of Study	Fully reported (any kind of qualitative study)
A	Approaches	Electronic and citation snowballing
R	Range of years	Fully reported 2000 until 2019
L	Limits	Language (English)
I	Inclusion and exclusions	Inclusion (qualitative method, specifically benefits of construction automation. Exclusion (quantitative or mixed methods)
T	Terms used	Complete search strategy published in Online Supplemental Data
E	Electronic sources	Google scholar, Science Direct, Research Gate, Springer Link , ASEE, IAARC, JCME, ASCE

Step 4: Analysing and synthesising qualitative findings

The process of data analysis begins with the categorisation and organisation of data in search of patterns, critical themes and meanings that emerge from the data. In analysing data, the researcher made use of the constructionist ground theory.

Step 5: Maintaining Quality Control

The purpose is to provide clear descriptions and explanations for the choices made. Established approaches to the synthesis of primary qualitative research studies were used like audit trails. CASP and the grounded theory were both used to appraise the quality of the primary qualitative research studies, as well both electronic and manual search strategies to locate all relevant articles pertaining the area under study.

After CASP, only those articles with the acceptable scoring range remained and were used in the next step of data extraction for the purpose of this research. Articles were reduced from 45 to 25 for the benefits of CA and these were the final articles that were only considered for this research.

In order to determine and screen the number of documents that would be considered for this study, CASP is used to narrow down the documents. This is the process of examining research evidence systematically in order to access its validity to the current research, the results of that research and its relevance before using it to inform a decision (Hill & Spittlehouse, 2003). The principal aim of CASP is to assess as to whether the articles selected address research questions and context is relevant to the study under review (Hannes, 2011).

Table 4.9 below outlines the articles that were subjected to CASP to come up with the articles that would be considered for this study.

Table 4.9 CASP Evaluation of Advantages of Automation

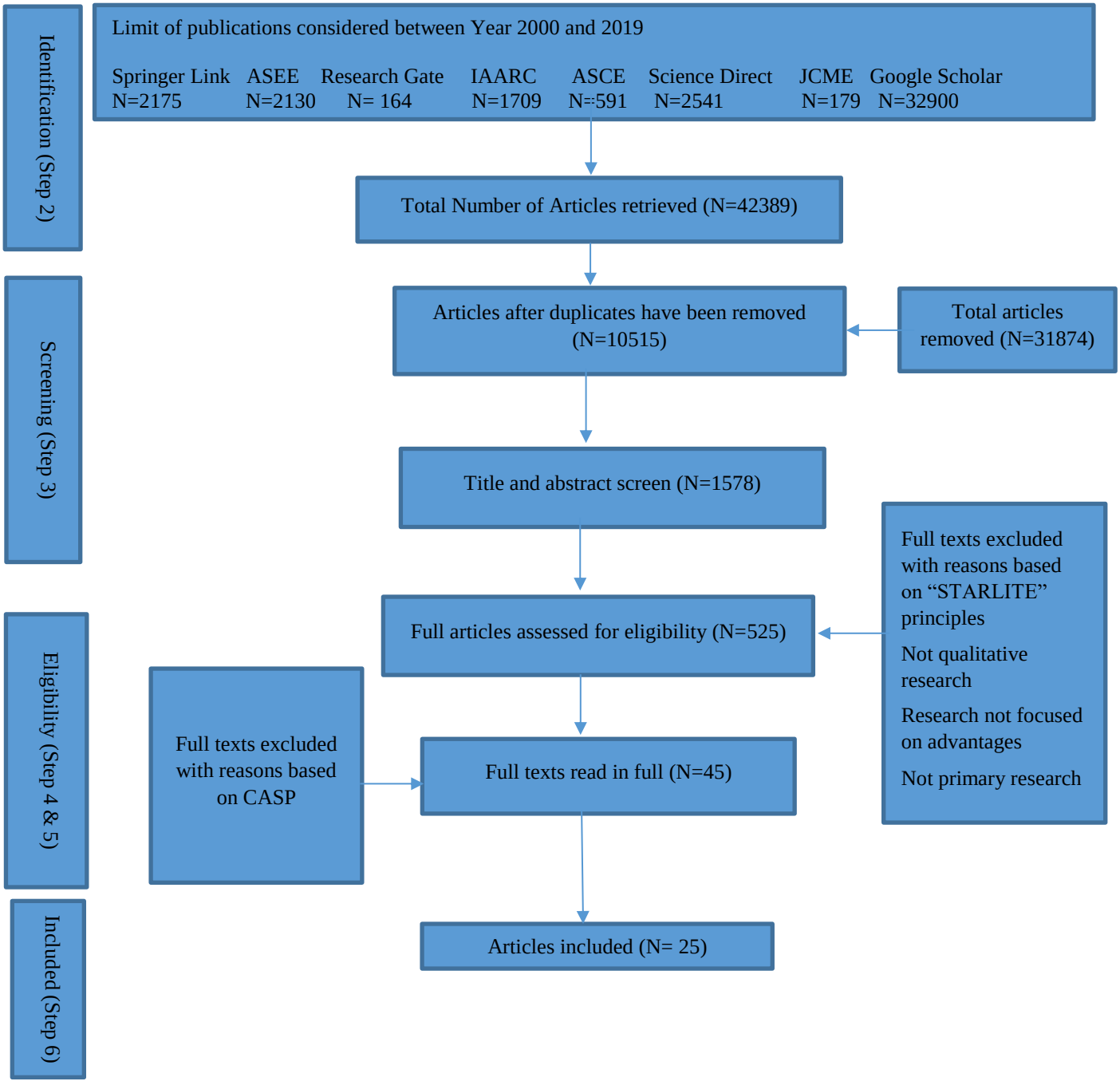
	Study is qualitative	Qualitative research is clearly justified	Research questions clearly stated	Study context is described	Sampling method is described and appropriate to the research question	Data collection method is described and appropriate to the research question	Ethical considerations taken into account	Data analysis is described and appropriate for the research question	Claims are supported by sufficient evidence	How valuable is the research	CASP Total Score (%)
Pappas MP (2004)	**9**	**9**	**10**	**8**	**9**	**9**	**9**	**9**	**10**	**10**	**92**
McKinsey (2017)	**9**	**10**	**9**	**9**	**8**	**8**	**9**	**9**	**10**	**10**	**91**
Folkesson & Lonnroos (2018)	**9**	**9**	**10**	**9**	**8**	**9**	**9**	**8**	**10**	**9**	**90**
CITB (2018)	**8**	**9**	**10**	**9**	**8**	**9**	**7**	**9**	**10**	**10**	**89**
Vaha et al., (2013)	**8**	**10**	**8**	**9**	**8**	**9**	**8**	**9**	**9**	**10**	**88**
Elattar (2008)	**8**	**9**	**7**	**9**	**8**	**9**	**9**	**8**	**9**	**9**	**85**
Fassbender et al., (2018)	**7**	**8**	**10**	**9**	**8**	**9**	**7**	**9**	**9**	**9**	**85**
Gerbert et al., (2016)	**8**	**9**	**8**	**9**	**8**	**8**	**7**	**9**	**8**	**10**	**84**
Sunder et al (2012)	**9**	**9**	**8**	**8**	**7**	**8**	**8**	**9**	**8**	**9**	**83**
International Federation of Robotics (2017)	**8**	**9**	**8**	**9**	**8**	**9**	**8**	**8**	**7**	**9**	**83**
Momin et al., (2015)	**9**	**8**	**9**	**8**	**7**	**8**	**7**	**9**	**9**	**9**	**83**
Strukova & Liska (2012)	**8**	**8**	**9**	**8**	**7**	**8**	**9**	**9**	**8**	**9**	**83**
Ardiny et al., (2015)	**8**	**9**	**10**	**8**	**7**	**9**	**6**	**8**	**9**	**8**	**82**
Bock & Pachon (2012)	**9**	**8**	**9**	**8**	**8**	**9**	**7**	**8**	**8**	**8**	**82**
Joshi and Shah (2010)	**9**	**8**	**8**	**9**	**7**	**8**	**6**	**8**	**9**	**9**	**81**
Mistri & Rathod	**8**	**9**	**6**	**8**	**9**	**8**	**8**	**9**	**7**	**9**	**81**
Pan et al 2018	**8**	**8**	**7**	**9**	**9**	**7**	**7**	**8**	**9**	**9**	**81**
Sandberg et al., (2016)	**8**	**8**	**7**	**8**	**7**	**9**	**9**	**8**	**8**	**9**	**81**
Wisskirchen et al (2017)	**8**	**8**	**9**	**8**	**7**	**8**	**7**	**8**	**9**	**9**	**81**
Sadique & Mahesh (2016)	8	7	8	8	7	8	9	7	7	6	75
Bock (2015)	8	8	5	5	7	8	9	8	7	8	73
Grant Thornton (2015)	8	8	7	6	8	5	8	7	8	8	73
Taylor & Wamuziri (2005	8	7	8	9	5	8	5	8	7	8	73

Balaguer & Abderrahim (2008)	8	8	7	7	9	8	5	7	5	7	71
Chu et al., (2009).	8	7	8	5	8	7	9	8	7	4	71
Rajgor. & Pitroda. (2013)	8	7	8	5	8	5	8	9	7	5	70
Hokkenen, (2012)	9	9	8	5	7	5	5	7	6	8	69
Nof, (2009)	8	8	7	6	5	8	7	4	8	8	69
Li, (2018)	9	8	5	7	8	5	7	5	9	6	69
Wakissaka & Furuya (2000)	8	7	8	5	8	6	6	6	7	7	68
Tejankar (2015)	7	7	6	8	6	7	7	7	6	7	68
Koutsogiannis (2017)	8	7	8	5	8	7	5	7	8	5	68
Maas & Gassel (2004)	8	9	7	5	8	4	8	6	8	5	68
Bock & Jacob (2012)	8	7	8	7	8	4	7	5	6	7	67
Holt et al., (2015)	8	7	5	8	7	6	8	4	7	7	67
Selvakumaran (2016)	8	7	7	5	8	5	8	5	8	6	67
Bock (2014)	8	7	6	8	7	5	5	7	5	8	66
Gangadara. & Kumar (2014)	8	8	7	8	7	6	7	4	5	6	66
Hsiao et al., (2017)	8	7	5	7	6	5	8	4	8	8	66
Olsen and Tatum (2012)	8	6	7	4	7	6	5	7	7	6	63
Skills Guernsey (2012)	7	5	8	5	8	5	7	8	5	5	63
Mahbub (2012)	7	5	6	7	5	6	7	7	5	7	62
Giretti et al., (2009)	7	7	5	8	4	7	6	5	7	5	61
Faltinsky & Tokunova (2018)	8	5	7	6	4	5	8	5	7	4	59
WEF (2018)	9	8	5	5	5	7	4	2	4	8	57

After vetting and scoring the articles using CASP, articles were reduced from 45 to 25 for advantages of CA and these were the final articles that were only considered further for this research. These 25 articles were found to be within the suitable scoring range.

Figure 4.4 below summarises the meta-synthesis process that was followed based on Sandelowski & Barroso, (2007)'s six step process of meta-synthesis for qualitative research.

Figure 4.4: Meta-synthesis flow chat - Advantages of Construction Automation



Step 6: Presenting Findings

Results from synthesising literature on the benefits of CA established that the benefits of automation can be broadly categorised into potential to; (i) increase productivity (ii) efficiency (iii) Financial (iv) environmental (v) Ergonomic. The results of which are presented in Table 4.10 below which summarises the list of the authors whose articles were considered for the research based on their CASP scoring.

Table 4.12: Identified Advantages of Construction Automation

Resources	Codes	Category
Pappas MP (2004); Sandberg *et al.,* (2016); Bock & Pachon (2012); CITB (2018); Elattar (2008); Folkesson and Lonnroos 2018); Gerbert et al., (2016)	Increased productivity Enabling efficiency and quality gains along the value chain	**Productivity**
Pappas (2004); Joshi and Shah (2010); Strukova & Liska (2012); Sandberg *et al.,* (2016); Bock and Pachon (2012)	Reduces potential for reworks Increases the quality of work as compared to unskilled workers	
Elattar (2008); Strukova & Liska (2012); Bock and Pachon (2012); Gerbert *et al.*,(2016); McKinsey (2017) Mistiri & Rathod (2014)	Efficiency, safe and easy of carrying out tasks Easy management of Project information	
Joshi and Shah (2010); Elattar (2008); Sandberg *et al.,* (2016); Bock and Pachon,(2012); McKinsey (2017)	Results in uniformity and increased quality of the product	
Sandberg *et al.,* (2016), Ellator (2008); McKinsey (2017)	Helps reduce the effect and impact of skilled labour shortages	
Sandberg *et al.,* (2016), Ellator (2008); McKinsey (2017)	Free up skilled labour supply for more creative tasks making the industry more attractive	
Sandberg *et al.,* (2016); Bock & Pachon (2012); Momin (2015)	Helps address complex tasks of planning and managing design and construction processes	
Pappas (2004); Elattar (2008); Strukova & Liska (2012).	Reduces accidents /incidents on construction sites	
Pappas (2004); Strukova & Liska (2012); McKinsey (2016); Mahbub (2012); Gerbert *et al.*,(2016)	Efficient use of materials and resources	

Ardiny et al (2015) Folkesson and Lonnroos 2018); Gerbert et al., (2016); Sandberg et al (2016); Pappas (2004)	reduce the construction process duration; shorten project lead time; Used for automated measurements, of satisfactory accuracy, which is less time consuming	**Construction Duration**
Pappas (2004)	schedule performance	
Ardiny et al (2015), Folkesson and Lonnroos (2018); Monin (2015); Sandberg et al (2016); McKinsey (2017); Mistiri & Rathod (2014); Vaha et al (2013)	reduce the construction process duration; Shortens and reduces construction duration; reduces the duration and laborious work	
Pappas (2004); Elattar (2008); Strukova & Liska (2012); Joshi and Shah (2010); Folkesson and Lonnroos (2018); McKinsey (2017); Strukova & Liska (2012); Vaha et al (2013)	Carry out jobs much easier which is hardly done by labours	
Pappas (2004); Sandberg et al (2016) Folkesson and Lonnroos (2018); McKinsey (2017); Gerbert et al., (2016); Mistiri & Rathod (2014); Strukova & Liska (2012); Vaha et al (2013)	Find and correct problems faster than humans which saves time; Let the computer do time demanding routine work and frees up time for more creative development work	
Pappas (2004); Elattar (2008); Strukova & Liska (2012); Sandberg *et al.,* (2016); Gerbert *et al.*,(2016); Fassbender et al (2018); McKinsey (2017); Mistiri & Rathod (2014); Momin (2015); Sunder (2012); Vaha et al (2013)	Reduces construction costs; optimal resource allocation and scheduling at the construction site BIM facilitates the operations and maintenance (O&M) of a building by providing a virtual model of it sustainable construction	**Financial**
Gerbert et al., (2016); McKinsey (2017); Mistiri & Rathod (2014); Vaha et al (2013)	reduce the number of manual inspections and unexpected failures, and the amount of preventive maintenance, this would give a needed boost to economic growth and prosperity	

Strukova & Liska (2012); Ardiny et al (2015); Fassbender et al (2018) Folkesson and Lonnroos (2018); Pappas (2004)	Lower cost construction; resulted in a 30% reduction in construction time	
Ardiny et al (2015); Elattor (2008); Fassbender et al (2018); Folkesson and Lonnroos (2018); Gerbert et al., (2016); Pan et al (2018); Pappas (2004)	Cost-effective. Contributing to higher profit and revenue. Supporting value engineering - such as automatically generating and evaluating design alternatives,	
Joshi and Shah (2010); Ellattor (2008); Momin (2015)	Eliminating complains about noise and dust concerning works such as removal, cleaning or preparation of surfaces	**Environmental**
McKinsey (2017)	social and regulatory acceptance will affect the pace and scope of automation	
Ardiny et al (2015); Fassbender et al (2018); Folkesson and Lonnroos (2018); Gerbert et al., (2016); Joshi & Shah (2010); Momin (2015); Pan et al (2018); Strukova & Liska (2012); Sunder (2012); Vaha et al (2013); Wisskirchen et al (2017)	prevent worker injuries; Improved Safety	**Ergonomics**
Ardiny et al (2015); Elattor (2008); Strukova & Liska (2012); Joshi & Shah (2010); Momin (2015); Vaha et al (2013); Wisskirchen et al (2017)	Improving work environment as conventional manual work is reduced to a minimum, so the workers are relieved from uncomfortable work positions	
Elattor (2008); Joshi & Shah (2010); International Federation of Robotics (2017); McKinsey (2017); Mistiri & Rathod (2014); Momin (2015); Strukova & Liska (2012); Vaha et al (2013); Wisskirchen et al (2017)	Higher safety for both workers and the public through developing and deploying machines for dangerous jobs. the most complex and hazardous tasks will be assigned entirely to autonomous or semiautonomous construction equipment	

Ardiny et al (2015); Elattor (2008); Folkesson and Lonnroos (2018); Momin (2015); Strukova & Liska (2012); Vaha et al (2013); Wisskirchen et al (2017)	perform construction tasks where human presence is impossible, undesirable, or unsafe; can be used for repetitive and heavy lifting tasks which increases ergonomics for workers,	
Joshi and Shah (2010); Tejankar (2015); Elattar (2008)	Replaces labours in those tasks which involve difficult physical work.	
Balaguer & Abderrahim (2008); Tejankar (2015); Elattar (2008); Faltinsky & Tokunova (2018); Strukova & Liska (2012); Holt *et al.*, (2015)	Enhance work environment because workers will be distanced from uncomfortable work position.	
Balaguer & Abderrahim (2008); Tejankar (2015); Elattar (2008); Holt *et al.*, (2015)	Conducts labour tasks at dangerous locations for example at substantial height places	
Ellattor (2008); McKinsey (2017); Mistiri & Rathod (2014); Momin (2015); Sandberg et al (2016) Sunder (2012)	Uniform quality with higher accuracy than that provided by skilled worker.	**Quality**
Bock & Pachon (2012); CITB (2018) Gerbert et al., (2016); Pan et al (2018)	boost the quality, quality is an aspect that will increase with automation	
Sandberg et al (2016) Strukova & Liska (2012) Sunder (2012) Vaha et al (2013)	does everything in the same way every time which implies a quality control since the process of designing can be standardized to a certain degree	
Folkesson and Lonnroos 2018); Momin (2015)	industrial robots in the construction industry have potential benefits such as improving quality	

After conducting meta-synthesis on the skills in short supply globally as well as the advantages brought about the implementation of CA to augment labour, the next step of the research is to analyse data specifically related to the South African construction industry. The skills in short supply are identified in SA and the potential use of CA with the view that the use of AI and CA will brought about the same benefits as those economies that have started to use automation and AI in their construction processes.

4.2 DATA ANALYSIS – INTERVIEWS

In quantitative research, measurable data is used in formulating the facts and uncover patterns in a research. The quantitative approach prefers objectivity and helps with knowing the changes over time.

4.2.1 RESPONSE RATE AND GENERAL INFORMATION

For primary data collection relating to the South African construction industry, five of the seven semi-structured interviews that the interviewer has scheduled to conduct were carried out representing a 71% response rate. This satisfies the minimum rate of 52% recommended by Baruch & Holton, (2008) for academic researches. The interviews were carried out with the client organisation, multi-disciplined consultant firm, project managers, grade 9 CIDB grading contracting firm and grade 4 CIDB grading contracting firm whose responses are recorded and used for data analysis, presentation and interpretation in this section. According to Cohen *et al.,* (2007), the deductions made from the respondents maybe generalised for the whole population since a high response rate equates to the reliability of the population presented. This is taken to be the representation of views and opinions of the majority of the targeted population.

GENERAL INFORMATION

This section focuses on the statistics on the characteristics of the respondents to present the frequencies of their responses to the later sections of the questionnaire.

PROFILE OF THE RESPONDENTS

From the layout of the questionnaire, the respondent's general information are in **Section A: Demographic Information,** to extract the background information of the respondent relative to the study.

Below is Table 4.14 that illustrates the profile of the respondents,

Table 4.14: Profile of Respondents

Respondent	Gender	Profession	Experience
Client Organisation	F	Quantity Surveyor	23 Years
Project Managers	M	Construction Project Manager	42 Years
Large Contractors	M	Contracts Manager	33Years
Emerging Contractors	M	Architect	27 Years
Consultants	M	Civil Engineer	38 Years

PROFESSIONAL BACKGROUND

For the successful delivery of the project, all professions need to be well represented right from the inception of the design to put them in a position to influence the direction of the project. The sample of the respondents is a well representative of the stakeholders involved in the project delivery. Due to the complex nature of the projects and the costs involved, project design and planning now require more attention as any error / deviation from the design during the construction phase may have a dire cost implication on the project (Faltinsky & Tokunova, 2018).

The development of BIM and Simulation on the other hand had made it possible to visualise the completed project even during the design stages and to cost all the viable options before any physical work can start on ground. All viable options can be brainstormed, tried and costed with easy before the final design can be agreed upon and selected. As evidenced from the profile of the respondents (Table 4.14), most of these professions are represented for the purpose of gathering information relating to their various responsibilities during the design and delivery of the project.

RESPONDENTS' WORKING EXPERIENCE

From the presentation of Table 4.14 above, all the respondents have been involved in the construction industry for more than 20 years in construction serving at different levels and capacities. This goes to show that data for the purpose of this research was collected from people who are well experienced with the delivery of construction projects to provide informed responses. This group most likely have worked in the management and delivery of diversified projects over years and as such, are aware of the challenges faced in the delivery of projects and how to overcome such. The exclusion of the group with less than 10 years' experience,

given the recent trends in technological advancement an AI and computer software might mean that there is a gap in the information collected. This is however overcome by the Continuous Professional Development (CPD) courses that are offered from different service providers to equip participants with the latest trends and development in the industry. Most of the interviewees are in senior management responsible for their department.

TYPES OF PROJECTS UNDERTAKEN

Respondents were asked about the type of projects that they engage in and the results are recorded in Figure 4.7 below. The type of projects that topped the list are residential properties followed by commercial/industrial, roads and highways and dams and tunnelling the least. This is due to the demand of the projects within the market, the cost implication and the return on investment of the project.

Figure 4.7: Types of Projects Undertaken

4.2.2 UNDERSTANDING OF CONSTRUCTION AUTOMATION

After capturing the general information from the respondents, the next section of the interview is to get an overview of the familiarity of the respondents with the concept of CA, robotics and AI and what they perceive it to be.

- ***What do you understand by the term automation or artificial intelligence when they are applied in the construction industry?***

The general understating of the terms automation and AI by the respondents was important in ascertaining whether they are knowledgeable and familiar with the topic and as to whether their responses will be relevant to the study area. All the five respondents demonstrated that they had a general idea and appreciation of what automation and AI is when applied to construction.

They claimed to be familiar with the concept of automation since all their responses aligned their definitions as involving the use of computer software, machines and or robots to do the work thereby limiting or minimise human interference in the process to some extent.

Due to their demographic profile, all of the respondents confessed that during their college years, the use of automation or AI was very limited in the construction industry, the school curricula also was missing on it and whenever they got to hear of robots and AI, the automobile and manufacturing industry would come into mind. This has however changed with the turn of the millennium when web-based project management, e-Work, parametric modelling, Wi-Fi, ultra-wide band for tracking and positioning, machine vision, mixed augmented reality and nanotechnology began to be introduced in the construction industry.

Though the respondents during their college days, CA was not as popular as it is now, they are getting more knowledgeable of the use of CA and AI from professional development workshops, construction news and through interaction with other professionals from other countries through interaction and engaging in international contracts. Since the respondents hold senior positions and head divisions, they are always up to date with the latest developments in the construction industry so that they are not left behind with the wave of latest development and trends in the industry.

- ***In your opinion, is there any clear cut difference between robotic use and artificial intelligence or they can be used interchangeably?***

Although the terms robotics and AI cannot be used interchangeably, the respondents agreed that there is a thin line between them. To differentiate between the two, robotics they said it involves the use of machines that are programmed with sensors and actuators that are embedded in them to undertake a certain task either autonomously or semi-autonomous, while AI involves the use of computers and computer programmes to complete tasks as human intelligence.

4.2.3 ENABLERS FOR USING CONSTRUCTION AUTOMATION

- ***Which automation tools, (hard or soft) are you aware of and their role within the construction?***

All the respondents however agree that they integrate soft / design automation especial during the conception design of the project or when deliberating variations to the original designs

during the construction. This is mainly due to the cost benefit it will have during construction and maintenance phases of the project. Soft automation is mostly useful and beneficial especially during the conceptual design stages where the Client, Consultants, Contractor and Project Managers will be interacting in coming up with the most cost effective design that meets all the functional requirements of the project.

The project stakeholders all agree to the use of BIM and simulation. Due to the complexity nature of the projects and the costs involved, any mistake that will result in reworks may cost the project millions in monetary value and time for completion, therefore after the appointment of the Project Manager and the design team (Consultants), they engage and streamline all designs to come up with one that is cost effective. This is one area of automation that they seem to all agree to, engage before the project physically starts and make all "*what if*" including getting the cost estimation of each proposed change. The use of BIM, simulation and other computer programmable software's also have helped a lot in giving accurate estimates.

- ***Within your organisation what kind of work would you normally automate/ use artificial intelligence to perform?***

The respondents noted that, any kind of work in the construction industry is capable of being automated, but because of the social responsibility of organisations to create employment and high cost involved, the use of automation and AI is therefore limited. The response from the Project Managers Contractors Consultants suggest that, AI is used mainly during the development of design drawings or when evaluating possible alternatives to come up with the most cost effective solution to implement.

Hard automation and robotics are not a common feature due to the cost involved and that they go against the social responsibility of employment creation. All the respondents acknowledged that at the present moment they do not have any project which is currently utilising machine automation, though they always integrate software during planning and sequencing of the work.

- ***What would you put up as your motivation when faced with a decision on whether or not to automate?***

The shortfalls in traditional construction methods especially when it comes to high wastage of materials, productivity issues, high fatality rate and quality issues were mentioned by all as the pushing factors for the implementation of automation. The drivers for the adoption of

automation were highlighted as "*benefits that accrue should automation be embraced in the industry"* by the consultants.

All the respondents save for the client organisation described the implementation as "*still*" to happen in SA. As put by the Contracts Manager, *"the incorporation of autonomous equipment and robotics on our construction sites is close to none existence*". They feel that there is very limited use of automated equipment on our construction sites.

- ***From the following list, what would consider as the most driving force for the implementation of automation and use of AI within your organisation?***

During the interview, respondents were asked to rank on the benefits of automation from meta-synthesis as the drivers for advocating the adoption of automation within their different organisations. The rankings were done as to whether they perceive that the adoption of automation will have positive impact on; increased productivity; quality; financial benefits; environmental and ergonometric and impact on construction duration.

Table 4.16: Drivers for Construction Automation

Factor	Client Org.	Large Contractors	Emerging Contractors	Consultants (Designers)	Project Managers
Increased productivity	4	5	6	4	6
Quality of the work	1	1	1	3	3
Impact on construction duration	3	2	2	2	1
Financial benefit	5	4	4	1	4
Environmental	6	6	5	6	5
Ergonomics	2	3	3	5	2

From the table above, three of the organisation respondents (Client, Large Contractors and Emerging Contractors) said they will advocate for automation since it has the potential to increase the efficiency in which the work is carried out.

- Apart from the list for the drivers of automation highlighted above, the client, consultant and the main contractor added that, automation helps to solve design challenges fast, easily and elegantly as automation technologies amplify and augment human abilities to make work easier to do.

4.2.4 THREATS FOR AUTOMATION

- ***What do you think is holding the South African construction industry in the implementation and adoption of automaton?***

In responding to the factors that are holding the implementation of CA, the Contracts Manager has this to say, *"Despite reports of high levels of skills shortages experienced in the country and beyond, the issue of CA is like a taboo in SA construction industry."* This was the general view of all the other respondents mainly especially because of high unemployment rates among the youths and previously disadvantaged groups.

This feeling is also shared by other stakeholders, the Quantity Surveyor, representing the client organisation raised this during the interview saying that, "*even when debating about or advocating for CA, during stakeholder meetings, the first reaction one will be presented with from the audience is the serious issue of unemployment which the government is struggling to contain*". The Architect highlighted the unavailability of skills to congruent with the implementation of automation. Although the respondents all seem to agree that the construction industry is faced with skills shortages and appreciates the benefits brought about by automation, they seem to be divided when it comes to the adoption and implementation of automation as a measure to cushion the shortages. Irrespective of having to bear the consequences of skills shortages in the industry, resorting to full automation as a measure seems is likely highly impossible firstly due the high unemployment rate in the country and secondly due to unavailability of skilled people to successfully implement full automation.

- ***What can be done to promote the use of automation and artificial intelligence in the construction industry?***

The education curriculum needs to be revised first to include training for the use of AI and automated equipment. A campaign on the benefits of using automation and the threats faced by the construction industry should the industry continue to shun the use of technology in its line of business. This should be done to take away the negative perception they have on robots and AI.

4.2.5 AUTOMATION AND SKILLS SHORTAGES

- ***In your own opinion, are we experiencing skills shortages in the construction industry? If yes, which skills would you consider to be in short supply?***

Although the respondents unanimously agreed that the country indeed is experiencing shortage of skilled people especially for highly qualified position, the nature of the skills shortages is the nexus between professional certification and skills trade. Many of the advertised post now require professional registration with the relevant professional bodies and despite the level of education and work experience, if not registered professionally one will not qualify for that position. Another issue highlighted is the employment equality. Where employment preference will be for a designated ethnic group. Potential employees from other ethnic groups won't be considered even if they meet all the other requirements for the post. "*Considering these requirements would we say the country is really experiencing shortages, what will be the measure of such shortages*?"

Shortages were reported for Engineering staff and competent project and contract managers. The quantity surveyors, programme managers, occupational health and safety professionals and artisans (welders, plumbers, carpenters and roofers) were also reported as in short supply.

- ***What would you say are reasons for skills shortages in the construction industry?***

On the issue of skills shortages, the respondents, articulated different reasons for causes of skills shortages but all boiled down to an education system that is not preparing the youth work in the industry. The quality of education at the different tertiary institutions paces those graduation from highly ranked institutions with better employment prospects than those from lowly ranked institutions. The advent of Apartheid blamed the shortage where access to education and opportunities was limited to only a few privileged mostly whites who again at the dawn of freedom migrated overseas leaving a void in the labour market which is taking long to close up. The bad image of the construction industry, in that the work is mostly performed outdoors and it separates people from the comfort of their homes made many youths and women to shun careers in the construction industry.

- ***In your own opinion, what do you think should be done to permanently address the issue of skills shortages?***

In order to address skills shortages in the industry, the main issue has to do with changing the mind set especially with the present generation. While many view graduating from technical schools as not glamorous compared to a university degree, and thereby avoiding technical school and end up acquiring degrees and certificates that does not help in in addressing skills shortages something the DBE commented on during the 2017 matric top achievers function.

These graduates will at the end of the day unemployable as they do not poses the required skills and it gives rise to skills shortages in other sectors while for other sectors, there will be an oversupply.

Speaking ahead of the release of the 2018 class of matric, Director General for Basic Education Mr Mweli to change 6 out of 10 schools to become technical schools may also help in arresting the issue of skills shortages before it becomes out of control especially where these technical schools are to respond to sills in short and likely to be in short supply in the near future (Times Lives 2019). These sentiments were also reiterated by the president in his 2019 State of the Nation Address. As an example as to how this might help curb skills shortages in the country, one of the respondent (consultant) gave an example of Germany and Italy. Obtaining a technical skill is highly regarded in these countries and assures the candidate of secured employment in future. This ironically is in contrast to the situation in the country.

How if so, can the use of automation and artificial intelligence be used to solve the issue of skills shortage?

Automation though it offers a quick solution to the issue of skills shortages. Although the respondents did not agree to the implementation of automation as a short term solution due to the high levels among the youths and previously marginalised by the Apartheid system. But however the is room for the development of CA and AI to address skills shortages. There are so many developments in the area of AI and or robotics in to augment and imitate human labour, although some of these technologies are not yet SA, trends show that's where we are heading to.

The following were mentioned as areas where AI and automation have been developed.

- for better design of structures
- to increase productivity and output
- address skilled labour shortages
- offsite construction
- construction safety
- project planning
- risk mitigation
- prevent cost overruns
- post construction management and
- big data in construction

- ***Do you have any comments about the adoption of automation and robotics in the construction industry and the survey in general?***

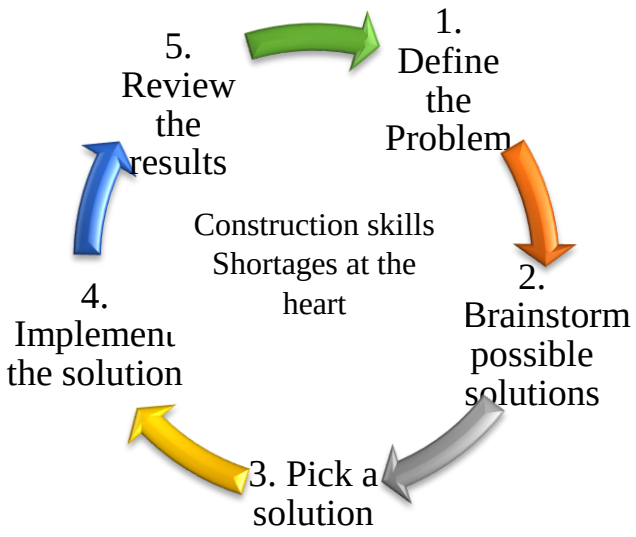
At the end of the survey, all the respondents were asked for their opinion on the adoption of automation in the construction industry in general. This was an open ended question with no guided response. There were mixed feeling as to whether CA is likely to replace human labour, but there was a general consensus that the adoption of CA, will alter the way work is carried out in the construction industry. With the world inclined on Revolution 4.0, AI and automation is the future and "*is not anything we should fear"* the consultant was quoted as saying. For industry policy makers. They should embrace automation and view AI as another important tool as the construction industry continues to move towards increased automation to increase safety and on-site productivity, and should be included in the school curricula.

CA will no doubt help reduce expensive errors, worksite injuries and make building operations more efficient. Those that consider automation in the near future should prioritise investment based on areas where AI can have the most impact on their company's unique needs in that early movers will set the direction of the industry and benefit in the short and long term.

4.4 THE POTENTIAL OF AUTOMATION TO ADDRESS SKILLS SHORTAGES.

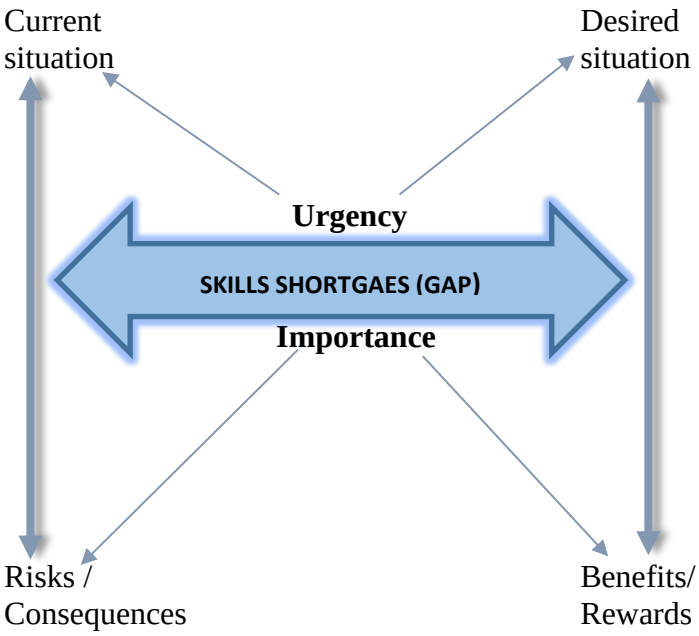
Before concluding on the potential of using automation to address skills shortages, a five stage cycle was followed which starts with defining the problem being a skill that is in short supply. The skill is identified, then a number of possible solutions to overcome the challenged are tabled before a selection is made. The selection of a solution largely depends on the budget, the time frame in which the skill challenge has to be overcome have to be identified as either depending on the project schedule. The selected solution is then implemented and reviewed at time interval to see if it is yielding the desired results as far as addressing the shortage. Should the solution proposed not yield the desired results, the process repeats again with a different solution from the previous one until the optimum solution is found.

Figure 4.8: A Cycle to Identify and Address Skills Shortage



As highlighted from the cycle above, addressing skills shortages has to do with closing the gap in skills supply that prevents an organisation from attaining the desired situation and the associated benefits. The aim of closing the gap is to move from the current situation characterised by skills shortages and risks and consequences associated with skills shortages which have the effect of hampering prospects for a smooth project delivery to get to the desired situation with rewards and benefits as were identified from synthesising the literature.

Figure 4.9: Closing up the skills gap



Current situation:
Shortage of skilled labour in the construction industry

Desired situation:
An economy with a balanced skilled labour supply for optimum economic growth

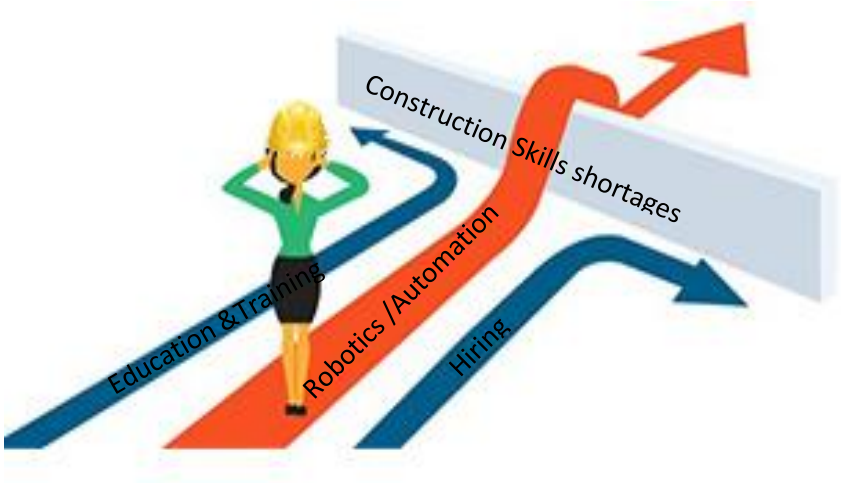
Risks/Consequences:
Increased construction costs; time overruns; poor quality product; high fatality rates on sites

Benefits/Rewards:
Increased productivity, time and costs reductions; improved worker satisfaction and efficiency in completing tasks

Urgency/Importance:
Timing especially for those projects with a tight delivery schedule.

With the high levels of skills shortages experienced in the construction industry, it's not a surprise that almost every organisation at one point in time faced with issue skills shortage and has contemplate a way forward. When faced with skills shortages, while education and training has always been the first option, robotics and automation are also proving to be the alternative to the woes in the construction industry. Education and training has the main advantage of improving the socio-economic wellbeing of the citizen by reducing on unemployment. With education and training the process may take long to train and then certify them as competent to do the work. Hiring on the same time can be long especially where there are no local people available, the immigration process on its own can be tiring as a result the construction process may be prolonged and a monetary incentive may be required to attract the best. This can have the effect of increasing the construction cost while there is no guarantee on the quality of work. The type and duration of the project both comes into consideration when contemplate whether or not to automate. As it is, automation is suited mainly for long duration and complex projects with a tight delivery schedule or where the possibility of using human labour is not possible (as in high rise building where lifting of materials by human labour might not be possible).

Figure 4.10: Skills Shortages Crossroad



As skills shortages have a cost implication on the project, it has to be considered as to whether hiring or skills training may be an option. From the figure 4.10 above, although robotics and automation offers a fast solution to get over skills shortage challenge, the choice of use should not be to the detriment of the unemployed.

Table 4.17: The Potential Use of Artificial Intelligence and Construction Automation

Skills in Short Supply	**Enablers**	**Threats**	**AI / Automation tool**
Designers / Engineers/ Architects	Reduced human errors Reduces potential for reworks Savings in skilled labour Useful tools to evaluate the performances of construction projects under alternative resource Increasing productivity and work efficiency	High resistance from those who view automation as taking away "our jobs" High levels of Unemployment Lack of necessary skills to implement and manage	Generative Design, Cloud based workstations, BIM
Project Managers / Contracts Managers			Doxel, Drones
Quantity Surveyors			Generative design, BIM
Emerging Skills			
Machine Operators			Self-driven vehicles
Bricklayers			Semi-automated brick laying machines
Carpenters			Offsite manufacturing
Welders			Mobile welding robots
Electricians			
Plumbers			
Roofers			

4.5 SUMMARY

The purpose of this chapter is to present the results and findings of the study. Meta-synthesis was carried out to establish the nature and extend of skills that are in short supply in the construction industry as well as the advantages of using AI and automation with the aim of showing that, the issue of skills shortages is not only in the country, but it a global one. Interviews were then carried out to make a conclusion specifically for the South African industry. Results of the findings were presented, analysed and conclusion are drawn on the potential use of automation and AI to augment skills shortages in the South African construction industry.

CHAPTER 5: DISCUSSIONS

5.0 INTRODUCTION

This chapter is the conclusion of the study. It details the restrictions and limitations that the researcher encountered during the course of the study and makes recommendations based on the findings of the study. The recommendations are based on the outcome and implication of the study. The conclusions are drawn from the findings and analysis from the meta-synthesis and the interviews.

Aim and objective of the study

The aim of the research was to investigate the potential of adopting automation in addressing skills shortage in the South African construction industry. With the following as the research objectives:

- To establish the current skills shortage records in the construction industry
- To identify the benefits of automation in overcoming construction skills shortage
- To identify the enablers and threats for using automation in the South African construction industry.
- To show the extent to which automation can be used to address skills shortages in the South African construction industry.

5.1 DISCUSSION OF RESULTS

After the presentation and analysis of the data from both meta-synthesis and interviews, this section details the thorough discussion of the data collected against the literature reviewed in Chapter Two to answer the research questions outlined in Chapter One. Data was collected for this research with the intent of answering the main research question, *"How can automation be used to augment skills shortages being experienced in the South African construction industry?"*

5.1.1 WHAT ARE THE SKILLS SHORTAGES CURRENTLY EXPERIENCED IN THE CONSTRUCTION INDUSTRY?

Results from the interviews show that indeed the country is suffering from shortage of skilled labour with Engineers, Project Managers, Emerging Skills and Quantity Surveyors as the hard to fill vacancies. The CIDB had drafted the Contract Participation Goal in the hope of

combating the skills shortage within the construction sector. However, despite efforts by companies to offer trade skills to locals through contract participation goals in South Africa, the demand for artisans and craftsmen seem to be upsurge.

Skills shortages in the country has been blamed on the education system which is failing to produce the desired quality pass mark for the matriculates to further study in skills in demand. The Architect commented that, "*Given the high annual university dropout rates, the concept of matric pass is just an illusion and a farce*", as it does not bear any substance in the general academic performance. This was also reflected by the results of the study by OECD (2010) where SA was ranked third from last among the G20 Nations on the PISA scale for proportion of students attaining basic literacy in mathematics and science from commencement of primary to end of secondary schooling. In 2016, the country came last of the 139 countries that were surveyed by WEF on the quality of maths and science subjects.

The Apartheid system and the cyclical nature of construction work coupled with the labour brokers, policies on employment were also blamed for skills shortages. With the Apartheid, the majority of black people were denied quality education and skills yet they make up the bulk of the population, the cyclical nature of construction project have caused many to consider working in other industries which offer permanent employment prospects. The existing policies of employment equity have caused many employers to report "*difficulty"* in filling positions yet people are available who meet the experience but are not considered as they are outside the employment group.

Results from meta-synthesis were in coherent with the results of the interviews. From literature review, reasons for skills shortages were given as the unattractiveness of the construction industry among the younger generation while at the same time the industry is faced with an ageing population among those employed, skills mismatch between demand and supply in the labour market and an education system that is not preparing the graduates (Rust & Koen, 2011; Tshele & Agumba, 2014; Mbeki, 2014; Windapo, 2016).

Skills shortage in the construction industry is an international phenomenon which has threatened and hampered the successful delivery of many construction projects. According to a survey by Turner and Townsend, 56 percent of the markets it operates in are experiencing skills shortages. These include; North America, the UK, Australia, Asia, SA and parts of mainland Europe (Turner & Townsend, 2017).

Taking a look around the globe, employers in Japan, and 83% of employers reported that they were struggling to fill open positions (Manpower Group, 2016). In Ireland the Quantity Surveyors and Commercial Managers were listed amongst the scarce skills with the supply of trades like plasterers, carpenters, electricians, brick layers and plumber dwindling. In UK, the Federation of Master Builders (2014) have acknowledged that the industry has been hit by a serious shortage of skilled labour with bricklayers and carpenters being the most affected and this seepage being experienced with other key trades like roofers and plumbers. 200,000 construction jobs were left unoccupied across the United States in 2016, while 86% of contractors reportedly struggle to fill the positions (WEF, 2016).

Most of the authors reported the shortages among the tradesmen and artisans. These skills needs hands-on when doing the work, while many of today's youth are fond of working with computers and technology. Results from literature on skills in short supply show the following as skills as in short supply;

- Artisans/Craftsmen
- Engineers / Architects
- Electricians
- Project Managers
- Commercial / Contract Managers
- Surveyors and Estimators
- Machine Operators
- Emerging Skills

5.1.2 WHAT ARE THE BENEFITS OF USING AUTOMATION IN THE CONSTRUCTION INDUSTRY?

Having identified the skills that are in short supply, the aim of research question number two was to identify the benfits of using automation in the construction industry.

Since the birth of the Second Industrial revolution in the mid 1940's, many industies have been advancing in the operation of automation and robotics in their production line. Since the implementation of robotics in the production line in the automobile industry, productivity has increased by over 1500%, with efficiency in the use of resources and uniformity in the products increasing as well. On the contrary, the construction industry's productivity has remained the stagnant for the past six decades (Holt *et al.*,2015, Pachon, 2012). When it comes to wastage

use of materials and resources, the construction industry on average looses US$ 90 billion due to materials waste and time. Several articles, associations and organisations have been established in the past to drive the advancement of automation and robotics use in the construction industry. Although these organisations meet occassionally to discuss issues around the implementation of automation in the industry, its full implementation in the construction industry is still to materialise (Bock, 2015). From the results of meta-synthesis, many of the previous authors agree that the use of automation in the construction industry results in efficiency, safe and easy of carrying out tasks, uniformiy and increased quality of the end product.

As was noted by Holt *et al.,* (2015), the construction productivity has remained stagnant over the years, automation in the construction industry is thought to helps increase overal industry productivity and efficiency by creating a safe working environment and simplifying tasks to be carried out. Since the invention and introduction of robotits and auotmtaion in the production lines especially for repetative tasks, productivity has increased immensily in the manufacturing industry leaving the construction industry lagging in its productivity level. The intoduction and employment of automation and robotics in the construction industry as such is deemed to yeild the same positive results as it has done in other industries.

However, the respondents from the interviews have different opinions as that of Holt *et al*, (2015), who say that, CA and AI results in increased productivity. They argued that, the uniqueness of construction projects makes it the benefits that accrue due to the employment of CA and AI in projects subjective especially with robotics and hard automation. The huge costs involved in automating any system made differing opinions with Client and Emerging Contractors citing high costs involved, they argued that the cost involved might outweigh the benefits and because of the high cost, they do not consider it as really a driver for them to automate

Metasynthesis grouped the advantages of CA into four main categories; productivity/efficiency ergonomics, financial/ economic, quality, construction duration and environmental benefits. The benefits were further broken down into;

- Increased productivity
- Reduction in the potential for reworks
- Efficiency, safe and easy in carrying out tasks
- Uniformity and increased quality of the product

- Reduction in the effect and impact of skilled labour shortages
- Frees up skilled labour supply for more creative tasks making the industry attractive
- Efficient use of materials and resources
- Reduction of construction costs
- Shortened construction duration
- Easy management of project information
- Addresses complex tasks of planning and managing design and construction processes
- Elimination of noise and air pollution due to the works
- Improvement in the work environment due to reduction of conventional manual work to minimum, the workers are thus relieved from uncomfortable work positions.
- Reduction in accidents /incidents on construction sites
- Replacement of labourers in tasks which involve difficult physical work.
- Conducts labour tasks at dangerous locations for instance at substantial height places.

5.1.3 WHAT ARE THE ENABLERS AND THREATS FOR USING AUTOMATION IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY?

AUTOMATION ENABLERS

After identifying the skills in short supply and the advantages of CA, the aim of this question was to identify the push and pull factors to the implementation of automation. From literature several drivers were mentioned for the implementation of automation. According to Gerbert *et al.,* (2016), automation and the use of robotics increases the output and cut on construction duration thereby reducing significantly the unit cost of the output. For an industry faced with acute shortage of skilled labour, automation can be used as a means to retain workforce in construction industry should human labour be replaced with robots for hard and difficult to work tasks (Joshi & Shah, 2010; Elattar, 2008). Automation and robotics can indeed be a solution to the current public construction skills, as for almost all skills there is a counter robot or AI can be employed to complete fast and efficiently.

The Project Managers and the Consultants considered as the number one driver especially if the financial implication of the project is considered. For large contractors, they highlighted that robotics and automation makes more sense for those projects which involves repetitive

work in order to capitalise of the cost of acquiring of setting up the automated system, i.e. where the automated system can be used on more than one project so as to spread the costs.

On the other hand, environmental conservation was ranked lowly due to the recycling of construction materials or environmental analysis before the waste could be released. The Client's side is very reluctant and seem to have no motivation for pushing for automation, this is because they seem to rely and entrust the management and supervision of the project on the appointed agents acting on behalf of the Client for the delivery of the project.

The Project Manager on the other hand seem to be more concerned with getting the most cost effective design before the appointment of the contractor or evaluate if it's a design and build by the Contractor. The appointment of the Project Manager limits their use of automation to mainly soft and site inspection tools like drones upon which they rely for the provision of site progress. They favour drones over physical human inspection because of they are fast and efficient in gathering information which if physical inspections are conducted, may take days to complete. Drones also have the advantage of reaching out and accessing even areas that are hard and impossible to reach by humans.

The main motivation for CA especially the use of robotics rests with the contracting firm who generally have the responsibility of delivering the project within time, quality and cost parameters. The benefits of the adoption and implementation of CA as highlighted earlier has to do with cutting on unnecessary costs, increasing productivity and efficiency in the way the work is done. Besides that contracting firms are capable of utilising both the soft and hard automation especially with large and diversified firms. For smaller and emerging contracting firms, the idea of embracing automation is still far from being realised, especially where their terms of appointment is for construction phase only or to fulfil government or project requirements on contractor incubator programmes. The use of automation would go against their terms of appointment besides the cost implications to set it up.

THREATS TO THE USE OF AUTOMATION

The South African education system is not preparing skills for Revolution 4.0. The adoption of automation and AI can be done on condition that the benefits accruing from automation are shared to minimise unemployment lest unemployment will surge and skyrocket in the country plunging everyone in adverse poverty. This is in line with the findings of the Harvard Group (2008) which acknowledged that the issue of skills shortages on itself limits the potential for

economic growth and hamper on the creation of employment. Unemployment rates are very low in developed countries than in developing countries because of the correlation between economic growth and the level of automation (Prettner, 2017; Aghion, *et al.*, 2017, Folkesson & Lonnroos, 2018). High unemployment was singled as the greatest threat to the implementation of CA among the interview respondents. The complexity and uniqueness of construction projects means that not every construction activity is best suited for automation nor is it viable to fully automate the construction processes lest the unemployemnt levels will scourge. Not every skill in short supply should be approached with automation as the ultimate solution. Education and or training should be considered first as they have the advantage of employability and help in curbing unemployment and poverty. The nature of the skills in short supply, available training and duration of training for one to master the concepts to work independently all plays a role when faced with the dilemma whether or not to automate the work.

Since for most of the activities on the project there is a corresponding CA that goes to augment human skills involved. It would be unwise and at certain times uneconomical to automate all activities on a project lest this will go against the need to fight unemployment in any economy.

5.1.4 HOW AND TO WHAT EXTEND CAN AUTOMATION ADDRESS SKILLS SHORTAGE IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY?

Having identified the skills in short supply and the advantages of automation the pull and push factors for the implementation of automation, the purpose of this question was to integrate the findings of the first three questions to answer the aim of the study which is, "*to investigate the potential of using automation to address skills shortages in the South African construction industry.* Data from both literature and the interviews concurred that in fact AI and automation can be used in addressing the shortage of skilled labour in the construction industries. Several software and robotics have been developed that is being used in the industry though some of these have not yet "*arrived*" in the country. The following were mentioned as areas where AI and automation have been developed.

- **For Better Design of Structures**

Because of the of the diverse stakeholders involved in the construction industry even before the physical work starts, physical interaction between the design team to come up with the most

effective design maybe time consuming if not impossible. Simulation on the other hand, seeks to optimise the design with no need to make a physical stereotype. Conventional construction methods that allow construction to start before construction drawings are fully developed and the need to cut unnecessary costs have led to the development of BIM, a 3D model based process that allows all project stakeholders project insights to efficiently plan, design, construct and manage structures. The birth of the Internet of Things and Generative Design Software has made it possible to use the cloud to generate different design options to choose the most optimal solution from. Generative design is used to automate time consuming tasks, but construction and cost functions have been slower in coming to market.

- **To Increase Productivity and Output**

The use of robotics and AI based applications is aimed at helping the workers do their jobs more accurately, quickly and efficiently. There is a correlation between the level of production and profit margins. Robots and other forms of automated equipment maybe used for repetitive tasks like, bricklaying, welding, pouring concrete or demolition among other tasks. Artificial intelligence-based applications provide help to workers to do their job with accuracy and speed. It follows that; increase productivity is coupled with an increase in profits on every project.

Most excavation and site preparation works can now be performed by self-sufficient or semi-autonomous bulldozers, which can prepare the site with the aid of a human programmer to exact specifications. This liberates human workers for the construction work and reduces the overall time required for the completion of the project. Project Managers can also track job site work in real time by using facial recognition, onsite cameras, and other technologies to assess worker productivity and adherence to procedures.

- **Address Skilled Labour Shortages**

The use of CA and AI is driven by the current skills shortage and the need to boost the industry's low productivity levels. Through real time data analysis, there is a possibility of increasing construction productivity by more than fifty percent. This is according to 2017 McKinsey report. AI and machine learning is being used to better plan and manage the distribution of machine and labour across different work stations. The evaluation of on-site job progress and the location of workers and equipment by a robot enable project managers to advise which job sites have enough workers and equipment to complete the project on schedule,

and identify the ones falling behind where additional labour could be deployed. Experts anticipate construction robots to be more intelligent and self-sufficient with AI techniques.

The idea is that robots can perform complex processes that are presently extremely labour-intensive and time intensive through algorithmic programming and machine learning. This liberates human employees for the construction work and condenses the overall time required to complete the project. This is one of the many ways enhanced automation will take on manufacturing duties, making up time for humans to concentrate on greater design and engineering dares.

- **Offsite Construction**

Construction companies are increasingly depending on off-site factories staffed by independent robots that assemble together components of a building, which are then joined together by human workers on-site. Structures like walls are completed assembly-line style by autonomous machinery more efficiently compared to their human counterparts, leaving human workers to finish the detailed work like; plumbing, HVAC and Electrical systems when the structure is fitted together.

- **Construction Safety**

The construction industry is prone to high fatalities with falls, struck by objects, electrocution, and caught-in/between as leading causes of deaths. Algorithms can analyse and scan jobsite photos for safety hazards such as workers not wearing protective equipment or practising unsafe work practices and relates the images with accident records. From the information, risk ratings can be computed to be discussed at toolbox talks whenever a threat is detected. By using AI to track interactions of workers, machinery and objects on site, AI can be handy in alerting supervisors of potential safety issues, construction errors or issues to do with productivity.

- **Project Planning**

Neural Network can be used in controlling the budget uses 3D scans of the site and feeds into algorithms that classify the difference in real-time between sub-projects triggering the management team to step in if things are off track. This serves to deal with small problems before they grow into major issues. Future planning and sequencing is made possible through the use of a technique that allows algorithms to learn on a trial and error basis. It works on endless arrangements and options based on similar projects to assist in project planning and

employ the best path and correct itself over time. The software involuntarily produces detailed schedules and resource allocations, which precisely estimate the cost and time frame for a project. Users understand the construction process through an interactive visualisation, and can quickly modify a schedule to reflect the shifting realities of the construction cycle.

- **Risk Mitigation**

Risk is an integral part of any construction project which comes in the form of quality, cost time and site safety where multiple sub-contractors work on different trades in parallel. General contractors can benefit from the use of AI and machine learning solutions in monitoring and prioritising risk on the job site, affording the project team to focus their limited time and resources on the biggest risk factors. AI is used to automatically assign priority to issue as such construction managers can work closely with high-risk teams to mitigate risk because subcontractors are rated based on a risk score

- **Prevent Cost Overruns**

Construction cost overruns has become a major concern for almost all construction projects despite employing the best project team and taking every precautionary measure to avoid them. New software Artificial Neural Networks have been developed to predict cost overruns based on project size, contract type and the competence level of the project managers. The programme is based on historical data like the planned start and end date to envision realistic timelines for future projects

With certain projects taking long to complete and bringing in new people at different stages of the project, AI assist staff remotely access real-life training material which helps quickly develop their skills and knowledge. This reduces the time bring on board new resources onto projects. As a result, project delivery is expedited.

- **Post Construction Management**

Post construction, AI can be used in monitoring the building performance and schedule maintenance based on information about the structure stored on BIM.

- **Big Data in Construction**

With heavy reliance on historical project information to monitor the project and for future reference, AI systems and algorithms are exposed vast amount of data to learn from and improve every day. Data generated from images captured from mobile devices, drone videos,

security sensors, building information modelling (BIM), and others have become a pool of information. This presents an opportunity for construction industry professionals and customers to analyse and benefit from the insights generated from the data with the help of AI and machine learning systems to better manage the delivery of projects.

However, from the responses and literature review, resistance is high on the implementation of on-site construction when compared to the use of AI in the design and planning management of projects. This is mainly because, the software used for the design and planning tend to improve efficiency and are relatively cheaper and readily available compared to automation and robotics technologies used in on-site operation.

CHAPTER 6: CONCLUSION & RECOMMENDATIONS

6.1 CONCLUSION

Although construction skills shortages are regarded as critical, they are not unique or new. In South Africa, skills shortages was cited mostly as one of the key features hindering economic growth. Due to lack of necessary skills ranging from managerial, professional and technical skills, it is impossible for the economy to be fully productive. For an economy to progress it needs to grow and expand. The expansion and growth of the South African economy is clutched with both external and self-inflicted inherent forces which weakens its potential to tap into viable economic opportunities. The unavailability of skilled workforce is one thing that is constraining expansion of business operations in the country and business owners and economists concurred that skills shortages are posing a significant limitation on the economic growth potential in the long run.

Previous researches into the correlation between the levels of automation and unemployment have squashed these fears showing a positive correlation between automation and employment. In most European countries which are leading in digitalisation, the overall demand for labour have increased with the rise in digitalisation creating over 11 million jobs between 1999 and 2010 as a result of computerisation. This suggests that, the job-creating effect of robotics and computers overcompensated the job-destructing effect. While over 800 000 low skilled workers in the UK lost their jobs due to technology advancement, 3.5 million high-skilled new jobs were created and for countries with high robot density like Germany, Japan and Korea, they also have the lowest reported unemployment rates.

This goes to show that automation complements labour, raises output in ways that lead to higher demand for labour and interacts with adjustments in labour supply. Due to the massive growth in automation and AI in recent years, unemployment in industrialized nations is quite low. Japan, United States, and Germany which are ranked as the of the most automated countries in the world, currently have unemployment rates of roughly 2.3 percent, 3.7 percent, and 4.9 percent, respectively.

To help elaborate on how other European countries managed to harness the benefits of AI to grow their economies and cut on unemployment Professor Gronau, Chair of Business Informatics,

Processes and Systems at the University of Potsdam in Berlin, Germany has this to say "*People need not fear the Fourth Industrial Revolution, as it's an opportunity for job creation – as long as companies recognise the need for automation and upskill their workforce."* In order to harness the benefits of automation and create more jobs, there is need to manage the integration of AI in the reindustrialisation of the economy and reskilling the workforce for an automated economy. Instead of being replaced by machines, as humans, we need to learn to collaborate with machines to enhance our own productivity and ingenuity. We must learn to "run with the machine"

The construction industry has for long been embroiled with skills shortages mainly due to its unattractiveness and unappealing nature to the young generation while it is faced with an ageing workforce. In the South Africa, the main challenge for skills shortages was blamed on a dysfunctional education system that is not preparing the graduates for the practical working environment. According to DHET, the major constraints to sustainable job creation in the country lies on the structural mismatch between the demand and supply of labour. To effectively tackle the issue of skills shortage in the construction industry, there is need for collaboration between the design, engineering and construction firms, industry associations, the government and academic institutions as the key issues that affect the industry and measures to resolve skills shortages should be holistically and be pursued at company; industry and government levels.

The issue of skills shortages as such cannot be effectively tackled from one angle, but from the industry, companies and government alike need to come together and implement measures and policies that help tackle this problem. Even though these measures take different approaches to address the issue of skills shortage they can be broadly categorised into three; upskilling the current workforce, enticing new employees and using technology to increase productivity and alleviate demand for more talent.

And while still faced with high unemployment and skills shortages, automation and AI is fast disrupting and changing the nature of work in the future. Trends already highlights significant shifts in employee skills that will be demanded in future due to 4IR. Over the past years, automation have shifted the requirements of workplace skills with high demands predicted in the technological skills. The 4th Industrial Revolution Partnership for SA (4IRSA) was founded to fully understand the drivers of automation and to shape a coherent national response to the

4IR in the country. One thing to understand and bear in mind in the quest to respond to skills shortages and the 4IR, is that, while machines increase productivity and tend to be cheaper in the long run, they neither buy nor consume goods and services, they do not drive the purchasing power and consumption as humans do. When humans are employed and get paid, they consume and spend progressing the society, and the opposite is true, if humans don't work, they don't spend resulting in economic regression. This is why there is so much resistance by the workers and labour unions to adjust and embrace the human machine interactions at the workplace as they fear and feel that machines and AI might completely replace and make them redundant.

The perception that automation will reduce the need for human workers entirely is not all that correct as employers are anticipating an increasing need for people with even higher skills than those that can be replicated by automation. Automation will not replace jobs but it will make them more interesting and help attract new generation who are fond of technology and innovation. The cyclical nature of construction work makes it very difficult to retain workforce as many specialised trade workers tend to switch industries and professional workers migrating to other areas at the end of project or during recession. Results of a study carried out in 2018 by Accenture showed that if South Africa is to double the pace at which the workforce acquires relevant skills for human-machine collaboration, it can reduce the number of jobs at risk of being lost as a result of automation from 20% (3.5 million jobs) to just 14% (2.5 million) by 2025. Further it was found that, AI has the potential to add 1% point to the annual economic growth doubling the economy size five years earlier if AI is embedded.

Because construction automation is currently in its infancy stages, it cannot at this stage be considered as the immediate solution to the current skill shortages. Apart from automation contradicting with the government policies on employment creation and EPWP, the current education system is not commensurate with the skills set required for an automated economy. A gradual transition is ideal and the launch of the 4th Industrial Revolution Partnership for SA is a move in the right direction to prepare for this gradual process.

6.2 RECOMMENDATIONS

Construction companies must strategize and plan the demand and supply of workforce, improve in-house training and learning and adopt new technologies to improve technologies to improve productivity and job satisfaction to reduce talent drain. Companies must work on

creating an appealing image and diversify for young generations to consider careers in construction and increase the percentage of women employed in the industry.

It is the role of the construction industry associations to run image campaigns to promote a career in the construction industry thereby targeting prospective new talent and offering career guidance to learners from grades ten, eleven and matriculates to consider the construction industry as their choice for further studies. But this can only be achieved should the academic institution work on improving the quality of education and grades in the STEM subjects. There is a growing to tendency perceive the problem of skills shortages on a poor and weak education and training system. The argument is that, the only way to address skills shortage is through an increase in the public investment on education and training and changing the education system (Rasool & Botha, 2011). Over the past decade the government and private sector heavy invested in the education and training of the workers but the results are not in consummate (Silva 2018) and SA has been a good case to prove this perception (Rasool & Botha, 2011).

The main cause for skills shortage is an education system that does not train people for future skills. With the Fourth Industrial Revolution around, the economy should plan skills supply to address this, otherwise we will be faced with even more skills shortages. The Fourth Industrial Revolution which is characterised by fast paced technological progress will likely to transform the labour market hence the need to align education with skills needed in the labour force. The government has adopted Skills Gap Analysis in the form of a national gazette on "*Occupation in High Demand*" which provide a detailed analysis and insight into the skills needs of the economy and society. This information is useful for policy decision and workforce planning for the future especially where the labour market in the country is characterised by high levels of unemployment on one hand and skills shortage on the other (RSA, 2018). Industry associations should also make career paths more transparent and join forces on training with academia and vocational training providers.

The government on the other hand must use its role as regulator and main owner of public infrastructure projects to come up with regulations and support initiatives that incentivise innovation thereby increasing the attractiveness of the industry. Building standards must be consistent to make projects simple and less labour intensive. Also, there is need to initiate public-sponsored apprenticeship and academic programmes to include training on new skills and boost support for job services. Research findings concurred with the previous researches

in that, by embracing mechanical equipment construction companies can substitute hazardous, dirty, vigorous tasks and prompt the processes. One example cited was in remote-controlled demolition robots which proved to be safer and more efficient than conventional tools for demolishing concrete, particularly in confined spaces.

The use of prefabrication modules and shifting some of the tasks to prefabrication tasks not only free some of the much needed labour to other tasks but can improve working conditions by allowing remaining on-site work to consist mainly of a project's final stages, reducing workers' exposure to job-related risks and speed up the construction process. The adoption of prefabrication-based modular construction has created a safer work environment and increased productivity and can be adopted by the government to meet up with the 2014 – 2019 Medium Term Strategic Frame Work, by the Department of Human Settlement in the delivery of 1.5 million housing opportunities by 2019. Prefabricated housing units are by far safer than the current RDP housing units which some of the beneficiaries are shunning due to poor construction methods.

6.3 CONTRIBUTIONS TO ACADEMICS AND PRACTITIONERS

With the wide spread of skills shortages in the construction industry, this research highlighted the potential use of AI and automation to help curb those shortages. AI and automation can be integrated into the construction process from the initial planning phase weighing in the different design options and their financial implications, buildability right through the life cycle costing of the project. Information about the project can be stored in the cloud and different speculative maintenance can be scheduled from there. Findings of this research makes a number of contributions if implemented will add value to the academics and construction practices. The two sections are elaborated separately below.

Contribution to Practice

This research offers a number of practical implications on the potential use of AI and automation for the as highlighted in **Section 4.3.4** of this research**.** Overall, this research:

- Stimulates awareness on the potential use of AI and CA to help address the challenges faced by the global construction industry particularly regarding skills shortages and productivity.
- Provides a practical solution to the challenges of skills shortages that has been ongoing for more than three decades.

- Outlines major challenges faced by the construction industry and how automation and AI maybe used to overcome each and every challenge highlighted.

Contribution to Academic Field

This research also makes a number of contributions to the academic domain. In brief, this research:

- Provides a deeper understanding of the academic principles surrounding the causes of construction skills shortages.
- Broadens causes of skills shortages into skills mismatch and general shortages and how to tackle each cause.
- Highlights academic reforms necessary to address the challenges of skills shortages.
- Presents opportunities on the potential use of CA and AI in the construction process to explore further areas that are best suited for automation and AI.

In a nut-shell, CA and AI offers a whole lot of potentials in addressing skills shortages. Although there is a wide range of speculation that automation will result is job losses, previous researches have shown a direct correlation between unemployment rates and the level of economic growth. Due to the continuous reports of skills shortages, it is recommended to weigh in the potential use of automation across the construction value chain to augment the limited human resources available.

6.4 AREAS OF FURTHER RESEARCH

From the findings of this research, the issue of skills shortages in the construction industry is not a new phenomenon but it is a recurrent one. Results of the survey and literature review indicated several researches have been conducted on skills shortages with recommendations on education and training as a measure to address this since it also have a benefit of making people employable. But education and training alone is failing to combat skills shortages this is evident from the results from various surveys conducted globally which still portrays a dire situation when it comes to skills shortages in the industry.

There has been limited researches that sought to determine the correlation between the level of automation in an economy and the level of skills shortages. Further investigations and investment in Research and Development into the use and application of automation tools and

software in the construction industry is needed to ascertain the extent to which automation can be used to curb skills shortages in the construction industry.

The areas of further research proposed above could help in the construction industry to plan and manage with the limited number of available workforce and direct them to more challenging tasks that cannot be carried out by robots or programmed.

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APPENDIX A: ARTICLES READ FOR SKILLS SHORTAGES META-SYNTHESIS

Results of meta-synthesis on skills shortages

Author	Article Name
APEC (2014).	A Report on the APEC Region Labour Market: Evidence of Skills Shortages and General Trends in Employment and the Value of Better Labour Market Information Systems
Baloyi & Bekker (2011)	Causes of Construction Cost and Time Overruns: The 2010 FIFA World Cup Stadia in SA.
BCI Economics 2011	Preview: Australian Construction Market Outlook Report 2018/2019: The Swings and Roundabouts of a Changing Economy.
Building Sight (2018)	Tackling The Global Skills Shortage: Construction Projects at Risk
Campbell (2016)	The UK's Skills Mix: Current Trends and Future Needs
Chang-Richards *et al.,* (2015)	Effects of a Major Disaster on Skills Shortages in the Construction Industry: Lessons Learned from New Zealand
CITB 2018	Unlocking Construction's Digital Future: A Skills Plan For Industry
Gambin *et al.,* (2012)	Sector Skills Insights: Construction. Evidence Report 50.
Gambin *et al.,* (2016)	Research to Understand the Extent, Nature and Impact of Skills Mismatch in the Economy. Department for Business, Innovation and Skills, UK
Hajela (2012)	Shortage of Skilled Workers: A Paradox of the Indian Economy
Healy *et al.,* (2015)	Adjusting to Skill Shortages in Australian SME's
IOM (2012)	Labour Shortages and Migration Policy
Karimi (2017)	Quantitative Analysis of the Impact of Craft Labour Availability on Construction Project Performance
KPMG (2017)	Make It or Break It: Reimagining Governance, People and Technology in the Construction Industry. Global Construction Survey 2017
Li (2018)	Robots for the Construction Industry
Makhene & Twala (2009)	Skilled Labour Shortages in Construction Contractors: A Literature Review
McGrath-Champ *et al.,* (2006)	From One Skill Shortage to the Next: The Australian Construction Industry and Geographies of a Global Labour Market

McKinsey (2017)	A Future That Works: Automation, Employment and Productivity.
Mitra & Tan (2012)	Lessons Learned From Large Construction Project in Saudi Arabia. Benchmarking: An International Journal
Mkhonza & Letsoalo-Fuze (2017)	Understanding the Hard to Fill Vacancies in the Public Service Sector: The Case of Provincial Departments.
Mohd-Rahim *et al.,* (2016)	The Challenge of Labour Shortage For Sustainable Construction.
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Olsen & Tatum (2012)	Bad of Business: Skilled Labour Shortages in Alabama's Construction Industry.
Oseghale *et al.,* (2015)	An Evaluation of Skilled Labour Shortage in Selected Construction Firms In Edo State, Nigeria.
Othman (2014)	A Conceptual Model for Overcoming the Challenges of Mega
Rasool & Botha (2012)	Push and Pull Factors in Relation to Skills Shortages in South Africa. The Nature, Extent And Effect of Skills Shortages on Skills Migration in South Africa
Silva *et al.,* (2018)	A Review of The Skill Shortage Challenge in Construction Industry in Sri Lanka
Skills Guernsey (2012)	Construction Sector Skills Gap and Training Needs Survey
Society of Chartered Surveyors Ireland (2018)	SCSI – PwC Construction Survey 2018
Turner & Townsend (2017)	International Construction Market Survey 2017: Building Momentum.
Wang & Bhanugopan (2010)	Assessing Skill Shortages in China: Exploring and Rebuilding National Capability Development Framework
Watson (2012)	Concerns for Skills Shortages in the 21st Century: A Review Into The Construction Industry, Australia
Windapo (2016)	Skilled Labour Supply in The South African Construction Industry: The Nexus between Certification, Quality Of Work Output and Shortages

APPENDIX B: ARTICLES READ FOR ADVANTAGES OF AUTOMATION META-SYNTHESIS

Author	**Article Name**
Ardiny *et al.,* (2015)	Are Autonomous Mobile Robots Able to Take Over Construction? A Review
Balaguer & Abderrahim, (2008)	Trends and Robotics in Construction
Bock & Jacob (2012)	Automated Construction – An Efficiency Analysis and the Socio-Economic Impact
Bock & Pachon (2012)	Construction Site Automation: Guidelines for Analysing its Feasibility, Benefits and Drawbacks
Bock (2014)	Construction Automation and Robotics
Bock (2015)	Construction Robotics Enabling Innovative Disruption and Social Supportability
Chu *et al.,* (2009).	Robotic Automation System for Steel Beam Assembly in Building Construction
CITB (2018)	Unlocking Construction's Digital Future: A Skills Plan for Industry
Elattar (2008)	Automation and Robotics in Construction: Opportunities and Challenges.
Faltinsky & Tokunova, (2018)	Information Technologies and Construction Sector: Why Construction Loses Competition for Innovations to Other Industries?
Fassbender *et al.,* (2018)	Improved Productivity, Efficiency and Cost Savings Following Implementation of Drone Technology in the Surveying Industry
Folkesson & Lonnroos (2018)	Construction Automation – Assessment of State of the Art and Future Possibility
Gangadara & Kumar (2014)	Trends in Robotics and Automation in Construction
Gerbert *et al.,*(2016)	Digital in Engineering and Construction: The Transformative Power of Building Information Modelling
Giretti *et al.,* (2009)	Design and First Development of an Automated Real-Time Safety Management System for Construction Sites
Grant Thornton (2015)	Automation: The Pros and Cons
Hokkanen (2012)	Methods for Automated Civil Construction Production Control

Holt *et al.,* (2015)	Emerging Technology in The Construction Industry: Perceptions from Construction Industry Professionals
Hsiao *et al.,* (2017)	An Occupational Safety and Health Perspective on Robotics Applications in the Workplace
International Federation of Robotics (2017)	The Impact of Robotics on Productivity, Employment and Jobs
Joshi and Shah (2010)	Automation in Construction Industry
Koutsogiannis (2017)	Robots on Jobsites: The Future of Robotics in Construction
Li (2018)	Robots for the Construction Industry
Maas & Gassel (2004)	The Influence of Automation and Robotics on the Performance of Construction
Mahbub, (2012)	Readiness of Developing Nations in Implementing Automation and Robotics Technologies in Construction: A Case Study of Malaysia.
McKinsey (2017)	A Future That Works: Automation, Employment and Productivity.
Mistri & Rathod	Remedies Over Barriers of Automation and Robotics for Construction Industry
Momin *et al.,* (2015)	Enhancement of Road Construction Sector Using Automation.
Nof, (2009)	Handbook of Automation
Olsen & Tatum (2012)	Bad of Business: Skilled Labour Shortages in Alabama's Construction Industry.
Pan et al (2018)	A methodological approach to implement on-site construction robotics and automation: a case of Hong Kong
Pappas MP (2004)	An Assessment of Implementation Requirements for the Tier II Construction Workforce Strategy
Rajgor & Pitroda (2013)	Automation: A New Millennium Technology for Construction Industries
Sadique & Mahesh (2016);	Barriers to Mechanisation and Automation in Indian Construction Industry
Sandberg *et al.,* (2016)	Design Automation in Construction – An Overview
Selvakumaran, (2016)	Is the Term "Construction Industry Outdated"
Skills Guernsey (2012)	Construction Sector Skills Gap and Training Needs Survey

Strukova & Liska (2012)	Application of Automation and Robotics in Construction Work Execution
Sunder et al (2012)	Information Technology, Construction Innovation and NIST
Taylor & Wamuziri (2005	Automated Construction in Japan
Tejankar (2015)	The Use of Automation in the Construction Industry.
Vaha *et al.*, (2013)	Survey on Automation of the Building Construction and Building Products Industry
Wakissaka & Furuya (2000)	Automated Construction Systems for High-Rise Reinforced Concrete Buildings
WEF (2018)	Shaping the Future of Construction: An Action Plan to Solve the Industry's Talent Gap.
Wisskirchen et al (2017)	Artificial Intelligence and Robotics and their Impact on the Workplace

APPENDIX C: INTERVIEW QUESTIONS

CAN AUTOMATION AND ROBOTICS BE USED IN THE CONSTRUCTION INDUSTRY TO AUGMENT ENGINEERING SKILLS SHORTAGE PREVAILING IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY?

SECTION A: DEMOGRAPHIC INFORMATION

1. Years of Experience within the Built Environment

Experience: Less than 10 Years 11-20 Years 21-30 Years

31 – 40 Years +41 Years

Role within the organisation

……

SECTION B: CONSTRUCTION AUTOMATION

2. Understanding of construction automation

a) What do you understand by the term automation or artificial intelligence when they are applied in the construction industry?

b) In your opinion, is there any clear cut difference between robotic use and artificial intelligence or they can be used interchangeably?

3. Enablers for using automation

a) Which automation tools, (hard or soft) are you aware of and their role within the construction?

b) Within your organisation what kind of work would you normally automate/use artificial intelligence to perform?

c) What would you put up as your motivation when faced with a decision on whether or not to automate?

4. Threats for using automation

a) When it comes to the implementation and adoption of automation in South Africa, what do you think is holding us back?

b) Can something be done to promote the use automation and artificial intelligence in the construction industry?

SECTION C: SKILLS SHORTAGES AND AUTOMATION

5. Skills shortages in the construction industry

a) In your own opinion, are we experiencing skills shortages in the construction industry? If so, which skills would you consider to be in short supply?

b) What would you say are reasons for skills shortages in the construction industry?

b) In your own opinion, what do you think should be done to permanently address the issue of skills shortages?

c) How if so, can the use of automation and artificial intelligence be used to solve the issue of skills shortages?

SECTION D: COMMENTS

Do you have any comments about the adoption of automation and robotics in the construction industry and the survey in general?

APPENDIX D: INTERVIEW GUIDE / PROTOCOL

As defined by Saunders *et al.*,, (2016), an interview is a purposeful conversation between two or more people and it is through conducting an interview that the researcher will get rich and detailed qualitative data in order to understand the participants' views and opinions on the study area (Castilli-Montonya, 2016). There are three types of interviews namely, open ended, focused and structured (Yin, 2003) and an interview protocol/guide sets the guidelines upon which the researcher will conduct the interview. When preparing to conduct interviews, care must be placed on the selection of participants and building trust between the participants and the researcher, location and length of interview time (Rubin & Rubin, 2012). An interview protocol will not be complete without the mention of the order, quality and clarity of questions (Patton, 2015; Rubin & Rubin, 2012); and the overall process of conducting an interview (Brinkmann & Kvale, 2015; Patton, 2015). The purpose of an interview protocol is to ensure that interview questions are set out to align with the research questions and objectives that were outlined in Chapter One.

Castilli-Montonya, 2016, designed and come up with a four step interview protocol comprising of the following steps:
Step 1: Alignment between interview questions and research questions
Step 2: Constructing an inquiry-based conversation
Step 3: Receiving feedback on the interview protocol
Step 4: Piloting the interview protocol

Step 1: Alignment between interview questions and research questions

When designing a research protocol, the first step is on ensuring the alignment between interview questions and research questions. In Chapter One, the purpose of the research and research objectives were defined. To ensure alignment of the interview questions, interview questions should be set out in such a way that they completely answer the research questions. To help check on this alignment, the researcher created a matrix as proposed by Castilli-Montonya, (2016) to map interview questions onto the research questions. The purpose of the matrix is to help display whether or not any gaps exist between the research questions and the interview questions lest one will notice the information gap until after data collection is complete. The matrix also helps in sequencing the questions i.e. at the beginning, middle or end and to check whether too many questions are asked related to one question or too few for other questions. In summary, Step 1 focuses on the researcher developing an interview protocol aligned.

Step 2: Constructing an inquiry-based conversation

From the definition of an interview given above, an interview protocol in an instrument of inquiry, a platform on which specific information related to the aims of the study are asked (Patton, 2015). To guide a conversation and move an inquiry forward takes both care and hard work (Rubin & Rubin, 2012). Step 2 of the interview guide assist the researcher with the development of an inquiry-based conversation through an interview protocol. The protocol contains; interview questions written differently from the research questions but aligned to the purpose and aim of the research, an organization following social rules of ordinary conversation, a variety of questions and a script with likely follow-up and prompt questions (Castilli-Montonya 2016).

In order to develop a protocol that promotes an inquiry based conversation, the interview questions should be worded differently from the research questions but strive to answer them. As highlighted in Step 1, research questions are different from interview questions. In order to clarify this functional difference, Maxwell (2013), has this to say "*Your research questions formulate what you want to understand; your interview questions are what you ask people to gain that understanding*". An as a researcher in formulating interview questions, your knowledge of the context and study area helps to write questions that are understandable and accessible to the selected participants. This was emphasised by Brinkmann and Kvale (2015), saying that "*The researcher questions are usually formulated in a theoretical language, whereas the interview questions should be expressed in the everyday language of the interviewees*". As such, when designing interview questions, the researcher should consider those terms used by participants, and questions should be asked one at a time, and avoid the use of jargon (Patton, 2015) and interview questions should follow the following sequence according to Rubin & Rubin (2012);

i. Introductory questions,
ii. Transition questions,
iii. Key questions, and
iv. Closing questions

With introductory questions, they serve to help the researcher start the interview with easy and non-threatening questions that are often directly linked to the participant and his position within an organisation. Introductory questions help in creating the mood for the interview. Transition questions move the interview toward the key questions (Krueger & Casey, 2009) and keep the

conversational tone of the interview. Whereas Key questions, often referred to as main questions seeks to obtain the most valuable information on the study area from the participant (Rubin & Rubin, 2012). The closing questions are easy and present the participant with an opportunity to raise any questions or issues about the study area which the researcher did not address. It affords the participant to add on any valuable information which the researcher might have overlooked when designing the interview questions.

During the interview, the researcher may include a script which is a written text that will guide the researcher during the interview (Castilli-Montonya, 2016). Though the researcher may not read the script word-for-word when the actual interview is underway, having a prepared script can mentally prepare the researcher for the art of keeping an interview conversational. When preparing the script, the interview should also consider any prompt or follow up questions, designed to solicit further information from the participant or to clarify an issue should the participant not get the first question right.

Step 3: Receiving feedback on the interview protocol

After completing Step 1 (Alignment between interview questions and research questions) and Step 2 (Constructing an inquiry-based conversation) of the interview protocol, the following step will be to obtain feedback on the interview protocol. The purpose of obtaining feedback is to provide the researcher with information about how well participants understand the interview questions and whether their understanding is close meeting the set research aim and objectives (Patton, 2015). Apart from engaging a third party, the researcher may undertake to close read the interview protocol or vetting the protocol through a think-aloud activity. After close reading and the think aloud, the researcher engaged the view of others in order to get their views on the interview questions and interview guide as a whole. (Maxwell, 2013). This insight into what participants are thinking as they work through their responses to the interview questions can elucidate whether questions are clear, whether interviewees believe they have relevant answers, and whether aspects of questions are vague or confusing and need to be revised (Hurst *et al.*, 2015). Obtaining feedback on interview questions may be one way for a researcher to check on how his/her evolving questions will be heard and therefore responded to by participants.

Step 4: Piloting the interview protocol

After obtaining feedback on the research questions, the fourth step will be to run a pilot interview as in real conditions as possible with the people who mirror the sample of the actual participants of the interview (Maxwell, 2013). The idea is to simulate the actual interview in as real conditions as possible and according to Merrian, (2009, this is the best way to tell whether the designed and order of questions is perfectly suited for the actual interview. It is during this step that the interviewer conducts interviews simulating rapport, process, consent, space, recording, and timing in order to "try out" the research instrument. Through piloting, the researcher aims to get a realistic sense of how long the interview takes and whether participants indeed are able to answer questions (Castilli-Montonya, 2016)

Below is a table of the summary of what each step entail and the information it aims to obtain.

Table 1: Interview Protocol / Guide Process

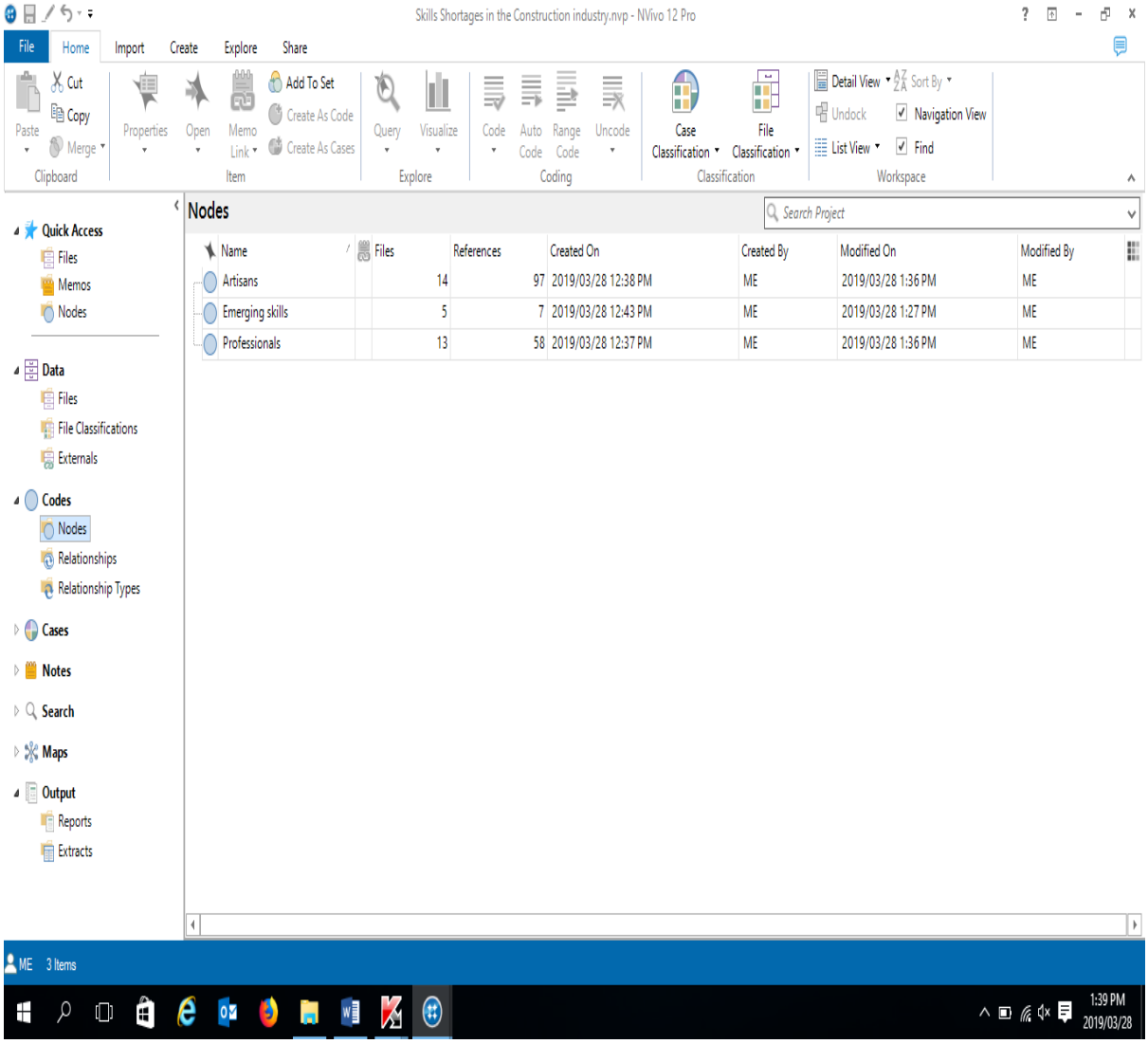
Step	**Purpose**
Step I: Ensuring interview questions align with research questions	To create an interview protocol matrix to map the interview questions against the research questions
Step 2: Constructing an inquiry-based conversation	To construct an interview protocol that balances inquiry with conversation
Step 3: Receiving feedback on interview protocol	To obtain feedback on interview protocol (possible activities include close reading and think-aloud activities)
Step 4: Piloting the interview protocol	To pilot the interview protocol with small sample

AIM: As set out in Chapter One, the aim of the study is to investigate the potential of using automation in addressing skills shortage in the South African construction industry. This interview guide is designed to answer the following **Objective Questions**:

- **What are the enablers and threats for using automation in the SA construction industry?**
- **How and to what extend can automation address skills shortage in the SA construction industry?**

RESEARCH QUESTION: Can automation be used in the construction industry to augment skills shortage being experienced in the South African construction industry?

APPENDIX E: NVIVO – CONSTRUCTION SKILLS SHORTAGES


Skills Shortages in the Construction industry.nvp - NVivo 12 Pro
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Create As Code
Create As Cases
Item
Query
Visualize
Explore
Code
Auto Code
Range Code
Uncode
Coding
Case Classification
File Classification
Classification
Detail View
Sort By
Undock
Navigation View
List View
Find
Workspace
Quick Access
Files
Memos
Nodes
Data
Files
File Classifications
Externals
Codes
Nodes
Relationships
Relationship Types
Cases
Notes
Search
Maps
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Reports
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Artisans 14 97 2019/03/28 12:38 PM ME 2019/03/28 1:36 PM ME
Emerging skills 5 7 2019/03/28 12:43 PM ME 2019/03/28 1:27 PM ME
Professionals 13 58 2019/03/28 12:37 PM ME 2019/03/28 1:36 PM ME
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Skills Shortages in the Construction industry
2019/03/28 2:15 PM

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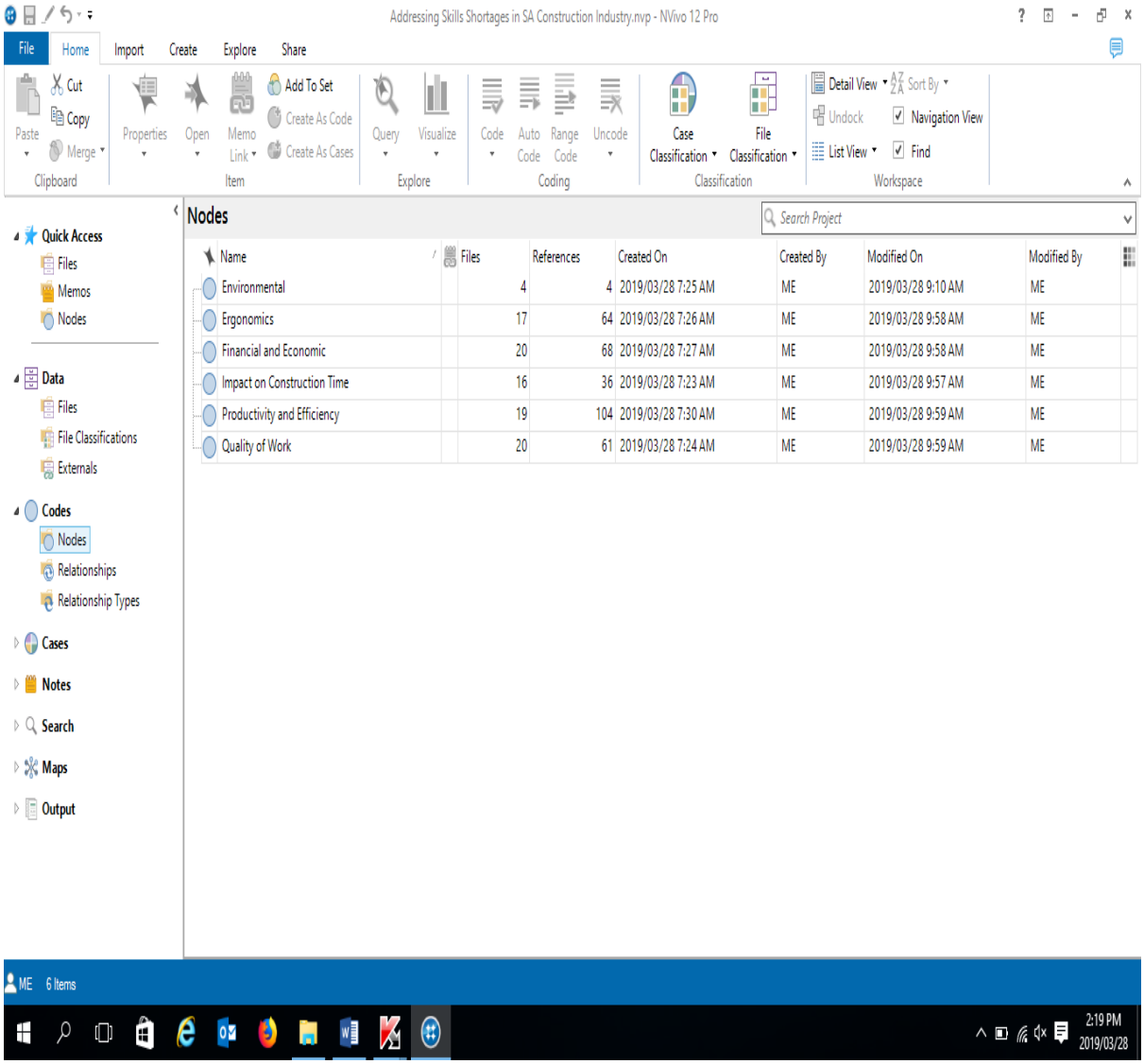
Nickname:					
Classification:					
Aggregated: No					
PDF	14	97	197	97	
Nodes\\Emerging skills					
Nickname:					
Classification:					
Aggregated: No					
PDF	5	7	21	7	
Nodes\\Professionals					
Nickname:					
Classification:					
Aggregated: No					
PDF	13	58	148	58	

APPENDIX F: NVIVO – ADVANTAGES OF CONSTRUCTION AUTOMATION


Addressing Skills Shortages in SA Construction Industry.nvp - NVivo 12 Pro
File
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Paste
Merge
Clipboard
Properties
Open
Memo Link
Add To Set
Create As Code
Create As Cases
Item
Query
Visualize
Explore
Code
Auto Code
Range Code
Uncode
Coding
Case Classification
File Classification
Classification
Detail View
Sort By
Undock
Navigation View
List View
Find
Workspace
Quick Access
Files
Memos
Nodes
Data
Files
File Classifications
Externals
Codes
Nodes
Relationships
Relationship Types
Cases
Notes
Search
Maps
Output
Nodes
Search Project
Name
Files
References
Created On
Created By
Modified On
Modified By
Environmental 4 4 2019/03/28 7:25 AM ME 2019/03/28 9:10 AM ME
Ergonomics 17 64 2019/03/28 7:26 AM ME 2019/03/28 9:58 AM ME
Financial and Economic 20 68 2019/03/28 7:27 AM ME 2019/03/28 9:58 AM ME
Impact on Construction Time 16 36 2019/03/28 7:23 AM ME 2019/03/28 9:57 AM ME
Productivity and Efficiency 19 104 2019/03/28 7:30 AM ME 2019/03/28 9:59 AM ME
Quality of Work 20 61 2019/03/28 7:24 AM ME 2019/03/28 9:59 AM ME
ME 6 Items
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Code Summary

Addressing Skills Shortages in SA Construction Industry

2019/03/28 2:21 PM

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Node					
Nickname: Nodes\\Environmental					
Classification:					
Aggregated: No					
PDF	4	4	70	4	
Nickname: Nodes\\Ergonomics					
Classification:					
Aggregated: No					
PDF	17	64	864	73	
Nickname: Nodes\\Financial and Economic					
Classification:					
Aggregated: No					
PDF	20	68	814	70	
Nickname: Nodes\\Impact on Construction Time					
Classification:					
Aggregated: No					
PDF	16	36	399	42	

File Type	Number of Files	Number of Coding References	Number of Words Coded	Number of Paragraphs Coded	Duration Coded
Nickname:	**Nodes\\Productivity and Efficiency**				
Classification:					
Aggregated:	**No**				
PDF	19	104	1,252	112	
Nickname:	**Nodes\\Quality of Work**				
Classification:					
Aggregated:	**No**				
PDF	20	61	607	68	

APPENDIX G: ETHICAL CLEARANCE