DOCTOR OF PHILOSOPHY

Application and effects of emerging technologies on variation minimisation in the UK construction projects

Noruwa, Bolanle Ireti

Award date:
2020

Awarding institution:
Coventry University

Application and Effects of Emerging Technologies on Variation minimisation in the UK Construction Projects

Bolanle Ireti Noruwa

A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

April 2020

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
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Date of approval:

08 February 2019

Project Reference Number:

P75868

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Acknowledgements

I want to express my profound gratitude to my Director of Studies, Dr Andrew Arewa, for his unceasing support towards my PhD study, for his patience, motivation and immense knowledge. My sincere thanks to Dr Christoph Merschbrock from Jönköping University, Sweden, for enlightening me in research work. My special thanks to Professor D.R. Ogunsemi, Deputy Vice-Chancellor of the Federal University of Technology, Akure for his valuable academic intelligence advice. Thanks to my colleague Brandon Ballard, your support helped me during this research.

I am indebted and grateful to my husband, Matthew Noruwa, who funded this research study and provided all the moral, emotional and spiritual support in my life. I am grateful to my two beautiful daughters, Esosa and Oghosa, whom I have to deny my motherly love and affection in pursuit of this academic research. I want to thank all my family members and friends who have supported me along the way. My exceptional gratitude goes out to all my brethren and members of Deeper Christian Life Ministry for their support, encouragement and prayers.

I want to acknowledge the following organisations for their support: BDP Manchester Studio, Buro Four London, Crossrail, Willmott Dixon Construction Limited, BAM Construction, Mace Construction, HGP Architects, 4D Freeform, Kier Construction, Semple McKillop Belfast, CPUK, Winvic Construction Ltd and McAvoy Group Northern Ireland.

I want to thank all construction organisations and stakeholders that have completed the research survey and participated in the interviews, without your fantastic contributions, it would not be possible to carry out this research.

I am grateful!

I can do all things through Christ, which strengthens me. Now, therefore, my God, I thank thee and praise thy glorious name (Philippians 4:13; 1Chronicles 29:13).

Abstract

Delivering construction projects on time and budget is a challenge that has always plagued the construction industry in the UK. Variation is a major root cause of project cost and time overrun and one of the most controversial issues in construction contracts. The industry is, however, on the cusp of a veritable technological revolution. Modernising the industry through the implementation of appropriate emerging technologies minimised variations along with other benefits. Hence, the UK government is committed to the Construction 2025 strategy; to achieve a 33% reduction in the initial cost of construction works and 50% reduction in the overall project time.

This research aims to investigate the application and effects of emerging technologies on variation minimisation in UK construction projects. The study adopted a mixed methods approach comprising literature review, semi-structured interviews, close ended survey, open-ended survey and a framework development. Participants were limited to those that have practically implemented some emerging technologies on their construction projects. Agency theory was used as a theoretical lens to address problems associated with principal-agent relationships that exist in construction contracts.

The findings of this study addressed some reasons given in literature to justify the inevitability of variations on construction projects. Technologies enabled risks associated with construction project complexity, health and safety, communication issues, buildability, team fragmentation and design errors to be identified and mitigated early. Key findings revealed that BIM played a vital role in minimising variations; however, the combined effects of other emerging technologies alongside BIM are indispensable. Stakeholders can visualise a digital twin of their proposed structure and make desirable changes before actual construction activities. Implementation of appropriate technologies minimised variations on construction projects of participants. Research findings resulted in the development of a framework that suggests useful emerging technologies to implement in minimising potential variations.

Barriers to adoption and implementation are surmountable. The present teething problems will extinct with further training, research and development. The construction industry in the UK is slowly advancing in its journey to modernisation. Findings of this research empirically contribute to the achievement of the commitment of the UK government to reduce construction cost and time. This research contributes to fewer studies and pioneering work that discussed variation minimisation from agency theory perspective.

Findings also provide practitioners and researchers' insight into how current practices may be improved; as well as areas where more research on variation minimisation is needed.

List of Appendices

List of Abbreviations

UK	United Kingdom
CDE	Common Data Environment
VR	Virtual Reality
AR	Augmented Reality
MR	Mixed Reality
IoT	Internet of Things
BIM	Building Information Modelling
ONS	Office of National Statistics
AEC	Architectural Engineering and Construction
IT	Information Technology
MEP	Mechanical Electrical and Plumbing
AI	Artificial Intelligence
NBS	National British Specification
HSE	Health and Safety Executive
R&D	Research and Development
UAV	Unmanned Aerial Vehicles
ROI	Return on Investment
SaaS	Software-as-a-Service
SPSS	Statistical Package for the Social Sciences
HVAC	Heating, Ventilation and Air Conditioning
KPIs	key Performance Indicators
RFIs	Request for Information
EC	Engineering and Construction
ROI	Return on Investment
CAD	Computer Aided Design
GPS	Global Positioning System
SMEs	Small and Medium sized Enterprises
BERA	British Educational Research Association

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Chapter One
Introduction to the study

1.0 Introduction

The construction industry is closely associated with cost overruns, late project delivery, contractual disputes and slow adaptations of technological change. This research investigates the application and effects of emerging technologies on variation minimisation in UK construction projects. The image of the construction industry in the UK is tarnished by excessive cost and time overrun exacerbated by variations. The UK government is determined to redeem the image of the industry through a clear and defined set of aspirations for the industry. For the industry to improve its strength in the global market, improved performance of its project delivery is imperative. This chapter looks at the background to this study, the aim and objectives, research problem, methodology outline and contribution to knowledge. The chapter conclude with a brief outline of the structure of all chapters in the thesis. Agency theory established the framework underpinning this study.

1.1 The Research Problem

Globally, the construction industry is confronted by many challenges, especially iterative cost and time overrun (Oladapo 2007; Ahiaga-Dagbui 2014). Frequency of variations (i.e. changes to original construction contracts) is alarming and disrupts planned construction projects. Construction practitioners in the UK face diverse contractual issues in the management of construction projects to meet the critical parameters required for successful project delivery. Lately, utilising emerging technologies support project teams, simplify construction processes and to tackle the industry's longstanding challenges. While the potentials of emerging technologies in construction are enormous; their typical applications and effects on variation minimisation should be well grounded in research to stimulate implementation and adoption.

Motawa et al., (2006) found that variation constitute a major cause of delay and disruption and their effects are difficult to quantify and frequently lead to disputes. Similarly, Ma and Ma (2017) affirmed that "Variations that occur during the construction phase are the main cause of over-budget cost" in construction projects. Alnuaimi et al., (2010) attributed reasons for variations as lack of buildability of design and additional works requested by construction clients. Selection of good designer and signing design standardised contract eliminates variations in construction projects according to the research. Variations in construction management practice is a matter of practical reality and a necessary evil (Ssegawa, 2002). Many researchers argued that even the most thoughtfully planned project would experience inevitable changes (O'Brien, 1998). Inclusion of variation clauses as part of the contractual agreement allows for contract flexibility to the intent that the end product of construction process may be fit for purpose and meet the owner's latest required business or personal goal. However, impacts of variations constitute problems for construction clients when entering into the construction contract due to the inability to forecast their overall financial commitment to the project. Incessant change to the original project scope intrinsically leads to cost overruns, late delivery and dispute.

Jones (2001) discussed the cumulative disruptive impact of many client-directed variations whose impact on cost surpass the actual cost of the changed work. Sun and Meng (2009) through a comprehensive and systematic review of relevant research papers on variation measured the direct and indirect impact of variations. This research highlighted the tangible and intangible negative impact of incessant variations on construction projects. Some tangible effects are time and cost overrun, increased risk on site, deterioration of working conditions, and damage to staff morale as part of the intangible impact.

Excessive variation leads to project cost overrun, contributes to low labour productivity and disruption to project performance (Ibbs 2012). The construction industry in the UK is popularly known for lack of innovativeness and resistance to change (Gu and London, 2010). The industry activities are mostly long-term, capital intensive with high risk. The Office of National Statistic (2016) reported that UK construction industry productivity has been fundamentally flat since 1994, while the whole economy has improved by around 30%. In comparison to other UK traditional industries, agriculture has undergone a rapid change with the adoption of new technologies that lead to an increase in productivity of 250% since 1973. According to Figure 1.1, a more recent report shows no substantial productivity growth in the construction industry.

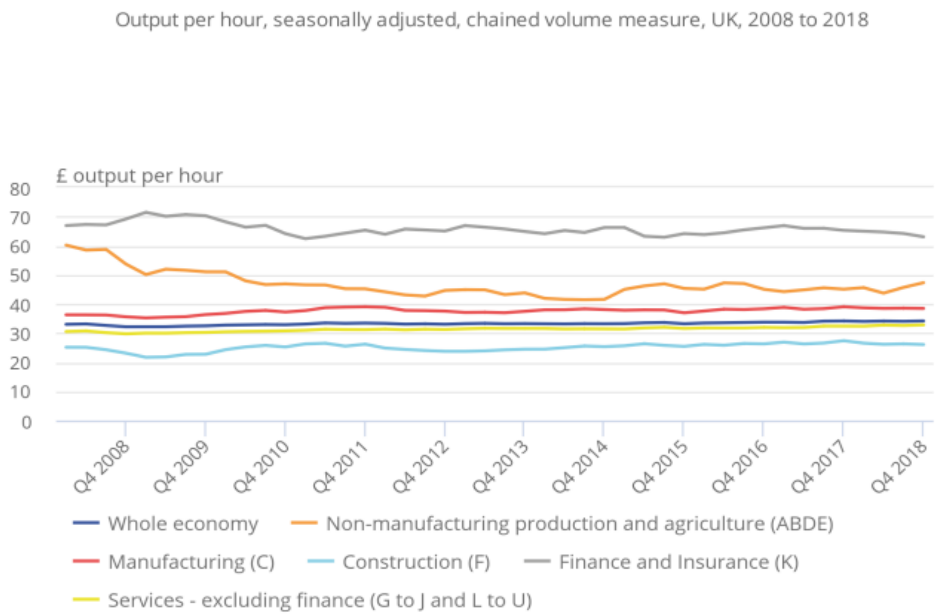

Figure 1. 1: UK Labour productivity (2008-2018) from the Office for National Statistics.

1.2 Research Justification

The UK Government strategy for the construction sector "the Construction 2025 strategy" published in 2013 seeks to reduce construction cost by 33% and overall construction time from inception to completion by 50% by 2025. Yet, scant research exists that examines how variations can be minimised or proactively eliminated during the construction planning process. To attract more young people to the construction sector, the government sought to change the public perception of the industry work environment to a more diverse workforce. Targets are set by the government to improve investment in research, innovation and commitment to Building Information Modelling (BIM) to make the sector a desirable place to work. Construction management processes are old-fashioned with little or slow desire to embrace technological development when compared to other industries such as manufacturing, automation and Information and Communications Technology (Writer, 2017).

The fragmented nature of the construction industry is a critical barrier to an innovative transformation that limits knowledge production and the root cause of persistent low productivity (Latham, 1994; Egan, 1998). Farmer (2016) report on the Construction Labour Model, stressed that the construction industry in the UK faces 'inexorable decline' unless longstanding problems of lack of innovation and collaboration, dysfunctional training model and non-availability of research and development culture are addressed. While catastrophic weather may be experienced occasionally during construction, there is enough evidence through research that demonstrates that most causes of cost overruns are due to human errors and, therefore, are within human controls.

Table 1.1 gives a list of known technological tools which are springing up that can help keep construction cost and time under control. Several immersive multimedia technologies are now widely used in construction due to various government reports pressurising the industry to modernise. The potential financial benefits of implementing these innovations are difficult to estimate (Love et al., 2013); the impacts are stacking up. Arguably, technologies such as BIM, 3D scanning, Cloud Computing, Internet of Things (IoT), Artificial Intelligence (AI), virtual reality (VR), augmented reality (AR), robotics, drones, autonomous vehicles, construction wearables and new innovative construction materials have boosted the performance of construction processes. While wealth of research on BIM implementation and its benefits on the construction process is building up, gaps in knowledge exist on how combined forces of emerging technologies can minimise the occurrence of variation in the UK construction projects. Thus, to minimise variations in construction projects effectively, this study argues that, combined implementation of appropriate emerging technologies along the construction process is required.

Table 1.1: Emerging Technologies in Construction Industry

Technologies classification	Examples
Digital	Mobile smart devices Construction Applications Cloud computing Common Data Environment (CDE) Big data Artificial Intelligence (AI) Advance analytic Digital collaboration platform Building Information Modelling (BIM) Sensors Internet of Things (IoT) Spatial measurement, Geolocation tracking Augmented Reality (AR) Virtual reality (VR) Mixed reality (MR)
Automation	3D scanning, 3D printing 3D mapping Robotics Drones Autonomous vehicles Construction wearables
Innovative materials	High Performance Concretes High Performance Steels Innovative Timber Ethylene Tetra Fluoro Ethylene (ETFE) Prefabrication in Construction

1.3 The UK Construction Industry

The UK construction industry is a segment of the economy that is engaged with the construction of buildings and civil engineering works. The construction industry is always a political priority because it is a significant sector that plays a crucial role in the social and economic development of any country. The UK construction industry is very diverse. The industry is unique and unusual due to the high proportion of self-employment in the sector. According to Rhodes (2019), the construction industry in the UK contributes £117 billion to the economy, 6% of the total UK GDP. Table 1.2 summarises the economic contribution of the construction industry in 2019. As at the second quarter of 2019 the industry accounts for 2.4

million jobs, 6.6% of total UK employment. The industry is extremely fragmented due to its project-based nature, lengthy supply chain and risk aversion. Players in the industry seek to satisfy its client goal within limited resources and cost.

Construction sector in the UK, 2019		
		% of UK
Economic output (£ billion)*	117	6%
Jobs (million)	2.4	7%
Businesses (million)	0.3	13%

Table 1.2: Construction Economic contribution to the UK in 2019 adapted from Briefing Paper, Construction Industry: statistics and policy

1.4 Emerging Technologies in Construction

Emerging technologies, as used in this research, refers to the implementation of new products, tools and processes that construction firms have not traditionally used in their operations. Technological innovation comprises of activities that contribute to research, development and design of new products, services or techniques, or to improve existing products, and generates new technological knowledge. Implementation of a wide range of emerging technologies to increase effectiveness and efficiency in designing and managing construction projects is on the increase. From conceptualising of designs to demolition, various technologies can be applied at different phases of the construction process to avert inherent construction challenges and fulfil the UK government aspiration, as shown in Figure 1.2.

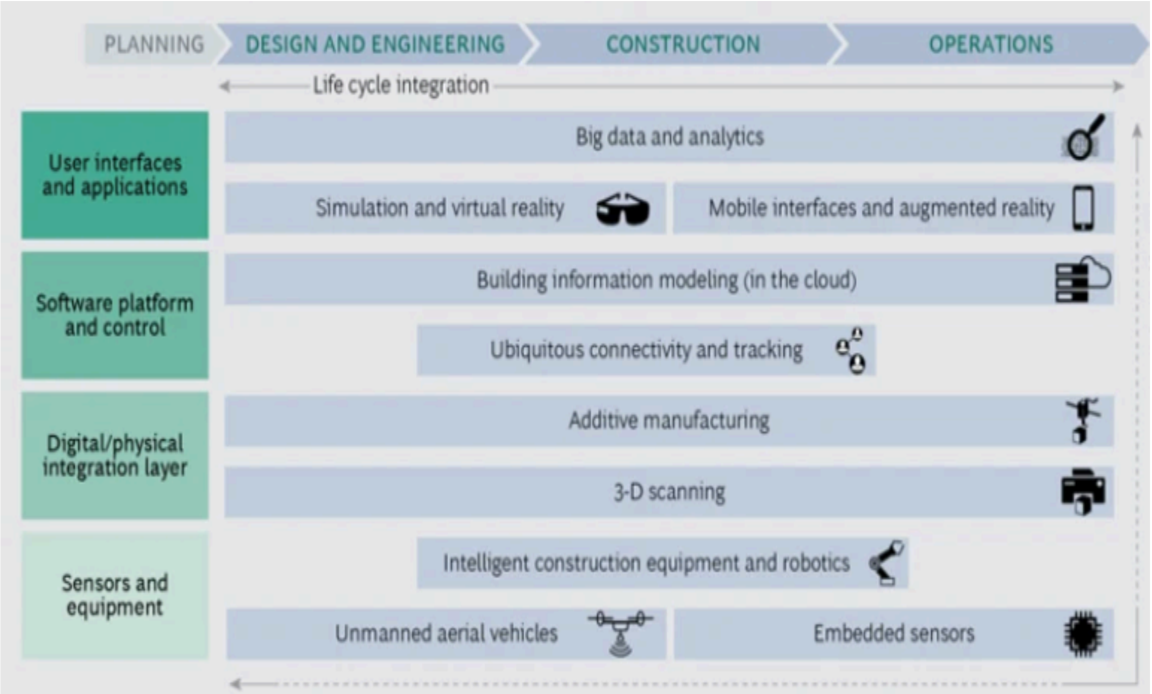

Figure 1.2: Various technologies applications in construction process adapted from www.bcg.com

Emerging technologies are recognised as a source of improvement, competitive advantages to construction firms and as a critical solution to the shortage of skilled labour. Technologies enhance the safety of construction workers and boost efficiency (Ho *and Liu*, 2003). The Construction industry in the UK is experiencing a gradual move from the traditional methods of manual labour to the use of automation to combat the shortage of skilled labour and enhance efficiency (Nath et al., 2015). New technologies have the potential to address issues of information integration by helping stakeholders remain informed and track development through a single integrated model. Emerging technologies, however, pose risks and threats to traditional trades and laggards' practitioners that resist change and innovations.

1.5 Variation in construction projects

Variations are changes to design, material, scope or method different from what the original signed contract specified. Variation can be defined, therefore, as an amendment to the agreement of a signed contract. Hibberd, (1986) stated "there is no single definition of what a variation is" but referred to variation as any amendment to the original agreement. Variation is a paradox in the management of the construction project because it is inevitable and a necessary evil. According to

Soares (2012), it is one of the most controversial issues in construction contracts. Variation is considered inevitable in construction projects no matter the size or magnitude (CII 1994; O'Brien, 1998, Ibbs et al., 2001; Sun and Meng 2009), the impact may be deleterious or beneficial.

Introduction of variations to construction contracts, no matter the benefit to the variation, creates direct and indirect harmful consequences to all parties in the contract (Arain and Pheng, 2007; Sun and Meng, 2009). Variations are not accidental nor stand-alone problems; they are rather introduced along the construction process to resolve contractual issues which can be averted. To date, there is no all-encompassing, proactive measure to eliminate the occurrence of variation in management of construction project. However, researchers have proposed many approaches to managing variation; many of these are reactive and non-technological. For successful project delivery, elimination or minimisation of causes of variation is crucial. Excessive variations are detrimental to clients and contractors. Thus, this study seeks to examine the application and effects of emerging technologies on variation minimisation.

1.6 Contextual contractual issues in the UK construction industry

Design errors

The construction industry cannot overstress the importance of designs. Designs are more than what the building looks like but puts structures on a cycle trajectory. According to Han et al., (2013), design errors are the primary cause of variations and major contributor to cost overrun and schedule delay. Construction projects are prone to change owing to designer improper capturing of clients' requirement during the briefing process. However, the commonest reasons for variation are issues of errors in design and incompetent detailed drawings. Lopez and Love (2012) found that design errors cost among various project types, no matter the procurement methods adopted, is almost the same. Even when competent designers are engaged early in design, lack of constructability of the design may arise (Alnuaimi et al., 2010). This challenge necessitates the need for designers to model and tests the constructability and suitability of the design before actual physical construction on site to overcome the challenge of design errors.

Client dissatisfaction

Construction contracts are entered by clients who have little or no experience of the construction process and designs, which consequently results in the 'inevitable' changes. Customer satisfaction is a goal or measurement tool for quality improvement. Latham (1994) long advocated for client-centred innovation in the UK construction industry to address dissatisfaction of project delivery, quality of service and the predictability of cost as expressed by many clients. Alshdiefat (2018) found that "changes initiated by clients and design errors as the major causes of change orders which are responsible for cost overruns". The limitation of traditional 2D drawings to construction industry stakeholders, which is the inability to visualise the design, is a fundamental problem (Walasek and Barszcz 2017) that often necessitates variations. Many of these clients are one-off customers needing considerable assistance of seasoned professionals to arrive at a comprehensive brief. Variations appear to bridge the gap when designers do not capture the ideas and knowledge that resides in the minds of construction clients in its entirety at the early stage of the construction process.

Contractors' incapability

Construction projects are in-site activities that may involve complex operations and co-ordination of many inter-dependent sub-contractors. Inadequate managerial skills and poor workmanship on the part of a contractor inevitably leads to unplanned variation or rework through variation order. Construction clients often regard contractors' inefficiency in poor site management and supervision, inadequate managerial skills and improper control over site resource allocation as part of the reasons for delays in project delivery (Chan and Kumaraswamy, 1997).

Impact of External factors

Construction projects involve numerous onsite works usually carried out in an external environment. Influence of extreme rain, wind and temperature slow down site operation workers, plants and equipment. Unforeseen climate and weather conditions contribute to inevitable unscheduled variations (Al-Momani, 2000; Lee et al., 2015). Site and ground conditions are external factors beyond the control of parties in the contract. Difficult geological site terrain resulting in inadequate soil investigation could necessitate amendments to contract and designs during the construction phase.

Fragmentation in the UK Construction Industry

Fragmentation is a well-known challenge plaguing the construction industry. Fragmented nature of the construction industry is a critical barrier hindering innovative transformation that limits knowledge production and the root cause of persistent low productivity (Latham, 1994; Egan, 1998). Construction projects are complex and hard to manage, for easy constructability, it is common to divide works into packages for different trades and subcontractors to undertake. This division becomes problematic for the interdependence of stakeholders, especially when these parties are from several diverse countries of the world. Also, when procurement strategy adopted on a project separate design and construction as in the case of design-bid-build, fragmentation of project teams may be an apparent challenge. The ripple effect of fragmentation is lack of transparency and ineffective communication among the project team that further increase project complexity, time and cost.

1.7 Research aim and objectives

The occurrence of variation is one of the main factors that lead to disparity in original and final cost or duration of construction projects; whereas the goal of construction clients is to procure a construction project that meets their requirements within a limited budget and time. Therefore, to avoid cost and time overrun; minimisation of variations in construction projects is crucial to successful project delivery.

Research aim

To investigate the application and effects of emerging technologies in minimising variations in construction projects in the UK. Key findings of this study lead to the development of a framework that suggests useful emerging technologies to implement in construction projects to minimise variations.

To attain this aim, four major root causes of variations affecting construction cost and time were identified. The research objectives are:

1. To investigate the impact of emerging technologies in minimising variations caused by design errors.
2. To ascertain the role of emerging technologies in understanding clients' needs to avoid variations.
3. To examine the effect of emerging technologies on contractors' early engagement and its resultant buildability performance onsite.
4. To identify the impact of emerging technologies on project team fragmentations.
5. To develop a framework that elucidates the potentials of emerging technologies on variation minimisation in construction projects.

Research target and scope

Targeted participants for this study are practitioners and stakeholders that have practically utilised some technologies listed in Table 1.1 or other new technologies in the management of construction projects in the UK. The scope covered in this study are the measurable and significant effects of emerging technologies in minimisation of variation in recently completed or ongoing construction projects in the UK.

BIM plays a central role amid emerging technologies that are springing up in the construction industry. BIM is a key enabler and facilitator for other technologies in construction. Figure 1.3 demonstrates several applications and importance of BIM. BIM application and effects are not just useful in the design phase; it is a platform for integrated design, planning and collaboration throughout the life cycle of a building. While the application and effects of BIM are central to this study, equally, due attention is given to explore the impact of other emerging technologies listed in Table 1.1 that are collectively shaping the construction industry.

Figure 1.3: Application of BIM in the life cycle of a building adapted from The Boston Consulting Group

1.8 Methodology Outline

This research positioned within the philosophical standpoint of a pragmatist because consequences of actions are investigated and measured. Teddlie and Tashakkori (2003) considered pragmatism as the optimal worldview for mixed methods research. Mixed methods design mutually validates data and findings to produce coherent research output. Mixed method design provides a complete understanding of a problem and validates one set of findings with the other (Creswell and Clark, 2018). Chapter four discusses in detail the approach adopted in this research. The discussion in the chapter comprises trend in research in the field of construction management, philosophy assumptions, research strategy, design and method. Figure 4.4 in chapter four presents a flowchart illustrating the research process undertaken to achieve the set aim and objectives of this study.

Research process

An in-depth literature review was carried out and reported under chapters two and three. An extensive review of existing literature relevant to variations and management of variations in construction projects was carried out in chapter two. Agency theory is the framework underpinning the study. The review indicated that variation order is often abuse. Nonetheless, abuse of variation has not received much attention in literature despite the extreme importance of variation in construction contracts. Chapter three is an in-depth study of the application and effects of emerging technologies in the UK construction industry. Also, the chapter discussed the strategic importance and challenges confronting the UK construction industry and review of literature carried out to establish the research aim and objectives.

The study adopted convergent mixed method with qualitative method taken a predominant position. Triangulation approach to the research ensured data from different dimensions are captured on the same phenomenon and that validity is ensured. Semi-structured interviews were conducted with targeted participants sourced from document analysis, referrals and attendance of national construction events. Details and analysis of the interviews are presented in chapter six. Findings from interviews provided substantial information on how the implementation of technologies is revolutionising various aspects of construction. A copy of the research questionnaire used for data collection is given in Appendix C. Details of quantitative data analysis, results and findings are presented in chapter five.

1.9 Summary of main findings

Attempt to achieve total elimination of variations on construction projects emerges to be irrational due to uncertainty and complexity of construction works. Nonetheless, this research findings establish that variations can be minimised to a possible smallest number on projects by proper implementation of combined appropriate technologies. Research participants alluded that BIM plays a prominent role in variation minimisation. Empirical findings of this study produced valuable insight into complementing roles of other technologies. The use of technologies in construction is intimately interconnected and explicable by reference to the whole.

Findings from this research highlighted direct ways by which technologies minimise variations in construction projects—digital representation of project designs in 3D increase clients understanding and their early involvement in construction processes. Design errors and clashes are detected early. Collaborative working environment and platforms overrule fragmentation of project teams. Technologies mitigate many project risks that are associated with human errors, project complexity, project coordination and offers better approaches to contractors on how to execute works on site. Collation of benefits derived from utilising emerging technologies from research findings led to the development of a framework to expound the roles of technologies in variation minimisation.

1.10 Contribution to Knowledge

This research empirically contributes to how the commitment of the UK government to reduce construction cost and time reduction can be achieved and sustained. The framework produced is capable of explaining how the implementation of emerging technologies can minimise variation in construction projects to construction stakeholders. Also, this study established that BIM as an enabler of innovation in construction requires combined impact of other emerging technologies to minimise variations in construction projects effectively. Thus, the findings of this study provide practitioners and researchers' insight into how current practices may be improved; as well as areas where more research on variation minimisation is needed.

This research process produced two conference papers and a journal article. A list of these publications is included in this thesis as Appendix A1.

1.11 Thesis Structure

This research work comprises of nine chapters. All chapters start with an introduction to provide the reader with the purpose, procedure and argument in the chapter. Also, a chapter summary to highlight the essential features presented in the main text at the end of each chapter.

Chapter 1- Introduced and set out the research problem, aim and objectives, contextual issues in construction project management, a summary of the research methodology, the scope of the study, summary of key research findings and contribution to knowledge.

Chapter 2- Reviewed literature on variation and management of variation in the existing body of literature. Also discussed agency theory as a framework that underpins this study. The chapter provides insight into abuse of variation order and the possibility of variation minimisation, avoidance and elimination in literature.

Chapter 3- Reviewed literature of various emerging technologies in the construction industry that are springing up and their effects on construction projects across the UK. This chapter also discusses the opportunities and threats posed by technology integration into construction.

Chapter 4– Outlined the adopted research discussion, philosophy and approach, identified and justified the mixed method approach for this study. The chapter discussed systematic approach followed to ensure robust research instrument design; pilot study and reliability and validity throughout the research process. This chapter also outlined the framework development and validation process.

Chapter 5- Presented descriptive and statistical analysis, results and findings that emerged from quantitative survey and trend in technologies in use in the UK construction industry.

Chapter 6- Presented qualitative data analysis, results and findings. This chapter presents findings from primary empirical data collected from seasoned professionals on effects, potentials and barriers of utilising technologies and semi-structured interviews conducted.

Chapter 7- Discussed research findings in relation to research aim and objectives. Results and findings from the two databases were compared for convergence and divergence before integration. Key findings were also related to fundamental viewpoints of agency theory.

Chapter 8- Presented the development of a framework that suggests useful emerging technologies to implement that is capable of minimising potential variations. Discussion on the need for the framework, overview of framework and validation process.

Chapter 9- This conclusion and recommendation chapter presented research overview and drew on the study's results and findings to establish the research contribution to knowledge and suggest future studies.

Appendices provides relevant information of this study that cannot be included in the main body of thesis.

1.12 Chapter Summary

The construction industry in the UK as a significant contributor to the economy and occupies a crucial position. Excessive variations will hamper construction 2025 vision of 33% reduction in the initial cost of construction and 50% reduction in the overall time from inception to completion of construction projects. This chapter portrayed variations in construction projects as a necessity overlaid with predominantly preventable causes. While some causes may be justified, the impacts are enormous. This introductory chapter argued that the existing management approach is reactive and hence ineffective. Technological approach inevitably prevents the occurrence of avoidable variations. The following chapter review literature on variations and its management in construction projects.

Chapter Two
Variations in Construction Projects

2.0 Introduction

This chapter covers an extensive review of existing literature relevant to variations and management of variations in construction projects. The chapter discussed agency theory used as the framework underpinning the study. The chapter then starts with a brief overview of construction contracts in the UK, followed by definition, causes and types of variation. Evaluation of the impact of variations on various aspects of construction projects that necessitate minimisation and possible avoidance are then discussed. This chapter later examines existing approaches to variation management and indications of abuse of variation clauses. Finally, recommendations from existing literature advocating for minimisation, avoidance and possibility of elimination of variations are presented.

2.1 Theoretical Lens

Establishing a theoretical basis for construction management research is becoming a topic of interest. Betts and Lansley (1993) acknowledge that the empirical nature of most research in construction management may compensate for its lack of theoretical base. However, the authors argued that "the discipline is becoming rather inward-looking, self-referential and lacking guidance from and contribution to theories". This research concurs with the assertion of Betts and Lansley that the existence of a theoretical base in academic research signifies the maturity of a discipline. The use of Agency theory strengthens the contribution of this study to the existing body of knowledge and construction management practice.

The aim of using agency theory is to examine how the implementation of emerging technologies address problems associated with principal-agent relationship and thereby enhancing variation minimisation in construction projects. The choice and appropriateness of agency theory are hinged on the fact that the theory focuses explicitly on the relationship between the principal (e.g. owner) and agent (e.g. contractor). Construction contracts are undertaken by two major contractual parties, the client and contractor. This relationship is like a principal-agent relationship. The client is acting as the principal and contractor as the agent.

Need for theory in research

Theories establish why research is essential. Research without theory is likened to a mere data-gathering exercise without a statement of what is known as a prelude (Bernath and Vidal, 2007). Existing literature on variation and management of variations in construction projects is too descriptive. Lack of theoretical create generalisation vacuum due to scarcity of descriptive empirical research grounded in theoretical knowledge (Packendorff, 1995). Garrison (2000) defined a theory as "a coherent and systematic ordering of ideas, concepts and models, with a purpose of constructing meaning to explain, to interpret and to shape practice". In the same wave, McMillan and Schumacher's (1984) definition of theory stated, "theory is an explanation, a systematic account of a relationship among phenomena".

Agency Theory

Agency theory is a prominent theoretical perspective frequently utilised in management and social research. Although the theory is mostly used to understand and explain corporate governance phenomena, a vast stream of research has benefited from a principal-agent relationship. Based on fundamental assumptions, agency theory argues that agents are self-interested, bonded rationally and different from principals in their goals and risk-bearing preferences. Agency theory, as portrayed in Figure 2.1, suggests that problems may occur when a principal-agent employs another agent to make decisions and to act on their behalf. Due to the two contractual parties' different interests, the value of a principal-agent relationship is not optimised.

The principal incurred agency cost as a result of conflicts of interest, inefficiencies, dissatisfactions and disagreement on results of actions to be taken. The amount and impact of cost incurred require close monitoring and incentives systems to curb costs associated with opportunist behaviour that may be exhibited by agents. Information asymmetry refers to disparities in the availability of quality of information accessible by different project participants. This information asymmetry makes it difficult to ascertain if decisions taken by contractors are optimal for clients (Osipova, 2015). Agency theory deals with target conflicts and information imbalance, a common occurrence in construction project management. The use of this theory explores effects of emerging technologies in minimising agency cost that is common in construction contracting relationships.

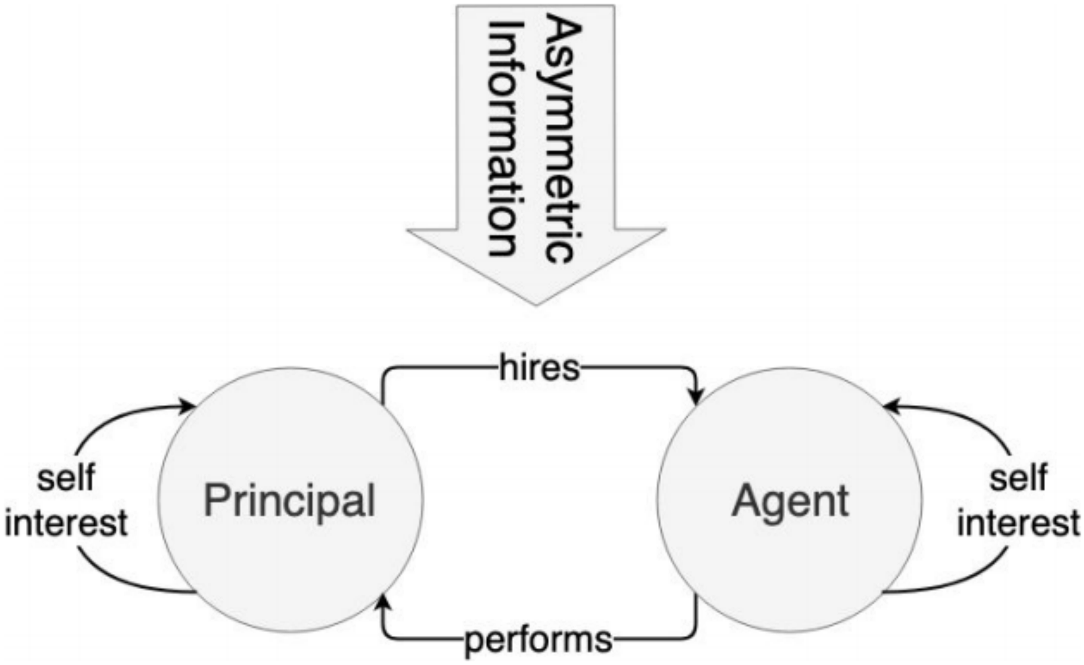

Figure 2.1: Principal-agent relationship flowchart

Critical perspective of agency theory and variation minimisation

The potential opportunistic behaviour of agents at the expense of the principal and how the principal-agent might control such behaviour is what agency theory is concerned with (Steinle et al., 2014). For example, contractors may disregard some risks at the tendering stage to a contract to win a contract. Detailed discussion of this attitude is under section 2.11 on abuse of variation clause. Also, initial risks at project inception may change, and new risks that could lead to variation may emerge. Ma et al., (2017) stated that"…. Contractors rely on change orders to obtain profit from construction projects". This behaviour is closely associated with the relationship between construction client and contractor. There are incompatible levels of risk aversion between contractual construction parties, a central issue often addressed by agency theory as well. A critical review of the principle of agency theory and variation minimisation show that there is a close relationship. The theory explains and resolves disputes over priorities in the relationship between principals and agents by "reducing agency loss". Increasingly, government, organisations and industries are turning to different mechanisms to circumvent issues of agency cost and agency problems. The use of emerging technologies in construction is perceived to enhance collaboration and transparency, hence, may be considered as one of those dynamic approaches.

Ultimate, construction client desires to obtain a final product that meets its functional requirements, constructed to required quality/standard and delivered within budget. The contractor's goal may be to provide clients with service that delivers high quality construction projects in a safe, professional and timely manner. In delivering a construction project to clients, the ultimate aim of any contractor is to make a profit from the client. According to Construction Financial Management Association (www.cfma.org), the percentage of an average pre-tax net profit for general contractors is between 1.40 -2.40%; an incomparable profit to compensate the risk that contractors take in construction projects.

Previous research has established that variations are inevitable due to the complex nature of construction and increasing demands from clients. However, Keane et al., (2010); Arain and Low (2007); Clough and Sears (1994) and Dickson et al., (2015) have established that the predominant cause of disputes in construction project management is variations. As illustrated in Figure 2.1, adversarial relationship often exists between contractual construction parties which results in parties being more concerned about their self-interest. This study seeks to explore how the implementation of emerging technologies along construction process can minimise variations, the agency cost in this case.

2.2 Overview of Construction Contracts in the UK

Construction contract means an agreement with a person, a corporate body or some individuals and a client to carry out construction operations (Redmond, 2008). Without a signed contract, legal protection to enforce variation is weak. Construction contracts are governed under the established law of contract. The rights and obligations of parties to construction contracts are created by the acts of an agreement which can be in standard forms, modified or bespoke. Conditions of contract included in the contract set out legal relationship and allocation of risk. Construction clients usually appoint consultants and independent advisers at the early stage of a project to advise on how best to procure the project. Construction procurement is a strategic process of how contracts for construction work are formed, coordinated and delivered. Procurement is how a construction project is acquired; it is more than purchasing but funding and management of all stages of work. Construction contracts are formed through the process of tendering to secure the prospective contractor who would construct the works. Procurement and tendering methods give the framework within which the contract legal and contractual arrangements, including management of variations are made. Figure 2.2a and 2.2b presents standard forms of contract and tendering methods commonly used in the construction industry in the UK and their level of usage.

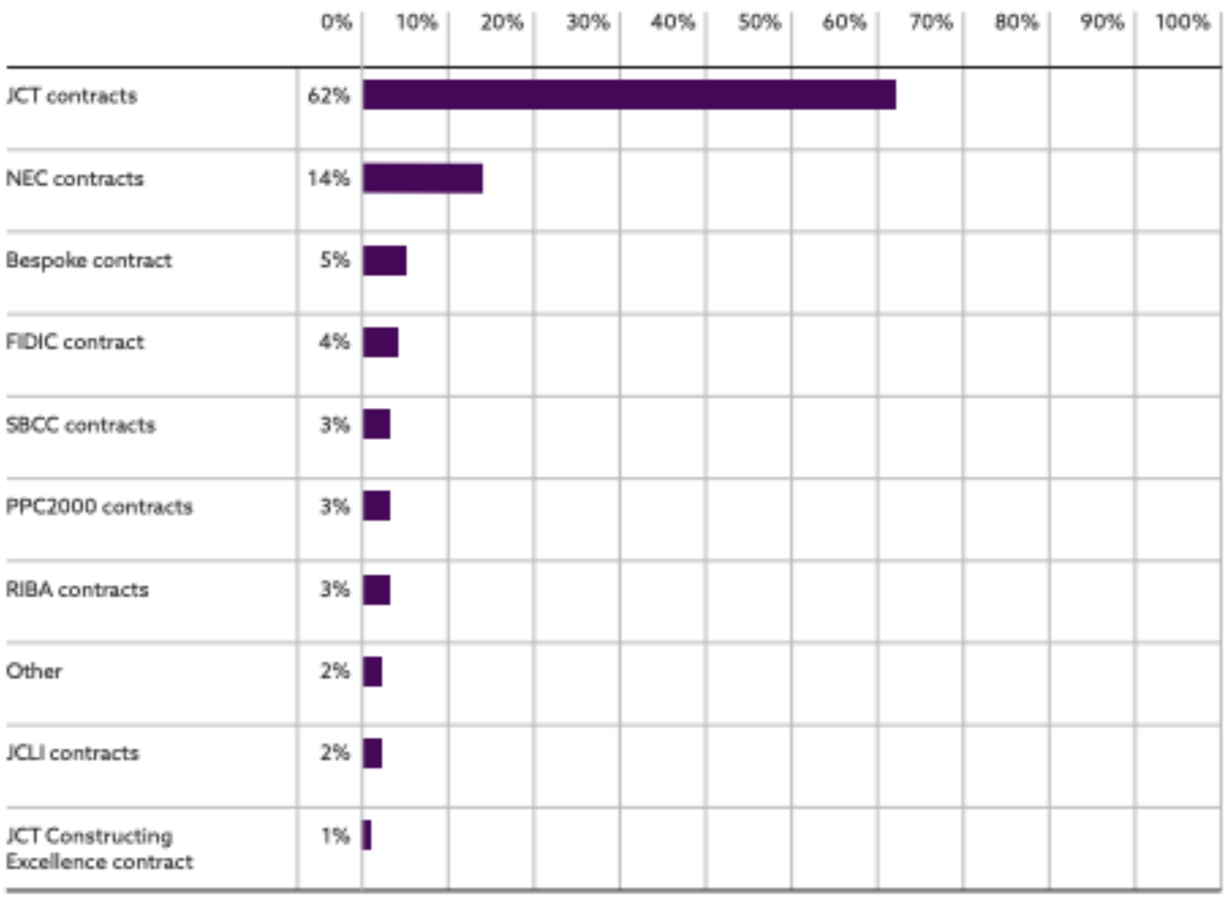

Figure 2.2a: Procurement method most frequently used in UK construction adapted from National Construction Contracts and Law Survey 2018

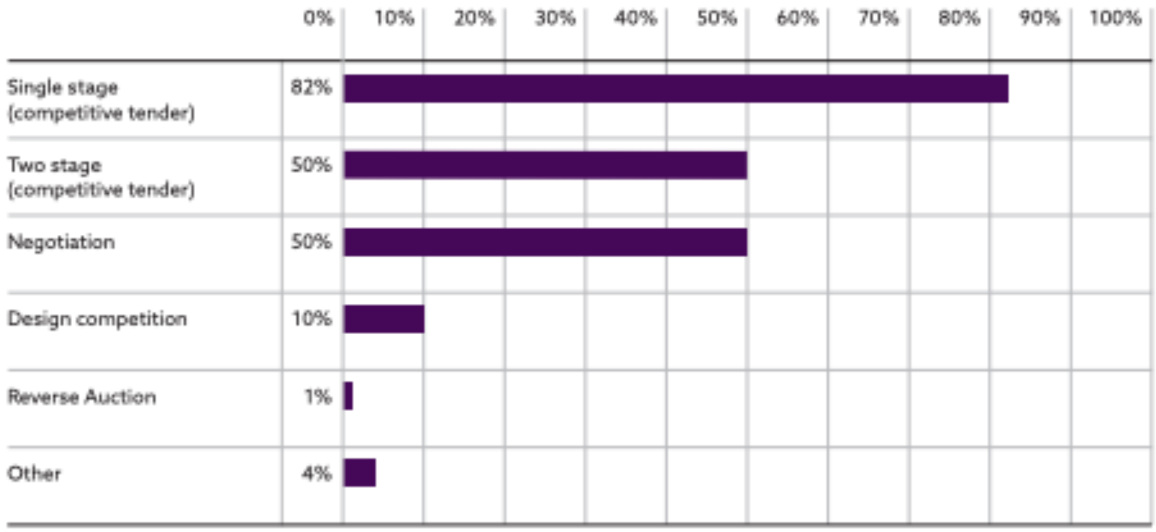

Figure 2.2b: Tendering method most frequently used in UK construction adapted from National Construction Contracts and Law Survey 2018

2.3 Definitions and meaning of variation

Variation is a change in design, material, scope or method different from what was initially specified in a contract. Hibberd (1986) stated that "there is no one definition of what is a variation" but referred to it as amendments to the original agreement after the contract was let. Wambeke *et al.* (2011) defined variation "as the difference between what was planned and what actually happened". Variation is a generic term that denotes amendments to a contract. It is a subject of extreme importance to construction contracts (Turner and Turner, 1999).

Table 2.1 presents arrays of variation descriptions by various authors in literature. JCT Standard Building Contract with Quantities (2016) defined variation as "the alteration or modification of the design, quality or quantity of the works. Variation is considered inevitable and common in all construction projects no matter the size or magnitude" (CII, 1994; Fisk, 1997; O'Brien, 1998, Ibbs et al., 2001) due to peculiar nature of construction works. Every construction project is unique and different from one another in many respects. Existence of variation is not inconceivable, but the impact of variation can be tremendous either directly or indirectly to construction process and management.

Table 2.1: Description of variation by different authors

Description of Variation	Authors
Necessary evil	Ssegawa (2002)
A common phenomenon in construction	Memon et al. (2014)
Normal and common to all types of project	Tilley and Gallagher (1999); Oladapo (2007); Thomas *et al.* (2002); CII (1994); Fisk (1997); O'Brien (1998); Ibbs et al. (2001)
Fact of construction	Comp and Revay (2002); Hao et al. (2008); Akinsola et al. (1994)
Necessary regardless of reasons	Arain and Pheng (2007)
Natural result of disintegration of design and construction.	Soares (2012)
Inevitable, regardless of planning and resources	Chappell *et al.* (2008); Harbans (2003); Hanna (2002); Finsen (2005); Wainwright and Wood (1983); Ibbs (1997); Cox et al. (1999); Sun and Meng (2009); CII 91994); Fisk (1997); O'Brien (1998); Ibbs et al. (2001); Mokhtar et al. (2000); Akinsola et al. (1997); Merna & Bower (1997); Bolin (2017)
Cannot be avoided completely	Mohamed et al. (2011)
Expected to a degree	Love (2002)
Almost impossible to eliminate	Karriri (2012)
Most controversial issues in construction contracts.	Soares (2012)
Changes within a contract and not changes of the contract	Turner (1984)
Epidemic	Ibbs (1997)
Make construction dynamic and unstable	Park (2003)
An essential problem in the construction industry	Halwatura and Ranasinghe (2013); Eigbe (2016)

2.4 Variation Order

Standard forms of contract generally make provision for contract administrator or architect to instruct variations. For example, JCT 2016 Section 5 described management of variations in the standard building contract with quantities. Variation and variation order are often used interchangeably among construction practitioners; in the real sense, they mean different things. Variation order is a formal written instruction from the client or client representative to the contractor authorising a change in the work within the terms of the contract. Variation order is an official document of the contract; the issuance amend the original contractual agreement, and hence it is part of the contract documents (Arain and Pheng, 2005). Variation order specifies the actual change to be made, which should include the following:

- The description of the change.
- Reason for the change.
- Change to the contract sum.
- Changes to other items affected.
- Approvals or authorisation by the client or client's representatives.
- Agreement by the contractor.

2.5 Variation Clauses and form of contracts

The construction industry uses preprinted standard forms of contract in the award of contract. The standard form of contract can be modified or bespoke. They are used as the primary contract document which comprises the articles of agreement, the condition of contract and the appendix. Variation clauses come under the condition of contract. The advantage of standard form of contract in contract administration is that it allows variation instructions to be carried out without disruption to the smooth running of the construction and without the need to enter into another agreement or contract. Variation clauses allow parties to freely initiate variation orders within the jurisdiction of the work scope while the original contract remains intact (Ndihokubwayo and Haupt, 2008).

2.6 Types of variation

From literature review, there are different types of variations identified by various authors. Table 2.2 presents types of variations, brief description and authors as collated from previous research.

Table 2.2: Types of Variation and Authors

Types of Variation	Description	Author
Formal	Client issued change by variation order	Cox (1997)
Constructive	Extra-contract work as a result of problems for which the client is responsible	Cox (1997), Bartholomew (2002)
Cardinal	Significant deviation from the project	Cox (1997)
Detrimental	Change that makes a wide range of negative impact on the contract	Ibbs (1994); Ibbs et al. (2001); Arain and Low (2005); Ndihokubwayo and Haupt (2008)
Beneficial	Necessary change for improvement	Ibbs 1994; Ibbs et al. 2001; Motawa et al. (2006); Sun and Meng (2009); Chang (2002); Charles et al. (2015); Arain and Low (2005); (Ndihokubwayo and Haupt 2008)
Required	To fulfil legal, statutory and business objectives	Ibbs (1994); Lazarus and Clifton (2001)
Elective/Proactive	To enhance business objectives but originally anticipated	Ibbs (1994); Lazarus and Clifton (2001)
Bilateral	Agreed between both parties in accordance to the contract	Fish (1997); CII (1986a)
Unilateral	To expedite to carry out emergence of protest work.	Fish (1997), CII (1986a)
Additive	Add to the original work scope	CII (1990); Fisk (1988)
Deductive	Remove work from the original scope	CII (1990); Fisk (1988)
Minor	Have no impact on time or cost	Rashid et al. (2012)
Major	Due to third party actions such as strikes, riots, 'Force Majeure', public objections, issues with approvals, and permits.	Rashid et al. (2012)
Proactive	Intend to improve the performance of the finished building	Charles et al. (2015)
Reactive	To correct flaws in development process	Charles et al. (2015)
Anticipated	discovered during the project and before the occurrence	Sun et al. (2006)
Emergent	spontaneously and are not intended	Sun et al. (2006)
Compensable	proposed by the client in response to their needs	Chang (2002)
Excusable	proposed by the consultant to resolve technical problems or possible documentation errors	Chang (2002)
Gradual	Happens slowly over a long period and its impact is usually low	Cao et al. (2000)
Radical	Happens suddenly, dramatic and has a marked effect	Cao et al. (2000)
Controllable	those which their cause sources are under the control of the contractor	Antill and Woodhead (1984)
Uncontrollable	the contractor has less or no effective control	Antill and Woodhead (1984)

2.7 Causes of variation

Identification of causes of variation is useful in project planning and management to avoid potential occurrence. Literature review on causes of variation reveals many reasons why variation orders are issued. Previous research indicated that the desire of stakeholders on aesthetic, design errors, fragmentation of project team and buildability of designs among others are significant causes of variation. Kadefors (2004) found that errors or omissions in drawings, change in specification, and change in user market needs leads to issuance of variation orders. Kumaraswamy (1997) identified inadequate contract duration while Sun and Meng (2009) recognised design changes as reasons for variations. Sikan (1999) alleged the length of time taken to complete construction projects, changes to design due to complexity, technology advancement, aesthetic and statutory regulation necessitate variations. Turner (1986) pointed out that weather, geological and geotechnical reasons for variations. Kean et al. (2010) based reasons for variations on the contracting parties, which includes owner-related, consultant-related, contractor-related and other variations.

Naoum (1994) and Arain *et al.* (2004) concur that lack of project team collaboration and communication as reasons for variations. Jaeger and Hok (2010) gave several reasons for variations such as; changed conditions and circumstances of project owners, technical innovations, changes in quantities, changes in client requirements, errors within the contract documents, erroneous presumptions and different conditions from those which were anticipated by both parties. Smith *et al.* (1999) argued that technological changes might necessitate variations, competitors' activities, customers' expectations, and internal pressures such as company management policy change or survival strategy. Chen and Hsu (2007) identified 17 reasons out of which are change in scope, workforce, over-inspection, rework, scheduling, technique change, value engineering and scheduling, among others as causes of variations. Pourrostam (2012) identified 26 causes and added that change of plans or scope by the client as the most significant causes of variation orders. Clough and Sears (1994) asserted that the influence of profoundly changing variables and unpredicted factors from different sources are consequences of variation orders. Kumaraswamy *et al.* (1998) highlighted inclement weather as one of the primary reasons for variation orders claiming that 50% of projects surveyed were delayed due to this reason. Hsieh *et al.* (2004) concluded that challenges experienced in planning and design stages accounted for 23.71% of all causes of variation orders, and reasons critical to safety representing 17.08%. Hsieh et al., (2004) blamed fragmentation of designs and construction process in conventional project procurement methods as causes of variation orders. Arain and Low (2006) listed 53 factors that cause variation orders, ranging from errors and omission in design to noncompliance of design with government regulations.

Halwatura and Ranasinghe (2013) revealed that inadequate estimation as the most significant cause and also stated that causes in local context differ from that of international context. Asamaoh and Nyako (2013) and Mohammad *et al.,* (2010) agreed that the vintage position of construction clients influences the occurrence of variations to meet their financial challenges and aesthetic preference. Soares (2012) supported this standpoint and blame the disintegration of designs and construction process as the aftermath of iterate variation orders. Oladapo (2007) surveyed 50 project participants to establish that change in specification and scope of work as reasons for variations. Jackson (2002), Olawale and Sun (2010) and Burati et al., (1992) attributed changes to original designs as a cause of variations.

2.8 Rationalisation for the inevitability of Variations

Justification for variations is beyond reasons and causes of variation. The inevitability of variations are critical factors; many of which are beyond human control which explain why variation clauses are included in the form of contracts. The ultimate goal of construction clients is to procure construction projects that meet their requirements within a limited budget. Variation clause allows clients to seize opportunities as they emerge in the construction process to achieve the goal of the project. Justification for inclusion of variation clauses in construction contracts is an indication that variation may not be eliminated. Variation can be minimised and optimised to reduce its negative impact on construction contracts and the construction industry. Latham (1994) sees the reality of commercial schemes as a dictate of design by construction clients who are, in turn, responding to external pressures. Researchers often argued that it is practically impossible to complete all planning, processes, designs and contracts documentation before the commencement of construction projects (O'Brien, 1998; Ibbs et al., 2001; Mokhtar et al., 2000; Akinsola et al., 1997; Merna & Bower, 1997; Bolin, 2017). Some research alleged that elimination of variations on a project might result in a rigid finished product. A rigid project that excludes any form of variation, though executed within the anticipated budget and time, may not deliver value for money for the client. It is believed that construction projects without variations may achieve maximum project performance indicator to the deprivation of the stakeholders' needs.

Flexibility and value for money, especially for construction clients, are part of justification for variations. Variation allows for a relatively quick approach to accommodating changes without renegotiation of the entire contract. Changes in life and likewise, construction projects are inevitable and may not be avoided (Harbans, 2003; Hanna, 2002 and Finsen, 2005). Variations in construction contracts allow end products of the construction process to be fit for purpose and meet the required business or personal needs. Unlike automobile and manufacturing industries that produce products through the replica process, construction industry final product is directly opposite. The final product of construction is made mostly at a fix location through a complex and uncertain environment. Some of these complex factors, such as adverse weather, unpredictable ground/soil condition and social unrest, are not within the stakeholders' power to regulate.

To further justify the occurrence of variations, Alnuaimi *et al.*, (2010) found that contractors benefit the most from variation, then followed by consultants and then clients. Ndihokubwayo (2008) revealed that most variations are beneficial. Sun and Meng (2009) discovered that some construction projects benefited from positive changes made. Charles et al. (2015) argued that change could be a good thing, especially changes that are introduced to improve performance beyond the originally expected performance level. Sikan (1999) pointed out that statutory regulation and a new bye-law or amendment to the prevailing laws may cause changes to be made.

Bolin (2017) captured justification for variation as factors that establish variations. These factors according to Bolin (2017) include delays to nominated sub-contractor services and materials unavailability; added cost incentives; inappropriate rejection of contractor work; restricted/delayed/denied access to project site; force majeure delays, among others. Enshassi et al., (2009) alluded that no one can state that variation can be avoided completely. Mohamed (2001) and Ssegawa *et al.,* (2002) agreed that resources unavailability, environmental conditions, performance and involvement of other parties in the work might justify variations.

Variations are justified and cannot be eliminated due to the over-regulated, complex and dynamic environment in which construction projects are executed (Mbachu and Cross, 2015). The construction client's desire to procure structure that the final product is not out of date at completion may lead to variations. This is very relevant in projects such as hospitals, cinema houses, media and concert studios with a high degree of technical contents and features. Variations are justified to be an integral part of the construction contract. The probability that construction contract could be completely void of any change whatsoever, no matter how negligible, is low and very close to zero (Chappell, 2011).

The communication network of construction teams that is complex with diverse business process and parties lead to changes in the contract (Charoenngam et al., 2003). The uniqueness of construction projects and sites with associated different designs and construction techniques always play vital roles in project procurement, designed, managed and the finished product. Therefore, combinations of these factors, which are not static, influence variations (Akinsola *et al.,* 1997). A construction project is a means to an evolving end (Akinsola, 1997; Merna and Bower, 1997), which means that at inception, the final product may not be fully established.

Based on these arguments in literature, it is apparent that elimination of variation may be unachievable in the management of construction projects. Nevertheless, some indications suggest variations can be minimised to the smallest possible number with the implementation of appropriate technologies. Innovative technologies that are springing up can overcome almost all the challenges and justification for variation given in literature. The objectives of this study, as stated in Section 1.7, captured many of these justifications for variations. This study seeks, therefore, to explore how emerging technologies implementation in construction projects can minimise variations. It is anticipated that variations can be reduced to the smallest possible number on construction projects by utilising appropriate technologies properly.

2.9 Impact of Variation on Construction Contracts

It is often argued that there are variations in construction that are beneficial or even reduce final project cost (Sun and Meng, 2009; Chang, 2002; Charles et al., 2015); such variations are very rare or exceptional in practice. No aspect of construction project is exonerated when it comes to measuring the impact of variations. Although some variations may be beneficial to construction contract as discussed in Section 2.8 above, many variations lead to negative direct and indirect impact. Almost 40 per cent of construction projects experience over 10 per cent change from the original contract sum to the final project cost. When changes made are limited to 5 per cent, construction project is enhanced to exceed planned rate by approximately 60 per cent of projects. Construction project falls well below planned rate when changes made to the project exceeds 20 per cent (Ibbs, 2012). Arain and Pheng (2005) affirmed that variations present problems to all the parties involved in construction. Whenever a change is introduced in life and so also in construction contracts, the change introduced often leads to direct or indirect impact. Impact of the change is felt no matter how beneficial the change is.

Oladapo (2007) ascertained variations as the major cause of cost and time overruns in construction projects. No change should be introduced to the contract without significant reason and benefit due to impacts of variation. Variations issued must be scrutinised and verified through formal variation process before approval because changes should be with the intent to improve the performance of the contract (Charles et al., 2015). Even though beneficial, proactive and necessary variations impact negatively on contract duration, cost and quality. Ahiaga-Dagbui (2014) stated that "Nine out of ten construction projects overrun their budget”. Variation from any project type or size always contributes significantly to cost and time overruns. Ndihokubwayo’s (2008) research revealed that 10 per cent of variation orders led to waste. Akinsola et al., (1994) asserted that variations are the major causes of delays and disruptions on construction projects. Latham (1993) stressed that variations and their effect on construction project is a major problem faced by the industry. According to Hsieh et al., (2004) “one of the main defective aspects of public projects is the excessive number of change orders during construction, causing project delays and cost overruns”.

Ibbs (2012) quantified the impact of variation on project cost, schedule and productivity. The result revealed that 19 per cent ratio of the final project cost to the estimated project cost. Productivity and its predictability deteriorate with an increasing number of variations. Ismail *et al.,* (2012) identified time and cost overrun and disputes as effects of variations, these always impact project performance. Arain and Pheng (2005) gave a list of potential effects of variations as an increase in overhead expenses, rework, demolition, and schedule delays increase in project cost and more payments to contractors. Bolin (2017) affirmed that delay to contract schedules occurs by carrying out variation order work. Project delays and cost overrun are major impacts of variations (Arditi *et al.,* 1985; Ehrenreich-Hansen, 1994; Zafar, 1996; Al-Saggaf, 1998; Hanna et al., 1999 and Bower, 2000).

According to Hsieh *et al.* (2004), 10-17% ratio of variation cost to total project cost is common to metropolitan public works. Sun and Meng (2009) indicated most changes made to construction projects interrupt the flow of the work; causing time and cost overrun. Jones (2001) discussed the cumulative disruptive impact of many client-directed variations whose impact on construction cost surpass the actual cost of the changed work. Variations are always the reason behind the inability of many construction contractors to meet with the stipulated completion date (Amu *et al.,* 2005).

Introduction of variations increases managerial pressure, increase in workload leads to poor professional relations due to fatigue and low staff morale which have a ripple effect on the project and quality of the work (Hanna, 2005; Arain and Pheng, 2005). Introduction of additional work which requires extra safety measures may lead to poor safety conditions (Arain and Pheng, 2005). Variations also lead to heavy administrative load because they require many reviews, discussion, and tracking. Literature reports dispute among professionals, increased risks of coordination failures and construction clashes, among others. Perera et al. (2019) highlighted that variations-specific dispute is inevitable in construction without measures to mitigate variations. Table 2.3 presents the possible effects of variations collated in literature.

Table 2.3: Possible effects of variations

Possible effects of variation	Authors
Impact on progress	CII (1994)
Increase in project cost	Clough and Sears (1994)
Employment of new profession expert	O'Brien (1998)
Increase in overhead expenses	O'Brien (1998)
Delay in payment	CII (1990); CII (1995)
Productivity degradation	Ibbs (2012)
Procurement delay	Hester *et al.* (1991)
Rework and demolition	Clough and Sears (1994)
Logistics delays	Hester *et al.* (1991)
Damage to firm's reputation	Kumaraswamy (1998)
Poor professional relations	Fisk (1997)
Poor safety conditions	Arain *et al.* (2004)
Additional payments for contractor	O'Brien (1998)
Disputes among professionals	CII (1986)
Completion schedule delay	Ibbs (1997)
Additional work	Arain and Low (2005)
Increase risks of coordination failures and errors	Han et al. (2013)
Major source of delay and disruptions	Akinsola et al. (1994)
Design and construction clashes	Øystein Mejlænder-Larsen (2015)

2.10 Management of Variation

Every valid variation instruction or order issued, leading to extra or less work to be carried out by the contractor must be valued (Murdoch and Hughes, 2002). Management of variation is the procedure of dealing and monitoring of variations introduced to existing contracts. Variation management is a continuous deliberation and a permanent agenda on the agenda of every project meeting (Soares, 2012). Variation management is necessary to alleviate some negative impacts of variation. Effective management of variation increases the degree of project success and ability of the project team to have a clear perspective to predict variation and their impact (Mirshekarlou, 2014). Existing fundamental principles of variation management system are based on the following six principles, as identified by Arain and Pheng (2007):

- Identify variation for promotion of balanced variation culture.

- Recognise variation.
- Diagnosis of variation.
- Implement variation.
- Implement controlling strategies.
- Learning from experience.

Variation management is built on anticipating, recognising, evaluating, resolving, controlling, documenting and learning from past variations to achieve optimisation and viability of the project (Arain and Pheng, 2007). Many frameworks for variation management has been suggested in literature. Framework consists of concepts that can be followed to ensure pre-decision to implement variation pass through three phases. These phases are screening, choice of a better alternative and dominance building based on the theory of dominance structuring by (Montgomery, 1983). Creation of a clear communication line by project managers in all aspects of project planning with genuine interest to offer help by clarifying issues has been found beneficiary to variation management. Effective communication correlates with successful project delivery and management of variations.

Chen (2008) developed a knowledge-sharing model that effectively aid information sharing among contract parties to eliminate litigious variation disputes. The model was designed to help knowledge sharing from past resolved court disputes without going to court. The intention is to save time, money and create a win-win platform for construction stakeholders. Arain and Pheng (2005) developed a Knowledge-Based Decision Support System (KBDSS) capable of displaying various data relevant to variations experienced on a project. The system output intention is to help project managers on timely decision making for appropriate variation control. Othman (1997) determined precise areas of contention over variations. The study identified time and money issues and advocated for revision of variation clauses that are vague and not providing guidance and direction to adequately compensate contractors for clients' unilateral issuance of variation orders.

Zou and Lee (2008) agreed that variations are difficult to control, and they are the usually sensitive part of construction project management. The study argued that a project with a formal variation management procedure witness low number of variations compared to projects that put more premium on business drivers and success criteria. Sun et al. (2009) produced the Change Management Maturity Model (CMMM) framework for assessing the project team's ability in dealing with variation. The model is capable of assessing the overall maturity of project teams in the management of variations.

Charoenngam et al., (2003) developed a web-based Change Order Management System (COMS) capable of establishing excellent communication and cooperation among members of the construction project team. The system proposal is to utilise the advantage of internet technology in a timely, remote and accurate way for information sharing to manage variation process. Bolin (2017) asserted that there is no "one fits all" process or set of procedures for variation management on construction projects. The study proposed an effective procedure that can be adopted in the management of variations, as shown in Figure 2.3.

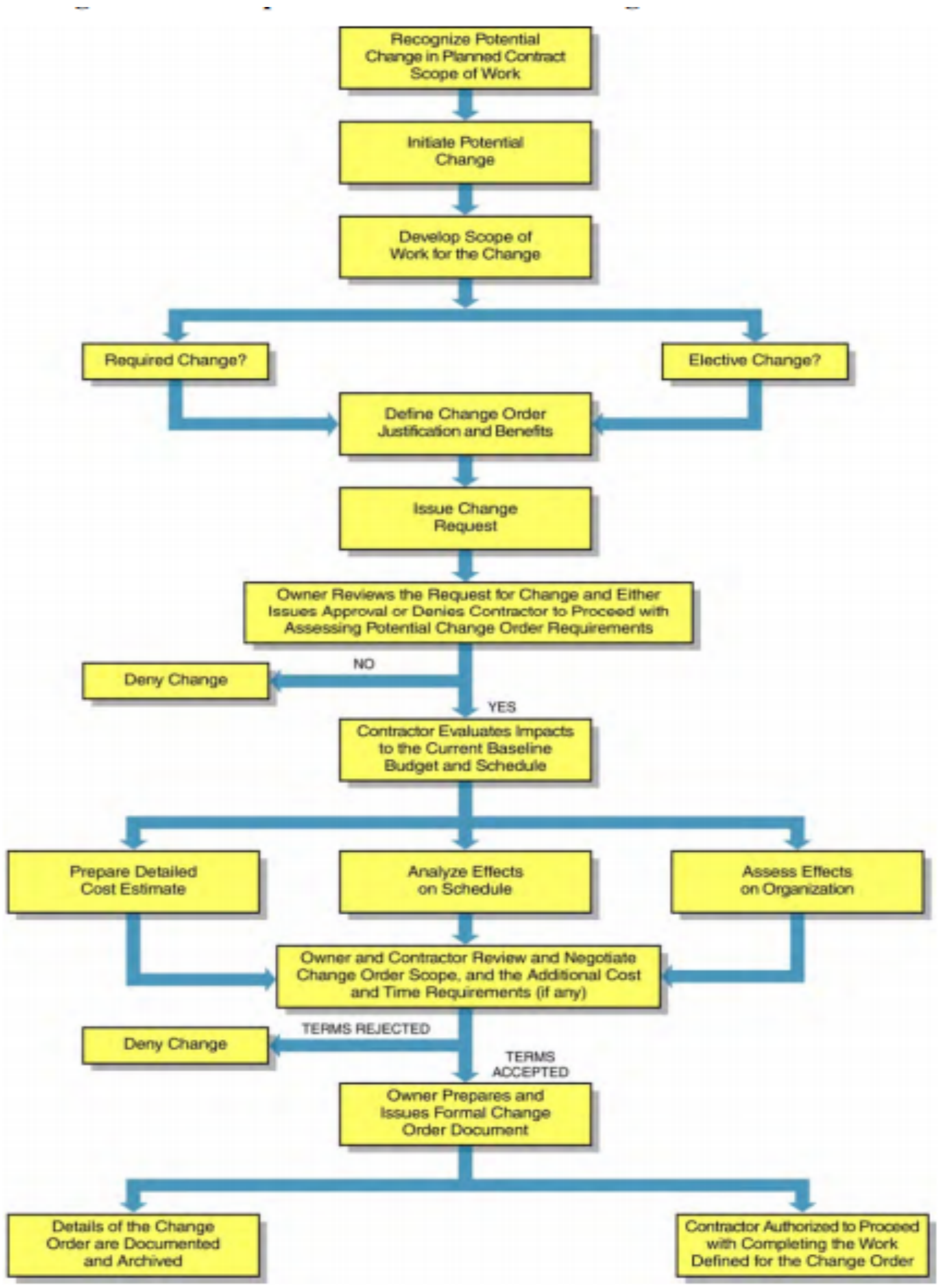

Figure 2.3: Variation order procedure adapted from Bolin (2017)

2.11 Abuse of Variation in Construction Project

Hibberd (1986) argued that variation clauses could be abused and gave three reasons to support the argument. First, that variation clauses abuse occurs when a construction project is not fully designed before tender but was tendered for as if it was entirely designed. Second, where variation clauses are used by professionals to cover up for their incompetence and error in an inconsiderate and inappropriate manner. Third, when a project manager exercises authority in the usage of the clause without justification. There is possible that variation clauses can be subjected to manipulation to facilitate corruption among construction industry professionals. Since variation is changes made after the initial contract, the process of approval receives less scrutiny than the original contract documents submitted for tender and contract award process. Ma et al., (2017) stated that "….in China, contractors rely on change orders to obtain profit from construction projects". Variation in construction contracts can be an easy way to fraudulent means of acquiring funds by members of the construction management team if not monitored and scrutinised correctly. Many reports of abuse of variation leading to poor performance downgrade the flexibility advantage of variation clauses to construction projects (Othman, 1997).

Possible Signs of Abuse

Abuse is common, but silence is cruel. According to the Ethic Intelligence report (2017), the following are red flags of variation abuse in construction projects:

- Poorly justified or documented change order requests and approvals.
- A very low bid contract awards that are followed by change orders that increase the price of the contract.
- A pattern of sole-source contract awards just below the competitive bidding threshold that are followed by change orders that increases the price above the threshold.
- One or a few contractors receive a disproportionately high number of change orders compared to other contractors in similar contracts.
- Known culture of corruption among project officials and inspectors.
- Weak controls and lax procedures regarding the review and approval of change orders; for example, situations in construction management where the same official that certifies the need for the variation order also approves it.

Lo *et al*. (2007) described the concept of survival strategy as “Opportunistic Bidding Behaviour (OBB)” and claimed that some contractors explore the opportunity of reducing their profit margins significantly when tendering. Contractors use this approach under the guise of subsequent variation claims when executing the project to compete favourably with other contractors during tendering. Aguilar et al. (2000) highlighted the importance of comparing project management approaches that explain the actual progress made and the planned progress of work initially. This approach explains any significant variations in projects to reduce corruption and fraud. Soares (2012) explained two different ways that contractors can use variation to promote different behaviours in construction contracts. One, if the selection of a contractor is based on low bid analysis, the contractor extensively explores all avenues in the contract to invoke and justify a variation. Two, if the selection of a contractor is made using the unit costs and quantities of the initial design, variation is perceived as a means to rupture the contracted price. Sikan (1999) described abuse of variation as a nightmare, whereby construction clients are forced to pay for oversights and errors of judgement during the design stage. Excessive variations should be challenged through professional ethics and sound code of conduct. However, this is outside the scope of this research study.

Chappell (2011) stated that "a contractor usually welcomes the opportunity to carry out additional work and thereby earn money in the valuation of the variations and possibly in the formation of a claim for disruption or prolongation". Several reasons attributed to cost overruns include suspicions of foul-play and corruption. Wachs (1990) advocated for proper professional codes of ethic to eliminate abuse, suspicions of foul-play and corruption in project management. Wachs (1990) added that it is not uncommon in practice to have misleading and underestimation of the contract sum as this approach may be the only way some get projects started.

Cook (2016) argued that "even in a hard-bid environment where all bids are sealed, and the lowest bidder wins, it may involve change order fraud". It is commonly reported that there is a possibility of contractors colluding with project officials to submit a very low bid to win construction contracts with the intension that variations raised subsequently on the project compensate contractors. Ahiaga-Dagbui (2015) argued that unrealistic cost estimate, misguided trade-offs of time, cost and scope of work, suspicion of foul play and corruption are significant causes of cost overrun in construction projects. Variation clauses tend to encourage clients to change their minds by embarking on building projects without having adequately thought of the project requirements (Finsen, 1999). All these research studies highlight the reasons for variation minimisation in construction projects.

Although, Uff (2005) pointed out that clauses permitting variation of works is an essential feature of any construction contract, without it the contractor is not bound to execute additional work or to make omissions or changes. Designers tend not to crystalise their intentions on designs before construction since variation clauses permit them to finalise their intentions during the term of the contract (Wainwright and Wood, 1983). Ashworth (2001) added that the advantage of the variation clause is that it allows the architect or other designers to delay making some decisions until the last possible moment. Lo et al., (2007) blamed the competitive bidding system and considered it as the leading cause of poor project quality. From literature review on abuse of variation, it is apparent that technological intervention may perhaps prove valuable in minimising variations and promoting transparency in the construction industry. A transparent and technologically advanced industry has potentials to attracts more workforce.

2.12 Possibility of minimisation, avoidance and elimination of Variation

Arain and Pheng (2007) argued that collective action of project teams taken to identify problems early minimised variations and that project team should take advantage of lessons learnt from similar projects. The magnitude of the impact of changes introduced may not be fully comprehended when the work is immediately executed, and hence authorisation of variation orders should be done with caution and conservatively (Ibbs, 2012). Chan and Yeong (1995) found that variation reduction is an essential strategy for time and cost management. The study gave a list of ten strategies to reduce variations as follows:

- Establishing and sustaining the right attitude to control.
- Comprehensive site investigation.
- Clear and thorough project brief.
- Thorough detailing of design.
- Avoiding the use of nominated subcontractors.
- Awarding the tender to the right contractor.
- Use of alternative contractual arrangements.
- Appointment of an independent cost manager for cost control.

- Quality contract documentation.
- Excellent communication and cooperation between building team members.

Minimisation of Variations in Construction

Ibbs (2012) advocated for minimisation of variations for good project performance owing that both predictability of construction works, and quality deteriorates with an increasing number of variations a project encounter. Hsient *et al.,* (2004) supported minimisation and avoidance of undesirable situations of cost and time overruns as a result of variation mismanagement. The study stated that an effective mechanism for handling variation in construction contract mitigates possible impacts. From reviews of BIM benefits, Doumbouya et al., (2016) established that BIM is fulfilling its purpose across all phases of construction projects by reducing design errors and improving design quality. The use of BIM ultimately reduces construction costs. Also, Moayeri et al., (2015) developed a model to minimise variations. The model is capable of comparing the original model of a building with a revised model after introduction of variations by using BIM. The model purportedly discourages iterate variation in construction by enabling clients and construction teams to visualise the ripple effect of the change in architectural, mechanical, electrical and HVAC systems.

Avoidance of Variation

Potentials for the construction industry to avoid incessant variations in construction projects is huge. Variation inevitability is based on the argument of the complex nature of construction works. Construction work comprises of outdoor activities, where the atmospheric condition cannot be controlled or scientifically manipulated. This argument in literature is being challenged. Modular construction mitigates the impact of adverse weather in modern construction methods and saves 30-50% less time than traditional methods. Modular construction and prefabrication potentially eliminate variations and encourage sustainability in construction.

It is feasible and vital to reduce variations to every possible extent and then manage what cannot be eliminated (Wambeke et al., 2012). Soarces (2012) stated that "when construction delivery is under the master builder concept due to the total integration of the project change orders are non-existent ". This standpoint is on the argument that variations in construction projects are consequences of separation between design and construction. The study advocates for amalgamation of design and construction process and early engagement of key contractual parties to eliminate variations.

Conflicting Views on Elimination of Variations

There are conflicting views on the subject of elimination of variations in construction projects. Some researcher viewed variation elimination in construction projects as a fallacy (Love, 2002; Mohammed, 2001; Kariri, 2012; Ibbs, 1997). Sun *et al.* (2006) commented that changes at the later stage of construction projects are inevitable sometimes. The study maintained that the goal of project variation management should not be to press to eliminate all variations on a project, but rather to minimise the adverse effects of beneficial ones and avoid the unnecessary. Charles et al. (2015) argued "change can be a good thing", stressing that some changes made in the course of construction add value to the project even though with overrun of the initial budget. Charles et al., (2015) argued that variation might significantly reduce the life-cycle cost, elevate project performance level beyond initially expected level and reduce the whole-life value of resultant built environments leading to insignificant cost overrun compared to the initial construction cost. Arain and Pheng (2007) see variation as a matter of practical reality and justified that changes may be necessary even with a well-planned project due to various unprecedented factors.

On the contrary, Award (2001) argued that the occurrence of variation and subsequent waste could be eliminated if their origin and causes are determined. Taylor et al. (2012) put reasons for variation as the imperfection of contracts, stating that reinforcing preliminary project plan leads to avoidance of variation. Minimisation of variation encountered on a project to the smallest possible number or degree benefit all construction stakeholders. Shipton et al. (2014) argued that variations on construction projects should be minimised and firmly controlled. Ma et al., (2017) found that elimination of variation hinged on the approach that encourages contractor and designer to report potential variation to prevent economic request compensation truthfully. The study established an incentive mechanism on a new project delivery model called Integrated Project Delivery (IPD). IPD approach is to combat the problem of cost and time overrun that is associated with the Design-Bid-Build (DBB) procurement method by involving contractors early in the design phase to optimise designs and using incentive mechanisms as compensation for elimination of variations. In recent time, emerging technologies implementation in the construction process is applauded for combating many causes and justification for variations in construction project management.

Many attempts have been made by the researcher to minimise variations through various variation management processes and development of models; these approaches are rather reactive. Elimination of variations in construction projects may be a futuristic goal, with increasing adoption of a vast number of technological innovations. A proactive radical approach that minimises the occurrence of variation is required. This study, therefore, seeks to investigate the application and effects of emerging technologies in minimisation of variations.

2.13 Chapter Summary

Agency theory in this chapter established that clients and contractors are involved in a principal-agent relationship. This chapter discussed the meaning of variation, causes, impact, existing management approaches, abuse, and possible strategies for minimisation from literature. From review of literature, there is the possibility of reducing the number of variations on construction projects to the smallest possible. Several strategies, framework and models proposed by researchers are reactive rather than proactive. Little or no effort has been made in literature to investigate how the occurrence of variations can be eliminated by leverage on the combination of emerging technologies. Despite the direct and indirect impact of variations on construction projects, abuse of variation has not received much attention in literature. This chapter concludes with a review of how variations can be minimised or avoided. Possibility of minimisation and elimination of variations is explored during project planning by the application of emerging technologies in chapter three.

Chapter Three

Application and Effects of Emerging Technologies in the UK Construction Industry

3.0 Introduction

Technology is revolutionising every aspect of life. Until recently, the construction industry in the UK suffers from a traditional hesitancy to embrace emerging technologies to improve its outdated construction process and methods. Nevertheless, the UK government is committed to a 33% reduction in construction cost and 50% construction time reduction by the year 2025. This chapter is an in-depth study of applications and the effects of emerging technologies in the UK construction industry. The main focus is to investigate their impact on variation minimisation.

This chapter discussed the strategic importance and challenges of the construction industry. Also, the chapter presents a review of the applications and effects of technologies emerging in the management of construction projects. Opportunities, risks and threats posed by these technologies to the industry are reviewed in this chapter. "Your Home Made Perfect", a TV programme on BBC Two publicised the use of BIM and VR in architectural designs. Engagement of construction clients to view what their future home would look like before actual construction through digital visual effects strengthens the review of literature in this chapter.

3.1 Profile of Construction Industry in the UK

Strategic Importance

The UK construction industry is of strategic importance and plays a vital role in the country's economic development and growth. The industry provides shelters for other sectors and citizens of the nation; the industry is key to the success of other industries and sectors. The economic advancement, security, quality of life and competitiveness of every nation of the world depends mainly on the newly built infrastructure and continual maintenance of the old ones. The construction industry is one of the significant drivers for measuring the economic performance of a nation. Globally, the construction industry is always a political priority. The strategic importance of the construction industry in the UK and any other nation of the world put the industry under constant scrutiny, assessment and relentless demand for efficiency.

Global Construction Industry and UK Uncertainty

Worldwide, the construction industry is one of the most significant industrial segments of the economy, accounting for 13% of global GPD. According to projection, the recent annual worth of the global industry of $10 trillion will rise to $14 trillion by 2025. Turner and Townsend (2017) demonstrated in Figure 3.1, the uncertainty and sluggish growth prediction in the Eurozone due to the UK leaving the European Union, but an optimistic projection is still forecasted. As the industry is coming to terms with Brexit, the possible implications on skill shortage and importation of construction materials are as yet unknown. Brexit is creating uncertainty for the UK construction industry with the potential of losing the pool of European labours. Although there is no significant impact felt, for now, tension is building up, and many construction companies are closely monitoring immigration development surrounding Brexit and possible mitigating options.

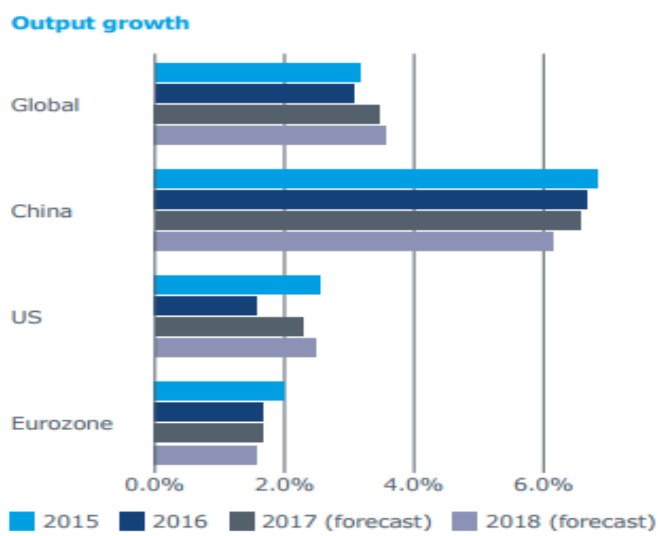

Figure 3.1: Construction Global growth statistics adapted from Turner and Townsend (2017)

Activities of the UK construction industry

The UK construction industry, like any other nation, is very diverse. Activities in the industry include construction of new buildings and infrastructure, maintenance and refurbishment of old structures, mining, quarrying, manufacture and supply of construction products, operation and disposal. Government Construction Strategy divides the industry into three main sectors, namely:

- Commercial and social.
- Residential.
- Infrastructure.

There is a strong correlation between construction and the economics of the nation. Good performance of the UK construction industry is a sign of a healthy economy. Activities of construction industry are mostly long-term, capital intensive with high risk.

Construction in Comparison with other Industries

The UK construction industry is popularly known for lack of innovativeness and resistance to change from its traditional approach to business. Pressures are mounting on the industry to adopt new technologies and techniques to improve the quality of construction works and to minimise construction cost and time (Gu and London, 2010). The construction industry to date is considered as one of the least digitalised industries, compared to other industries, according to the McKinsey Global Institute (2016). The construction industry in the UK is purportedly witnessing a paradigm change and rising demand for innovations. The aspiration of the UK government for the industry to overcome many of its persistent challenges of cost overrun and unpredictability remain unassessed. Persistent review of activities of the industry demonstrates the determination of the UK government to see disruptive, radical change expected in the industry. Figure 3.2 indicates that the UK government is an activist to improve the construction industry through its policies.

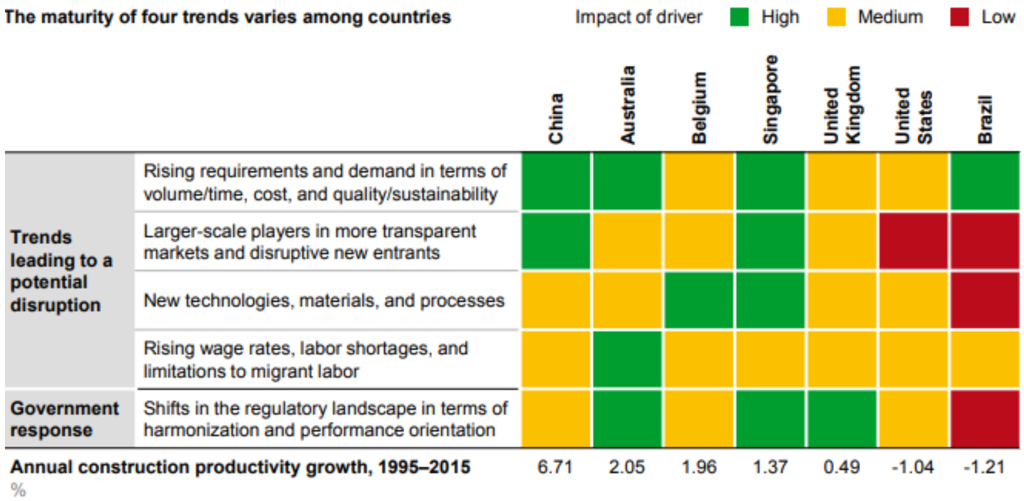

Figure 3.2: Commitment of the UK Government to increase construction efficiency adapted from McKinsey Global Institute (2017)

An industry ripe for disruption

Figure 3.3 portrayed the construction industry as a relatively low digitised industry among other industries. The construction industry, therefore, is ripe for disruption (Pistorius, 2017; McKinsey, 2016). The demand for radical improvement in the industry can be traced back to 70 years ago. For many decades, the industry has been challenged with many concerns. Since 1929 when the first significant report was produced, the UK construction industry performance has been subjected to review by the government (Cain, 2004). Due to its pivotal position in the economy and dependence by many other sectors, the UK construction industry must succumb to pressure by adoptions of emerging technologies to overcome many of its limitations.

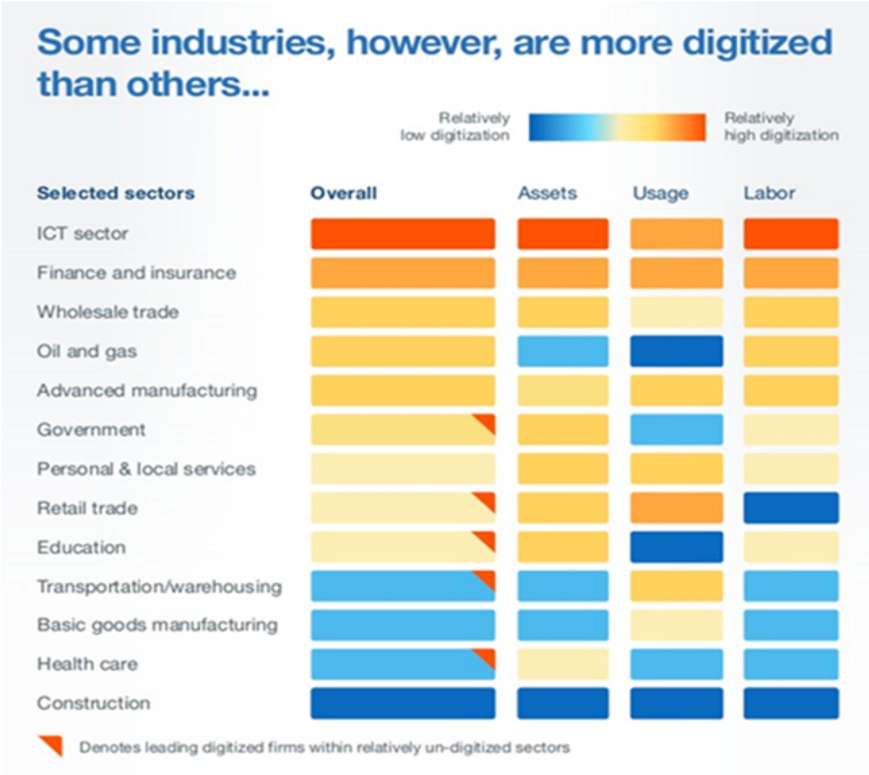

Figure 3.3: Construction digitalisation index compared to other industries adapted from the McKinsey Global Institute (2016)

Intense Pressure for a Radical Change

The construction industry underpins the UK economy and society. Kagioglou et al., (2001) evaluated useful performance metrics that optimised the internal and external performance of different sectors in the marketplace and analysed their performance to indicate potential areas of improvement. Analysis of the construction sector raises cause for concern for the construction industry for its underperformance. Output in the UK construction industry has been fundamentally flat since 1994. Farmer (2016) stated:

> ***"The evidence reviewed indicates that the construction industry and its labour model is at a critical crossroads in terms of its long-term health. While the diagnosis points to deep-seated market failure; certain industry trends and wider societal changes are happening now that represent both unprecedented risk and opportunity for the industry and its clients. If the opportunities are not harnessed, the risks may become overwhelming".***

Farmer report concluded that construction sector must 'modernise or die'. The report investigated the current labour model and found that its workforce is shrinking; there is a lack of innovation and collaboration and non-existence of research and development culture. Radical change to safeguard the industry's future was suggested. Table 3.1 demonstrates the continual effort of the UK government, demanding that the construction industry must change from its traditional approach through periodic reports and assessment. Areas of concerns were identified to appraise the extent of transformation required in the industry.

Table 3.1 Past major report commissioned by the UK Government

YEAR	Report title and authors	Major Areas of concerns
2016	Modernise or die, Mark Farmer	identified ten acute symptoms of failure and poor performance.
2013	Construction 2025, UK government	Procurement, integration and reduction of construction cost and time.
2011	Government Construction Strategy: UK government	Integration of supply chain, use of BIM and clear communication among construction team.
2009	Wolstenholme Report: ‘Never Waste Good Crisis’	Collaboration, lean approach to construction.
2002	Sir John Egan Report: Accelerating Change	Client leadership and integration of supply chain in construction projects.
1998	Egan Report: Rethinking Construction	Partnering, customer focus and commitment to people.
1994	Latham Report: Constructing the Team, Sir Michael Latham	Fragmentation of construction industry. Partnering, integration and use new forms of contract that encourage collaboration.
1975	The Wood Report, Sir Kenneth Wood	The damaging impact of lowest price tendering Insufficient time spent during design.
1964	Banwell Report: The Placing and Management of Contracts for Building and Civil Engineering Work	Against separation between design and construction, encouragement of teamwork and building relationship.
1962	Emmerson Report: Survey of Problems Before the Construction Industry	Standard forms of contract and lack of cohesion among construction parties.
1944	Simon’s Report: Placing and Management of Building Contracts	Insufficient pre-contract preparation. Extensive variation orders after the contract are placed. Indiscriminate competition tending and adoption of the lowest standard.
1929	Bossom Report: Reaching for the Skies	Time and cost overrun, fragmentation and adversarial relationship among construction parties.

3.2 Emerging Technologies and their effects on variations minimisation

Current development in the Architecture, Engineering and Construction (AEC) industry indicate a range of new technologies that are collectively driving several changes in project management. Technologies promise a great increase in efficiency and effectiveness of the planning and design process in construction (Froese, 2009). The concept of utilising emerging technologies and new innovative materials in construction is to significantly mitigate many challenges in the construction industry (Rogers et al., 2015). Emerging technologies will not only contribute immensely to address the challenges of the industry but leave behind a transformative impact (Pistorius, 2017). Only implementation and adoption of various emerging technologies will enable the UK construction industry to meet its national and industrial expectations and also be abreast to compete with other industries' efficiency and performance. Table 1.1 discussed the three classifications of emerging technologies.

Digital Technologies

Digital technologies are electronic resources, tools, systems and devices with the capacity to store, generate and process data. Digitalisation allows information to be accessed or viewed using electronic equipment or gadgets. Digital transformation is a significant global trend affecting all segments of human endeavour; no industry of the world is left untouched. Table 3.2 gave a range of digital technologies in the UK construction industry and their brief description and application. BIM is considered the most promising development to the construction industry for its ability to produce accurate virtual models (Eastman et al., 2011). 3D models produced by utilising BIM enables clients without specialist architectural training to engage profitably with projects before construction. BIM plays a central role as it is the key enabler and facilitator for many other technologies (The Boston Consulting Group, 2016).

Digital technologies are recognised as the main source of improvement and competitive advantage to construction firms and also as critical solutions to the shortage of skilled labour, safety for construction workers and boost to efficiency (Ho et al., 2003). Major digital technologies among those listed in Table 1.1 further discussed examples of technologies that are currently driving change in the UK construction industry:

Cloud computing

Sultan and Bunt-Kokhuis (2013) stated that a commonly accepted definition of cloud computing is "clusters of distributed computers like data centres and servers which provide on-demand resources and services over a network internet. The use of cloud computing in construction is vast and subtle that many practitioners may not explore. Cloud computing allows construction practitioners faster access to a range of computing services, storage, databases, networks, servers, software and analytics over the cloud for effective project management. According to Abanda et al., (2018), cloud computing offers enhanced accessibility of project data and site images only by remotely linking mobile devices with a dedicated remote server. Designers, contractors, engineers can leverage cloud computing to collaborate on BIM projects in real-time even though they are at different geographical locations. National BIM Report (2020) found that in 2020, for the first time, the use of Microsoft's online version of Office (365) surpassed its desktop counterpart. This finding is key in the progression of construction industry towards cloud-based ways of working.

Application and benefits of cloud computing to construction industry.

Chong et al., (2014) conducted a case study on a UK-based SME that has a reliable and efficient service. The study cited agility, elimination of capital expenditure, reduction of in-house IT staff, lower monthly costs, enablement of adoption of latest technology, information sharing simplicity, encouragement of standardisation and reduction of unused computing capacity as benefits of cloud computing. General application of cloud computing from literature includes data storage and file sharing in the cloud. However, many researchers have suggested that BIM must be upgraded with other technologies such as cloud computing and augmented reality to enhance design coordination and facility management. Abanda et al., (2018) enumerated the use of cloud BIM as follows:

- Accessing and sharing real-time data
- Requesting information and change orders

- Communication with other organisations
- Monitoring work task and resources
- Detecting potentials clashes due to design errors
- Collecting and retrieving progress information
- Liaising with and updating the progress of the project
- Coordinating partners and working groups engaged.
- Recording and managing project progress
- Coordinating construction schedules

Building Information Modelling (BIM)

Vanlande et al., (2008) defined BIM "as a process of generation, storing, managing, and sharing building information in an interoperable and reusable way". BIM represents physical and functional building characteristic virtually. It is an evolving technology used in the world of AEC industries although it has been used by automobile, aircraft and computer industries for design and delivery for decades. The premise of BIM in the UK construction industry is collaboration. Eadie et al., (2013) confirmed that collaboration aspects of BIM produce the highest impact among 92 UK BIM users. National BIM Report (2020) said "BIM is about managing information and doing so in collaboration with others. Apart from the collaboration of the project team, the UK government believes that the use of BIM will bring many efficiencies and benefits across the construction project lifecycle. BIMhub (2012) confirmed that BIM improves accuracy, design and construction through 3D visualisation. Holzer (2007) summarised the use of BIM as a more accurate way of working.

BIM and variation minimisation

Eadie et al., (2013) also found that Measuring the impact of BIM on variation minimisation, Barlish and Sullivan (2012) established through literature review that one of the most quantifiable benefits was a reduction of change orders. The research compared 408 projects over six years and found that 2D projects generated change orders represented 18.42% of the base contract, 3D projects generated 11.17% and collaborative BIM projects only led to 2.68%. Love et al., (2013) argued that investing in BIM not only reduces the capital expenditure of change orders but rework also. Giel and Issa (2013) highlighted reduced schedule overruns, fewer RFIs and reduced change orders as potentials savings to owners choosing to invest in BIM-based on measurable cost benefits. Handayani et al., (2019) developed a system that can detect altered building elements to evaluate the impacts of change orders to assist all project participants to visualise and quantify the impacts of the proposed change.

Interestingly, Guo et al., (2019) researched into negative impacts of BIM-enabled information transparency on contractors' interests and found through literature review that some contractor-related unethical practices at the construction phase which includes false variation claim by bribing architects who issue variations. One of the results of an anonymous questionnaire survey used revealed that transparency of construction techniques and methods could impair contractors' interest in BIM in the long run. The authors advocated for improvements in current working processes among stakeholders in BIM context to protect contractors' core competencies and prevention of unethical practices.

Digital collaboration platforms

Web-based collaboration platforms or software are designed to replace the traditional face to face meetings in management of construction projects in the journey of construction industry to modernisation. These virtual platforms present construction project teams with exchange document, promote better communication and enhance collaboration (Smit et al., 2005). Utilising collaboration platforms means all related project document and information are stored centrally in a secure data centre, and version control is managed effectively. Examples of collaboration platform in use in construction are CDE. Many software vendors around the world are developing CDEs; it is essential to choose the correct form. BIM involves constructing a structure in a virtual environment, CDE provides a platform for the graphical model and non-graphical data to be collected, manage and disseminate to the whole project team via the internet, intranet or in the cloud.

Digital collaboration platforms and variation minimization

There is no doubt, implementing collaboration platforms will have a direct and indirect impact on variations minimisation based on the following expected benefits as itemised by Smit et al., (2005):

- A single central repository for all project documents accessible 24hrs-a-day from anywhere;
- Reduction in paper copying costs;
- Reduction in distribution costs;
- Considerable time savings through more efficient processes;
- Increased document control;
- Increased accountability and audit capabilities;
- Increased transparency during design development resulting in earlier detection of defects;
- Reduction in the number of errors owing to out-of-date information or misinformation;
- Reduction in time for staff spent on paper and electronic document management;
- Improved project communication;
- Fostering a more collaborative approach; and
- Provide the operators and owners of projects with access to 'as-built' information.

Internet of things

Sundmaeker et al., (2010) defined IoT as “a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network". IoT is an emerging technology in construction that is gradually advancing possibilities of a smart approach to the management of various areas of application (Gbadamosi et al., 2020). A comparative review of literature by Gbadamosi et al., 2020 found that IoT application is more in post-construction as compared to design and construction phases.

Augmented Reality (AR)

AR creates an environment where computer-generated information is superimposed onto the user's view of a real-world scene. By using advanced sensor and camera technology, physical surroundings and computer-generated information are presented in real-time to users of AR. The technology is the overlay of digital content on the real-world environment. 3D images of a user's physical surroundings are projected as they walk through with a mobile device or special helmet. The technology is an interactive and reality-based display of environment that capitalise on computer-generated display, sound, textual content and effects to enhance the user's real-world experience (Loijens et al., 2017). Ahmed (2016) Through an extensive review of 84 relevant papers published from 1997-2018, discussed the benefits of AR in construction under the following headings:

- Scheduling and project progress tracking
- Communication and data acquisition
- Quality and defect management
- Time and cost management
- Employee training and safety management program

AR and variation minimisation

Variations affect construction time and cost and therefore, undoubtedly a significant issue of consideration in saving construction expenses and minimising variation. Designers and clients can preview designs and make changes before construction, thereby eliminating variations. According to Fan et al., (2015), physical reporting and inspection are time consuming exercise in construction. Users can virtually match building progress with its schedule and reveal issues. Changes can be made directly to models. Walls can be moved; site layout can be modified on AR-enabled device. The use of AR eliminates defects and construction rework based on Wong et al., (2014). AR allows engineers to troubleshoot errors in a virtual view before changes are applied to the physical structure.

Virtual reality (VR)

VR is part of immersive technologies the construction industry has been using to bring designs closer to clients. VR creates a virtual world of design in a way that users can interact with it through the use of a special headset. Unlike AR, VR creates an artificial digital environment that completely replaces the real world. This experience ensures that clients brief and expectations during the design phase are met. The use of this technology minimises client's variations later in the construction phase.

VR and variation minimisation

Construction projects can be monitored and controlled effectively to reduce cost and produce defectless projects thereby eliminating variations (Kamat et al., 2011; Whyte 2003b) Visualisation capability of VR is strongly connected to variation minimisation. The technology lends the opportunity to minimise variation by early decision making, changes to designs, features, test factors, eliminate errors and identify problems in the design process. By implementing VR for planning, design and construction, clients, designers, and contractor can achieve a better project.

Mixed reality (MR)

Dunston et al., (2003) argued that "application of MR may prove promising for effective communication of design for prefabrication, site installation, and the planning and execution of maintenance operations". Applying MR, virtual content is overlaid on the real environment (as in AR) and also anchored to and interacts with that environment. MR is a deeper immersive and interactive type of AR.

MR and variation minimisation

Fragmentation of project team leads to distorted information sharing, which potentially trigger variations. MR technology enables immersive communication experience that help project team collaborate more efficiently. Schubert et al., (2015) used MR in the early design and discussion stages of urban design projects to eliminate misinterpretations and misunderstandings between participants in the design process. The research physical volumetric models and hand-drawn sketches were connected with an interactive MR visualisation on a tablet, making it possible to see an interactive real-time view of architectural design in the context of the actual site. The use of MR can aid decision making process to lower variations.

Table 3.2: Application and a brief description of digital technologies in construction

Digital Technologies	Brief description and application in construction
Data, software, mobile devices and the cloud	Data is input generated from various software and applications presented in different formats. In construction, data originates from software, drones, 3D scanning, weather, sensors and GPS. These inputs formats are not typically the same or having compatible interfaces. The cloud storage allows transfers of data from device to local storage to 'somewhere' accessible everywhere, anytime and in real-time. The application of these in construction is for communication, reporting, collaboration and enhancement of decision-making.
Big data, Artificial Intelligence (AI) and advance analytic	Digitalisation leads to the creation of massive data from mobile devices, drones, sensors, and more, which may be useful for pattern analysis and trend. Advanced analytic tools are used to analyse big data in combination with AI. Analyses produced may be a descriptive analysis of the past or prescriptive analysis to enable decision making. Information obtainable from these technologies are provided to appropriate stakeholders in real-time. Result of analyses can also serve as essential information for maintenance setting. AI is used to predict cost overruns based on factors such as project size, type of contract, the competence of project teams. It is used to monitor developing problems and solutions, which helps with decision making in real-time.
Project management apps and digital collaboration platform	Wide range of project management apps specially created for the construction industry is now available in the market for construction industry practitioners such as Aconex, CoConstruct, WorkflowMax, Central Data Environment (CDE), CostX and more. These are specialised software and tools that work with mobile devices. More are being developed to enhance collaboration, assign tasks and assists contractors with administration, compliance with regulations and safety on site. Digital collaboration platform allows transparency and enables data mining on a large scale.
Building Information Modelling (BIM)	BIM is a computer-aided design which develops a building process digitally. BIM is a transformation tool that is changing how construction projects are designed and built, especially for large and complex projects. 3D BIM, in combination with intelligent data, offers comprehensive 3D modelling of design which allows virtual twinning of the structures, speed decision making process, manage change and enable workers to run various scenarios. BIM is at the centre of emerging technologies in construction. There are four distinct BIM maturity levels- BIM levels 0-3.

	BIM dimensions are different from maturity levels. BIM dimensions intimately connect to data that can become available through the process. There is currently 3D, 4D, 5D, 6D, 7D and 8D BIM for visualisation, construction sequencing, estimation, facility management, materials and objects tracking and accident prevention respectively. These dimensions can be found in BIM levels 2 and 3.
Sensors and Internet of Things (IoT)	IoT is the connectivity of many intelligent devices with the ability to communicate with one another and humans. This technology is useful for contractors, real estate and facilities management. IoT devices work with sensors to measure operational variables such as identification of individuals, tools, materials, speed, telecommunication devices, infra-red, body temperature, fatigue and environmental conditions. Included in this group are wearables items by workers, safety equipment and geotags. Building automation systems are enabled by IoT of various processes, especially in heating, ventilation and air conditioning (HVAC).
Spatial measurement, tracking and geolocation	The accurate measurement of distance, speed and location is known as spatial measurements in construction. Geolocation tools and equipment are used to track, identify and to monitor the movement of people. Global Positioning System (GPS) is an example of such device that helps information to be transmitted wirelessly from workers, tools, materials, vehicles and equipment to a designated server for display, process and analyses. Geolocation technologies are used for personnel safety, site security, fraud detection, scheduling and project management.
Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR)	AR is a technology which allows a live direct and indirect view of real world, physical environment by sensory input which is computer-generated. AR is useful onsite for archaeology to discover excavations, for workers to see through walls and exploration of dangerous environments. VR enables visualisation of designs in a 3D environment through a special headset. VR is used in construction before actual site construction to create 3D representations of the structure for intending users to see, move around in and feel the building. VR is also a powerful tool for training of operators; more importantly, it enables construction clients to interact and understand the unbuilt structure. Design changes can be made, and the immediate effect of the changes can be seen and felt. MR is used to produce new environments and visualisation where physical and digital objects co-exist and interact in real-time.

Automation Technologies in Construction

Automation is the replacement of human labour by robots or machines. Jamshidi and Parsaei (1995) defined automation as a "technology concerned with the application of mechanical, electronic and computer-based systems to operate and control production". As construction projects become more complex and sophisticated, automation of construction processes will help to integrate design and construction, enhance efficiency and reduce cost. Table 3.3 presents a brief description and application of automation technologies in construction. BBC News reported in July 2018 (www.bbc.co.uk/news/technology-44709534) that a family in France became the first family to live in a four-bedroom 3D printed house. The construction took 54 hours to complete and an additional four months for contractors to complete the installation of windows, doors and roof. Automation technologies such as a bricklaying robot in Figure 3.4 can operate successfully without any human intervention. It is a demonstration of potentials of automation technologies in construction.

Figure 3.4: Bricklaying robot adapted from https://www.autodesk.com/redshift/bricklaying-robot/

Table 3.3: Brief description and application of automation technologies in construction

Automation technologies	Brief description and application in Construction
3D scanning, printing and mapping	3D scanning is a process that creates digital 3-dimensional data of an object (Pistorius, 2017). 3D scanning creates 3D images of unbuilt structure which can be visualised in BIM and Computer-aided Design (CAD). 3D laser scanning is used to obtain correct measurements of a building. 3D scanning lowers contractor risks by making sure built drawings are accurate; it is a bridge linking the virtual world with the tangible world (O'Hare et al., 2017). 3D printing is a process of manufacturing to create a three-dimensional object. However, 4D printing allows the printed object shape to be manipulated or altered. Cement used in 3D printing is from compositions of various construction waste. Potentially, 90% of labour cost can be saved using 3D printing. It is used to print models of buildings, twisted construction forms or a whole small house. 3D printing is still in the early stage of adoption in construction. 3D mapping is a handheld system that utilises laser light to scan and record 3D images of structures to build up a 3D map of the survey environment. It is easy to use and requires no prior experience even in a daunting site.
Robotics	Most construction works take place in an unstructured environment which is hazardous to humans. A software-programmable machine, referred to as robot (Saidi et al., 2016), will be more suitable for many construction tasks that are repetitive and predictable such as bricklaying, demolition, tiling, and concrete dispensing. Construction robots also include diggers and robotic cranes. Speed of operation is a competitive advantage of robots to the construction industry, which could lead to considerable savings in construction time and cost.
Drones	Drones, which are also called Unmanned Aerial Vehicles (UAV) are human or computer-operated vehicles with full application in construction. Visual inspection of tricky sites and high-risk areas, maintenance inspections, materials inventory, aerial survey, transportation of items across sites and inspection for construction progress report can be done with the use of drones to reduce time and health and safety risks. There is a massive surge in the use of drones on construction sites in recent times.
Autonomous vehicles	Dowling (1989) defined it as "An Autonomous Vehicle is a self-contained machine that travels its world by sensing the environment to acquire knowledge of its environment, navigate and plan paths". Autonomous vehicles already in use in construction include excavators, backhoes and dump trucks that entirely remove the use of the manual labour of site and speed up project completion time.
Construction wearables	These are devices that are worn by workers onsite; they are capable of sending and receiving information from IoT sensors. Examples of construction wearables are Google glass, high visibility vests, footwear, hard helmets gloves, harnesses and wrist devices. They are used to monitor workers' health status, emotional stress and fatigue. This innovation could reduce health-related accidents on construction site.

The UK manufacturing industry lags behind other countries in the use of robotic technology for smarter, faster and cheaper buildings. Unlike Japan, Germany and Sweden with 213, 170, and 154 respectively per 10,000 employees, the UK has 33 employees according to a review of robotics and automation in transport construction conducted in 2018. Accurate digital representation of infrastructure is needed to develop distinct elements to enhance robotics in construction. As the industry moves to BIM level 3 and level 4, compatibility required with levels of robotic precision will be ensured.

Innovative Construction Materials

Study of innovative construction materials is beneficial to variation minimisation. Client variations orders to fulfil aesthetic demand is usually irresistible in practice. Construction materials generally define how construction projects are conceptualised. Construction by nature requires many and diverse materials that impact on construction cost, safety, efficiency. Availability of alternative materials that are sustainable, elegant and economical could inform the client choice and minimise variation. Development of alternative and innovative materials in construction will cut construction time and cost. Traditional construction materials such as concrete and steel require improvement to make them safe, cheap, light and environmentally friendly.

Emerging technologies that are applied newly in construction, such as BIM, integrate well with prefabricated components, industrial chains and support realisation of all-round information integration. To overturn the traditional construction industry, Bonenberg et al., (2018) suggested BIM technology will integrate with prefabricated buildings in a perfect way to promote innovation and development in construction. Following the tragic incident of Grenfell Tower fire in London in 2017, there is need for the construction industry to give attention to the safety of new materials and this is necessary also for the image of the industry.

Based on the large volume of construction materials needed to execute a project successfully, slight improvements made to increase the performance can have a tremendous impact on initial cost, lifecycle cost, efficiency, safety, durability and the environment. Innovative materials are useful in reducing greenhouse gas emissions, improving buildings durability and reduction of energy bills. These materials are to:

- Be recyclable
- Help construction firms to be competitive
- Reduce cost
- Offer quick installation
- Be more durable and lighter.

3.3 Other emerging technologies in construction

Blockchain technology (BCT)

One of the evolving digital technologies that are making headway and offering immerse opportunity for construction industry efficiency, transparency, productivity and sustainability is called Blockchain Technology. Nawari and Ravindran (2019) defined BCT as "a digitised, decentralised public ledger of data, assets and all pertinent transactions that have been executed and shared among participants in the network”. Due to each transaction information been recorded as a 'block' adding to the 'chain' at a scheduled interval to form incorruptible ledger of 'blockchain', the name blockchain was derived (Ramage, 2018).

Introduction of BCT to construction will contribute to the ongoing innovation disruption in the industry. Perera et al., (2020) posed a thoughtful question by asking, "was BIM successful in disrupting the construction industry"? In proffering answer to this question, the author argued that researchers (Eadie et al., 2013; Shourangiz et al., 2011; Zhong et al., 2019) found that BIM was able to change design paradigm but not able to create an impact on construction project procurement. BCT and BIM will be ultimately connected in construction industry as BCT has more potentials in addressing procurement issues (Perera et al., 2020).

Potentials of Blockchain in construction industry

San et al., (2019) discussed literature findings potentials of blockchain application in construction industry under the following headings:

- Contract management

- Electronic document management
- BIM
- Property management
- Supply chain management
- Funding management

Furthermore, the research discussed the application of BCT and its vast advantages to the industry by increasing the quality of data and improving time and cost performance under these headings:

- Workflow and time efficiency
- Cost efficiency
- Transparency and trust
- Data security
- International construction.

e-Procurement in construction

Procurement is a process that incorporates the strategy of how goods and services are acquired (Egbu et al., 2003). JCT defined procurement as "a term which describes the activities undertaken by a client or employer who is seeking to bring about the construction or refurbishment of a building". Procurement is crucial in the AEC industry, and the process is usually intensive. Nature of many construction projects, especially the large ones increases inherent risks. Understanding the risks associated with each procurement method is essential as all procurement route comes with some fundamental risks. There are four primary procurement methods in construction industry, namely, traditional, design and build, management and integrated method. For a chosen procurement method to be successful, all parties must diligently comply with their respective obligations as stated in the contract.

E-procurement is the process of acquiring goods and services without the use of paper (Przymus, 2003). According to Farzin and Nezhad (2010), e-procurement is an Internet-based business process for obtaining materials and services and managing their inflow into the organisation. As illustrated in Table 3.1, both UK construction process and procurement process have been under constant scrutiny through various government reports and investigation. As part of Construction 2020 vision, the UK government is encouraging the industry to engage supply chain early and consider e-procurement to deliver greater efficiency.

Benefits of e-procurement to construction industry

Eadie et al., (2010) identified general drivers for e-procurement from literature that are unverified as specific to construction industry. The research carried out a verification process to filter the drivers that are significant to the industry. Table 3.4 listed the potentials benefits of adoption of e-procurement to construction industry that are verified by (Eadie et al., 2010).

Table 3.4: Potential benefits of e-procurement to construction industry adopted from Eadie et al., 2010.

No	Drivers from Literature and Delphi Process	Banding
1	Process, Transaction and Administration Cost Savings	Cost
2	Service / Material / Product Cost Savings	Cost
3	Increasing Profit Margins	Cost
4	Strategic Cost Savings	Cost
5	Enhanced Inventory Management	General
6	Shortened Overall Procurement Cycle Times	Time
7	Shortened Internal and External Communication Cycle times	Time
8	Reduction in time through greater transparency (Less objections)	Time
9	Reduction in Evaluation Time	Time
10	Reduction in purchasing order fulfilment time - Contract Completion	Time
11	Reduction in time through increased visibility	Time
12	Increased Quality through increased competition	Time
13	Increased Quality through Benchmarking (Market Intelligence)	Quality
14	Increased Quality through increased visibility in the supply chain	Quality
15	Increased Quality through increased efficiency	Quality
16	Increased Quality through Improved Communication	Quality
17	Gaining Competitive Advantage	General
18	Increased Quality through increased accuracy (Elimination of errors through Computer use)	Quality
19	Convenience of archiving completed work	General
20	Develops the Technical Skills, knowledge and expertise of procurement	General

3.4 Literature review on the effects of emerging technologies on construction projects in the UK

Table 3.5 presents the result of literature review carried out to investigate the impacts of technologies on projects in the UK. All project details were gathered online and presented unedited. Sources of information obtained consist of available project information of completed construction projects in the UK from research papers, institutional reports, videos clips, press release, programme proposals and various public records that are placed in the public domain.

Table 3.5: Effects of emerging technologies on past construction projects in the UK

Project name	Location	Project available details	Source	Technologies used	Effects of technologies on the project
University Campus Suffolk	Ipswich, UK	Contract sum: £45M, A six-story academic building Floor area:15,000-sq-metre Contractor: RMJM	McGraw-Hill (2010a)	BIM	Able to identify all possible clashes. The design team saw some success with collaborative uses of BIM, benefits such as improved visualisation, clash detection and reduced re-entry of data proved valuable.
Aylesbury Crown Court	Aylesbury, UK	Contract sum: £35M, Floor area: 5,200m2. Designer: HOK Contractors: Turner & Townsend and AECOM	Constructing excellence.org.uk McGraw-Hill (2010a)	3D topographical survey BIM	When clients “see 3D model, they get enlightened. It helps sell the design and becomes a very relevant marketing tool". Having detailed quantities in the model, the team could efficiently track costs in real time to keep the client apprised of budget issues. On a project without BIM, it would have taken two months to design this scheme, and we were able to do it in a couple of weeks, revealed water table issues.
Young Offenders Institute	Kent, UK	Clients: Ministry of Justice Contractor: Faithful and Gould Two-Stage Tendering - Early Contractor Engagement Project: 3-storey stackable concrete pod, house block and a new 2-storey education building	Constructing excellence.org.uk http://archive.secbe.org.uk/documents/bim_project_of_the_year_2014.pdf	BIM Off-site manufacturing	Fewer issues onsite, ultimately reducing timescales, abortive work and cost. Dealt with coordination and change at an early stage, before construction. Regular sharing keeps all disciplines up to date with design changes and avoids the risk of receiving a large batch of changes late in the process. Use of 3D model in design meetings allows us to focus and visualise the issues quickly and accurately leading to efficient resolution. Ground models which collate all relevant site data provided tremendous benefits at the early project stages. In terms of visualisation of the site topography and assessing most efficient solutions for cut and fill, foundation design and contamination. Embed maintenance/access zones for plant and equipment enables us to verify spaces are kept clear, visible in both 2D and 3D and through automatic clash detection.

					The 3D model allowed non-technical personnel to understand and contribute to the scheme early in the process. Models drove operational FF&E cost/time efficiencies and supported the preparation of new operational staffing regimes – achieving cost savings of £850k. Off-site manufacturing delivered a £26k saving, against an allowance of £36k. The design resulted in a reduced programme of 44 weeks – delivering time and overhead savings which when benchmarked were approximately 20% of the total build cost. The technology secured collaborative platform for all project team.
St Helens and Knowsley Hospital	Merseyside, UK	35-year PFI procured £350 millions of dual hospital on two sites. 2006-2010. New build 75,000m2 and 12,000m2refurbishment. Contractor: VINCI Construction UK Ltd (VCUK) Avanti Consultant	Constructing excellence.or g.uk	BIM, Off-site manufacture Modular M&E installations Early design freeze	Developed a fully integrated set of production information to achieve a 10% saving by producing spatially correct information. The project Opened six months ahead of schedule. No impact on the operation of contiguous existing hospital services. Completed within budget. Waste is driven down, with 60-70% saving in time to find documents; 75-80% saving in design coordination; positive impact on the critical path.
Endeavour House	Stansted	Client: KLM			Saving of 10% project costs. Cost savings of 9.8% of project costs and 18% saving in the cost of drawing production (independently audited).
Palace Exchange	Enfield, London, UK	Standard Methods and Procedures (SMP) used. £30 million retail development that links the town's main stores and provides parking	Constructing excellence.or g.uk	BIM	Improvement on information management, estimated at nearly 800 working hours or £50k; but done at 24 man-weeks or £60k. Use of project extranet for information exchange saving up to 50% of effort and improved spatial coordination and cost certainty. Early access to all project information by all projects. Early involvement of the supply chain.

David Hockney Building	Bradford, West Yorkshire, UK	Bradford College. Six-storey building replaces three existing teaching blocks Construction 2010-2015. Architect: Bond Bryan, contractor: BAM Construction. Contract sum: £50M, Floor area: 23,000m^2	Building SMART	BIM	The building was completed two weeks early. The exported IFC data for spaces to produce quantity data at an early stage, giving them cost certainty. The collaboration between the architect and main contractor on IFC file exchange. BIM resolved file exchange of IFC data problem among contractor, consultants and client. Improvement in site management with BIM 360 Field.
Anglian Water @one Alliance		Innovative collaboration model approach with six key contractors Mott MacDonald, Bentley, Grontmij (Sweco), MWH and Skanska. Various Anglian Water's projects, numbering about 800 and costing about £1.2 billion ($1.5 billion) in total.	World Economic Forum (2016)	Digital technologies Virtual testing Augmented reality A fully integrated model, BIM	The Alliance achieved annual savings of 2 to 3% while increasing the quality of service delivery to its customers over the last ten years. Effectiveness of operations and maintenance. Virtually testing and operating assets with the help of augmented reality before construction allows to optimise designs before construction is initiated.
London Crossrail Network	London, UK	Contract Sum: £14.8 Billion, 42 km rail tunnels Due to open in 2019		BIM, 3-D model, point-cloud survey, AR, iPad, wireless sensors to monitor environmental conditions, GPS, laser scanning, CDE, BIM	Saved time and money by reducing costly construction errors. All project information in one place. It has saved millions of pounds per year. The model saves time and money because it offers a standard set of data for the thousands of contractors and consultants working on Crossrail. Contractors can also make changes to their part of the model, which, after review, get incorporated into the master model.
Wellcome Trust Sanger Institute	Hinxton near Cambridge, UK	£96M, New build, 2001-2005, space for 2,000 staff, laboratories, data centre, research facility and a dining, meeting, sports and	Constructing excellence.org.uk	BIM	The BIM aided cultural integration between the team and reduced the adversarial approach. Use of BIM has meant that the final building meets the design expectation. The project was brought in on time and budget and with zero defects.

		community facility. Construction manager: MACE			
Durham Cathedral	Durham, UK	August 2014 – November 2014, Scan to BIM. Preserving and capturing our heritage		3D laser scanning BIM Revit, The point cloud	Not only does it give us up to date images of the building in its current state which helps plan things such as installation and upgrade of new services but gives us accurate information on the building we have had before.

3.5 Opportunities, impact and benefits of emerging technologies

The Latham report (1994) investigated the means of improving the UK's construction industry. The report suggested that implementations of new technologies can reduce construction project costs by as much as 30%. Due to the fragmentation nature of the industry and the construction industry not been transparent, assessing technological benefits seems to be a complex and acute thing to do compared to other industries (Andersen at el., 2000; Marsh and Flanagan, 2000). Love and Irani (2004) argued that some benefits of emerging technologies like efficiency impact would only begin to emerge when the diffusion rate of the technology surpasses 50%. Review of literature indicated that emerging technologies in construction is offering some valuable opportunities and making some impact on the industry.

While many emerging technologies are collectively driving change in the UK construction industry, BIM is unique and central. BIM allows construction projects to be built virtually for better planning and coordination before they are constructed physically on site. Figure 3.5 illustrates the benefits of BIM in construction if projects utilise BIM technology correctly and throughout the construction process. Emerging technologies in the AEC industry is now a subject of a strong interest in research, training and development. New technologies can potentially provide fast, effective ways of managing construction resources, enable collaboration and integration of all stakeholders on a project.

Figure 3.5: Benefits of BIM adapted from Construction Tuts (2017)

The World Economic Forum (2016) reported that any improvement in productivity and successful adoptions of innovative modern processes would have a significant impact. The report claimed that "a 1% rise in productivity worldwide could save $100 billion a year". However, nearly all new buildings in the UK are still procured through one-off design and constructed in-situ. BIM level 2 compliance was mandated by the UK government on all centrally funded projects of £5 million and over by 2016. The NBS (2016) revealed that this mandate had not been enforced despite the perceived benefits of cost reduction. Literature review on opportunities and benefits offered by emerging technologies in the construction industry are discussed below:

Reduction of initial, operational and life cycle costs

Cloud computing allows remote access to project data no matter the site terrain. This technology reduces initial and operational cost for construction industry that is always mobile. The vast attention given to BIM in the AEC industry in recent times may be as a result of its benefits and increasing use in the industry. Noguchi (2003) reported that circa 8% reduction in the cost of prefabricated materials compared to similar site built. Life cycle costs of traditional materials can be five times more than initial capital costs (Evans et al., 1998). BIM through 3D design representation of information in a graphic form and accurate knowledge of quantities of materials used helps to prevent adverse decisions. Eadie et al., (2013) argued that substantial impacts could be achieved throughout all phases of the construction process.

Wu et al., (2016) found that although the use of 3D printing is still fragmented in the construction industry, the technology can achieve a significant reduction to construction cost and reduce workforce on site. Jin et al., (2015) affirmed that the implementation of BIM by many construction organisations is to overcome the significant concern of project time and costs caused by variations. Mahdjoubi et al., (2013) established the use of 3D scanning, and BIM is advantageous for construction projects and offers highest financial benefits for all construction stakeholders through effective collaboration of the project team (Eadie et al., 2013; Ku and Taiebot, 2011; Eastman et al., 2011). The potential benefits of BIM at all stages of construction project lifecycle to all stakeholders, according to Grilo and Jardim-Goncalves, (2010) are listed as follows:

- Owners- to understand project needs.
- Design team- to analyse and produce better design.
- Contractor- to manage construction better.

Reduction of Time of Construction

Nath et al., (2015) proposed there will be a significant improvement in overall construction efficiency of both processing and total time for precast elements of construction through the elimination of inefficiencies by adopting BIM. Contractors' profits will increase as a result of improved efficiency offered by BIM (Fan et al., 2014). As design and structures are becoming more sophisticated in the construction industry, potential benefits of automation and robotics will grow to reduce reliance on manual labour. This benefit will enhance efficiency and lessen the negative effect of construction activities on the environment (CII 2003). Figure 3.6 demonstrates the use of drones on the construction site. Drones are small objects with high levels of manoeuvrability; this makes them better alternatives to traditional vehicles on construction sites.

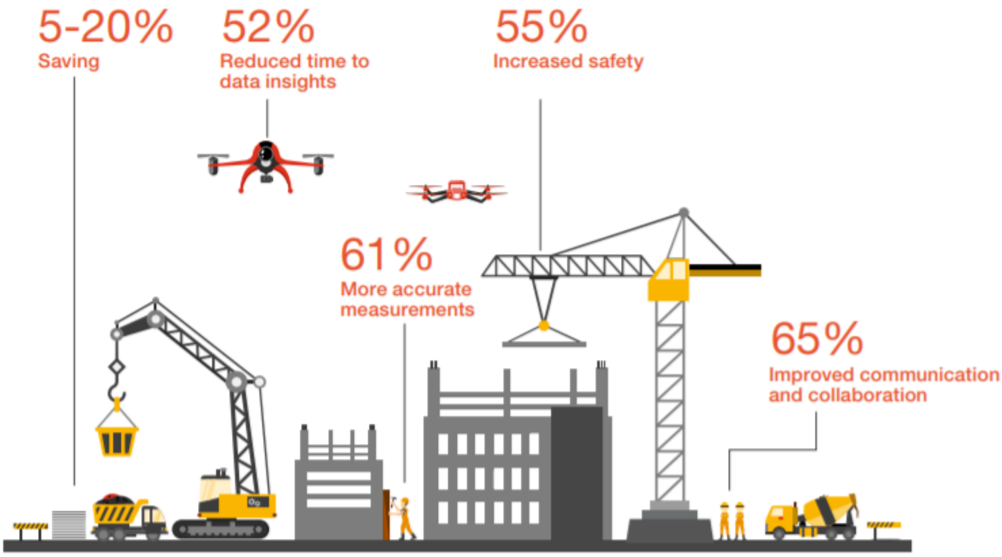

Figure 3.6: Benefits of drones in construction adapted from Autodesk (2018)

Reduction in the number of variations

Many tangible benefits of automation and robotics may not be measured adequately in monetary form for now, but the competitive advantage of the technology to the industry can improve efficiency and cost through reduction of labour hours (Slaughter, 1998; Goodrum and Haas, 2002; CII 2003). The World Economic Forum (2016) report projected that global increase in productivity by 1% could lead to a saving of $100 Billion per annum.

BIM plays a significant role in minimising and enhancing overall variation management process. Changes to designs and resulting time and cost impacts can be identified in the BIM model (Likhitruangslip et al., 2018). In Table 3.6, Fan et al., (2014) demonstrated that variation orders as a result of errors and omissions, design conflict and incomplete plans drastically reduced on ten construction projects. Khanzode et al., (2008) affirmed that based on a case study on a project with the use of 3D and 4D BIM tools for Mechanical, Electrical and Plumbing (MEP) coordination "there were no change orders related to field conflicts on the project". Other accrued benefits from BIM implementation gathered from literature is reduced design changes (Lopez and Love, 2012; Francom and El Asmar, 2015).

Table 3.6: Result of BIM implementation on variation reduction adapted from Fan et al., (2014)

No.	Project type	Project size ($M)	No. of change orders
1	Educational	15	7
2	Office	32	2
3	Hospital	231	9
4	Office	120	1
5	Med. Proc.	145	2
6	Educational	61	3
7	Hospital	8	1
8	Educational	78	3
9	Educational	42	2
10	Hospital	96	0

Training, education and job opportunities

Automation and robotics have great potential to reduce reliance on human labour. There will be opportunities to train and develop new streams of skilled workers, thereby creating more job opportunities in the construction industry. Education providers must update their curriculum to prepare learners to embrace emerging technologies in construction and to become competent in this arena. Opportunities abound for creating new careers in digital, automation and new materials in construction. Lately, degree and master courses in connection to these technologies are springing up, which will make Universities and other training institutions develop new curriculum to enhance the new technologies. Lack of expertise within the project team and construction organisations present opportunities for the industry to fill these positions (Eadie et al., 2013).

Improvement of health and safety

The construction industry is ranked high as one of the major high-risk industries of the world (Camino et al., 2008). Cheng and Teizer (2013) admit that the use of sensors and VR are valuable to protect and monitor workers onsite and those working on cranes. Wearable helmets, smart vests, smart glasses with a video camera and ultra-wideband are becoming popular among construction site workers. Wearable technologies allow construction teams to be in constant communication, monitor health, safety and security of site workers, and operators of equipment and vehicles.

New entrants and new companies emerging

Emerging technologies in construction will accelerate digitalisation which will lead to an influx of 'digital natives' to the industry. Digital natives are young people born into the digital age who cherish mobile and digital technologies. Also, implementation of emerging technologies will usher new successful entrants from other sectors of the economy into the industry to capitalise on its digitalisation competitive advantage. There will be increased demand for new skills leading to creations of jobs.

New organisation cultures, business models and best practice

The digitalisation of the construction industry has the potential to transform and address challenges faced by the industry in decades. With the increasing adoption of innovations, the industry will need to adopt practices that are common to other industries such as Software-as-a-Service (SaaS). This new culture will enhance procurement, logistics and supply chain management. Digitalisation will help the industry in peer-to-peer rental of equipment for construction. McGraw-Hill (2009) discovered that only 3% of BIM users acknowledged full benefits attainment. Kang et al., (2013) ascertain that technologies enhance best practice, front end planning, and management of change which all together lead to better construction project performance. Love et al., (2004) attributed the most significant benefits of Information Technology (IT) as, improved organisation, service quality, data management and process flexibility.

Image redeemer and transparency

The image of the industry is likely to change as the industry is actively participating in 3D printing (Wu et al., 2016). Waste reduction, design flexibility and reduction of human labour have been linked to the use of 3D printing in construction (Wu et al., 2016). Extreme fragmentation is one of the major challenges of the construction industry. The trend in BIM implementation in construction projects consistently affirms that close collaboration among construction stakeholders ranked high among many benefits (Azhar, 2012, Eadie et al., 2013). BIM model can allow various disparity of software tools and vendors to co-exist, interoperability helps efficiency through better coordination and communication of project participants (Grilo and

Jardim-Goncalves, 2010). BIM can be said to be a fusion of culture, technology and process (Macdonald, 2011).

3.6 Limitation, Risk and Threat of adopting Emerging Technologies in Construction

Implementation and adoption of emerging technologies in construction continue to gain momentum having potentials to bringing many opportunities and benefits to all stakeholders in the industry. Technologies adoption come with its challenges, limitations and risk. These will be becoming obvious and better understood as adoption and implementation become common and widespread. Emerging technologies in construction will have a disruptive impact on the industry; the implication will cause the extinction of some existing traditional skills and markets for another. Despite the increasing implementation and proven ability of new technologies to reinvent the AEC industry, there is lack of widespread uptake of these technologies. Reasons for slow uptake may not be far from the challenges, limitation and risks associated with adoption. Some of these challenges are discussed:

Cybersecurity risks

The construction industry, like any other sector, is not shielded to cyber risk witnessed in the past across the globe. Digitalisation brings about huge data. Storage and security of data are crucial to any organisation. Findings by Watson (2017) reported that security threat relating to data privacy breaches and cyber-attacks is in the ninth position of the Construction Risk Index of 350 construction executives. Love et al., (2004) identified security issues to be the most significant risk to digitalisation. Theft of software and hardware also form part of the risk emerging technologies utilisation poses to the industry. Klahr et al., (2017) reported that "Almost half of UK firms were hit by cyber breach or attack in the past year". Government and experts in related industries are making efforts to help organisations on how to protect their data and sensitive information.

Threats to some traditional professions and current skills

The paradigm shift from the traditional approach to digitalisation and automation will introduce new materials, support the use of technologies driven by data like artificial intelligence, analytics and big data. The modern approach to construction reduces reliance on human skills in the production of designs and bill of quantities. Professional bodies like RICS admitted technologies would take over some aspects of professional practice. Some other professional bodies insisted that digitalisation will instead provide professionals with quality time for analysis and advice. Changes to the nature of work and roles of construction-based professions like architecture, quantity surveying, structural engineering and building surveying are inevitable. Bricklaying robots could threaten the traditional bricklaying career.

Lack of industry expertise and training

Eadie et al., (2013) and Jin et al., (2015) indicated that lack of industry expertise is one of the major barriers to implementation of new technologies in construction. Many small to medium organisations utilising BIM seek the help of external experts to resolve problems encountered with implementation; this leads to an increase in expense of implementation. Lack of capability in house to use technologies will make the construction industry vulnerable to adhere to traditional methods of project delivery. The majority of research conducted in AEC on BIM technology express concern on lack of skill as a big issue.

Capital cost

Adopting and implementation of emerging technologies are expensive; this is a major factor to the slow uptake of BIM and other innovations, especially among SMEs (Azhar, 2011). The initial and maintenance costs, especially for small firms, are still substantial (Bryde et al., 2013). Low profit margin contributes to the inability of many small to medium construction companies to invest in new technologies to improve their business models and change from the traditional approach to construction. The need to upgrade technologies continuously pose a challenge to low profit margin industries such as construction. Cost of BIM software is charged per annum for a workstation; this cost is a very substantial overhead cost for SMEs.

Uncertainty of potential benefits, risks and law

There is a big quest within the construction industry to understand fully if the capital investment in emerging technologies is worthwhile. Return on Investment (ROI) approach in evaluations of uptake of emerging technologies must be used with caution for potential financial benefits as it does not reflect tangible and indirect real benefits (Neelamkavil and Ahamed, 2012; Love et al., 2013). Adoption and implementation of automation/robotics entail high risks and uncertainties; therefore, investors need a comprehensive investment evaluation process for strategic decision before uptake (Ho et al., 2003). Construction stakeholders require universal guide and framework to quantify the full benefits of emerging technologies in construction.

3.7 Chapter summary

The UK construction industry is of great significant importance to the nation but is an industry that is troubled and dogged by many challenges. Challenges plaguing the industry has attracted constant attention and publicity by the government for a radical change. Application and effects of emerging technologies that are collectively driving change in the industry were reviewed in this chapter. The benefits are stacking up; however, many of these emerging technologies are still in their infancy stage in practice. The construction industry must embrace a technological approach to overcome many challenges discussed in this chapter and to meet the demand of a rapidly changing world. Challenges of implementation is significant; however, the opportunities are enormous.

Chapter Four
Research Discussion, Philosophy and Approach

4.0 Introduction

This chapter explains the theoretical positioning of this research to achieve the set aim and objectives. The theoretical and philosophical stance of the study is established by discussing the research worldview, approach, design, data collection procedures, data integration, research ethics, reliability, validity and other research processes. Also, the chapter presents justifications for convergent mixed method adopted and framework development and validation process. This chapter further discusses the quantitative and qualitative approach of the study under a separate heading.

4.1 Research in the construction management field

Amaratunga et al., (2002) argued that research in construction and the built environment draws from a wide range of established discipline like natural sciences, social sciences and management field. Construction research is considered relatively new in comparison to these ancient disciplines. Research in construction management draws primarily from natural and social sciences and, therefore, many paradigms dominate its methodology (Knight and Ruddock, 2009). Seymour et al., (1997) criticised the dominance of the scientific theorising associated with realist ontological and epistemological positions in construction research given that the 'object' of most construction management research is people. Purely scientific perspective may underestimate the interpretive process in construction management research. It is imperative to change from the traditional dualisms of the old approach to combinations of methodologies to overcome the weaknesses of single-paradigm approaches.

Creswell (2009) stated that mixed methods research is relatively new in the social and human sciences as a distinct research approach. Most existing research in the construction management field utilises either robust qualitative or quantitative methodologies, although the mixed methods approach is beginning to gain ground recently. Demand for validation of heuristic principles within different "real world" situations in construction management is essential to refine and integrate research in construction. The research problem determines research method appropriateness; however, the use of a mixed methods approach in research is favourably suggested in the field of construction management. Mixed methods counteract the weakness of single methodology and to enhance research in the built environment (Amaratunga, 2002).

4.2 Philosophy Assumptions

Philosophy assumptions are assumptions about the grounds of knowledge or ways of acquiring knowledge (Bryman, 2001). Epistemological, Ontological and Methodological are three main assumptions in research. Other philosophical assumptions are axiological and rhetorical. These assumptions are discussed briefly:

The epistemological assumption is how natural science investigates the social world. Epistemology deals with the following questions: What is real knowledge or truth? How does it develop? What are the conditions necessary for knowledge to develop? (Krogh and Roos, 1995a). From a qualitative researcher viewpoint, there is no one truth or reality, and that truth is subjective to each person. In practice, researchers get involved in the field and participate to gain an understanding of the participant's views on realities. Quantitative researchers see truth as being one truth, an objective that can be studied. Also, that researchers and participants are independent of truth studied with little or no influence on the truth. Data collection using this approach is quick because researchers spend less time with participants, and analysis is done to gain real knowledge.

Ontological assumptions pose the question what is the nature of being, reality, and existence? What can be known about it? To answer these questions, researchers employ a qualitative approach and see reality as being multiple, subjective and that there is no reality independent of our minds. Therefore, the words of participants in such research are in quotes and themes to indicate differing perspectives. Quantitative researchers view reality as one, and that reality is objective and can be described independently of human perceptions. Hence, hard data is through surveys and observation that uses numbers and statistics.

Methodological assumptions ask the question, what is the process of research? Answers are proffered by the researcher using inductive logic to study the topic within its context before generalising and continually revising questions from experiences in the field (Creswell, 2007).

Axiological assumption poses the question what the role of values is? While qualitative researchers answer this question by saying facts cannot be separated from values or described as they are really but by the way we perceive them. Also, that research is bias and value-laden; therefore, researchers openly discuss values and include personal views in conjunction with the interpretations of participants to shape narratives (Creswell, 2007). In a quantitative study, the researcher believes facts should be separated from values by showing statistics to prove that the research is valid and reliable.

The rhetorical assumption is about what is the language of research. In answering this question, qualitative research writes narratively in the first person informally. The answer to the quantitative researcher to the language of research is in the third person as a scientific report. Table 4.1 summarises philosophical assumptions about questions asked and how different worldviews proffer answers.

Table 4.1: Elements of Worldviews and Implications for Practice adapted from Creswell and Clark (2018)

Philosophical Question	Postpositivism	Constructivism	Transformative	Pragmatism
Ontology (What is the nature of reality?)	Singular reality (e.g., researchers reject or fail to reject hypotheses)	Multiple realities (e.g., researchers provide quotes to illustrate different perspectives)	Multifaceted and based on different social and cultural positions (e.g., researchers recognize different power positionalities in our society)	Singular and multiple realities (e.g., researchers test hypotheses and provide multiple perspectives)
Epistemology (What is the relationship between the researcher and that being researched?)	Distance and impartiality (e.g., researchers objectively collect data on instruments)	Closeness and subjectivity (e.g., researchers visit with participants at their sites to collect data)	Collaboration (e.g., researchers actively involve participants as collaborators, build trust, and honor participant standpoints)	Practicality (e.g., researchers collect data by "what works" to address research question)
Axiology (What is the role of values?)	Unbiased (e.g., researchers use checks to eliminate bias)	Biased (e.g., researchers actively talk about and use their personal biases and interpretations)	Based on human rights and social justice for all (e.g., researchers begin with and advocate for this premise)	Multiple stances (e.g., researchers include both biased and unbiased perspectives)
Methodology (What is the process of research?)	Deductive (e.g., researchers test an a priori theory)	Inductive (e.g., researchers start with participants' views and build "up" to patterns, theories, and interpretations)	Participatory (e.g., researchers involve participants in all stages of the research and engage in cyclical reviews of results)	Combining (e.g., researchers collect both quantitative and qualitative data and mix them)
Rhetoric (What is the language of research?)	Formal style (e.g., researchers use agreed-upon definitions of variables)	Informal style (e.g., researchers write in a literary, informal style)	Advocacy, activist-oriented (e.g., researchers use language that will help bring about change and advocate for human rights and social justice)	Formal or informal (e.g., researchers may employ both formal and informal styles of writing)

4.3 Philosophical Worldviews

The term worldview is used synonymously as a paradigm. Creswell and Clark (2018) affirmed that there are four worldviews inform research, and these four worldviews provide general philosophical orientation to research. Creswell (2018) favours the word worldview to a paradigm. Paradigm suggests shared beliefs and values of research rather than specific discipline or community of scholar. Guba (1990) defines worldview as a basic set of beliefs that guide action. Philosophy worldview understanding helps to choose a suitable approach for research and to understand the type of knowledge the research contributes. These four different worldviews are discussed briefly together with the significant elements of each position in Table 4.2 below.

Table 4.2: Four Worldviews and their characteristic adapted from Creswell (2014)

Postpositivism	Constructivism
• Determination • Reductionism • Empirical observation and measurement • Theory verification	• Understanding • Multiple participant meanings • Social and historical construction • Theory generation
Transformative	**Pragmatism**
• Political • Power and justice oriented • Collaborative • Change-oriented	• Consequences of actions • Problem-centered • Pluralistic • Real-world practice oriented

Postpositivist worldview philosophy determines the effects or outcomes that are more suitable for quantitative research than qualitative. It is a traditional form of research. The postpositivist worldview is often called the scientific method and represents the thinking after positivism. The philosophy perception in this worldview is summarised by Phillips and Burbules (2000) as follows:

- There is no absolute truth.
- Research process make claims and abandons the less for, the more robust, by testing theory first.
- That data, evidence and rational consideration ultimately shape knowledge.
- Research strive for relevant information that can explain the situation of concern.
- A competent inquiry must be objective.

A constructivist worldview is a typical approach for qualitative research. Also, it is referred to as social constructivism or interpretivism. It is more dependent on participants' views of the situation being investigated. This worldview employs the use of open-ended questions to get insight into historical and cultural norms that operate in people’s lives. Unlike postpositivist worldview, constructivism develops theory through a pattern of meaning rather than testing theory. Some assumptions identified in constructivism, as discussed by Crotty (1998) are as follows:

- That man constructs meanings through interaction and interpretation of the world around them.

- Historical and social perspectives of man informed the sense they make of the world around them.
- That man derives social meaning through human interaction in the community.

Transformative worldview research is concerned with the reform agenda that can change peoples' life and work. Research is carried out to raise the voice for participants that are either marginalised or disenfranchised (Creswell, 2014). Transformative approach criticises postpositivist assumptions as implosive and marginalising some individuals in society. Transformative worldview assumes constructivism stance is not adequate in advocating help for the marginalised people; hence research in this worldview focuses on political change agenda. Mertens (2010) itemised key features of transformative paradigm as:

- Laying emphases on the lives and experience of a marginalised diverse group.
- The research revolves around inequities of all sorts.
- The action on political and social inequities in society.
- Adopt programme theory to understand oppression, domination and power relationships.

The Pragmatic worldview is not committed to any specific reality or philosophy. It is concerned with applications of what works and proffers solutions to problems (Patton 1990). Creswell (2014) stated pragmatism as a worldview arises out of actions, situations and consequences rather than antecedent conditions as in the case of postpositivism. This worldview focusses its attention on the research problem by using all approaches to understand the problem and to derive practical knowledge about the problem. Mixed methods studies underpin the philosophical paradigms of this worldview. Morgan (2007) provides a philosophy basis for pragmatic research as follows:

- Employ different philosophy and reality in mixed methods research.
- Freedom to choose methods, techniques and procedure that meet the needs and purpose of research.
- Adopt many approaches in data collection and analyses.

- For the best understanding of a research problem, uses both quantitative and qualitative data.
- Research is based on consequences of actions; therefore, the need to establish why mixing is necessary and rationale for collecting quantitative and qualitative data.
- Pragmatists believe research occurs in many contexts, including social, historical, and political and, therefore, studies may include this area.

Philosophical stance of this research

This research study is suited to pragmatic worldview because the study is problem-centred, seeking to provide solutions to a real-world challenge. The techniques and procedure adopted were designed to meet the research aim and objectives. This informed collection of both quantitative and qualitative data for triangulation. The investigation conducted on the application and effects of emerging technologies in minimising variation was carried out practically rather than abstractly. Construction stakeholders were directly engaged, participants were sourced across UK and processes of the investigation are evident.

4.4 Research Approaches

Creswell (2014) defined research approaches as "the plans and the procedures for research that span the decision from broad assumptions to detailed methods of data collection and analysis". Research approach involves the intersection of philosophy, research designs and research methods adopted for the research. Figure 4.1 illustrates the intersection of these three components, which form a framework of research.

Literature review process

Comprehensive literature review conducted for this study used distinguish traceable reliable sources such as journal papers, books, conference papers, blogs, newspapers, websites and electronic media which are related to variations and emerging technologies in construction. To identify relevant publications to support the review process, research based web such as Google Scholar, Scopus, Research-Gate, ASCE Library and Web of Science were searched with the following keywords:

variations in UK construction projects, reduction/minimisation of variations in construction, emerging technologies in construction, new technologies in constructions, change orders and BIM, other technologies listed in Table 1.1 were also searched for. The search words/phase helped identified numerous useful papers/articles across distributed sources. Some were printed out and links to access others stored on a desktop.

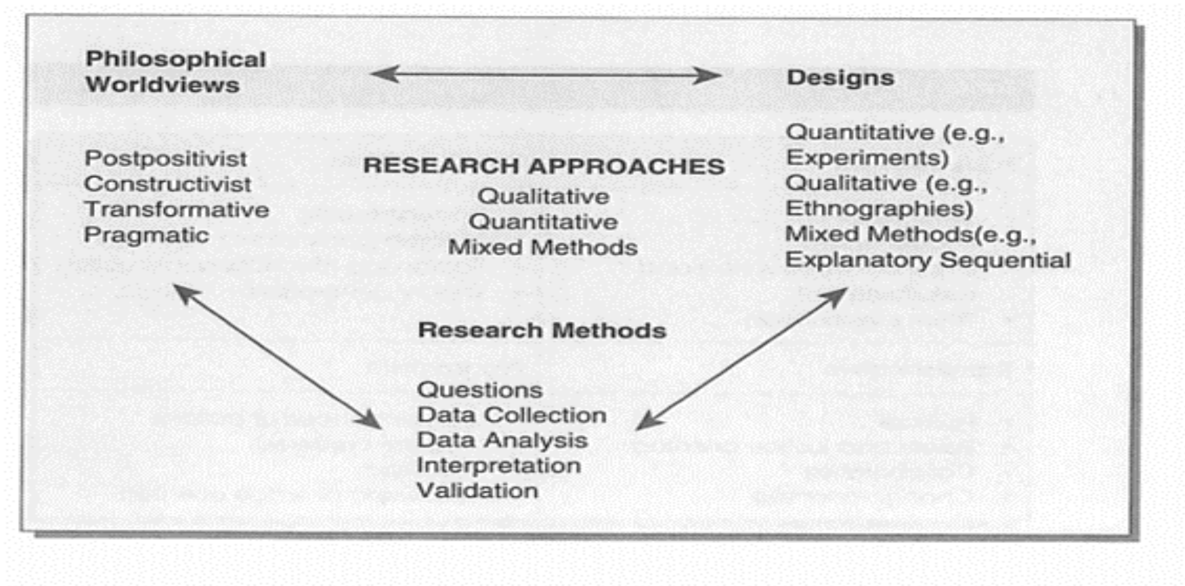

Figure 4.1: The interconnection of Worldviews, Design and Research Methods adapted from Creswell (2014)

The three approaches to research

There are three fundamental approaches to research; they are qualitative, quantitative and mixed methods. These approaches provide broad direction for procedures in research. Qualitative and quantitative approaches are viewed as rigid, discrete categories and polar dichotomies. Newman and Benz (1998) argued that these two approaches represent different ends on a continuum. Research can be more qualitative than quantitative or vice versa. Mixed methods research sits in the middle of this continuum for adopting elements of both qualitative and quantitative approaches. More research designs are now available for the researcher because of advancement in computer technology (Creswell, 2014). In any research study, there is a need to decide on the type of study within the three approaches.

Quantitative research is based on testing objective theories through relationship examination among variables. Variables can be measured on instruments using statistical procedures or hypothesis testing. Surveys and laboratory experiments are employed as strategies of enquiry. The researcher uses closed-ended questions/numeric data collected to support or counter research hypotheses.

Qualitative research explores to understand the meaning of an individual or group of people ascribes to human or social problems. A typical process in this approach involves formulating questions, collecting data from participant's settings, analysing data and interpreting analysed data to make meaning. Quantitative research is mainly associated with observations, interviews, archival documents and case studies (Saunders, 2011).

Mixed methods research entails collection of both quantitative and qualitative data; to better understand the research problem than in a single approach, this data were integrated using distinct designs. Mixed methods research is a special case of multi-method research (Collis and Hussey, 2009; Kothari, 2004) with the main advantages of providing strengths that offset the weaknesses of both quantitative and qualitative research.

Adopted research method for this study

This study adopted mixed methods research for reasons outlined below:

- Neither qualitative nor quantitative research alone is sufficient to capture the application and effects of various emerging technologies on variation minimisation due to the complexity and novelty of the study. According to Bryman (2006), combining both methods draws on their strength.
- Mixed methods research combines quantitative and qualitative techniques within a single study to overcome the limitation of single-paradigm approaches. The quantitative survey is capable of meeting the aim of this study by providing a general numeric solution to the research aim. Whereas, interviews and open-ended survey provided a deeper contextual understanding of the complexity of the research aim and objectives.
- Combination of multi forms of data collected via multiple questions with multiple answer survey, close ended questions, open-ended questions and

interviews drew on all possibilities to address the research aim and objectives. Findings from these multidimensional perspectives provided a comprehensive account to enhance and validate the study.

Research designs

This research adopted a mixed method approach; research design outlines the various frameworks available for data collection and analysis. Research designs or strategies of inquiry are types of inquiry within the three approaches to research (qualitative, quantitative and mixed methods) that give specific direction for procedures in a research study (Creswell, 2014). Within mixed methods design, the adopted research design for this study, there are three cores and four sophisticated mixed methods design that provides a robust framework for research according to Creswell and Clark (2018). Figure 4.2 illustrates a useful framework of the three core designs. The three core mixed methods designs are:

The convergent design, formerly referred to as the concurrent or parallel design, brings together the results of the quantitative and qualitative data analysis for comparison or to be combined. This mixed method design provides a complete understanding of a problem and validates one set of findings with the other.

The explanatory sequential design in mixed methods research is characterised by the collection and analysis of quantitative data in a first phase followed by collection and analysis of qualitative data in a second phase that builds on the results of the initial quantitative results.

The exploratory sequential design in mixed methods research involves the first phase of qualitative data collection and analysis followed by the second phase of quantitative data collection and analysis that builds on the results of the first quantitative phase.

Other four prominent types of sophisticated mixed methods designs are:

- The mixed methods experimental (or intervention) design.
- The mixed methods case study design.
- The mixed methods participatory-social justice design.
- The mixed methods programme evaluation design.

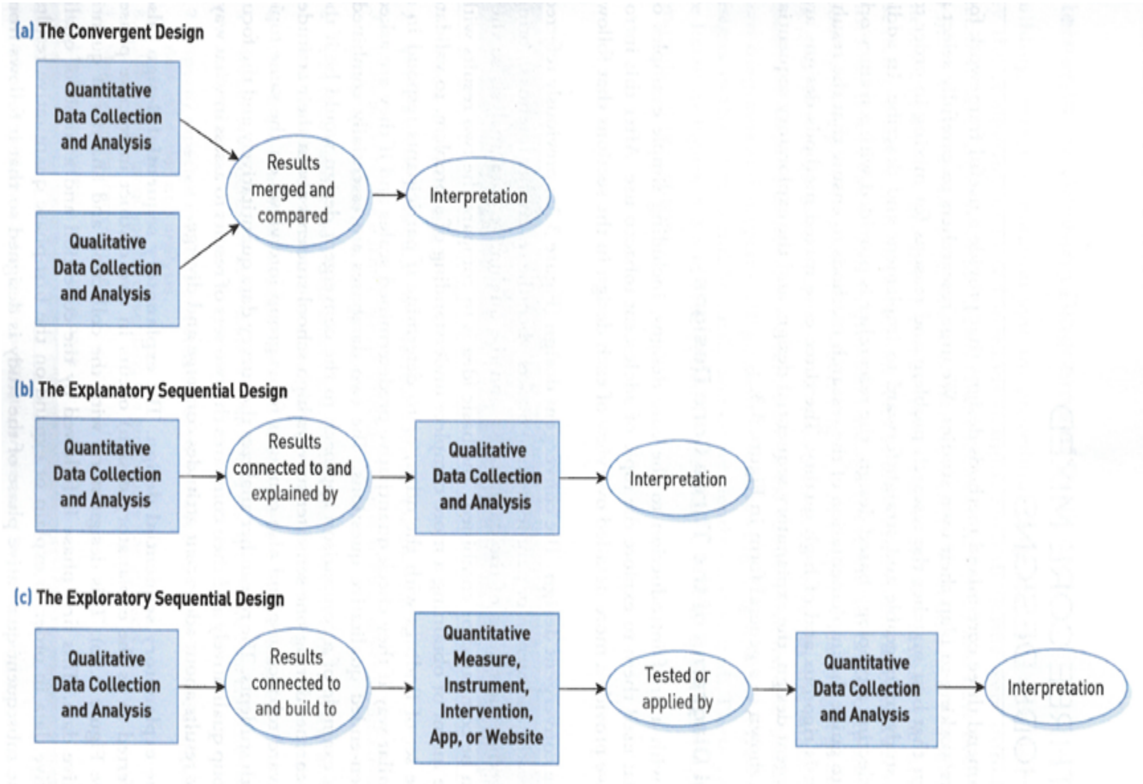

Figure 4.2: Three mixed methods core designs framework adapted from Creswell and Clark (2018)

The design adopted for this study

This research study adopted the convergent design; this design provides different types of information that when combined together, would yield the same result. Based on this characteristic, this study adopted the convergent design. The convergent design achieves different but complementary data on the same topic (Morse, 1991; Johnson and Onwuegbuzie, 2004), convergent design strengthens corroboration and validation purposes (Creswell and Clark, 2018). Nardi (2018) stated that "research on human social behaviour and attitudes is conducted for many reasons”. Reasons may include to explore, describe, explain and evaluate for better understanding an issue in-depth, arriving at decisions and making predictions". Since the purpose of an enquiry is subject to change throughout a study, these classifications are not concrete (Robson, 2002).

Convergent mixed methods design is a type of design that collect qualitative and quantitative data in parallel. Data collected is then analysed separately and later merged. The study explored multiple forms of data collection to utilise the flexibility offered by the mixed method approach adopted. Both qualitative and quantitative data were merged, and the results compared to validate and corroborate results. Combination of these two data led to a better understanding of the research problems and attainment of quality research outcome. To help describe the research procedure, Figure 4.3 illustrates the procedure followed in implementing the convergent mixed method adopted for this study.

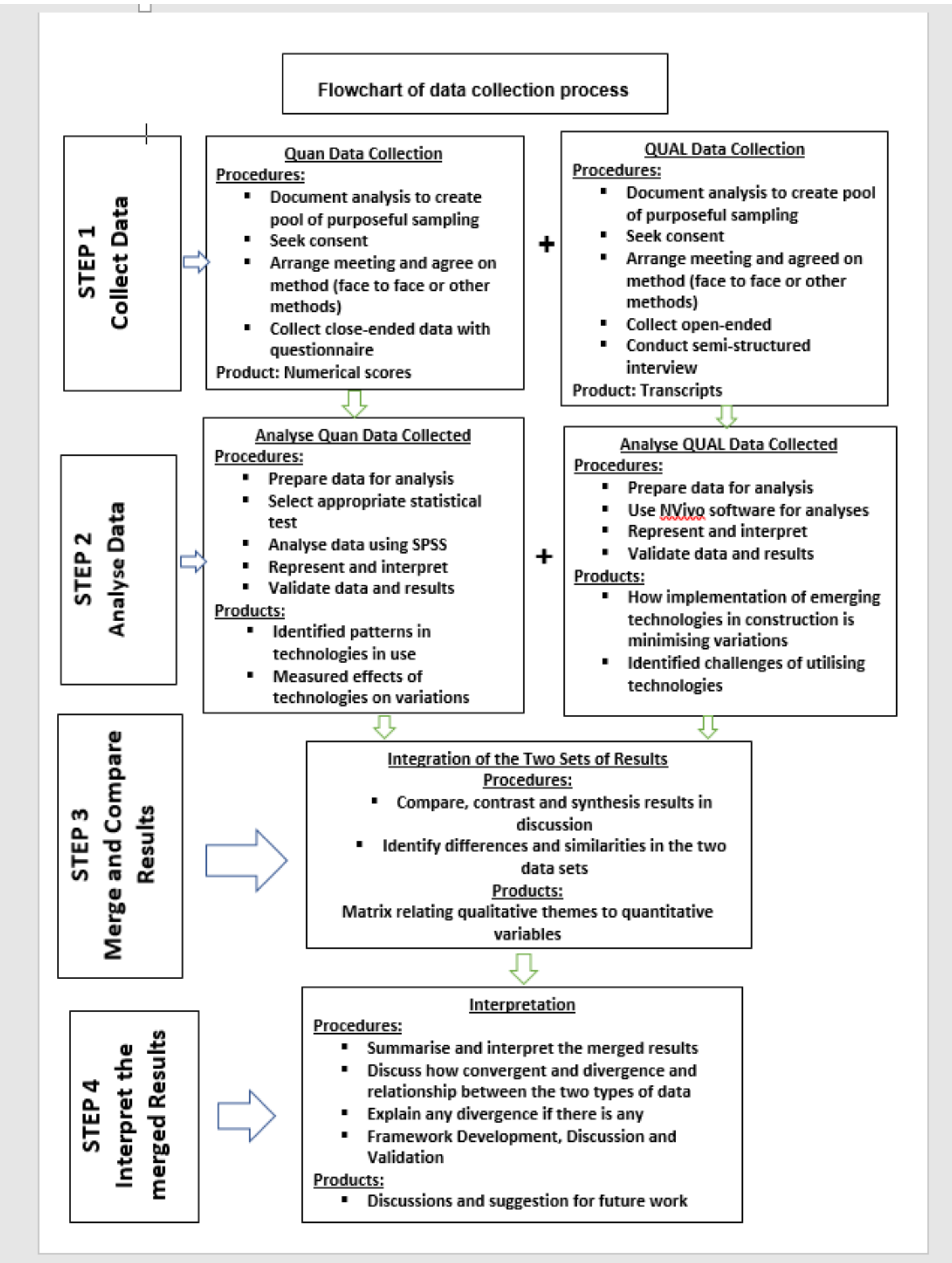

Figure 4.3: Flowchart of the adopted convergent mixed method design

4.5 Priority and Integration

According to Creswell (2009), priority is the importance or weight allocated to quantitative or qualitative research during data collection phases of research. The philosophical and theoretical underpinning of a study may have a place in deciding on the weight to be given to the two types of data collected, or it may intrinsically rest upon research questions. The primary aim of this study is to evaluate the effects of emerging technologies in minimising variations in construction projects. Research participants' perception of the impact of new technologies is vital; hence, the study chose to adopt QAUL-Quan sequence method. The interpretation of this is that qualitative data is given priority in the study.

Integration is regarded by Creswell and Clark (2018) as "a significant feature of mixed methods research; it involves the point in mixed method research where procedures qualitative research interfaces with the quantitative research. Figure 4.4 illustrates data integration process used to merge the two sets of results. Figure 4.4 is a simple indication procedure in implementing a convergent mixed methods design used in this study.

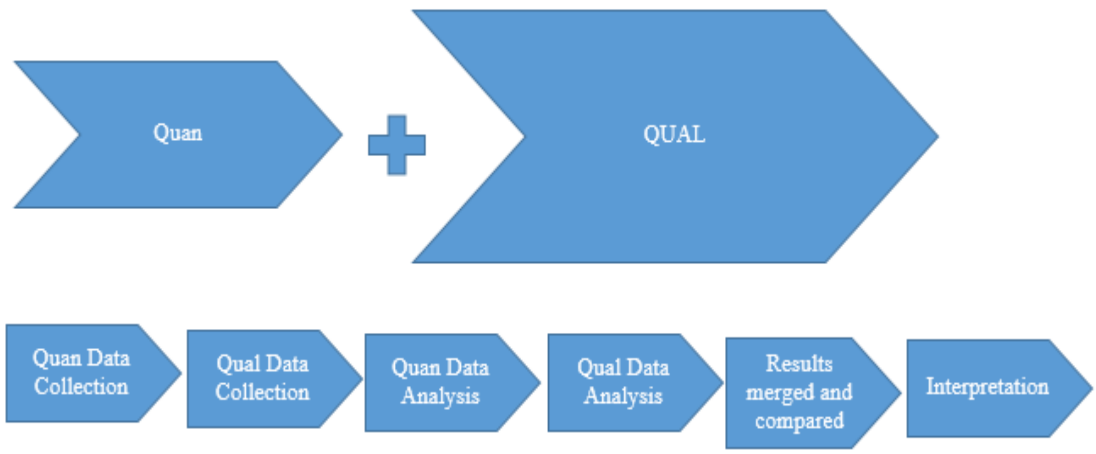

Figure 4.4: The adopted convergent design adapted from Creswell and Clark (2018)

Integration process: Integration is defined as the point where both qualitative and quantitative research interface together in the research procedure (Creswell and Clark, 2018). Data integration is central to the convergent design and any other mixed methods research. Depending on the types of mixed methods design, procedures to follow in data integration is different (Fetters et al., 2013). In convergent design, after concurrent collection of both qualitative and quantitative data, analyses are done separately before the two databases are merged. Integration can be achieved in two ways; the two sets of data are compared, or one set is transformed for conducting further analyses (Creswell and Clark, 2018). There are vital considerations as identified by Creswell and Clark (2018) that must be addressed during data integration analysis procedures. These are listed and addressed as follows:

- The intent of integration.
- Representation of merging integration results in a narrative discussion.
- Interpretation of integration results.

4.6 Strengths and limitations of convergent design

Convergent design is a popular design of mixed methods research; it is an efficient design which allows both qualitative and qualitative data to be collected at one phase of study almost at the same time. Also, each data collected can be analysed separately and independently with convention analytical techniques associated with both designs. Convergent mixed method design allows researchers to give their voice to participants in the process of data collection; allow statistical trends to be reported as well. On the downside, this design may be challenging in merging two sets of different data. Using convergent design may be more challenging when the need arises to explain divergent results that do not agree. Issue of different sample sizes may arise when data is collected for different purposes.

4.7 Population sample

Creswell and Clark (2018) stated that "sampling needs to be rigorous in both quantitative and qualitative strands of a mixed methods study". Understanding the difference between sample and population is useful for researchers in obtaining samples that are representative of the population. Dörnyei (2007) refers to a group of participants who take part in an empirical investigation as a sample, population as "the group of people whom the study is about". The population of interest for this study are those UK construction professionals, organisations and stakeholders with practical experience in the implementation of emerging technologies listed and discussed in Table 1.1 in chapter one. Probability sampling such as random and stratifies samplings are taken to be representative of the population, but purposeful sampling provides the opportunity to critically select participants based on a feature or process in which the researcher is interested (Silverman, 2005). As mixed method research that seeks to ascertain the impact of emerging technologies in minimisation variations in construction projects, purposive sampling is considered more suitable.

Esterberg (2002) places prominence in the selection of participants who can provide the researcher with possible insights into the research topic. Selected participants for this study are those with hands-on experience through implementation. Relevant professionals/organisations are construction clients, designers, contractors, BIM coordinators, service engineer, project managers, quantity surveyors and others. Polit and Beck (2004) specified that sampling methods for quantitative and qualitative approaches should be different due to their specific aims. Professionals with theoretical knowledge of emerging technologies in construction without hands-on experience were excluded from both approaches. The reason for their exclusion is that they are unable to provide empirical data to support research aim and objectives.

Purposeful sampling proves to be an effective method when only a limited number of participants can serve as a primary data source due to the nature of research and research design. Document analysis of construction projects across the UK that adopted new technologies was undertaken. This analysis assisted in selecting purposeful sampling.

4.8 Ethical considerations

Ethics can be defined as principles that direct behaviour and activities. Morton and Wilkinson (2008) argued that "open and honest manner around data collection, analysis and publication" is required to conduct a research activity. Obtaining informed consent, avoidance of deceit and harm, respect for privacy and confidentiality are crucial and good practice around research ethics. Good practice in academic research demands adherence to established, recognised and standard ethical requirements. This convergent mixed methods design research complied with the established research ethics policy of Coventry University, the awarding institution. Ethics clearance certificate was applied for and received by the designated ethics department. A copy is attached as Appendix G. Some data collected is part of contract information which may be confidential to the organisations; all data will be used anonymously.

Bryman (2008) stressed the interconnection of privacy with confidentiality and anonymity. Nevertheless, Christians (2005) argued that watertight confidentiality is impossible. Real-life construction projects data and information were gathered from targeted construction stakeholders. These participants are not vulnerable people. Consented participants were briefed that the intent of data is for academic research only with no liability on the part of the research to disclose information obtained to any third parties. Besides, participants were assured that their data would be securely stored without it being disclosed to any third parties unless written permission is obtained from them. Research findings may be used subsequently for academic publications. Informed consent is a crucial aspect of ethical consideration in any research that requires more than getting participant to sign the informed consent document.

BERA (2011) guidelines demanded that anyone participating in research should be made aware of their right to withdraw at any time regardless of any or no reason. Participants were verbally told of their right to withdraw at any stage of questionnaire running or when conducting interviews. To adhere to this requirement, all participants of this study were made to sign the University consent form to meet the University ethics standard, a copy of which is included as Appendix B.

4.9 Quantitative approach to the study

Research instrument

Designing and developing a reliable and valid questionnaire is a challenging task (Johnson and Turner, 2003). A research questionnaire was designed and used to collect quantitative data. A questionnaire is the most convenient method of data collection in a quantitative study. Developing a quality questionnaire with strong psychometric properties takes time and hard work. The questionnaire used was designed uniquely in a way to collect data that will address the set aim and objectives of this study. Some questions were reversed deliberately reversed to check participants' understanding of the subject matter. Reversed questions are also aimed to reduce response bias. The research questionnaire was designed in a way to maximise the time spent with respondents and enhance both quantitative and qualitative data collection. A maximum of one hour is considered suitable for this purpose.

Questionnaire design

Since mixed method offers the opportunity to use multiform of data collection methods, this study questionnaire was designed into four sections to collect useful empirical data. Part A consists of a list of recognised emerging technologies used in the UK construction industry to determine trend and level of usage. This session was designed in the form of multiple choice with multiple answer style. Participants were asked to select one or several technologies used from the list provided using tick boxes. The response was restricted to the list provided to streamline and make analysis specific. Part B consists of 30 Likert-scale closed ended questions. These questions were drawn around prominent issues of variation as identified from literature review and impact of technologies in minimising these issues.

The attitude continuum used for each statement in the close ended questionnaire was constructed as described in Table 4.4. Part C contains open-ended questions designed to capture the empirical impact of technologies used on current and ongoing projects of participants. Data collected from open-ended survey was qualitative data and will be discussed and analysed as appropriate. Part D was used to capture demographic data from participants. Combining two types of questionnaire, i.e. close ended and open-ended contributed to both depth and breadth of the instrument.

Combination of these practical approaches to collect data was engaged to address the research problem better and provide satisfactory evidence to achieve research aim and objectives. Due to the novelty of this study, special attention was given to the questionnaire development and design. Assessing the number of variations on participant's projects to validate research findings may be unattainable given the space of time available for data collection. Closed ended survey was used as a means of gathering practical information on effects of technologies utilised by participants on variation minimisation. Details of the four-sectioned questionnaire used for data collection of this research is presented in Appendix C.

Table 4.4: Close ended questionnaire scale and interpretation

Rating scales	Measurement scale	Meaning of the scale
Very strongly agree	5	The participant did not doubt the certainty of the statement made.
Strongly agree	4	The participant, to a reasonable extent, did not doubt that the statement made is correct.
Agree	3	The participant generally agreed with the statement made or the principle underlying the statement.
Disagree	2	Participant clearly understands the statement but did not agree with the statement or the underlining issue being discussed.
Strongly disagree	1	Participant from personal experience knows the statement under discussion was not possible.
Very strongly disagree	0	Participant from personal experience knows the statement under discussion was entirely not possible.
Unsure	-	The participant was not sure and, therefore, cannot confirm or deny the importance of the statement under discussion.

Piloting the questionnaire

Dörnyei (2007) wishes researchers to pilot their research instruments and procedures before the commencement of data collection. A pilot project was conducted to verify the completeness of the questionnaire before the actual data collection. The four-sectioned questionnaire piloting process was done in two phases. In phase one, a questionnaire sample was designed and developed. In the questionnaire design and formulation, special attention was paid to avoid ambiguity, complexity, double-barrelled and double-negatives statements and questions. Participants were given explicit and polite instruction on to how to complete the questionnaire, as Lewin (2005) directed. The questionnaire was sent out to 5 academics and 5 practitioners in the industry to complete and to suggest what can be done to enhance it before actual data collection.

Feedback based on the pilot study were incorporated into the questionnaire. Necessary adjustment, as suggested by experts and academics, was made to produce the final version used in data collection.

Variables in the study

Dependent variables (DVs) of this study herein refer to the four most causes of variation as revealed in literature; design errors, clients' dissatisfaction, fragmentation and contractor performance. Independent variables (IVs) of the study are emerging technologies that are presently being utilised in the construction process. It is assumed that independent variables have an appreciable impact on the dependent variables.

Data collection

Various methods were deployed to establish contacts with professionals with practical experience; document analysis was carried out to explore recently completed and ongoing projects across the UK that use BIM and other technologies. Few referrals to other practitioners by study participants was received. Visits to construction sites of interest were done, including attendance of national construction events and construction networking meetings. Examples of networking events attended, which ultimately led to data collection exercise are London Digital Construction Week in October 2018, various UK BIM Alliance meetings and BIM in Birmingham conference. Afterwards, initial contact with seasoned professionals who are interested in the research was made. Further communications that culminated to actual data collection were established through email and telephone calls.

Table 4.5 outlines the purpose of the sections of the research questionnaire. Face to face mode of administering questionnaire helped to build a good rapport with participants. By leveraging technologies, some questionnaires were completed online via Facebook and LinkedIn by posting the URL link to popular construction groups. More details on data collection exercise are given in Chapters five and six.

Table 4.5: Questionnaire sections and purpose

Method	Questionnaire sections	Purpose of data collection
Questionnaire Survey	Multiple choice with multiple answers	To access the level of usage of technologies currently in use in the UK.
	Close-ended questions	To measure the collective impact of technologies on variations and its root causes quantitatively.
	Open-ended questions	To measure the specific impact of each technology on participants' projects.
	Demographical questions	To enhance robust analysis. To access participants projects types, years of experience in construction and their organisation profile.

Data analysis

Data obtained from the questionnaire was edited, invalid and incomplete questionnaire were eliminated. The data was then coded by assigning numbers to the range of point scale, as illustrated in Table 4.6. The percentage score for each range was calculated; the score of 5 represents the highest percentage score of 100% down to 0%. In the Likert scale, the unsure option was not assigned any numeric value as it is an indicative choice of scale. Cross-tabulation of data was carried out manually on an Excel sheet with each questionnaire arranged in succession to another based on the collection order. Each question was denoted with P1, P2, P3 and so on and on the vertical axis. Statements in the questionnaire were arranged in a cross sequential manner. The main characteristic of convergent mixed methods research is that qualitative and quantitative data are analysed separately. The intent of convergent design adopted for this study is to develop and interpret the result to expand comprehensive understanding that is validated and confirmed (Creswell and Clark, 2018). In preparing the collected quantitative data for analysis, the following six steps were followed:

- Preparing the data for analysis: SPSS software was used to assign value to responses. New variables were derived by recoding and computing items.

- Exploring the data: missing data checked through visual inspection of trends in the data. Descriptive analyses for variables and basic assessment for reliability and reliability of the measures was conducted.
- Analysing the data: SPSS was further employed to perform statistical tests.
- Representing the analysis: statistical results obtained were summarised and reported duly by figures followed by a concise explanation.
- Interpreting the results: this stage of data analysis involved interpreting results in comparison with research aim and objectives. This action led to the identification of the limitation of this study and future research ideas.
- Validating the data and results: internal statistical validity and external validity procedure was carried out to secure the instrument using SPSS.

Appendix E and F give full details of data analysis in an Excel spreadsheet.

Table 4.6: Questionnaire measurement scale and code

Rating scale	Very strongly agree	Strongly agree	Agree	Disagree	strongly disagree	Very strongly disagree	Unsure
The number assigned to the response of each	5	4	3	2	1	0	-
% score of each range	$\frac{30x5}{150}$=100%	$\frac{30x4}{150}$=100%	$\frac{30x3}{150}$=100%	$\frac{30x2}{150}$=100%	$\frac{30x1}{150}$=100%	$\frac{30x0}{150}$=100%	-

Validity and reliability

Colton and Covert (2007) asserted validity and reliability as two main indications for testing instrument credibility and accuracy in quantitative research. Validity refers to the degree which an instrument measures what is intended. It is routinely used in quantitative research; however, many scholars argue that validity is meaningless in qualitative research (Maxwell and Mittapalli, 2010). Many steps or precautions were taken to ensure the validity of this research. The questionnaire was developed based on knowledge acquired through a robust review of literature; a summary of findings is listed in Section 1.9. Piloting the instrument subjected it to the scrutiny of both reasoned academic and practitioner experts. This action demonstrates content validity, according to Colton and Covert (2007).

Furthermore, all sections of the questionnaire were developed with research aims and objectives in view. Data collected were subjected to appropriate statistical tests before further analysis and interpretation. Reliability conveys consistency of a measure. Participants were kept focused in order to duly complete study questionnaires to the best of their knowledge. Efforts were geared to administer most questionnaire face to face contributed to the reliability of this study. Out of 70 completed questionnaires used for analyses, 59 questionnaires were administered face to face with participants, while 11 were completed online.

4.10 Qualitative approach to the study

Participant selection

Collection of multiple forms of data drawing on all possibilities is encouraged under mixed methods design. Document analysis was performed solely to create a list of potential purposeful samples for interviews. Data obtained was not subjected to any analysis nor used as part of the findings of this study. Purposeful sampling provides an opportunity to critically select participants based on a feature or process in which the researcher is interested (Silverman, 2005). This sampling method involves selecting and identifying individuals or group of individuals that are knowledgeable with a phenomenon of interest (Creswell and Plano Clark, 2011). Archive documents for this analytic approach were sourced online through rigorous searching of the world-wide-web. Information obtained consists of contract information of completed and ongoing construction projects in the UK. Sources are from institutional reports, videos clips, press release, programme proposals and various public records that are placed in the public domain.

Creswell and Clark (2018) stated that "sampling needs to be rigorous in both quantitative and qualitative strands of a mixed methods study". Document analysis is classified as qualitative research; it is employed in this study prior to the main quantitative and qualitative approaches to aid the effectiveness of the adopted purposive sampling. Details of databased formed based on this exercise is not evidence in this research to avoid a breach of confidentiality.

Data collection

Gaining permission, performing qualitative sampling strategy, preparing means for recording and storing the data are part of data collection (Creswell, 2014). Document analysis conducted to identify purposeful sampling yielded a pool of various construction stakeholders. A spreadsheet was created detailing information obtained from the search. Identified prospective participants were contacted through email and telephone calls to seek their willingness to participate in this research. Some interested participants responded to this invitation.

Sources of qualitative data for this study are through semi-structured interview and open-ended survey. The open-ended survey allowed the respondents to express their thoughts and beliefs in a more profound sense. Not all participants completed this open-ended session of the questionnaire due to time constrain and other reasons such as non-disclosure agreement as cited by some participants.

Semi-structured interview

Semi-structured interview allows researchers to collect data from participants in both formal and informal ways of asking questions. Table 4.6 present types of interviews and their characteristic. Semi-structured interview allows a smooth flow of information from participants; hence it was adopted. Interview questions for this study are included as Appendix D. The formulated interview questions corresponded to set research aims and objectives. Parallel comprehensive interview questions were prepared by taking into consideration the questions asked in the quantitative strand of inquiry into cognisant. Creswell and Clark (2018) stated that “merging the two databases works best if the researcher designs the study by asking parallel questions in both the qualitative and the quantitative data collection efforts. Interview questions were subjected to expert scrutiny and feedback before the final version was administered.

As suggested by Dörnyei (2007), the first few questions posed to participants were personal, followed by content questions, probes questions and then a closing question. Interviews allow asking probing questions that are not possible in a questionnaire. Having an interview protocol was helpful to structure the course of the interview and to ensure every area was covered.

Table 4.6: Types of interviews and their characteristic adapted from Baiden (2006)

Type of interview	Main characteristics
Structured	- data collected through formal style of questioning; - little scope for probing responses; - supplementary questions required to obtain more details and pursue new aspects; - respondents choose an answer from alternatives; and - same wording and question for all interviewees;
Semi- structured	- data collected through both formal and informal styles of questioning; - responses can be written and supplemented with recording; - responses limited to subject in question but interviewee is free to add more details if the need be; - provides more details about issue being investigated; - respondents provide topical answers; and - all respondents receive the same major issues.
Unstructured	- data collected through informal style of questioning; - recording responses is most suitable; - respondents say as much as they wish after a brief introduction by the interviewer; - they can be monologues with few prompts to ensure completion of statements; - answers are provided by respondent in any order they so wish; and - brief introduction of same key issues to all respondents.

Open-ended survey

Data triangulation in qualitative research involves the use of multiple data types and sources through multiple methods and lenses, thereby strengthening and enriching the subsequent interpretation (Rothbauer, 2008). Inclusion of open-ended survey as outlined in Table 4.4 is to obtain primary empirical data relating to the effects of technologies used and also to validate the findings of interviews. Four basic questions captured in the open-ended survey are; details of the project executed, specific technology used, the impact of the technology used on the overall project and impact of technology on variation minimisation. Table 6.1 presents the findings from this survey. It was assumed that more than one technology would be utilised on a project, in reality, enough space was provided for participants to enter at least three technologies and their impact on their recently completed and ongoing project. Integration of open-ended section in the survey addresses the issues of depth and breadth in data collection. Open-ended questions are regarded as qualitative data; however, this survey was piloted alongside the quantitative instrument described in Section 4.10 to eradicate any ambiguity.

Interview recording Procedures

Digital recorder, smart mobile phone and pen drive were used in the recording and storage of interviews conducted. Recorded audio files were later imported securely on Nvivo 12 platform. The right of interviewees to withdraw at any stage of data collection was re-established during the interview process to interview participants. Participants were aware in advance of the purpose of the study and the average length of time it would take to conduct the interview. Each audio file from the interview was transcribed and reviewed within a week of data collection to maintain the integrity of data analysis process. Transcribed word documents were uploaded to Nvivo software to match corresponding audio files. This approach aided secure coding and analysis.

Data analysis and interpretation

Proceedings of the interviews were recorded, transcribed and processed using Nvivo 12 qualitative data analysis software as described. Nvivo is described as the most advanced analysis tool for qualitative research which allows a wide variety of data from social media, documents, audio, video, questionnaires to be organised and explored. Nvivo software does not analyse data for the researcher; it is a useful tool when dealing with an extensive overwhelming qualitative data. Content analysis was employed by focusing on themes examination within the data collected. Predetermined themes and new concepts emerging during the process of data familiarisation were added to the list of 'nodes'. Coding is a fundamental process in qualitative analysis; it is used to develop themes within the raw data by recognising essential moments in the data and encoding it prior to interpretation.

During data examination and analysis, some inductive sub-codes were generated to enrich findings and discussion. Transcript from interview generates vast amounts of data owing that it is text-based compared to quantitative data. Nvivo software proved to be a useful tool in dealing with the extensive overwhelming qualitative data that this research generated. Nvivo enhanced transparency, quality and credibility of the time-consuming exercise of qualitative data analysis. Saunder et al., (2007) outline six phases of creating and establishing meaningful patterns in qualitative research. These phases are:

- Familiarisation with data.
- Generating the initial codes.
- Searching for themes among codes.
- Reviewing themes.
- Defining and naming themes.
- Production of the final report.

All these phases were duly followed during data analysis and interpretation.

How reliability was ensured

Qualitative research seeks to understand phenomena of context-specific settings in a naturalistic approach. Patton (2002) stresses that validity and reliability are factors that any qualitative researcher should be worried about while designing, analysing and judging the quality of the research. Reliability is always associated with quantitative research; Lincoln and Guba (1985) argued that reliability in qualitative research corresponds with how the researcher persuades their audience that the research findings are worth paying attention to the findings. Members checking process was embedded in the data collection process to ensure reliability than returning to participants to check if transcription was correct.

Morse (2015) argues that replication determines normative patterns of behaviour; member checking can be done by presenting quotations of the previously interviewed participant to another. During the data collection process of this study, responses from participants previously interviewed were verified with other participants. As a means of establishing truth, cogent statements made by participants that relate to how variations were minimised on their projects were noted down. These statements are then presented to other participants during the interview process to establish consistency or divergence of truth. To further maintain the integrity of data collected, each audio file from interviews was transcribed and reviewed within a week of data collection.

Trustworthiness

Examination of trustworthiness is crucial to ensure reliability in qualitative research. In all methodological tools, questions of validity and quality of research are issues around testing if the data slice gives the correct portrayal of reality. Unlike quantitative data, qualitative data lacks the statistical tests (for example, t-test or chi-square) that better shield the researcher from questions of validity. This weakness makes it more complicated to defend qualitative research results. Internal validity for qualitative research focuses on the possibility of researcher bias and any distortion. External validity focuses on how a researcher can generalise findings of research to other related situations (Gaber and Gaber, 2017). Despite the complication surrounding the validity of qualitative research, Creswell (2007) recommended of engagement of at least two validation strategies in qualitative research was adhered to in this study. Data triangulation in qualitative research involves the use of multiple data types and sources through multiple methods and lenses, thereby strengthening and enriching the subsequent interpretation (Rothbauer, 2008).

Data triangulation strategy's adoption of combining both interviews and close ended survey methods of data collection strengthened this study. Transparency in research methodology procedures, as described in this chapter, is intended to enhance trustworthy outcome. Quality of research findings and transferability has also been ensured through 'thick description' of the study. Detailed robust description of how data collection was carried out and how participants were selected contributed to study validity. Triangulation is also entrenched by employing document analysis for rigorous, purposeful sampling.

Debate on validity in mixed method research

Both quantitative and qualitative data are vulnerable to challenges of validity and reliability, therefore, in mixed method research validity has been identified as the most critical aspect of a research project (Tashakkori and Teddlie, 2010). Maxwell and Mittapalli (2010) pointed out the rejection of the use of validity in mixed method research for some reasons by many scholars. Validity is taken to be strongly associated with quantitative research. Nonetheless, Creswell and Clark (2018) still believe validity is the best term to use when addressing checks associated with both strands. Debates on definition and application of validity within mixed methods research is ongoing (Collins, 2015; Heyvaert et al., 2014; Plano and Ivankova, 2016). Explicitly, Creswell and Clark (2018) defined validity in mixed methods research as "employing strategies that address potential threats to drawing correct inferences and accurate assessments from the integrated data".

Many researchers understand reliability and validity from different perspectives. Traditional meaning and association of these two terms with qualitative research have changed over time.

4.11 Framework development and validation

Key findings from qualitative findings led to the development of a framework capable of explaining the relationship between the implementation of emerging technologies and variations minimisation in construction projects. The framework is aimed to establish the empirical impact of utilising technologies to control the occurrence of extreme variations to stakeholders across the industry. Secondly, the framework is to create awareness of the influence of emerging technologies among academics and to instigate further research. The validation of the framework was carried out in two phases. In phase one, participants that took part in the semi-interviews conducted were contacted to validate the framework. A questionnaire was designed to test the usefulness of the framework on how it can increase adoption and institutionalisation of emerging technologies in the UK construction industry. The second phase of validation carried out used another questionnaire design accurately to be completed by relevant academics. The proposed framework for academics was tested on how research findings can be used to create general awareness in the classroom and encourage further research. Details and discussion of the framework are given in chapter eight.

4.12 Chapter summary

This chapter discussed the philosophical, theoretical and methodological assumptions in research and construction management field to give a sound philosophy footing for this study. Convergent mixed method design informed by assumptions of pragmatism was considered more suitable and adopted for the study. Steps and procedures undertaken in quantitative and qualitative inquiry were discussed as illustrated in the research process flowchart. Participation for the study was limited to construction practitioners and stakeholders that have implemented emerging technologies on their completed or ongoing projects.

The research proceeded with the concurrent collection of questionnaire data and semi-structured interviews with seasoned construction stakeholders and practitioners. Data was collected through multiple choice questions with multiple answers; close ended questions, open-ended questions and semi-structured interviews. The use of Nvivo 12 software and SPPS 25 were employed to analyse data. Chapter five presents data analysis, results and findings that emerged following the research methodology described in this chapter.

Chapter Five

Quantitative data analysis, results and findings

5.0 Introduction

This chapter presents quantitative data analysis of research designed questionnaire survey consisting of multiple choice with multiple answers, close-ended survey and demographic data of participants. Data analyses of three different data sets are based on data collected through 70 valid questionnaire survey. Preliminary findings of representative sample describing study's participants, statistical tests performed using IBM SPSS 25 to verify reliability, homogeneity and trends of key technologies in use in the UK construction industry are discussed. Analyses present results and findings graphically to aid visualisation and interpretations.

5.1 Demographic Information of population sample

Table 5.1 presents an overview of the instrument used to collect data and the total number of valid questionnaires (n) analysed. Participant's profile analysis in research is vital to demonstrate that the data captured from the field truly represents the targeted population and that a normal distribution had been achieved to justify generalisation of findings. Population sample for this study is limited to those stakeholders who have effectively implemented some emerging technologies in their recent construction projects. The total number of construction practitioners reached to participate in this survey could not be ascertained due to various methods employed; hence response rate is difficult to calculate.

Table 5.1: Overview data collected using mixed method design

Method	Type of instrument	Number of participants
Questionnaire survey	Multiple choice with multiple answers	70
	Close-ended questions	70
	Demographic questions	70
Data collection method		
Face to face		59
Online (Facebook and LinkedIn)		11

Participants' demographic information

Section four of the research questionnaire comprises nine questions to capture demographic information from participants. Analysis of demographic data was found useful and contributed to achieving the aim of this research. For example, one of the demographic questions asked study participants to indicate project cost range of projects they have executed with the implementation of listed technologies. The analysis shows that even in projects of less than £5 million to over £500 million, at least two or more emerging technologies were used in the execution. This result could suggest that technologies usage is valuable in minimising construction issues irrespective of project size and that implementation may not be limited to large construction projects.

Profile of survey participants

Table 5.2 shows the profile of survey participants. Construction organisation of different sizes were represented, from small firms with less than 50 employees to large ones with over 500 staff. Responses came majorly from BIM coordinators, construction clients and practitioners in design and construction community. Data analysis shows 25% (n=18) participants were female and 75% (n=53) male. This distribution reflects the state of construction workforce in terms of gender inequality. The ratio of male to female participants is 1:4. This finding is a promising ratio in a male dominated profession. The result indicates that females in the industry are gradually rising to embrace technologies in construction. Analysis from Table 5.2 gives an insight that early adopters of technologies in construction are young professionals with lesser years of construction experience who are enthusiastic about exploring innovations for their advantage and competitive advantage of their organisations.

Table 5.2: Survey participant's profile

Parameter	Category	Response count	Response percentage
Job role	Client/Sponsor	10	14%
	Architect	15	21%
	BIM Coordinator	26	36%
	Project Manager	4	6%
	Quantity Surveyors	4	6%
	Service Engineer	4	6%
	Other consultants	8	11%
	Total	71	100%
Years of experience	Below 5 years	20	28%
	6-10 years	22	31%
	11-20 years	12	17%
	21-30 years	11	15%
	31-40 years	4	6%
	Over 40 years	2	3%
	Total	71	100%
Gender	Male	53	75%
	Female	18	25%
	Total		100%

Types of projects

The demographic section collected data of the project type undertaken by participants. Survey shows that the use of emerging technologies cuts across a wide range of projects such as education, health, leisure, office, industrial, mixed use and residential, among others. However, only a small percentage of 2.9% indicated they had implemented emerging technologies on privately funded projects. The reason for this might be due to the cost of implementation or lack of awareness among private clients.

There is need to create awareness and benefits of utilising emerging technologies in construction among private clients to drive adoption. Public and commercial projects are more likely to utilise emerging technologies, due to BIM mandate on public funded projects. There is increased utilisation of technologies among large construction organisations; this increase is driven by benefits of cost efficiencies and speed of delivery. There is a general notion that emerging technologies benefit large and complex construction projects only; this notion is not well substantiated by the result of this study.

5.2 Test of Reliability- Cronbach’s alpha (α) test

Cronbach's alpha test conducted to test the internal consistency reliability of quantitative data collected. Good quantitative research provides evidence of how reliability is addressed. Cronbach's alpha test is commonly used to determine if the scale used in multiple Likert questions in a questionnaire is reliable and to test the response score given by survey participants. The result is given in numbers between 0 and 1. An acceptable Cronbach’s reliability score is one that is 0.5 and higher, as indicated in Table 5.3. Result of analysis shows Cronbach’s alpha (α) of 0.945, which indicates an excellent level of internal consistency according to Cronbach and Shavelson’s (2004) interpretation table as illustrated below.

Table 5.3: Result of Cronbach’s test performed

Reliability Statistics

Cronbach’s Alpha	Cronbach’s Alpha Based on Standardised Items	N of Items
.945	.947	26

Cronbach's alpha	**Internal consistency**
α ≥ 0.9	Excellent (High-Stakes testing)
0.8 ≤ α < 0.9	Good (Low-Stakes testing)
0.7 ≤ α < 0.8	Acceptable (Surveys)
0.6 ≤ α < 0.7	Questionable
0.5 ≤ α < 0.6	Poor
α < 0.5	Unacceptable

Figure 4.6: How results of Cronbach's alpha test is scored

5.3 Test of homogeneity- Mann-Whitney U test

Mann-Whitney U nonparametric test is to determine if there are differences between data obtained through questionnaires completed online via LinkedIn/Facebook and those completed face to face. Mann-Whitney U test is equivalent to the independent t-test and was run with the aid of SPSS-25. Mann-Whitney U test was performed to compare the difference between two independent groups. The high response rate of one over the other necessitates the Mann Whitney U test to be performed before integrating the two databases. The total number of questionnaires completed online were 11, with 59 completed face to face. Despite joining 32 construction groups on LinkedIn and 24 on Facebook response rate was low compared to face to face questionnaire completion.

Table 5.4: Descriptive Statistics of Mann-Whitney U test

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25^{th}	50^{th} (Median)	75^{th}
FF	57	59.4856	14.31251	26.67	98.67	50.0000	59.3300	68.3350
online	57	62.7119	7.59285	30.67	94.67	62.7200	62.7200	62.7200

Ranks

		N	Mean Rank	Sum of Ranks
online - FF	Negative Ranks	22[a]	28.66	630.50
	Positive Ranks	35[b]	29.21	1022.50
	Ties	0[c]		
	Total	57		

a. online < FF

b. online > FF

c. online = FF

Test Statistics[a]

	online - FF
Z	-1.557[b]
Asymp. Sig. (2-tailed)	.119

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

The difference between online and face to face is Z = -1.557, Asymptotic sig. (2-tailed = 0.119). Tables 5.4a, b and c illustrate findings from the Mann-Whitney test. The result shows that p-value is 0.119. This result indicates that there is no significant difference between the 2 sets of data obtained face to face and online because the p-value is less than 0.5. To determine whether there was any significant difference between dataset collected, the result with the highest mean rank is more significant. Comparing the mean ranks of online and face to face results of 28.66 and 29.21, respectively, a mere inspection of these values shows there is no significant difference. The analysis shows that there is no significant difference between both tests conducted. Therefore, the two data sets were merged as one for further analyses.

Descriptive Statistics analysis

Table 5.5 shows descriptive statistics result of raw data scores of 30 questions in close ended survey. Descriptive statistics analysis conducted was done to describe the basic attributes of close ended data. Descriptive statistics test of variables performed includes the mean, range, sum, variance and standard deviation of data collected. The statistics analysis result gave the average mean score of 3.34, the standard deviation of 0.96 and a variance of 0.92. Standard deviation value indicates that participant's level of consensus of each variable ranking. Values that are less than a one-unit number is a better indication of high consensus rating of variables among survey participants.

Standard deviation figures are small when compared to each mean score; this means that the behaviour of the data is consistent. The analysis gave a result of average standard deviation value as 0.96; this suggested a reliable degree of consensus among participants. Yuan et al., (2011) adopted a score of 3.00., as a benchmark mean that is a significant variable, a mean score of 3.34 of this study reflects significant variables. The range analysis values from the analysis are high; this denotes that most participants agreed in response to questions asked.

Table 5.5: Descriptive Statistics analysis result

No. of Question	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Sum Statistic	Mean Statistic	Mean Std. Error	Std. Deviation Statistic	Variance Statistic
Q1	67	5.00	.00	5.00	208.00	3.1045	.12784	1.04641	1.095
Q2	69	4.00	1.00	5.00	247.00	3.5797	.12110	1.00595	1.012
Q3	68	5.00	.00	5.00	270.00	3.9706	.11847	.97691	.954
Q4	66	3.00	2.00	5.00	260.00	3.9394	.10984	.89234	.796
Q5	64	5.00	.00	5.00	185.00	2.8906	.13750	1.10003	1.210
Q6	65	5.00	.00	5.00	206.00	3.1692	.12123	.97739	.955
Q8	68	5.00	.00	5.00	242.00	3.5588	.12105	.99824	.996
Q9	67	4.00	1.00	5.00	232.00	3.4627	.12092	.98977	.980
Q10	67	3.00	2.00	5.00	240.00	3.5821	.10451	.85545	.732
Q11	65	4.00	1.00	5.00	191.00	2.9385	.12380	.99808	.996
Q12	69	4.00	1.00	5.00	252.00	3.6522	.10693	.88826	.789
Q13	66	3.00	2.00	5.00	221.00	3.3485	.10010	.81321	.661
Q14	63	5.00	.00	5.00	189.00	3.0000	.13764	1.09250	1.194
Q15	68	5.00	.00	5.00	235.00	3.4559	.12115	.99901	.998
Q17	63	4.00	1.00	5.00	211.00	3.3492	.10889	.86432	.747
Q18	63	3.00	2.00	5.00	210.00	3.3333	.12186	.96720	.935
Q19	48	4.00	1.00	5.00	144.00	3.0000	.14279	.98930	.979
Q20	63	4.00	1.00	5.00	208.00	3.3016	.11678	.92693	.859
Q22	53	4.00	1.00	5.00	132.00	2.4906	.13367	.97315	.947
Q24	69	2.00	3.00	5.00	293.00	4.2464	.10200	.84724	.718
Q25	63	3.00	2.00	5.00	217.00	3.4444	.11489	.91189	.832
Q26	63	3.00	2.00	5.00	211.00	3.3492	.11122	.88279	.779
Q27	68	3.00	2.00	5.00	235.00	3.4559	.09924	.81833	.670
Q28	61	4.00	1.00	5.00	212.00	3.4754	.13752	1.07404	1.154
Q29	50	5.00	.00	5.00	122.00	2.4400	.15429	1.09096	1.190
Q30	55	3.00	2.00	5.00	185.00	3.3636	.11710	.86845	.754
Valid N (listwise)	30								
Mean						3.3424		0.9557	0.92046

5.4 RII analysis- Trends in technologies in the UK construction industry

Relative Importance Index (RII) analysis carried out to rank major emerging technologies currently in use in the UK. The analysis was done based on data collected from multiple choice with multiple answers section of the questionnaire survey (Part A). The RII value had a range of 0 to 1, the higher the RII value, the more the usage. The result of the RII analysis performed is given in Table 5.6. The use of BIM ranked first with 0.63 RII value. The use of BIM is significant in minimising undesirable variation in construction projects by increasing coordination of designs and other construction documents. BIM produce digital design information that enables designers, clients, contractor and engineers to view, analyse and understand the unbuilt structures. Ability to visualise the proposed design in BIM eliminates ambiguities in contract documents which ultimately minimise variation when actual site construction begins. RII was calculated using this equation:

$$RII = \frac{\sum W}{A \times N}$$

Where:

W is the weight given to each factor by respondents (from 1 to 5)

A is the highest weight (i.e. always 5) and

N is the number of responses.

Table 5.6 Relative Importance Index of technologies application

Emerging Technologies	RII	Rank	N
Building Information Modelling (BIM)	0.63	1	70
Mobile application software on phones/tablets	0.47	2	70
BIM (3D)	0.47	2	70
Cloud computing	0.43	3	70
Digital collaboration platform	0.42	4	70
BIM (2D)	0.36	5	70
3D scanning	0.35	6	70
Prefabrication, Preassembly, and Modularisation	0.35	6	70
Project management application	0.32	7	70
Virtual Reality (VR)	0.31	8	70
Spatial measurement	0.23	9	70
3D printing	0.22	10	70
Drones	0.22	11	70
BIM (4D)	0.20	12	70
High Performance Concrete	0.19	13	70
Innovative Timber	0.17	14	70
Tracking and Geolocation technologies	0.17	15	70
Augmented Reality (AR)	0.17	16	70
3D mapping	0.14	17	70
Mixed Reality (MR)	0.13	18	70
Ethylene Tetra Fluoro Ethylene (ETFE)	0.12	19	70
Sensors and Internet of Things (IoT)	0.10	20	70
Big data	0.08	21	70
Robotics	0.08	22	70
Advance analytics	0.07	23	70
BIM (5D)	0.07	24	70
Autonomous vehicles	0.05	25	70
Construction wearables	0.04	26	70
Artificial Intelligence (AI)	0.04	27	70
BIM (6D)	0.03	28	70
High Performance Steel	0.01	29	70

Level of technology usage

For a better and more in-depth understanding of BIM usage in the UK construction industry, participants were asked to tick specific BIM dimensions they have used. The use of 3D BIM and hand-held mobile devises like smartphones and tablets on site ranked joint second. 3D BIM approach is unique in that it helps to connect the data chain from start to finish of the construction process, thereby creating an end to end efficiencies. Unlike 2D BIM with no integration to project data which also removes contractors and suppliers from full collaboration, 3D BIM implementation offers complete and total collaboration in planning, construction and operational life cycle of any built asset. There is a single source of data sharing, collection and storage; with immense benefit to variation minimisation.

The use of software and mobile applications is gaining traction in managing every aspect of a construction project. Benefits associated with the use of apps and variation minimisation is linked to swift information sharing, real time collaboration and better client satisfaction and relationship. Construction activities such as scheduling, data collection and data transmission between site workers and project managers in the back office are done seamlessly. Sharing project expense record, work records, and other verified documentation is carried out in real time.

Cloud computing ranked third technology in use with 0.43 value according to findings from this study. The ability to leverage the cloud quickly, inexpensively and easily by construction stakeholders to manage their project end-to-end justifies the implementation of cloud computing. Perera et al., (2019) argued that variation-specific disputes are inevitable in construction, implementing digital collaboration platform such as CDE, for example, plays a role in minimising such dispute. CDE is a central, single repository that houses all construction project information. Collaboration among remote and geographically dispersed project teams is no longer a challenge in the construction industry if digital collaboration platform is adopted. Low RII value result of technologies such as AI, Advance analytics, robotics and construction wearables may be as a result of their limited use to top large construction firms on complex projects.

Trends in technologies usage

As shown in Table 5.7, out of 32 technologies and materials listed; a substantial percentage of 52.86% are using ten or more. To further explore the level of adoption of emerging technologies listed in Table 1.1, participants were asked to tick all technologies they have used in their current or ongoing construction projects. Though the construction industry in the UK has a reputation for being slow to change, findings from this study point to an industry very much in a transition to an innovative future. A small percentage of 1.43% (1 organisation) reported the use of cloud computing as the only technology in use in managing their project. Result of findings suggests that construction companies in the UK are waking up to the fact that they need to stay up to date with the latest trend in technologies if they want to remain competitive in the market. This finding suggests that the role of emerging technologies is important in addressing current challenges in the industry, hence the implementation.

Table 5.7: Number of emerging technologies used by Participants (n=70)

Number of technologies used	% of participants	Number (n) of participants
1	3.13	1
2	6.25	2
3	9.38	8
4	12.50	5
5	15.63	2
6	18.75	6
7	21.88	7
8	25.00	8
9	28.13	6
10+	31.25	37

5.5 Trend in technologies usage

Usage by participants

Analysis of usage by participants presented in Figure 5.1 revealed far more profound insight into trends of different technologies used per participant. The analysis revealed the number of participants that have used specific technology. Out of 70 participants, 63 participants implemented BIM. The result of this analysis suggests that emerging technologies used in practice are intimately interconnected. When BIM, for example, is implemented on a project, other technologies are more likely to be adopted and implemented alongside.

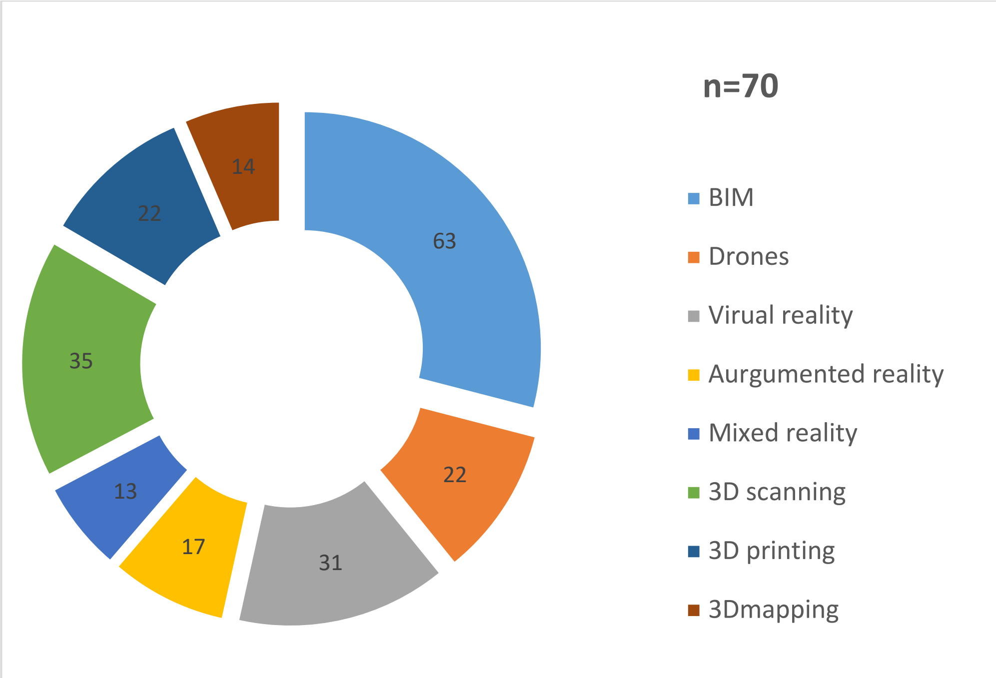

Figure 5.1: Usage of technologies by participants

Usage by categories

Emerging technologies in construction are grouped under three distinctive categories, as illustrated in Table 1.1 in chapter one of this study. Figure 5.2 presents results and findings of usage based on these categories. Technology is fundamentally changing the UK construction sector. Implementation benefits are huge, potentially more than the anticipated impact on efficiency of the industry. Adoption is empowering practitioners in the industry to think more critically and creatively by freeing up time along the construction process.

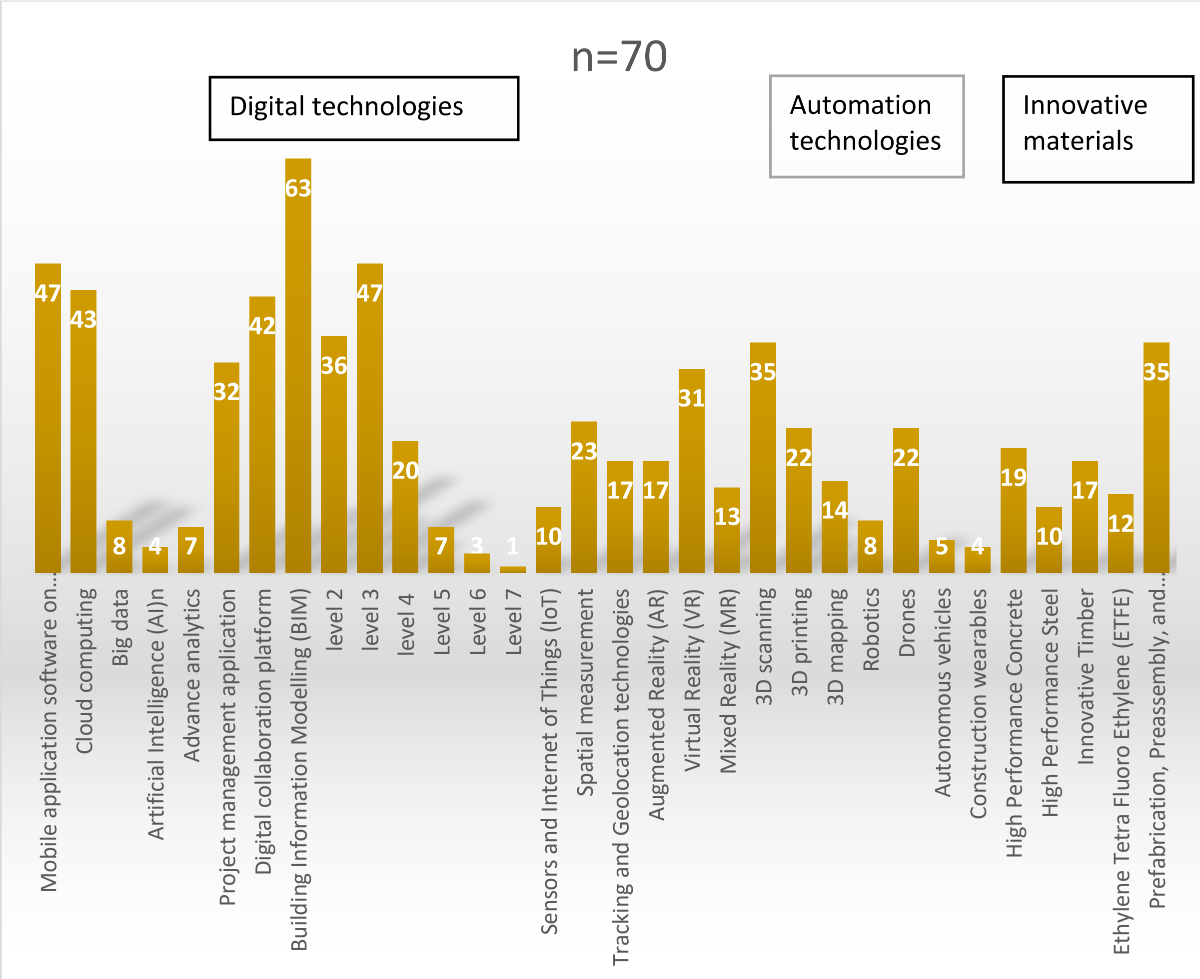

Figure 5.2: Usage of technologies by category

Result based on categories

Digital technologies

By mere inspection of Figure 5.2, digital technologies are taking the lead among the three categories. The use of BIM and mobile applications on smartphones are the most widely adopted technologies currently among construction practitioners nationwide. Digital technologies offer project managers, contractors and clients the opportunity to monitor work progress from the comfort of their office without needing to travel to remote, distant construction sites. Digital technologies are also beneficial to workers onsite for ease of operation. Smartphones are useful for sharing work progress, send digital pictures for inspection and monitor schedule of work. Krajacic (2017) described the establishment of smartphones usage as a mainstream product on Crossrail construction site in London. Another example of digital technology usage outside design and pre-construction planning is the use of BIM kiosks on construction sites.

BIM kiosks give opportunities to site workers to visualise 3D models in handling complex elements of designs efficiently. The use of digital technologies onsite enhances the level of face to face collaboration among site workers. Issues onsite can be clarified, and decisions are taken without delay to work progress. Efficiency and collaboration among workers on site are useful for avoidance of variations and rework. With less IT-literate workers preferring highly sophisticated virtual 3D models over paper drawings onsite (Merschbrock and Rolfsen, 2016) there is a thriving market for the increasing proliferation of related construction software and hardware.

The use of technology, such as VR is capable of minimising clients' variations due to its ability to enable clients to interact with the unbuilt structure. VR allows construction stakeholders better to understand design in 3D environment through a special headset. Integrating digital technologies in construction projects planning process aids consultants to produce quality contract documents with potentials to eliminate variation in post-contract stage. 3D models better depict designs; in reality, changes made to models can be made and communicated in real time to the project team. Although the use of technologies such as Big data, artificial intelligence and advance analytic recorded comparatively low percentages of 11%, 6% and 10% respectively, findings point to a gradually digitalised future for the industry.

Automation technologies

Application of automation technologies in construction is next to digital technologies in usage according to Figure 5.1. The result shows the possibility of 3D laser scanning soon becoming a mainstream tool in the construction industry. The growing interest in 3D scanning may be due to the ability to capture data accurately at scan time of three minutes in one million points per second. The use enables valuable data to be captured for design, thereby eliminating error and guesswork by the design team, a significant step in variation minimisation. 3D scanning is useful for detailed MEP works where a high level of accuracy is required. Application of 3D scanning is common in complex and retrofitting activities.

From the analysis in Figure 5.2, the use of drones in construction is growing significantly. In November 2019, drone’s usage was legalised in the UK by putting drone regulations in place. Users are required to register and pass a theory test. The trend in the use of drones could be that designers and contractors are finding it as a cheaper alternative for transportation and inspection. From new construction to retrofitting old buildings, good quality images captured by drones can reduce human hours, errors and risk in construction significantly. Dangerous site survey, aerial transportation of goods and real time monitoring of the construction site, construction site safety, security and workers safety are all benefits of implementing drones in construction. Drones can track work progress onsite and identify issues early before they lead to variations or delay work schedules.

Applications of construction robots, which includes robotic diggers and cranes on construction sites, is thriving in the UK. Balfour Beatty, a leading construction firm in the UK, predicts that construction sites could be human-free by 2050. Construction robot's usage is still in the development stage across the UK. They are very costly to acquire and may be limited to large construction firms. Future accessibility and affordability to SMEs will lower costs of production, address the current shortage of labour and speed up project delivery. Construction robots offer a higher degree of accuracy, elimination of waste and avoidance of human error. These benefits potentially prevent variations.

Innovative materials

Application of prefabrications and modular construction in the UK is increasing. Results put the use of 3D scanning, 2D BIM and prefabrication/innovative materials on the same pedestal. The reason is not far-fetched; BIM enables integration of architecture and engineering workflows that embrace prefabrication. The construction industry is witnessing the use of prefabrication materials other than commonly used stairs, wall panels, doors, walls, floor panels, roof trusses, windows. Innovative room-sized units, pre-engineered building units, structural façade building envelop, bathroom pods and many other advanced construction materials are introduced now along the construction process. The impact of usage on variation minimisation is enormous, ranging from ease of construction, improved high quality and reduction of overall construction cost.

The anticipated disruptive impact of emerging technologies in construction impacts more on cost, safety on site and efficiency if complemented with innovative materials. Radically innovative materials have an extremely powerful lever for innovation. Many innovative materials offer the construction industry entirely new capabilities (The Boston Consulting Group, 2016). Construction projects are conceptualised generally by the materials used. Traditional construction materials such as bricks, mortar, concrete and steel require improvement to make them safe, cheap, lightweight, sustainable and environmentally friendly. Development and use of alternative and innovative materials in construction reduce construction time and cost.

To minimise variation from a holistic viewpoint, based on the large volume of construction materials needed to execute a project successfully, slight improvements made to increase the performance of a material can have a tremendous impact on initial cost, life-cycle cost, safety, durability and the environment. The use of innovative materials is capable of minimising the impact of non-human causes of variation, such as inclement weather.

5.6 Analysis, results and findings of close-ended survey

This section reports data analysis, results and findings of close-ended survey (n=70) in accordance to set research objectives. Raw primary data collected using the researcher-designed questionnaire was examined and treated for voids. Duly completed questionnaires were prepared and inputted into Excel spreadsheet for statistical analysis. Leveraging on powerful functions of Microsoft Excel software for data analysis; graphically easy to understand presentation formats were generated based on results of responses from study participants.

Responses from thirty questions contained in the close-ended survey were grouped and analysed together under interrelated research objectives. Under each research objective, results of data analysis were presented visually firstly by figure displaying actual responses from participants, and secondly by summarised more exact figures that grouped participants' positive Likert scale responses as discussed in Table 4.4. Systematic description of relevant and significant findings are discussed to meeting research objectives. Appendix F1 gave details of data analysis that produced figures used in this section.

Objective 1: To investigate the impact of emerging technologies in minimising designs errors

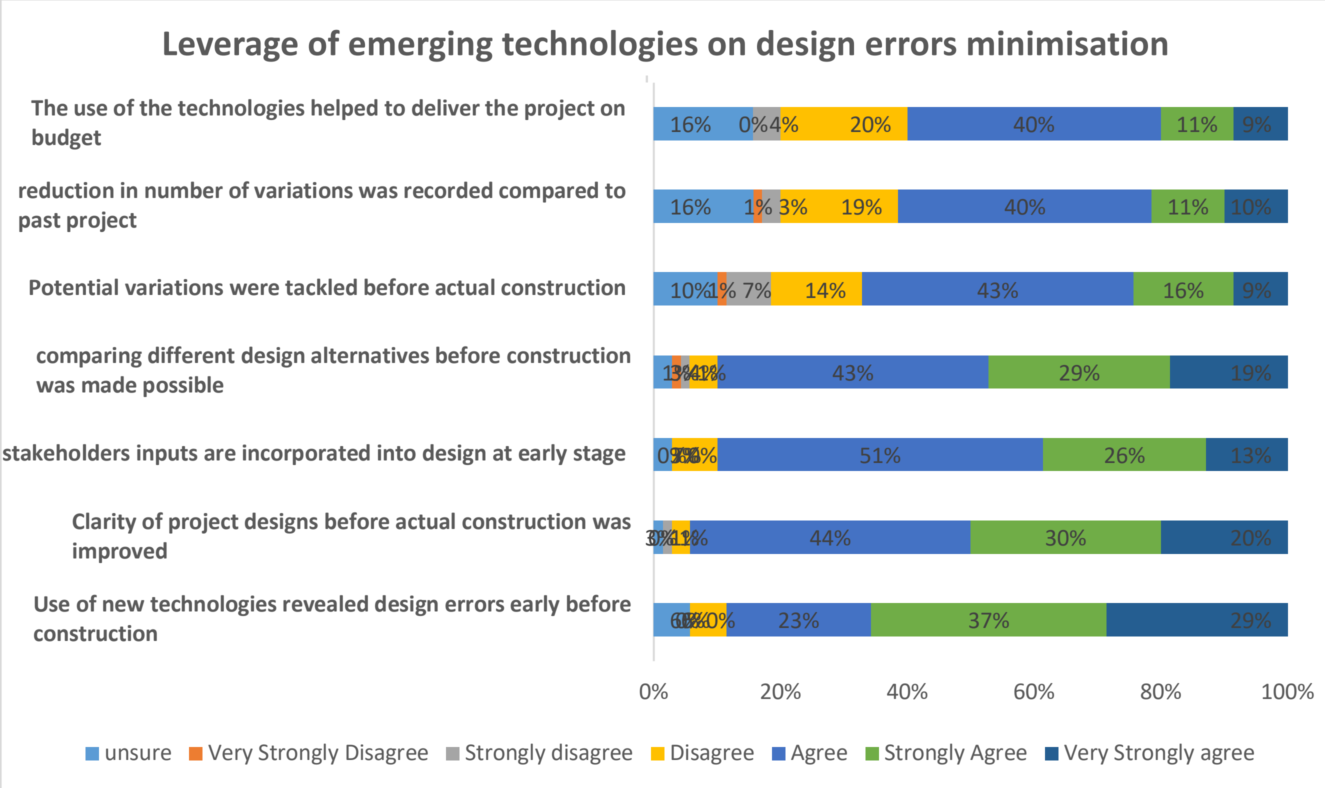

Figure 5.3a: Leverage of emerging technologies on design errors minimisation (n=70, survey questions 4, 12, 27, 8, 14, 16 and 23)

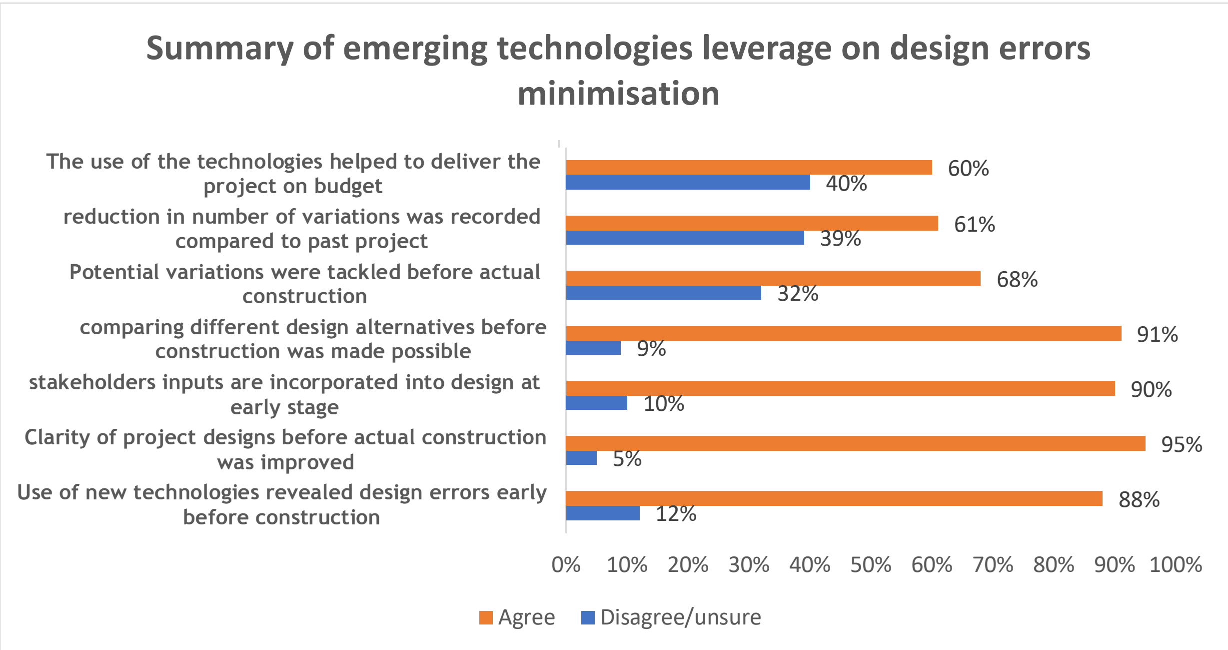

Figure 5.3b: Summary of impact technologies used by participants on design errors

Figure 5.3a in conjunction with Figure 5.3b illustrates 88%, 95% and 68% of study participants agreed that the use of emerging technologies on their projects exposed design errors before construction, enhanced clarity of design before actual construction and that potential variations were tackled before construction respectively. Study results are not surprising as emerging technologies are proving to be indispensable in construction. The most direct question to measure Objective 1 of this study is question number four of the survey, which received 88% agreement, with 12% of participants disagreeing or are unsure. Considering that both the technologies and expertise available presently to implement many of these technologies correctly are relatively new to construction, this result is very significant.

Findings revealed that 96% of participants agreed that the combined use of emerging technologies helped clients to understand design better. The use of BIM allows clients to visualise the entire projects in 3D. When BIM is used in combination with VR; construction clients can interact and understand the unbuilt structure better, thereby offering clients' ability to make changes before construction starts. This finding suggests that the use of 2D drawings contributes to an increasing number of variations because many construction clients find it difficult to read and interpret 2D drawings. Although only about 68% agreed that potential variations were tackled before construction, this percentage is still significant. Potential variations that are not tackled by technologies can be attributed to unforeseen ground conditions which are inevitable in construction. Furthermore, Latham (1994) sees the reality of commercial schemes as a dictate of design by construction clients who in turn are responding to external pressures. An error-free design may not prevent client variation at the construction phase.

On the contrary, despite almost all participants (95%) agreeing that clarity of project designs before actual construction was achieved by utilising emerging technologies, 40% of study participants indicated their projects were not delivered on budget. This finding suggests that while reductions in design errors may have a direct correlation to variations minimisation in the construction project, production of perfect designs may not guarantee delivery on budget. Compared to projects managed traditionally, findings signalled that the number of variations encountered on construction projects was minimised considerably with emerging technologies.

Objective 2: To ascertain the role of emerging technologies in enhancing client's satisfaction

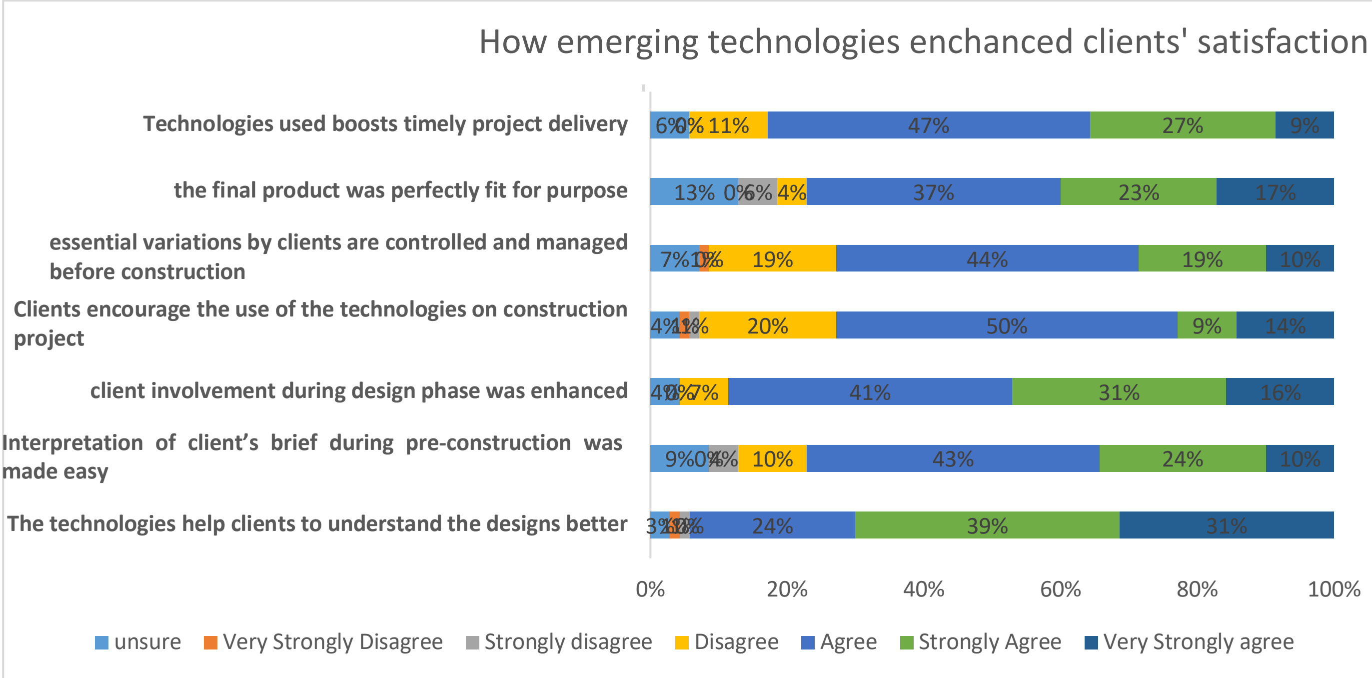

Figure 5.4a: How emerging technologies enhanced clients' satisfaction on construction projects (n=70, questionnaire questions 1, 6, 28, 13, 3, 7, and 10)

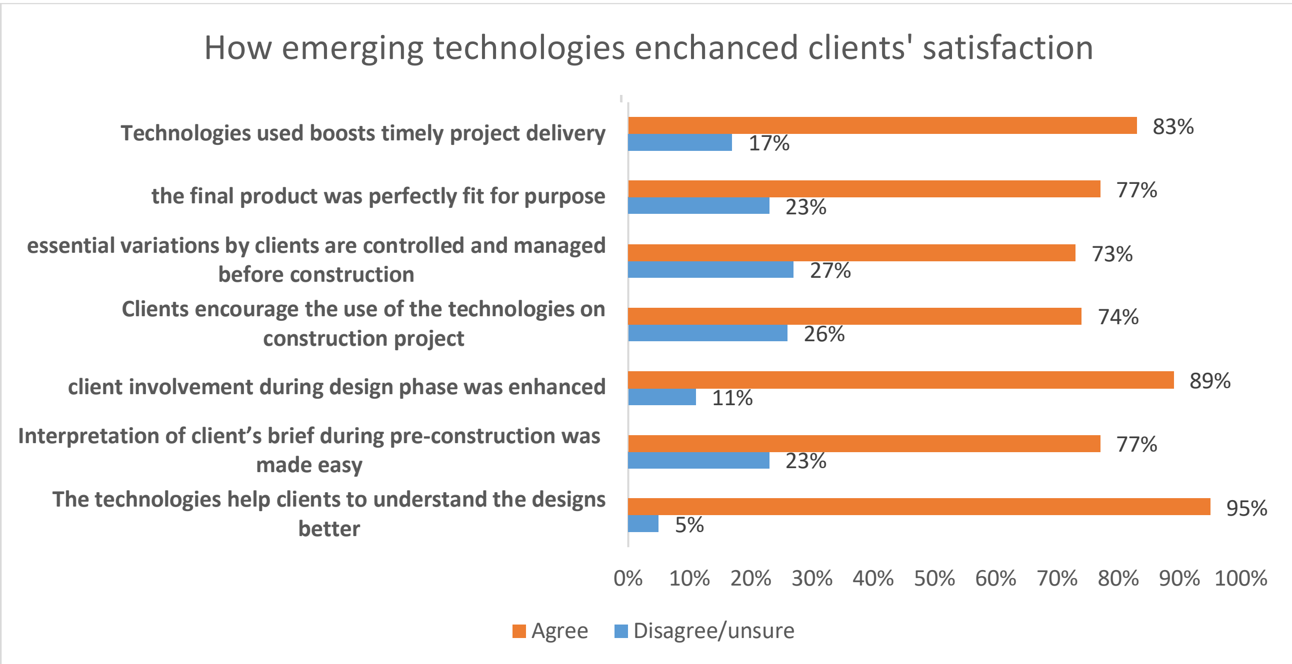

Figure 5.4b: Summary of impact technologies used by participants on clients' satisfaction

Figures 5.4a and Figure 5.4b present result of findings in relation to objective 2. An outstanding 95% result revealed from findings closely associated with the impact of emerging technologies in the enhancement of clients' satisfaction. Clients' understanding of project designs is central to variation minimisation and successful delivery of construction projects. A better understanding of designs by clients can be associated with clients' early involvement in design. Straightforward interpretations of clients' brief by designers scored 77%. Accurate visualisation of designs is made possible by 3D models which allow clients to examine how buildings align with their business goals. The use of many emerging technologies intuitively integrates clients early in the construction process. Enforcement of BIM level 2 on centrally procure construction projects is encouraging public clients to demand the use of BIM on their projects.

An impressive 77% of study participants were in agreement that the final product of their construction process was perfectly fit for purpose. It can be deduced that utilising useful technologies in construction delivers quality assurance to any design and construction project. Prefabrication, preassembly and modularisation units are useful in enhancement of building quality and aesthetic. Findings in relation to impacts of technologies in timely delivery of construction projects stand out at 83% in this research. Overall, the findings highlight that technologies are crucial to project success and achieving project key performance indicators.

The iron triangle concept (project delivery on time, under budget and according to specification) is highly criticised as being inadequate in modern project management. The concept is still accepted as being critical to the successful delivery of construction projects. Findings of this research also established a correlation between clients' satisfaction and technologies implementation. The central concept of BIM is to virtually build the project so that every phase can be planned out before going to site. Clients can make changes to designs, specification of materials and orientation of proposed buildings before construction. Design revisions are easier and quicker to produce.

Objective 3: To examine the impact of emerging technologies on contractors' performance on site

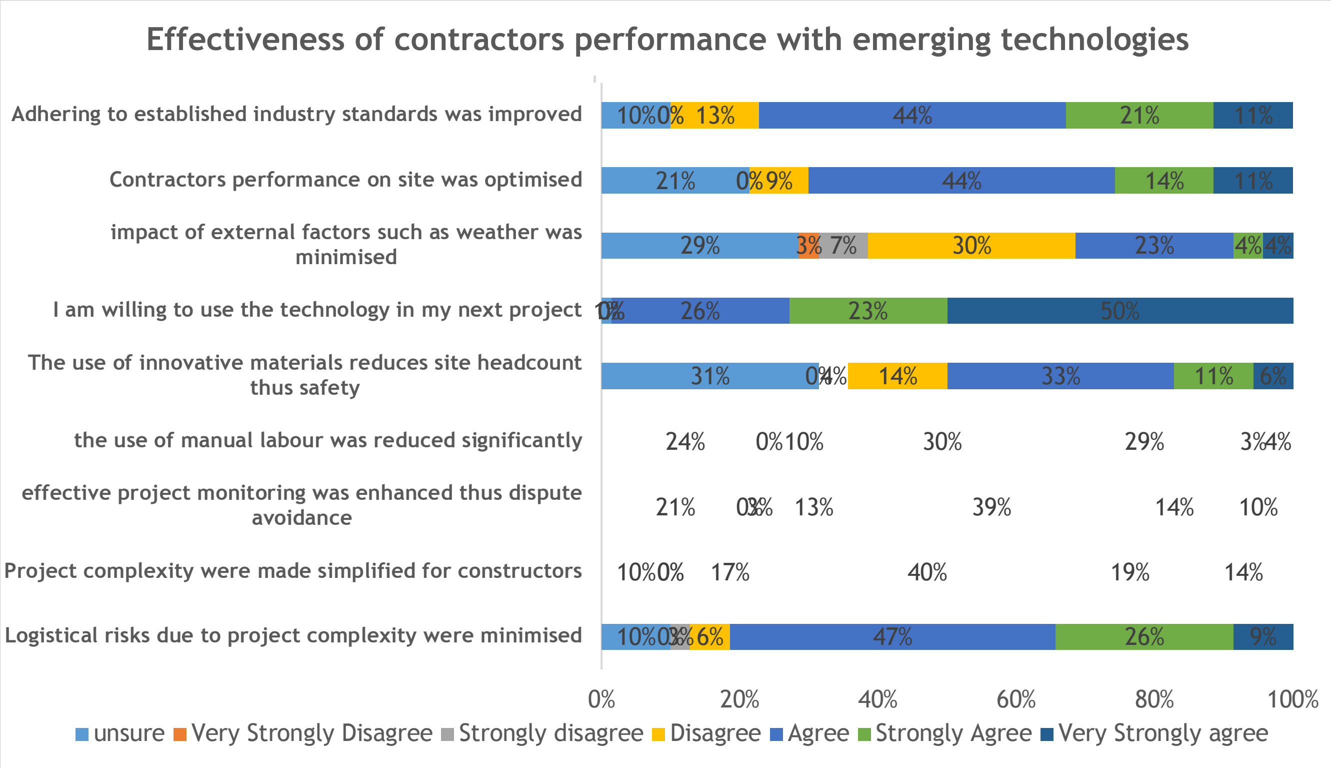

Figure 5.6a: How emerging technologies improved contractor's performance on site (n=70, questionnaire questions 17, 18, 21, 22, 19, 24, 30, 29 and 26)

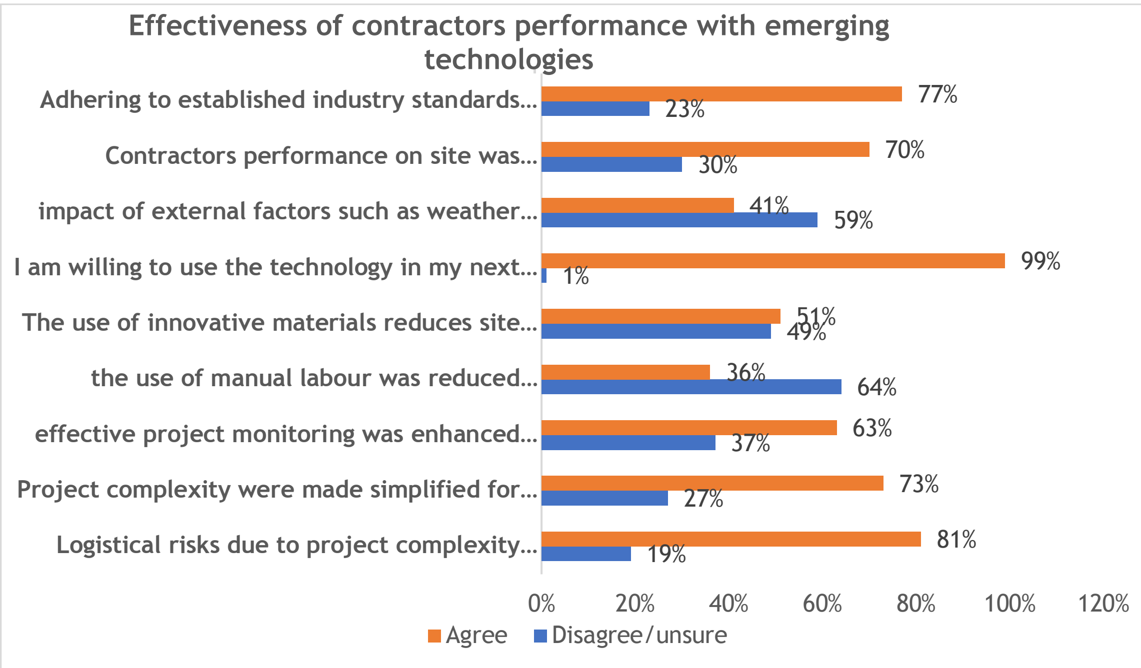

Figure 5.6b: Summary of impact technologies used by participants on contractor performance on site

Figures 5.6a and 5.6b present results of findings which measured the effectiveness of contractor's performance by utilising emerging technologies in managing construction processes and operation. Reduction of risks onsite due to project complexity scored 81% from the analysis. This finding implies contractors were able to anticipate and solve problems on virtual environment through better coordination and collaboration rather than onsite. The use of drones to capture and assess the construction site at any stage of construction in real time is a promising, faster and efficient new way of managing construction for contractors.

BIM enables contractors to receive full data-rich models that help them to minimise risks. Another significant finding is 77% impact of technologies on contractors being able to adhere to industry standards. The term 'standard' refers to published documents that define specifications, methods and procedures to ensure quality, compatibility and compliance. These approved national standards are rooted in BIM, which enhanced the contractor's ability to meet legislative and environmental requirements.

In contrast, 49% of study participants disagree or are unsure that the use of innovative materials has reduced the number of workers required; hence, safety level has not improved significantly onsite. This finding could suggest that research on alternative materials to concrete and other construction materials has not been as aggressive and intense as it should be. It was revealed from findings also that the use of technologies has not reduced dependence on manual labour and impacts of inclement weather. These findings suggest that variation elimination may be an impossible aspiration in construction. Despite this setback from findings, 70% agreed technologies boosted the contractor's performance on site.

Technology like IoT creates huge opportunities for contractors to collect and manage site data on performance, safety, materials for work and operational workflow more effectively. Artificial intelligence in construction is useful for contractors in analysing multiples streams of data from integrated digital workflow to resolve issues onsite speedily. The use of AI is limited in practice to leading construction firms. Effective performance of contractors in carrying out works diligently prevent rework, dispute and delay, which often leads to variations. Overwhelmingly, 99% of participants are willing to continue utilising technologies they have tried. This result is a step forward from adoption to the institutionalisation of new technologies in the construction industry. Research findings challenge the status quo that construction industry is lagging in taking advantage of new technologies.

Objective 4: To assess the impact of emerging technologies on project team fragmentation.

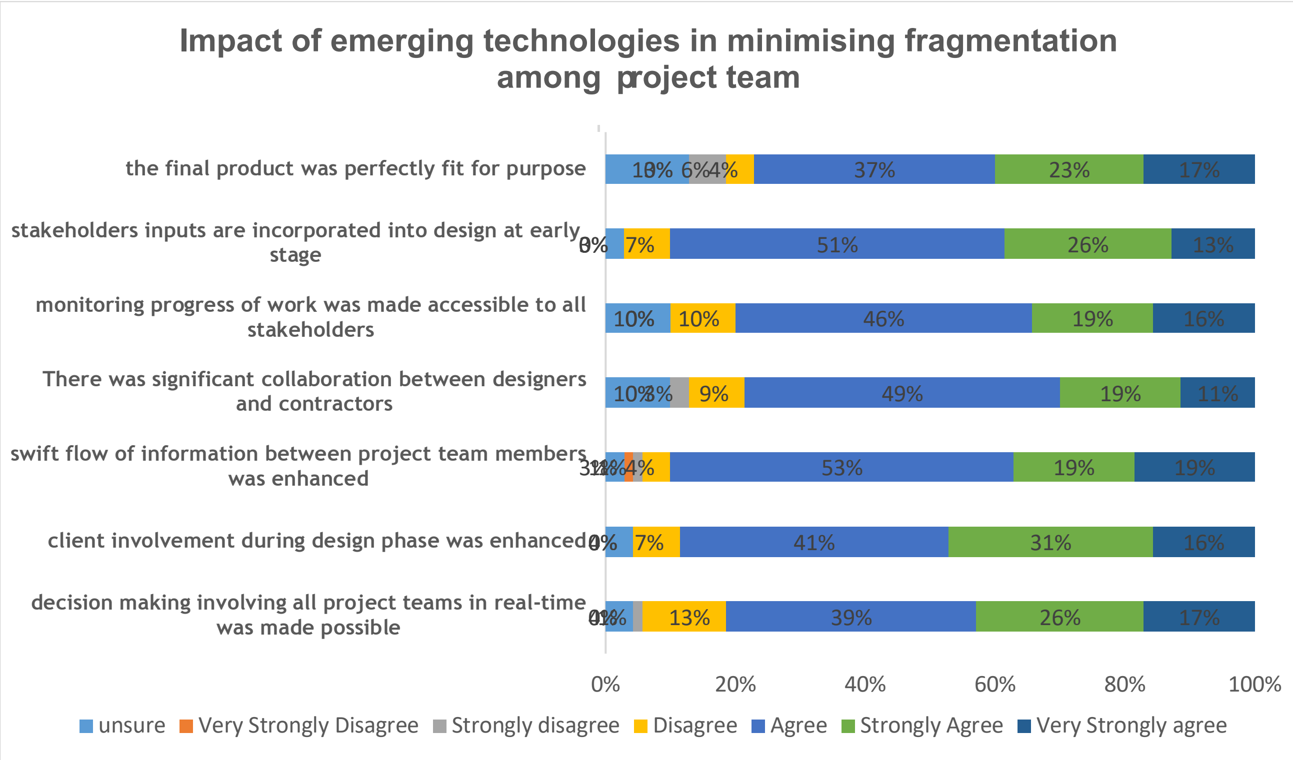

Figure 5.7a: Leverage of emerging technologies on design errors minimisation (n=70, questionnaire questions 4, 12, 27, 8, 14, 16 and 23)

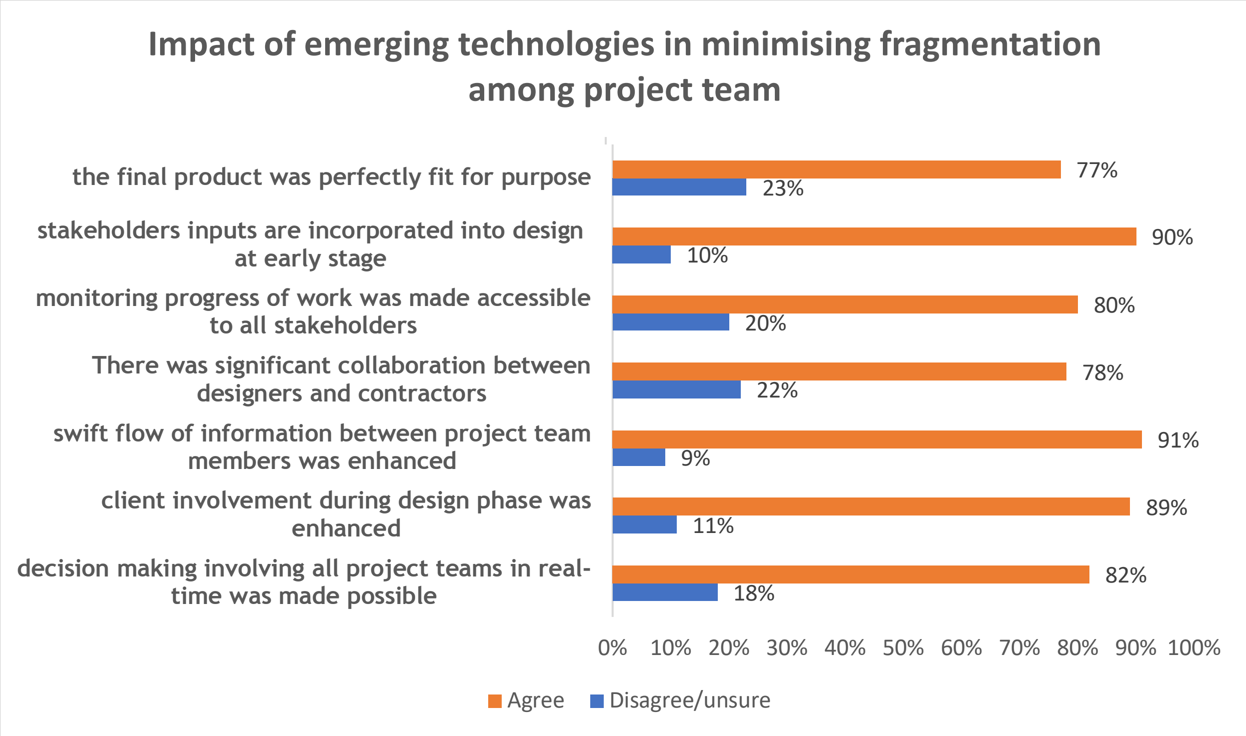

Figure 5.7b: Summary of impact technologies used by participants on fragmentation among project team

Figures 5.7a and 5.7b depict the capacity of technologies in minimising fragmentation among project teams and the potential to eradicate fragmentation in the building process over time. Findings show that 91% of participants agreed that technologies used enhanced swift flow of information among the project team. This finding concurs with the result of RII in Table 5.2, which places mobile application software on devices as the second most widely used technologies in construction. Mobile devices, construction apps and cloud computing allow site workers to share and access important project information onsite with their office staff. Issues arising onsite are resolved on time without leading to variations.

VR enables clients to interact with and better understand design in 3D environment through a special headset. Cloud computing facilitates information sharing and collaboration across project teams within a central repository. This technology enables swift sharing of information and a seamless decision-making process. Stakeholder inputs are often neglected or incorporated later in the traditional approach to construction; this generates variations in the later project phase. Findings demonstrate that 90% of stakeholders' inputs are incorporated early into designs, and 77% agreed that technologies made their final structure produced perfectly fit for purpose.

Use of technologies in construction brings clients, designers and contractors early together to achieve common goals through mutual understanding and agreement that is beneficial to all. From findings, all questions relating to fragmentation minimisation received the significant result of over 77% according to Figure 5.7a. The overall impact of emerging technologies on construction activities is more pronounced on its collaborative influence on construction project teams. The findings of this research demonstrated that combinations of effects of technologies minimise fragmentation and encourage collaborative working as defined by Constructing Excellence (2011).

5.7 Chapter summary

This chapter presented how quantitative data was tested and processed. Cronbach's alpha (α), statistical analysis performed to verify the reliability of data from research survey was excellent. From the study descriptive analysis result, essential attributes of data were within an acceptable range. Profiles of survey participants revealed good sample representativeness of major stakeholders in the construction industry. Practitioners with 0-10 years' experience in the construction industry were found to be front runners of adoption and implementation of emerging technologies in practice. This chapter also examined prominent technologies that are in use in the UK construction industry. The direct and indirect impact of these technologies on variation was discussed. Findings show that BIM is leading the path to modernisation in the industry. The use of BIM, in combination with other technologies, is striving together in the journey to a very digital revolution in the UK construction industry.

Chapter Six

Qualitative Data Analysis, results and findings

6.0 Introduction

This chapter presents qualitative data analysis, results and findings of research open-ended survey and 32 semi-structured interviews. The focus of interviews conducted is to discover how implementations of emerging technologies minimise variations. Based on findings on empirical data obtained from constructions clients and practitioners that have utilised technologies on their projects. The construction industry has been criticised as a slow adopter of new technologies, techniques and materials to streamline its processes, cost and time. The UK government is determined to transform the industry trend of iterate cost overruns, late delivery and contractual dispute that symbolises the industry. There is an increasing number of projects that have been executed successfully by utilising various emerging technologies. The modern approach to construction delivery calls for in-depth investigation through exploratory interviews. The chapter concludes with challenges and barriers of hampering full benefits of technologies based on participants' experience.

6.1 Participants' profile and sample representativeness

Targeted UK based construction clients and practitioners from SMEs and large organisations participated in this research. Figure 6.1 presents the job role of interview participants. Analysis reveals higher participation among contractors, followed by architects and clients. This finding suggests these construction parties are early adapters or parties that encourage technologies implementation in the industry. The use of new technologies in construction is producing new roles such as innovation manager, director of digitalisation, and BIM manager which were not previously used in the construction industry before the last decade. Duly represented in the population sample are construction clients and other consultants. Due to the centrality of BIM among other technologies, BIM manager is required to manage multiple teams in the collaborative preparation of project information and models. The purpose of these new strategic positions in large construction organisations is to boost production and competitiveness through the adoption of new technologies.

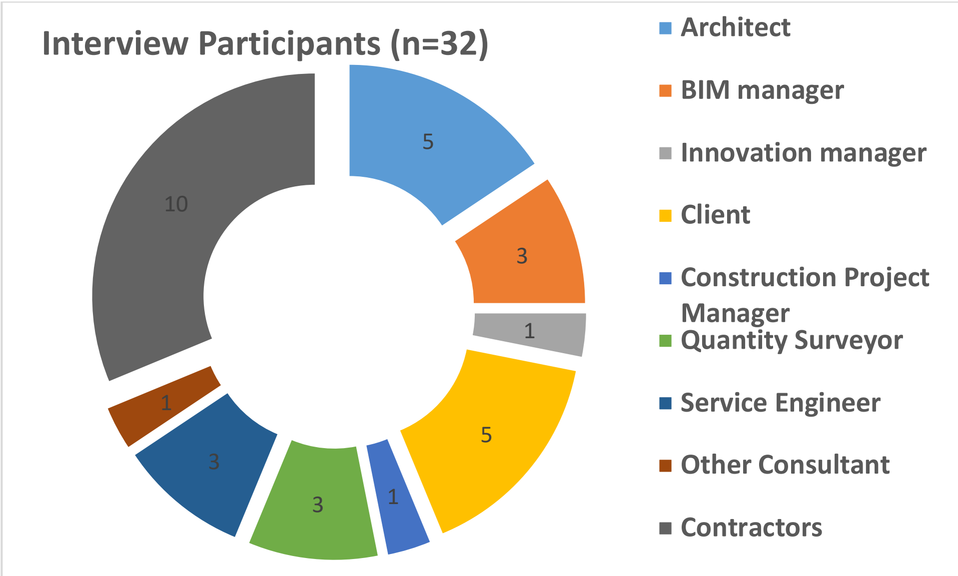

Figure 6.1: Interview participants' job role

6.2 Presentation of findings from open-ended survey

Table 6.1 presents 80 projects compiled from written and typed responses of participants from the research survey. Some project details provided in the table with project information is abridged for ethical reasons. Open-ended survey generated massive text-based data of effects of technologies used by participants. Only fifty-three participants out of seventy completed the Part C session with open-ended questions. This section was included in the survey to serve two reasons, one to collect primary empirical data to enhance the robustness of this research and two to validate research findings. Unequal sample sizes in convergent mixed methods posed a challenge, the use of open-ended survey mitigates this limitation on this study by strengthening the qualitative strand. Based on their experience of implementing technologies on recently completed or ongoing projects, participants were asked to give the name, location, technology used, the impact of technology on the project and impact of technology on variation minimisation.

Table 6.1: Findings from open-ended survey

S/NO	PROJECT	TECHNOLOGY USED	EFFECTS OF TECHNOLOGY USED ON THE PROJECT	EFFECTS OF TECHNOLOGY IN MINIMISING VARIATION
1	Central Foundation Boys School – London	Mobile application software on phones/tablets	1. Improved engagement of contractors 2. Reduced RFIs due to collaborative approach 3. Improved client involvement in designs 4. Project complexity was simplified for contractors by using technology on site	1. Revealed design errors early to minimise construction delays/cost
2	Mountview Academy – London	Revit BIM Software	1. Improved client sign off on designs 2. Contractor performance improved on site 3. Clarity of design before construction for contractor and client	1. Reduction in on site variations due to confident conclusion in design before construction 2. Information transparency between design team members reduced unknowns removing risk in construction 3. Increase in variation during design period (lower cost than on site variation)
3	Gresham SEN – London	Aconex CDE (Design collaboration platform)	1. Improved communication channels between design team members and contract team 2. Improved sharing of information – always up to date 3. One source of information, which improved work monitoring	1. Reduction of RFIs due to complete design pre-construction 2. reduction in variations as clarity provided through CDE to all design & contract team – clarity of information 3. Minimised project complexity by using 3D viewers built into CDE, i.e. viewable via internet explorer so no capital investment cost for smaller sub-contractors
4	The Curzon Building - Birmingham City University	BIM LEVEL 4	1. Reduced errors	1. Less time spent looking for information

			2. Clearer views of designs 3. Centralised project information	2. More accurate spatial coordination 3. Timely programme
		3D Scanning	1. Accurate as-built models/drawings 2. All model objects in the model	Unknown
5	The Seacole Building	Point Layout (Autodesk)	1. Setting out on site using model data	1. Improved spatial coordination
6	Hunts Café	BIM LEVEL 3	1. Stakeholders communication vastly improved 2. Improved marketing 3. Student engagement improved	1. No abnormal change recorded
7	Beatrice Shilling Building, Coventry	BIM level 2	1. Effective stakeholder engagement 2. Clash detection before construction 3. Improved constructability	1. No variation
8	Park Grange Data Centre, University of Birmingham	Navisworks Manage Software	1. Identified mistakes in design models 2. Clash avoidance	1. Ensured water supply pipework is installed as in the drawings
9	University of Birmingham, Old Gym	Matterport 3D Camera Pro	1. Identified discrepancies in models to as installed equipment in plant room	1. Allowed mistakes to be highlighted before model being used in facilities management
10	Wyre Road, Pershore (Mirabelle Gardens)	Mobile Application Software	1. Call off system easily trackable 2. Monitor progress from tablets on site progress	1. Less replacement of items
11	Herdwick Gate, Shipston-on Stour	Robotics (Remote Operator Plant)	1. Cut and fill was completed by remote control plant/machinery	Unknown
12	Silber Boulevard, MK – All Saint Development	Cloud computing	1. Improved communication over drawings	1. Drawing report up to date, working from same drawings / less remedial

13	Upgrade of Rbioz Head Office	MS Project	1. Management of change requests 2. Variation 3. Time	1. High impact
14	Clinic	MS Project	1. Effective management of change requests	1. High impact
15	D Primary School	MS Project	1. Effective management of change requests	1. High impact
16	Metro route Wolverhampton	Revit	1. Allowed for a more accurate representation of the surrounding 2. Better understanding between teams 3. Very good for representation	1. Base dimension can be shown better
17	NVH, Gaydon	A-Site	1. A central resource to smart information 2. Built-in model viewer 3. Rfi Management	1. Easy access to current information
18	Churchill, Coventry	Revit10	1. Track coordination issues 2. Collaborate over decisions (and audit trail)	1. Driving down issues by managing issues
19	Broad St, Birmingham	Solibri	1. Clash decision 2. Digital walk-through	1. Identify issues “out of sight."
20	ESF Priority Schools - Built 5 buildings in East Midlands	BIM Level 2	1. Client communication 2. Speed of construction 3. Site error reduction	Unknown
21	Rolls Royce Process Plant, Derby	BIM Level 2 / Offsite Manufacture	1. Offsite speed construction 2. Process equipment integration	1. Client understanding from the start

22	National Automotive Innovation Centre, University of Warwick	BIM Level 2 / VR / Offsite / Modular	1. Quality finished product 2. Reduce onsite labour 3. Reduce site errors	
23	Ritterman Building, Middlesex University	Vectorworks	1. Positive overall impact add value to the design	1. Offer the client a large number of details
24	Data Centre	BIM 360	1. Coordination easier 2. Quicker file share 3. Cost saving	Unknown
25	London Clinic	Collaborative Model (BIM)	1. Made installation of services a lot easier 2. Coordination of complex geometries possible	Unknown
26	Walthamstow Hospital	3D Scanner		Unknown
27	Dulwich Health Centre	VR	1. Helped enhanced user experience	Unknown
28	Dulwich Centre	BIM Level 2, Revit	1. User engagement 2. Enhance contractors processes on site 3. Design team collaboration	TBC (Not on site yet)
29	Heston Centre	BIM Level 2, Revit	1. User engagement improved 2. Collaboration improved	
30	Waterside Campus, University of Northampton	BIM	1. Good in that contractors used clash detection and were able to demonstrate various designs 2. Were able to achieve our expectations 3. Would not have undertaken the project without it	1. The amount of variations has been reduced but not necessarily minimised 2. Useful in minimising change

31	SHB – Alison Gringell, Coventry University	BIM	1. Better coordinated design 2. Clash detection and clash avoidance 3. COBIe for maintenance	1. Reduced rework 2. Reduced variation in design 3. Reduced variation in Asset Information at handover
32	Godiva Place – Student Accommodation, Coventry University	BIM	1. Enhanced design coordination 2. Better project planning and management 3. Better understanding of students' needs with the design	1. Reduced variations in design 2. Massive impact on the accuracy of Building information at handover
33	Pre-Boarding Zone	BIM/VR/Offsite Construction	1. Client engagement with VR 2. Enhanced design and construction 3. Better speed of construction	1. Improved the structural design 2. Reduced the variations of the Architectural layout
34	Sythwood School – England	BIM	1. Better model coordination 2. Stakeholder engagement via the CDE 3. Better information management in the Common Data Environment	1. Optimal design 2. Reduced variations in Architectural and structural design
36	New Cross Hospital - Wolverhampton – New A & E Building	BIM	1. Helped with high level spatial coordination 2. Visual understanding	1. Variation is minimal as the client was not in a position to conclude 2. Too costly to implement small changes
37	RAF Shawbury – New Helicopter Training Building Hanger Refurbishment	BIM	1. Good visualisation of the project to understand the logistical issues 2. Good coordination and more extensive services 3. Fell down on finite details	1. None as designs were too late to change to achieve budget
38	Cryfield Student Village	BIM	1. M&E large scale spatial planning, good	1. Client variations are limited by budget

			2. Good help to site team to visualise the project 3. Generally, we are around 98% of the way towards a trouble-free model	2. Variation of subcontractors are high as models quality is not as high as it should be, or changes are late from the design team
39	Melgarve SSE, Scotland	Site based data capture	1. 5% cost saving (assessed through workshop) 2. Speed of handover	1. Reduced number of RFI's 2. Reduce delays
40	Hinkley Point C	Machine Guidance	1. Reduced number of surveyors 4x 2. Increased efficiency 3. Increased safety due to fewer surveyors with machines	1. No rework
41	Lincoln Eastern Bypass	4D planning	1. Identified opportunities + risk before agreeing on project price	1. Less commercial change
42	Grand Airport	BIM	1. Collaboration 2. Time saving 3. Efficiency overall	1. Reduced variation 2. Effective variation management 3. Visualisation of variation and digital record
43	Parkside Student Accommodation, Coventry	Mobil Apps on phones	1. Helped programme – fast 2. Helped design implication 3. Helped with valuations/record keeping	1. Design implications – reduced
44	SMOG	Collaboration Platform	1. Increased safety 2. Visualisation 3. Collaboration	1. Design changes reduction
45	BASF Ludwigshafen	BIM	1. Budget 2. On time	1. No improvising on site

			3. Safety	
46	Burfull Tunnel	CDE	1. No search for information on site	1. Fewer drawings – information digital
47	Television Tower	BIM	1. impossible to do without it 2. Quality enhancement	1. One working solution
48	Crossrail, London	Database - Common Data Environment (CDE)	1. Improved collaboration and effectiveness 2. Single source of truth to ensure only current valid data used 3. 3D model used as a tool for managing design and construction processes	1. Speed of consuming information and making decisions is much improved 2. Everyone using the same (up to date) information
49	CNUM Montreal	Codebook	1. Management of assets significantly increased 2. Coordination of assets and changes improved 3. Speed up delivery	1. Changes in software before installation 2. Moves and changes managed at a higher level 3. Optioneering enhanced
50	Coventry University Low Carbon Tech Centre, Coventry Technology Park	BIM	1. Coordination of design disciplines in a very complicated design 2. Clash detection exercises further reducing on-site coordination errors 3. Visualisation as a by-product from consultant models – informed and happy customer	1. CIC BIM protocol had to be added to the contract 2. There was a dispute over who had responsibility for clash detection (yet to be resolved) 3. There was a dispute over the provision of COBie data (contract amended)
51	Grow on Space Business Development Space, Market Harborough	VR	1. Client has good understanding of the design 2. Client also has a better notion of the size of spaces in their asset, something which rendered images cannot convey 3. Positive reaction from this and other customers led to own investment in more VR tech.	1. Design disputations reduced

52	George St. offices, Oxford City Council, Oxford	Digital collaboration platform	1. Participants have access to the right data at the right time 2. The system handles drawing revisions – nobody builds off an out-of-date drawing 3. Security, control and automatic drawing archiving for use years from now.	1. Addition of CIC BIM protocol 2. So far, no alterations related to design or qualities
53	50m Pool, Alan Higgs Centre Coventry	4D planning simulations	1. Complex refurbishment – 4D simulations described the demolish/build process 2. Concerns about traffic and circulation were addressed 3. Simulations augmented the bidding process	1. Alterations to working conditions and sequence of work minimised
54	Fairfax Street Student Rooms, Coventry	Drones	1. Remote monitoring 2. Enhanced quality check	1. Client can view to comment
55	Southgate Rooms, Leicester	3D Mapping	1. Helped design and client understand each other 2. Helped with future design of services	1. No delays and budget cost maintained
56	Moxy Hotel Stratford	ED Controls	1. Better human collaboration 2. More transparency 3. Better quality assurance	N/A
57	Student Halls	Laser scanning + Revit Modelling and utilities	1. Speed up design process 2. Verification of on-site data	Unknown
58	Barnet Leisure Centre	Navisworks (Clash detection)	1. Minimised clashes between site items	1. Less waste of time on site

59	Wymondham Leisure Centre	Revit (Design Software)	1. Easy scheduling of items	1. Less time in design
60	Transforming Cancer Care Project, Liverpool	BIM	1. Helped at some point	
61	M5 Oldbury Viaduct	Design Software (3D + 4D Synchro)	1. Embedded LOD-LOI in the model as client request 2. Collaboration between contractor and client from Day 1	1. Minimising the errors on site 2. Client isn't changing his mind as before
62	M62 SMP	Cloud based, 360 Glue/Field	1. We will be able to embed the information from site easily into the cloud to be saved in CDE for handover documentation	Unknown
63	Lismore Croft (Skye Court)	Spatial Measurement	1. We will be able to embed the information from site easily into the cloud to be saved in CDE for handover documentation 2. Speed of use 3. Ease of maintenance	1. Unknown
64	East of Brade Drive	Geolocation	1. Speed of measurement 2. Accuracy of levelling 3. Minimum cost	1. Unknown
65	Office accommodation	Cloud computing	1. Security of data 2. Minimise manual backups 3. Data collection and duplication	1. Unknown
66	Industrial Hodges Way	High Performance Concrete	1. Speed of use + quality 2. Self-levelling capability	1. Unknown

			3. Loss of reinforcement (overall cost reduction	
67	Land Rover Bar America's WP HQ, Portsmouth	BIM via Graphisoft, ArchiCAD	1. Full design coordination of specialist manufacture items 2. Ability to meet tight deadline, improved documentation 3. Offsite manufacturing implemented	1. Improved level of documentation, reduced unknown errors 2. Offsite manufacture – less changes on site 3. Early client involvement – less changes through project
68	London Bridge Station	Detailed 4D Sequences for Offsite	1. More certain timescales 2. Safer working due to operations team input into logistics	1. Closer working and enhanced understanding between design and construction teams
69	Bishopsgate	VR	1. Safer, more efficient logistics arrangements 2. Project management ream improved planning 3. Impact of design changes visualised to show option1 vs option 2 for contractor -client dialogue	1. Variations agreed quicker, earlier, leading to lean project delivery
70	Battersea Power Station	4D Sequencing for Bathroom Pods installation	1. Very well planned, detailed installation of bathroom pods 2. Reduced re-work 3. More predictable programme	1. Reduced delays across floor plates due to well-planned works – transparency for supply chain
71	London Velodrome	Timber SIPS (Structural Insulated Panels)	1. High programme saving 2. Quickly watertight building achieved 3. Sustainable (Lower embodied carbon)	1. Use of SIPS on a cable net roof for the first time required detailed analysis and planning with designers and contractors – meaning there was less (no) change on site
72	New Museum of London	BIM	1. Use of real scanned 3D data saved time building model 2. Identifying inconsistencies/clashes early in design	1. Use of actual scanned data = less assumptions = less changes 2. Clashes are resolved earlier in project

			3. Engaging the client	3. Client teams who are not used to reviewing construction drawings can visualise the space
73	New Museum of London	Drones	1. Use of drones to 3D scan inaccessible/unsafe roof 2. Design team had real scanned data to earlier in project 3. Less change in future	1. Use of actual data means design can progress with confidence 2. Fewer variations
74	Data Centre	BIM	1. Real-time, collaborative design and mark-up for multi-discipline parties 2. One version of the truth' – transparent and up to date data for all stakeholders in any location 3. More efficient, almost paperless workflows – helping remove human error and duplicated work - huge saving on man-hours	1. Design changes agreed collaboratively and quickly, with models and drawings being 'frozen' before being released for implementation 2. Software used on site set out strict processes and gateways that required verification of completion - consistent work from contractors – increased quality and less rework 3. With data being kept in one place and accessible to everyone, stakeholders could make well informed decisions easily, saving time and changes
75	Jump Factory	Modular	1. Increased efficiency – extremely fast rate of assembly achieved on site as well as other trades 2. Safe, factory-quality environment 3. Less labour required on site, increasing safety	1. Huge volume of modular components required early agreed sign-off on design 2. Contractors had complete control of one floor at a time, increasing the quality of the output and handover, as well increasing their speed 3. We took complete control of materials arriving to site, packaging up contractors' daily materials, controlling workflow and minimising waste
76	Camden Lock	Drones	1. Quick, easy-to-understand progress updates for teams and clients	1. Better informed decisions

			2. Promotional tool for clients 3. Reducing risk and cost of claims and disputes	2. Greater accountability for quality handovers between trades
77	Data centres	VR	1. Collaboratively solving problems in multidisciplinary teams 2. Supporting ‘right first time’ delivery 3. De-risking the construction sequence	1. Better client engagement – co-develop the brief and faster signoffs 2. Collaborative design changes – better informed decisions made, reducing rework 3. Safer, well-rehearsed work
78	Sterilization Facility – Derbyshire	Revit / NavisWorks	1. It made it possible to coordinate an extremely complicated structure containing masses of reinforcement bars, conduits and M+E services – this enabled project to keep to programme	1. The use of clash detection avoided the potential need for on-site adjustments during construction that would have otherwise caused delays 2. Client driven changes were not reduced as they were driven by market forces associated with their business
79	Distribution Centre, Durham	Revit	1. Aided easier coordination of design rather than sharing traditional 2D drawings. 2. Traditional 2D drawings were still required to illustrate the project details in full tender purposes.	1. No impact on minimising changes as changes are driven by the client’s need to adapt to their market
80	Warehouse/Distribution Centre, Chesterfield	Procore (Collaboration Platform / Portal)	1. An online depository for all project related information produced by the design and construction teams 2. It ensured up-to-date info was available to everybody at any time, but it required manual checking of the database to see what had changed	1. Many client driven changes occurred on finishes, due to them “changing their minds”; although the portal didn’t have any effect on the need for change, it did ensure the construction teams were kept abreast of the latest requirements

6.3 Summary of findings from open-ended survey

Presenting qualitative survey findings can be challenging and lengthy. Lengthy results and findings may overwhelm readers. Word clouds are great options for instant visual presentation of qualitative data. Figure 6.2 presents word cloud of responses of open-ended survey from Table 6.1. Text data obtained from open-ended survey was typed and saved in Microsoft word file and then uploaded to Nvivo 12 platform. More frequent or important words are large and bold, this helps to identify trends and patterns. From the word cloud generated, design, improved, site and BIM take the centre stage of findings.

Figure 6.2: Word cloud generated from open-ended text uploaded to Nvivo 12

The following summarised findings from the survey from Table 6.1:

- Variation minimisation does not appear to be the primary reason for implementing technologies.
- Benefits of implementation centred around avoidance of rework, avoidance of delay, risks mitigation, clarity of project documents, client better understanding of design and early engagement of stakeholders.

- Implementation of technologies contributes to variation minimisation or helps to manage inevitable variations that occur on projects effectively.
- Some participants were unable to identify concise evidence of impact of technologies used on variation minimisation.
- Client variation remains unavoidable in the management of construction projects. Although client engagement was enhanced, client variations that are driven by market forces are inevitable according to these quotes from findings:

"Many clients' driven changes occurred on finishes, due to them changing their minds".

"Client's driven changes were not reduced as they were driven by market forces associated with their business".

Participants raised challenges they were confronted with on their projects which they were unable to resolve before going to site. These unresolved challenges made them experience many variations. Those issues raised from open-ended survey by participants are summarised as:

- Some small-scale potential variations identified in 3D models before construction were too costly to amend due to lack of in-house BIM personnel.
- Low quality model resulting in variations due to works carried out by subcontractors.
- Disputes over who had responsibility for clash detection and provision of COBie data.

6.4 Analysis, results and findings from semi-structured interviews

Figure 6.4 is a screenshot of 'Nodes' captured on Nvivo 12 software used during analysis. A list of deductive codes formulated helped to capture relevant quotes that addressed the research objectives and to organise the uploaded data in a meaningful and systematic manner. Coding reduced the massive transcribed data into small meaningful chunks. On examination and analysis of data, some inductive codes and sub-codes were generated to enrich findings and discussion. Codes were not entirely pre-determined; instead, some themes developed; some modified, and new ones added through the coding process. Nvivo software proved to be very useful in dealing with the large dataset this study generated. Codes generated were organised into descriptive themes; themes are patterns that capture significant points in the data and are relevant to research objectives.

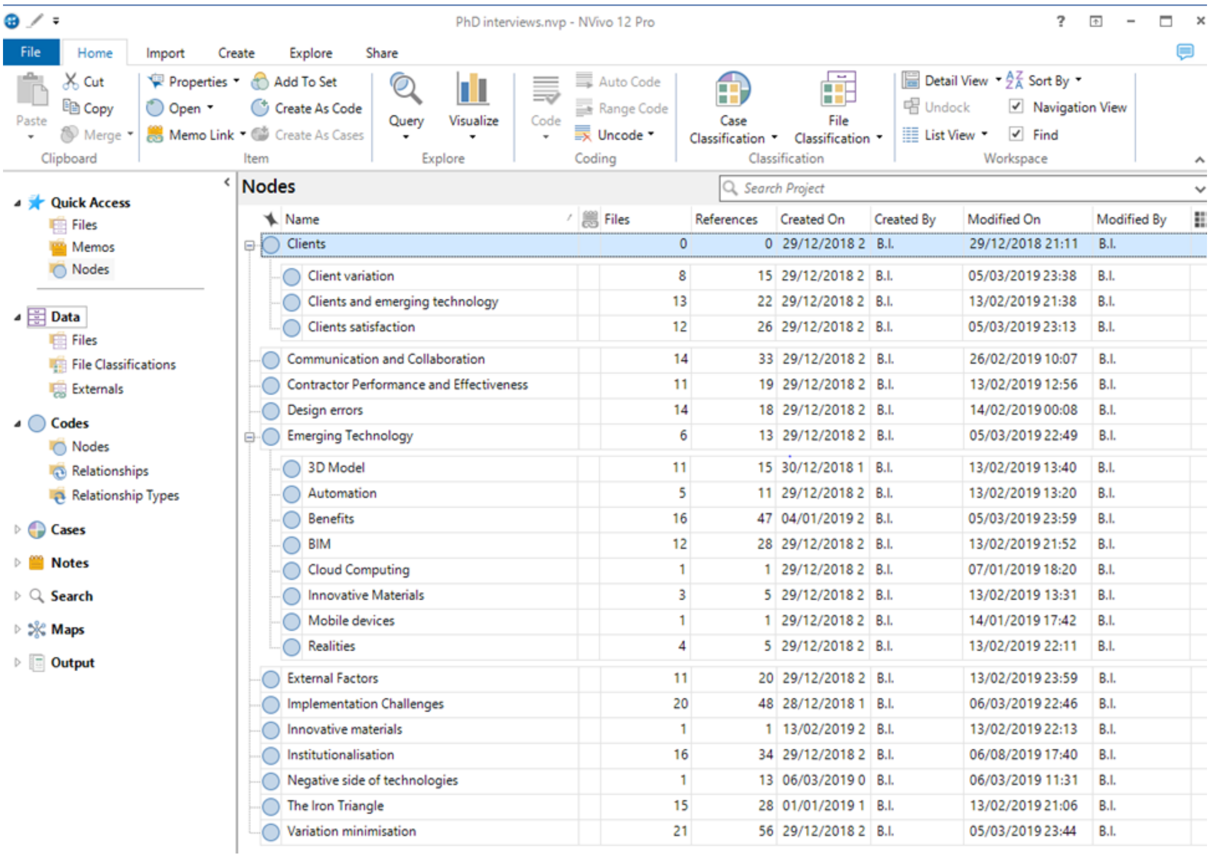

Figure 6.3: Screenshot of inductive and deductive nodes in Nvivo 12

Profile of interview participants and their organisation

Table 6.2 gives brief details and description of interview participants and their organisation. Thirty-two semi-structured interviews were conducted over 12 months, as discussed in chapter four. Semi structured interview is an essential means of collecting data that has a 'direct bearing on the research objectives' (Cohen et al., 2007). Each interview on average lasted for about 45 minutes. Appointment, time and method of interview were dependent on the preference of participants. Twenty-four interviews were conducted face-to-face, five were conducted on phone and 3 via Skype. Proceedings of all interviews were recorded, transcribed and processed using Nvivo 12 qualitative data analysis software. Figure 6.5 is a generated cloud words from interview transcript uploaded to Nvivo. Comparing Figures 6.2 and Figure 6.5, one major divergent is that findings from open-ended survey centred on design while interview findings revolved around clients.

Table 6.2: Details of interview participants and their organisation

CODE ASSIGNED	CAPACITY	INTERVIEW METHOD	GENDER	JOB ROLE	BRIEF DESCRIPTION OF PARTICIPANT'S ORGANISATION
P32	Designer	Telephone	Female	Architect	Award-winning architectural firm established in 1968 on the South coast.
P31	Designer	Skype	Male	Digital Engineer	A contracting and interior fit-out group founded in 1852.
P30	Project manager	Skype	Female	Project Director	An international independent company of project managers.
P29	Client	Face to face	Male	Quantity Surveyor	A higher institution of education in the Midlands.
P28	Contractor	Telephone	Male	Digital Construction Lead	A multinational infrastructure and construction group founded in 1909. This company is rated the most profitable contractor in the top 100 in the UK.
P27	Client	Face to face	Female	Director	A higher institution of education in East Midlands. It was formed in 1999. Moved to brand new £330 million campus in 2018.
P26	Designer	Face to face	Male	Architect	Medium size architectural firm.
P25	Digital consultant	Face to face	Male	Application Engineer	Leading manufacturer of GPS technology, e.g. laser earthmoving, robotic, imagery system to bring solutions to the process that design, construct on site.
P24	Contractor	Face to face	Female	BIM Coordinator	Large international construction company with headquarter in Camberley, UK.
P23	Contractor	Face to face	Male	Digital Construction Manager	One of Europe's largest contractors, with an annual turnover of £7billion. Established for more than 150 years delivering exceptional engineering, construction and investment services across the UK and internationally. Registered headquarters is in Hertfordshire.
P22	Client	Face to face	Male	Head of Projects	A higher institution of education in the Midlands.
P21	Contractor	Face to face	Male	Project Manager	A main contractor specialising in turnkey solutions for industrial, build-to-rent, student accommodation and commercial projects.
P20	Contractor	Skype	Male Female	Innovation manager	An international consultancy and construction company fully established in Europe, Middle East and North Africa, North America, Sub-Saharan Africa and Asia Pacific. Among top ten construction company in the UK.
P19	Contractor	Face to face	Male	Construction Manager	A leading UK construction and infrastructure service company. One of the top five UK contractors with 67 offices across the UK.
P18	Designer	Face to face	Male	Architect	A small Architectural and development consultancy service since 1979.
P17	Contractor	Face to face	Male	Quantity	Building and civil engineering company undertaking contracts worth £2-25 million

				Surveyor	in north of England and the Midlands.
P16	MEP Contractor	Telephone	Male	Service Engineer	A leading consulting engineering practice founded in 1997 based in Belfast. Provide services in Mechanical, Electrical and Plumbing (MEP).
P15	4D Contractor	Telephone	Male	BIM Manager	World class 4D Modelling service company. Building 4D models and running collaborative workshops since 2007.
P14	Designer	Telephone	Male	Architect	Offsite turnkey construction contractor.
P13	Contractor	Face to face	Female	BIM Coordinator	A construction international company.
P12	Subcontractor	Face to face	Male	Digital Engineer	Project management company that ensures efficient collaboration between contractors, subcontractors, fitters and other partners.
P11	Consulting Engineers	Telephone	Male	Electrical Engineer	Award-winning consultancy practice in Belfast working across all sectors of the built environment.
P10	In-house client consultants	Face to face	Male Female	Architect BIM Manager	A world top 100 University and part of the prestigious Russell Group.
P9	Manufacturer and Supplier	Face to face	Male	Head of BIM	Worldwide leading manufacturer and supplier of formwork and scaffolding systems. Established in 1969 in Germany, the UK headquarters is in Rugby.
P8	Client	Face to face	Male	Director of Estate	Higher institution of education established since 1843.
P7	Client	Face to face	Female	Architect and BIM MANAGER	A higher institution of education in the Midlands.
P6	Client	Face to face	Male	Mechanical Engineer	National company controlled by a local authority.
P5	Contractor	Telephone	Male	Head of Digital construction	An international design, build, refurbish and operate, established since 1874. Currently undertaking construction in more than 30 countries around the world.
P4	Designer	Face to face	Male	Architect	Award-winning architecture, engineering and design firm in Manchester.
P3	Designer	Telephone	Male	Principal Architect	Design practice championing BIM application and adoption. Specialise in Information management and design process with the application of appropriate new technologies.
P2	Project manager	Face to face	Male	Estimator	Medium land and engineering surveying company in the UK and Ireland. They service in BIM, laser scanning, setting out etc.
P1	Developers	Face to face	Male Male	Contract Manager Site Manager	A small to medium construction company in the West Midlands. Specialise in building for rental purposes only.

Interview analysis in Nvivo 12

Figure 6.4 presents a screenshot of audio files and codes in Nvivo 12 during analysis. Interview audio files were converted to compatible MPEG-4 audio format before uploading them to Nvivo. Content analysis was done by reading through the text data obtained from transcripts and listening simultaneously to responding audio files to make sense of the data. To identify patterns in the transcribed interview data, useful codes were selected, captured and organised under appropriate theme nodes listed in Figure 6.3.

Files

Search Project

Name	Codes	References	Modified On	Modified By	Classification
P1	0	0	24/07/2019 18:44	B.I.	
P10	10	20	24/07/2019 18:30	B.I.	
P11	0	0	24/07/2019 18:30	B.I.	
P12	5	7	24/07/2019 18:30	B.I.	
P13	8	15	24/07/2019 18:30	B.I.	
P14	0	0	06/08/2019 18:41	B.I.	
P15	5	12	24/07/2019 18:30	B.I.	
P16	0	0	24/07/2019 18:31	B.I.	
P17	6	9	24/07/2019 18:31	B.I.	
P18	14	29	06/08/2019 18:41	B.I.	
P19	2	15	24/07/2019 18:31	B.I.	
P2	7	12	24/07/2019 18:29	B.I.	
P20	13	32	24/07/2019 18:31	B.I.	
P21	9	15	24/07/2019 18:31	B.I.	
P22	0	0	24/07/2019 18:31	B.I.	
P23	9	12	24/07/2019 18:31	B.I.	
P24	5	8	24/07/2019 18:32	B.I.	
P25	10	27	24/07/2019 18:32	B.I.	
P26	10	13	24/07/2019 18:32	B.I.	
P27	4	6	24/07/2019 18:32	B.I.	
P28	6	9	24/07/2019 18:32	B.I.	
P29	5	7	24/07/2019 18:32	B.I.	
P3	0	0	24/07/2019 18:29	B.I.	
P30	13	24	24/07/2019 18:32	B.I.	
P31	10	14	24/07/2019 18:33	B.I.	
P32	12	28	24/07/2019 18:33	B.I.	
P4	10	40	24/07/2019 18:29	B.I.	
P5	7	19	24/07/2019 18:29	B.I.	
P6	12	53	06/08/2019 17:35	B.I.	
P7	8	13	24/07/2019 18:30	B.I.	
P8	9	12	24/07/2019 18:30	B.I.	
P9	7	8	24/07/2019 18:30	B.I.	

Figure 6.4: Screenshot of audio files of 32 interviews uploaded to Nvivo 12

6.5 Findings from semi-structured interviews

Figure 6.5 presents a word cloud generated from transcribed interview files uploaded to Nvivo. Word clouds are used in research to represent the frequency of words visually. It is useful to identify the focus of a written text. The word Clients formed the focus of interview data as illustrated in Figure 6.5 while designs formed the focus of open-ended survey according to Figure 6.3. Findings from these word clouds demonstrated that designs and clients are crucial to all activities of the construction industry. Enforcement of BIM level 2 on centrally procured projects in the UK is part of the radical efforts by the UK government to ensure quality designs are produced for construction projects. The UK government indeed is the largest client of the construction industry.

Figure 6.5: Word Cloud generated by Nvivo 12 from transcribed interview files

Question 1: How would you describe the impact of emerging technologies you have used in relation to minimisation of design errors in construction projects?

Design error is a preventable divergence from the established standard of practice in designs of construction projects. Design errors have been identified as root causes of variations. Traditionally, human psychological and physiological limitations make design errors inevitable in design. Lopez and Love (2012) argued that the cost of design errors in various project types irrespective of the procurement methods adopted is almost the same. However, with BIM implementation, design process is facilitated, and design errors are prevented. Quotes from findings to support the impact of technologies in minimising design errors are presented below:

> ***"It nearly goes as far as to say 9 out of 10, the biggest challenge we have in construction projects you know are down to poor design or incomplete design"- P13***
>
> ***"BIM eliminate errors because we can look at those 3D models, provide access to the site teams, construction teams so that they can look at it from a buildability point of view and start looking for those areas, um, and how they're going to build it. Does a precast solution work? Yes or no? Can we get access? Where do we put the crane? So yes, definitely it has helped. It could help more, but it has definitely helped in reducing design errors before going to site"- P18***
>
> ***"If you were looking at a plan or a section or elevation, you have to sort of think and visualise the 3D in your own mind rather than seeing it on a screen. So, from that point of view, it certainly makes it easier and less chance of missing something"- P25***

Architects and other design consultants interviewed said implementing BIM clash detection tools brings about cost efficiencies and increase the speed of delivery. They established that BIM enhanced quality of projects and specification information and motivates them to facilitate design process virtually. Participants alluded to BIM approach to construction enables contractors and builders to contribute early to the planning and design process. This early collaboration leads to quality designs that proactively eliminate variations and reduce planning and construction time. Some participants attributed variation order as down to imperfect or incomplete design inherent from 2D plans and elevations.

Ability to visualise designs in 3D certainly makes it easier for both clients and designers to resolve design and clash detection issues before going to site. Clients and designers leveraged on technologies to experience virtual real-life view of the finished product before it is built. Many researchers have evidenced BIM as a useful tool for reducing design errors and omissions. Participant P16 gave a more in-depth insight to BIM in relation to the reduction of design errors by saying:

> ***"BIM improves the performance of design but also requires people spending time to do it properly. Because again, if you're cutting corners, then it doesn't really matter what technology you're using, I think the biggest issues around implementation are really people, their approach and commitment to a project"- P16***

This response can be interpreted to mean that BIM detects problems in design early and offers opportunities to fix them before they become costly variation to the detriment of the project. There is a great deal of dedication and expertise required to achieve these benefits. Commitment and expertise of the project team are essential in leveraging on BIM and other associated tools to get the best.

Question 2: What is the impact of these technologies on communication errors on your projects?

Effective collaboration and seamless communication are fundamental in the decision-making process and variation minimisation. Mobile devices, CDE, digital collaboration platform, cloud computing and federated BIM model give access to members of construction team to obtain up-to-date project information to work with. When project teams are working with the latest version of all contract documents, variations due to obsolete or inadequate contract documents will be avoided. The pivotal position of digital platforms for information sharing in construction project as opposed to traditional face to face meetings and sharing via email is expressed from these quotes from participants:

> ***"The worst way of communicating within a project sense is by email. Is very common to go into a meeting and for someone to say, I sent you an email on this, and they are going, well I'll have to check my email box, and maybe I didn't receive the email"- P13***

"3D models establish clarity, remove any misinterpretation, any ambiguity of what people may think compare to when you're looking at something in 2D"- P32

"There has been a definite reduction in communication error using the new technologies because it's digital and it's stored online. It's not lost, it's not on pieces of paper. Through digital technologies, you create an auditable trail which thus helps to sort of hold people more accountable for their work that they produce. People sort of have to be more accurate and, because know they can sort of trailer your communication history on the project. And usually with those digital systems, there's an element of a predetermined values that you can put in and how you convey that information usually a lot clearer" P27

Digital collaboration platform is evolving and becoming prominent in sharing the latest project information among project teams to avoid delay and miscommunication that may require variations to amend later. However, it seems there is still a long way to go before the construction industry begins to reap the full benefits of emerging technologies. Findings revealed that there are laggard members of the construction team who are opposed to implementation. It is crucial to woo, educate and solicit commitment from project teams regarding technologies to be deployed on a project at inception and planning stage. This quote from participant P31 exposed such concern:

"They're practically helping to avoid communication errors for those that really do, but not everybody buys in. I think there's a lot of people that are scared because a lot of people use Excel and they like to keep it to themselves. But now they've got to share information with everybody"- P31

Question 3: Do you think the implementation of these technologies minimised variations, especially after the contract, has been signed?

Findings from participants in relation to whether various emerging technologies they have implemented minimised variations were very diverse based on their experience and understanding of what variation is. Variation minimisation is fundamental to successful project delivery. Occurrence of variation is a common experience of any project regardless of type or size. Variation will contribute significantly to cost and time overruns. Responses are relevant and concise to questions of variations minimisation; however, opinions of participants are divided. The following quotes explain the different opinions of participants on effects of technologies used on their projects and how it minimises variation:

> ***"Before implementing these technologies, we did find there were a lot of variations on our projects and we were called down to site a lot more, you know, things like we found this beam and it isn't in a place where is expected to be. We can't put this column there et cetera. But that happen less now"- P7***
>
> ***"Construction is a very complicated thing, there were a lot of unknowns, a lot of things that can go wrong, you know, we can go so far with predicting them and trying to coordinate better, but I'm sure they'll always be the odd thing that crops up, but you know, we can definitely do more to satisfy our clients"- P2***
>
> ***"It minimises variation by reducing rework, so we don't have to worry, we construct things and we build things in one build that is, we build correctly in the first place"- P27***
>
> ***"It does minimise variations from design point of view and can we build it correctly because if we can't build it, there's going to be changed, so technologies have had an impact" P18***

"I would not say it minimising changes. I think I would say it helps to manage changes effectively. Big projects need to be able to accommodate change and manage change because otherwise if they don't, we'll be out of date before we open. However, it would be impossible, I mean impossible to execute this project without these technologies, particularly with the use of BIM and common data environment, single source of truth" P6

"We use virtual reality, a digital tools and augmented reality tools, our clients can see things in a more realistic way, and they can understand the impact of the design more effectively. Using these tools definitely has made the biggest impact on reduction of variations. But sometimes a client had or want to make some changes. Those variations are inevitable so you cannot avoid those variation depending on the change in scope of design, you can't really avoid that. Sometimes you have to accommodate changes"- P5

"As client, we were satisfied with the design virtually, but then a contractor may come and decide that because of the way the jobs are going on site, he may change the socket positions in relation to where the desks are, all this kind of thing. They still do that in design and build contract despite the use of these technologies. So, that reduces the level of certainty and reintroduces the potential for variations"- P8

To interpret and extrapolate these quotes the following can be deduced. Managing construction project traditionally increases stress and makes construction activities hectic for all that are involved. Quality designs resolve unexpected problems that could have led to variations. By nature, construction works comprises of outdoor activities that makes elimination of variation an arduous task to embark on. However, minimising variation to barest minimum is a reality. Though variation has been accepted as a matter of practical reality and a necessary evil (Ssegawa et al., 2002) in construction projects, findings indicate implementing appropriate technologies influences the number of variations a construction project will encounter due to unforeseen circumstances. This agrees with the result of Fan et al., (2014) research that reported implementing BIM on ten construction projects reduced change order to one-digit number ranging from 0-9.

Implementing technologies facilitate early engagement of project stakeholders in the construction process, unlike the traditional approach to construction where contractor input and expertise to design and planning is missed out at the early stage. Early collaboration of consultants eradicates many mistakes that could result to rework and variations. Emerging technologies simplify construction activities to enable project delivery on time and under budget. Participant P6 gave a different insight into benefits of technologies on very large and high-risk projects and variations. On such projects, variations are not inevitable but also enormous. Two salient points from this participant emerged. One, that the use of emerging technologies on such large construction projects is a prerequisite. The scale of risk involved, and long project duration will make such project an impossible task to carry out without the use of technologies. Two, that variations that will inevitably occur in such projects are effectively managed with technologies. Technologies, therefore, accommodate predicted variations and proactively help the project team to mitigate its impacts on projects.

Goals of designers, contractors and other consultants' firms that are working in the industry are to make profit and to retain their clients. They bid for new contracts to achieve these goals. One easy way of achieving these goals is to accommodate their client's variations at any stage of the project regardless of the impact of such variations. From this study, utilising technologies makes these practitioners make profits and retain their clients. Organisations that are innovative will no doubt compete better than others that are laggards.

P8 raised a major concern on counteracting effect of design and build method of procurement and benefits of emerging technologies utilisation. Typically, in design and build contract, it is the responsibility of the contractor to design, plan, organise and control construction of works. This gives latitude to contractors to make adjustments that may diminish the clients' expectation based on virtual designs originally presented before construction.

Question 4: Do you believe that emerging technologies used improve your confidence and satisfaction of the entire project and that of your client?

Participant P32 described 3D view of designs as valuable experience for clients that are new to construction due to improved visualisation as opposed to 2D drawings. Many construction contracts are entered into by many clients who have little or no experience of construction process and designs. The use of VR and AR immerse clients in the unbuilt structure to interact, move and feel the building. Changes can be made, and immediate effect of the changes can be seen and felt prior to construction. According to finding of this research, the emotional attachment of clients who view 3D models with designers is far deeper than clients who are not familiar with or contributes to the construction process. 3D visualisation also makes clients feel better and confident about their project. Visualisation of the digital twin of the proposed building gives client better understanding of what the end product will look like.

Construction business is built on client relationships. Management of clients determines companies' future. Client satisfaction is one key performance indicators for the UK construction industry. Egan (1998) stated "More than a third of major clients are dissatisfied with contractors' performance in keeping to the quoted price and to time, resolving defects and delivering a final product of the required quality". The ultimate desire of the construction client is to obtain a final product that meets its functional requirements, of required quality and delivered within budget and timeframe. Using technologies helps designers to capture and depict ideas that reside in the minds of clients, at the early stage of construction process minimised variations. The following quotes from participants substantiate how technologies utilised on their projects enhanced satisfaction of clients and that of project teams:

> ***"What you really want at the end of the day is for your client to walk around their project and say this is what they wanted because you***

know, this is exactly what they need, and this is exactly how they can see themselves using it. And in order for that to happen, the best result is often when the client has been engaged through the BIM process"- P32

"I've found that particularly for clients which aren't used to construction, it's absolutely valuable getting that 3D view and you can choose what materials you want to show in that image, and you can show them a selection of different images with different options on. It really helps that process"- P30

"The transparent nature of the technology does give our clients our confidence and the satisfaction that you are trying to be open and honest and I'm being very visual"- P23

"I think sometimes it's the client that sees most of the benefit and we do that to keep our clients happy and move the industry forward and win more work"- P20

"They might be grateful for the building but if they haven't lived it with you from the beginning of the project their emotional attachment to it isn't the same as a client who come in and live in that 3D model with you throughout the process"- P26

Question 5: Do you think that the cost of implementation is justified with the performance of the contractors on site?

According to findings, digital workflows are becoming better streamlined and simple to use by even unskilled site workers. Distance between construction site and contractor's office is no longer a barrier to effective project management and monitoring. Contractors were able to leverage on hardware such as tablets, laser scanners and cloud computing to control and manage construction works in real time. It was apparent that emerging technologies helped contractors to minimise waste, increase efficiency and safety on site.

The contractor is responsible for providing material, labour, equipment and services necessary for construction. Contractor efficiency plays a major role in minimising variations in construction projects. Participants reiterated how the BIM process helped them to understand, plan and prepare prior to site activities due to early involvement during planning. Contractors utilised new technologies and innovative materials such as prefabrication to improve quality of final product and reduce cost. Complex deigns are easily understood by the construction team by using highly accurate building models and digital processes early before construction begins.

There is concern of sabotaging efforts among site workers who are unwilling to embrace change and use new technologies on site. Benefits accrued from utilising technologies were limited by some site workers who believe in the traditional approach to construction. The responsibility lies with contractors to train their workers and carry their team along the new way of managing construction works. Quotes from interview scripts reflecting on improvement of contractor performance on site are given below:

> ***"Contractors were able to grasp difficult details a lot sooner in the project rather than leaving it to onsite. So often we have workshops with both the client and the contractor and were able to walk through 3D model and they're able to kind of stop and view certain aspects that either we think is going to be difficult"- P4***

> ***"We manage our people on site a lot better as well in terms of where they're working and what they're doing"- P19***

> ***"We collect information, real time information about the construction and how everything is going according to baseline. So, we're able to***

define which subcontract is going behind their schedule so and also be able to record it and report it digitally"- P28

"We run our common data environment, we have a team over there who make sure this works and so all the contractors are dialling in remotely. It doesn't cost them anything"- P6

"The people in this industry are still the same people. When the new generation come up, then the more technology wise the better but at the moment the builders actually are still the same. Is probably about 5% of them who've actually upgraded in these technologies-" P3

Question 6: Is the project delivered on time, budget and quality?

From P22 perspective, technologies implementation kept cost and time overrun under control. The participant admitted that emerging technologies they used helped in timely delivery but warned that there is need for caution on over dependence on these tools. Other factors such as experience of project team, team spirit, timely payment of contractors and so on are important for smooth running of projects. P20 appears to be one of the early adopters that are reaping competitive advantage over others in retaining their clients or winning more contracts. P20 and P5 shared the same view on what makes projects to be delivered on time, budget and quality. The two participants believed that based on their experience technologies alone cannot contribute to successful project delivery but a combination of many other factors. Below are direct quotes of participants on impact on technologies on project delivery to time, budget and quality:

"The project still wasn't delivered on time or on budget because of many other factors. If those tools hadn't been used and issues picked up early, it may have been 9 months late or 12 months late. It may have been 15 months late or two years late on larger construction projects. So, the use of those tools has brought the cost and time

under more control, but not necessarily on time and on budget"- P22

"Our client gave us more work because we're proved to them that we can deliver on time, on budget, we gave them a project which is hassle free and, that's directly through using technologies"- P20

"I cannot say just because of these technologies projects have been delivered on time and within same budget. It is difficult to justify success just around technology because they are many other factors involved. And, uh, these digital technologies are playing a significant role, but this is not the only factor which makes projects to be completed on time and on budget"- P5

"We had all the three. We had a set time when the students moving in. Yeah. We hand in a day before. This is fine because we ran open book contract with the client, so every penny was scrutinised"- P21

"I think we have over 80 percent of projects across the organisation being delivered on time, on budget, to acceptable quality. The delays arise when you have things like weather and disputes and that sort of thing that is really beyond our control"- P21

"So, we were able to improve on own speed and budget. We are still ongoing, and I believe they are on budget from what I have heard, and the quality is exceptional. Apparently, it's clinical levels of quality we're achieving there. But again, because it is a repetitive project,

it's worked really well on such project owning to performance, and productivity"- P20

Question 7: Will you use these technologies again?

Many participants confirmed they will continue to utilise technologies they have adopted going forward. Some participants said they are trying a number of new technologies before their organisation take decision on technologies to adopt. This comment indicates that the construction industry is at a trial stage of adoption. Some frankly said they are not persevering because they were unable to derive benefits anticipated. P15 established implementation is a cheaper way of construction compared to the traditional method. This viewpoint resonates with P29 who said construction digitalisation is not an option anymore, it is a new way to construction that is being established. It is, however, obvious from the response from P8 that not all users of these technologies are getting the best out of them. To persevere in utilising emerging technologies suggests expected benefits are not being realised for many presently. The reasons may be different from one organisation to the other. Barriers to adoption and implementation are surmountable. It is expected that the present teething problems will disappear with further training, research and development. Technologies have started to shape the construction industry like other industries, it is important that the industry will keep up in a progressive pace. Relevant quotes to justify these arguments are given below:

"Right now, if you don't use those technologies, you will lose more. So cost of implementation is at the beginning, at the capital phase, but then you will gain a lot by implementing new technologies. The delays that happen by not using the technologies will be more expensive than just paying to use the technologies from the beginning"- P15

"You don't have a choice, you know, in the western world now, in larger projects especially, is not if you are digitised or not. You have

to be digital, that is the expectation. So, the question of will I or should I have passed"- P29

"I think we will persevere. Yes. It's definitely an open door to a better way of doing things even though we haven't quite got there yet"- P8

6.6 Challenges and Barriers to minimising variation

When implemented correctly, findings show that technologies have simplified the construction process through better integration of project team, production of quality designs, comprehensive contract documents and improved site coordination. Almost all participants described tangible benefits derived on their projects that can be related to variation minimisation. Some participants said that despite their huge investment in the technologies they have used; they still recorded many variations at the end of their projects. Some challenges and barriers identified by participants from findings are discussed under the following headings:

Not all buy into it

Findings discovered that it is still common to find some project team members that are reluctant to implement new technologies despite the potentials and increasing popularity. Laggard construction practitioners among the project team reduce the benefits of adoption. The ageing workforce group of people are found mostly in this bracket according to the findings of this study. Some participants argued that the attitude of resistance from this group of people is a deliberate attempt to avoid the transparency that comes with the implementation of technologies. Below are quotes from participants to support this finding:

"I've got to retire in two years, so I can't be bothered. I don't want to learn something new"- P28

"When you come down to what we're doing on site, we've got fairly levels of age experience, and reluctance to use equipment"- P26

Technical issues

Some participants cited instances where they have to abandon the use of BIM halfway through their project and revert to 2D drawings because the tool did not work as expected. A participant said BIM abandonment halfway through projects is common in public projects awarded for meeting the government mandate of BIM level 2. Some contractor claimed that the cost of making changes to designs and correcting mistakes to 3D models are more than the actual cost of carrying out the physical work on site. This experience is common with construction firms with no in-house BIM expertise but employs the service of a BIM expert when required. Another reason for abandonment given by participants relates to commercial projects that were delivered under tight schedules. One notable housebuilder said their design process always catches up with construction process on design and build projects due to time constraints. This experience makes BIM implementation irrelevant.

A participant said that “people think BIM works like magic at a click of a button”. Implementing technologies requires ample time during planning to derive full benefits. Many construction projects are awarded under 'time is of the essence' condition. Quality time is required for proper planning of any construction activity. When BIM implementation is intended to work as a mystical tool; the possibility of abandonment is high. The Carillon case comes to mind on improper use of technology, Sandwell and West Birmingham Hospitals on which the company collapsed was a BIM project.

Cost of Implementation

BIM is gaining popularity in the AEC industry. Despite this, there is little information about the actual cost of BIM. There is a divergent opinion from this research’s findings when it comes to the justifying cost of implementation as a barrier. Some Architects said since their organisations adopt the technology, irrespective of the size of projects, they have used it on all their projects. From this point of view, it is cost saving investment. Findings from SMEs contractors and consultants’ participants whose clients are majorly private, and from commercial sector contended that digitalisation and automation tools are a waste of resources when handling small projects. Since the same requirement and documentation is demanded small and large projects on BIM projects, return on investment for SMEs is seen as not being achievable.

Lack of training, research and development

Besides the initial high cost of acquisition, as generally claimed, some participants said additional cost of training staff due to lack of in-house experts is a challenge. Whilst some participants did not consider the initial cost to acquire technologies as a barrier, but the lack of time to commit to training by construction practitioners. Construction practitioners work under tight schedules to deliver projects. A participant said that the organisation considers the only available time to learn new technologies is during lunch breaks.

Lack of seasoned graduates

Unavailability of seasoned fresh graduates stands as a crucial challenge. One participant suggested an overhaul of education pathways and curriculums of related construction degrees to reduce the cost of training on prospective employers. This solution is capable of eliminating the current digital skill gap. The current situation with graduates skilled shortage in the industry is depicted with this quote below from a participant:

> ***"The difference I guess is that most graduates these days have a certain level of computer literacy, BIM literacy you know, is fairly limited"- P9***

Procurement route

Implementation of BIM and other technologies demand a new approach to procurement. According to a participant "There's a limit to how well BIM process can work when you're on a design and build contract". Design and build procurement route leave some latitude open to the contractor to redesign and, therefore, satisfaction derived by clients through the use of 3D models, VR and other visual tools at the early stage of construction can be diminished. A new form of contract is required for all stakeholders to benefit maximally from implementing these technologies. The introduction of a new Practice Note, BIM and JCT Contracts in May

2019 is expected to further the understanding of BIM related legal and contractual issues.

6.7 Chapter summary

Data analysis results and findings in this chapter focused on data from open-ended questionnaire survey and 32 semi structured interviews. Findings showed that utilising technologies early along the construction process improves visibility and transparency in the execution of construction projects. These benefits ensure that project schedules and estimated cost are benchmarked continually. After data analyses, from key findings in this chapter, it is evidenced that many variations on construction projects that implemented emerging technologies are waning considerably. Challenges limiting anticipated benefits by construction organisations have been discussed. However, benefits are staggering up to justify the cost of implementation for many.

From findings from this research, it is evident that increasing demand and expectation of construction clients coupled with growing complex nature of construction projects, implementing emerging technologies is a non-negotiable on large construction projects. Furthermore, trends in the industry suggest that for designers, consultants and contractors to win contracts even on small to medium construction projects, adoption of these technologies is crucial. Utilising emerging technologies in construction is becoming a new way of working, managing and dealing with challenges of construction projects. In the next few years, laggard organisations may not be able to compete with those already in the forefront of technology utilisation and those who participated in this research.

Chapter Seven

Discussion of research findings

7.0 Introduction

This chapter reflects on meaning, interpretation, importance and relevance of findings of this research to existing research and practice. Chapter 1 introduced the research problems and identified the research aim and objectives. Chapters 2 and 3 reviewed literature to deepen knowledge in the research area. The literature review aided a thoughtful robust research methodology in Chapter 4. Chapter 5 quantitatively analysed application, trends and effects of emerging technologies on construction projects undertaken by study participants across the UK. Chapter six presented findings from open-ended survey and 32 semi-structured conducted.

The study investigates the application and effects of emerging technologies in minimising variations in UK construction projects. By comparing results and findings from the two databases, this chapter discussed significant outcomes that emerged from data analysis and key findings with research objectives. This chapter present first findings through the theoretical lens of agency theory. Followed by discussion on convergence and divergence between quantitative and qualitative findings.

7.1 Findings based on agency theory framework

Agency theory introduced describes the framework of this study. Agency theory explains the relationship in which the principal delegates work to another agent who performs the job. The fundamental idea of the argument is that principal-agent relationship is close to client-contractor ties in construction contracts. This theory is highly applicable to adversary relationships and disputes that often occur between clients and contractor in variation management in construction projects. Utilising emerging technologies solved agency problems and cost from empirical results obtained from interviews with study participants. Findings from open-ended survey also contribute meaningfully from Agency theory perspective.

Eisenhardt (1989a) argued that adversity generated by different goals characterise relationships between contracting parties. Addressing this adversarial relationship is a fundamental suggestion of agency theory. Differences in parties' altitudes to project risk also contributes to adversarial relationships among parties. Through incisive questions during interviews, research findings revealed that contractual parties may still have some different goals despite the implementation of technologies. Conclusions emerging from open-ended questionnaire and interview responses demonstrated that the use of emerging technologies submerges these goals by minimising project risks, costs and disputes. Gil (2009) said that "contracts do not deliver projects, but drive behaviour". Findings of this research found that through effective utilisation of appropriate technologies, actions that tend towards project adversity were made transparent and mitigated early. A participant said that adversarial relationship is easy to manage and control with the use of technologies according to this quote:

> ***"If you come into disputes and you're being accessed in arbitration and reconciliation, you have sub-contractor or a designer that said I never received such drawing. You can go back to the common data environments, and you can see that it was issued not to personally but to that company and you can also see that it was accessed say ten times, that you can do straight away"- P5.***

Utilising useful technologies from project inception eliminates information asymmetry. Information asymmetry is secrecy of agents (contractors) by intentionally keeping information that will lead to agency cost and problem from principle (clients). Findings suggest a closed gap between theoretical potential and application of BIM, federated BIM model, CDE, cloud computing and smart mobile devices minimised adversary relationships among the project team. Participants saw BIM as representing a well organised project information solution due to its ability to provide a platform that allows information sharing in good time across various stakeholders and levels of organisations. Federated BIM model is rich in information; it enables selective data sharing according to individual project needs. Part or entire project information sharing is made possible to stakeholders based on project requirements. Project teams that were dispersed by geographic locations were enabled to access project information from anywhere through mobile devices in real time. A participant said:

"It's much easier to get a team environment, being able to see a model and being able to understand that in 3D rather than trying to communicate something via 2D or written email"- P32

Agency cost

Agency cost is compared to additional charges burned by construction clients leading to construction project cost overrun. Both the construction industry and its clients have long sought for ways of minimising project cost, reduce project delivery time, increase productivity and quality of the final product. Interviews conducted with construction practitioners with practical experience of implementing emerging technologies established benefits of technologies. Findings revealed increased clash avoidance and reduced rework through 3D visualisation of integration of different discipline models into a single platform. Participants reiterated that emerging technologies helped them to make timely informed decisions right from project inception resulting into avoidance of claims, litigations and better allocation of resources on site from contractor's perspective. Key research findings were related to agency-associated problems, and present a summary of how the issues were mitigated on participants projects is presented as follows:

Table 7.1: Summary of findings from agency theory perspective

Agency-associated problems	Application and Effects of emerging technologies in minimising variations
Project complexity	The use of drones, 3D scanning for initial site survey/planning and monitor progress eliminate many uncertainties. BIM reveals clashes in federated models and simplifies both project and construction management for consultants and contractors. BIM tacked multiple dimension of project complexity.
Self interest	Combination of different technologies creates and monitor collaborative relationship and collaborative working environment/platform based on common project goal.
Information asymmetry	CDE decreases secrecy and agents working with outdated information. Made open communication and detailed communication trailing assessable to project teams.
Project risks	Agents risks are aligned, established and addressed as common risks.
Adversary relationship	Strong collaboration and transparency that minimised the consequences of working with incorrect project information and maximises opportunities for all project team.
Quality of the final product	Alignment of project goals, the abundance of real time information led to less rework, reduction of project cost and time.

7.2 Discussion of research findings based on objectives

The research carried out in this study seeks to investigate the impact of emerging technologies in minimising variations in construction projects in the UK. Variations are changes requested by contract parties, mostly by clients or their representatives after contracts are let. Changes are required or may be necessary for construction projects, for numerous reasons. Frequent changes to design or scope of work at construction phase often threaten project with failures with many ramifications. Despite the detrimental impact of incessant variations on construction projects, variation minimisation was not the root purpose of technologies implementation from research findings.

As construction projects are becoming complex by the advancement of technologies and a competitive business environment, it is fundamental to minimise variations to enhance construction project performance proactively. The quantitative results were easy to follow and understand due to the statistical nature and graphical presentation in chapter 5. On the other hand, findings presented in chapter 6 from interviews and open-ended survey revealed overwhelming, exciting insights. Results of this research are now discussed based on research objectives.

Objective 1: To investigate the influence of emerging technologies in minimising design errors.

Findings from the quantitative strand revealed that designs produced by utilising technologies such as BIM, 3D laser scanning, drones, VR and AR minimise design errors and enhance design coordination. It is impossible to just eyeball the designs in a traditional way to detect two parts of designs conflict. For example, it is hard to discover if HVAC and electrical systems are routed through the same space. BIM detects clashes automatically in design and federated models.

Quality designs eliminate variation, conflict and potential litigation on projects. Finding shows improved clarity and quality of designs before construction; this enables speedy construction activities and removes the traditional approach of raising queries or requests for information. Stakeholders are engaged early in the planning and pre-construction stage. The digital twin of the proposed project enhanced their understanding, thereby allowing them to contribute meaningfully from the beginning. The findings addressed the argument of Love (2002) that variations are necessary due to the inability of clients to visualise the end product of the construction process.

The findings showed that BIM is the most widely used technology in the UK construction industry and crucial to minimising design errors. This result registers with NBS (2019) report found that 69% of respondents are aware and using BIM. BIM plays a central role as it is a crucial enabler of and facilitator for many other technologies (The Boston Consulting Group 2016). Findings found that other technologies combine effectively with BIM to minimise design errors. BIM detects clashes in design, and 3D scanning scans construction sites in complex construction projects. VR enables construction clients to interact and understand the unbuilt structure in the BIM environment. This technology allows clients to make changes to design or change specifications. This finding confirmed the benefit of VR technologies in providing a three-dimensional view that can be manipulated in real-time to explore and analyse design options and simulations of the construction process (Bouchlaghem et al., 2005).

Majority of participants (95%) said that technologies improved clarity of project designs. This improvement could be as a result of eliminations of avoidable client variations by accurate 3D BIM models that helps stakeholders to understand proposed designs. This finding suggests that the use of 2D drawings contribute to an increased number of variations because many construction clients find it difficult to read and interpret. According to Arain et al., (2006), clients will continually request changes until they achieve the project objectives they have in their minds. BIM allows designers to generate different design alternatives, 95% of participants attest to this. Alternate designs are useful for construction clients to decide on the best options that will satisfy their ultimate goals.

Study findings demonstrated that variations elimination is a possibility if their origin and causes are determined as suggested by Awad (2001). Results show that technologies implementation significantly minimised design errors and improved quality of designs, though many participants indicated that their projects were not delivered on budget. This finding can be explained partly by Love et al., (2011) research that said technology will considerably improve the efficiency and effectiveness of design process only when technology is placed alongside other organisational and project-related verified strategies.

From the qualitative strand of inquiry, it was revealed that design errors is the biggest challenge in the management of construction projects. Architectural and engineering designs are the primary documents on which construction projects are agreed and managed. Findings revealed that BIM produced designs of high quality and accuracy that led to variations minimisation in construction projects. Error laden designs will undoubtedly set the stage for project failure. The use of emerging technologies encourages early involvement of contractor expertise to avoid and manage project risks. Issues of buildability and site logistic of design are nipped in the bud to eliminate variations and extension of time. BIM produced high definition 3D visual images of proposed projects that are easy to relate to by all parties. Participants' implementation of BIM and collaboration platforms made early involvement and cooperation of stakeholders achievable and sustainable throughout construction processes.

Kazaz et al., (2017) recommended that preparation of architectural and engineering designs in 3D instead of 2D to detect errors in the planning phase. This research found that the ability to detect clashes from designs of different disciplines when integrated helps to resolve and minimise errors before construction. According to Wong et al., (2018), design errors, omissions and design changes contribute to delays, leading to rework and cost overrun. Immensely virtualising designs in 3D lessen the chance of error or omission of designs.

Objective 2: To ascertain the role of emerging technologies in enhancing clients' satisfaction

Findings of this research established that with keen involvement of clients throughout the construction process, their briefs are translated entirely into project designs leading to variation minimisation. Opportunities to visualise designs in 3D improved communication between clients and construction teams. The final products, according to research participants, are higher than expected and thus increases the satisfaction of their clients. A typical traditional approach to managing construction projects places designers as middlemen between client and contractor. Clients' involvement gradually diminishes after given the brief until completion and handover. Intermittently, meetings are held to discuss works progress on site and to make changes. Many mistakes on projects are not revealed or resolved until later. Many construction projects are, therefore, delivered below expectation, leaving clients unsatisfied. Alshdiefat (2018) stated that "changes initiated by clients and design errors were found to be the major causes of change orders which are responsible for cost overruns".

From quantitative findings, 95% of study participants alluded that clients' better understanding of designs contributed to enhanced satisfaction. Also, 89% agreed that early involvement of clients in the construction process enhanced their satisfaction. In an attempt to understand the motives behind emerging technologies adoption in construction, the result shows that most clients encourage the use of technologies on their projects. Contractors and designers demonstrated many benefits of implementation in terms of saving cost, reduction in construction schedules and request for information (RFIs). Torbica and Stroh (2001) argued that the magnitude of construction client dissatisfaction is known when most of their money have been spent during construction. Findings of this study established the reversal of this occurrence with emerging technologies. Majority (73%) believed that technologies helped to control and manage client variations before construction.

Figure 7.1 represents the place of CDE in project management. CDE is not just for sharing geometric information of construction information, it is a place for everything. Crucial project information such as contracts reports, registers, schedules, model information is shared among project team in a virtual space. Clients visibility on projects is enhanced and value for money is justified.

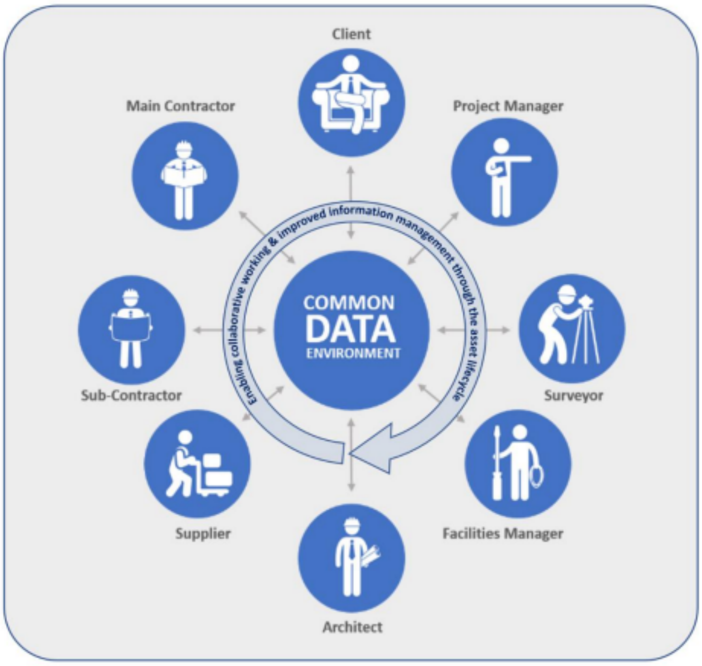

Figure 7.1: Central Data Environment adapted from www.scottishfuturestrust.org.uk

The Latham (1994) review on typical construction projects indicates that most construction clients remain unsatisfied with the outcome. Qualitative findings revealed that when are utilised correctly, technologies enhance the satisfaction of clients. Designers and contractors were able to deliver high quality products to fulfil the expectation of their clients. It is a lot easier for designers and contractors that offer exceptional service to their clients to win more contracts from a satisfied client than to win a bid from an unknown client. Ahiaja-Dagbui (2014) argued that nine out of ten construction projects overrun their budgets and concluded that maintaining client loyalty and retention remains a challenge for many construction firms. Utilising emerging technologies is helping contractors to retain their clients.

Ultimately, increased client satisfaction and engagement throughout the construction process minimises variation or reduces inevitable of variations to a barest minimum number. Dispute and inefficiency of project members lessen on most projects due to the ability of technologies to trace actions, documents and information accurately and seamlessly. Implementing useful technologies will prevent frightening experience, such as the construction of the Scottish Parliament Building. The project witnessed the death of the architect and resignation of two project managers which partly contributed to the increase in project cost from £10m to £414m and time overrun of 3 years. Implementing new technologies in construction assures clients of project continuity.

Objective 3: To examine the impact of emerging technologies on contractors' performance on site

Performance of contractor on site is crucial to protecting the design intent and delivering the result the client is expecting. This study discovered some mixed findings concerning the impact of technologies on contractor performance on site. Findings identified instances where contractors abandoned the use of some technologies halfway through the project when not making headway with implementation. Abandonment may be attributed to resistance to change among the older team members or frustration due to lack of in-house expertise, training and development.

Despite this misperception, most participants indicated their perseverance and willingness to use technologies they have tried in their next project. Contractor organisations leverage on technologies to access the right information at the right time to complete successful quality projects. Findings revealed that contractors were able to reduce construction cost in many ways though they had fewer opportunities for claims. Findings from contractors' performance perspectives established that when practitioners correctly utilised technologies, inefficiencies are eliminated during construction processes. Contractors found that close collaboration and reduction of risks helped them to deliver projects faster and safely. Research findings agree with the outcome of the NBS (2019) report on construction technology in Figure 7.2.

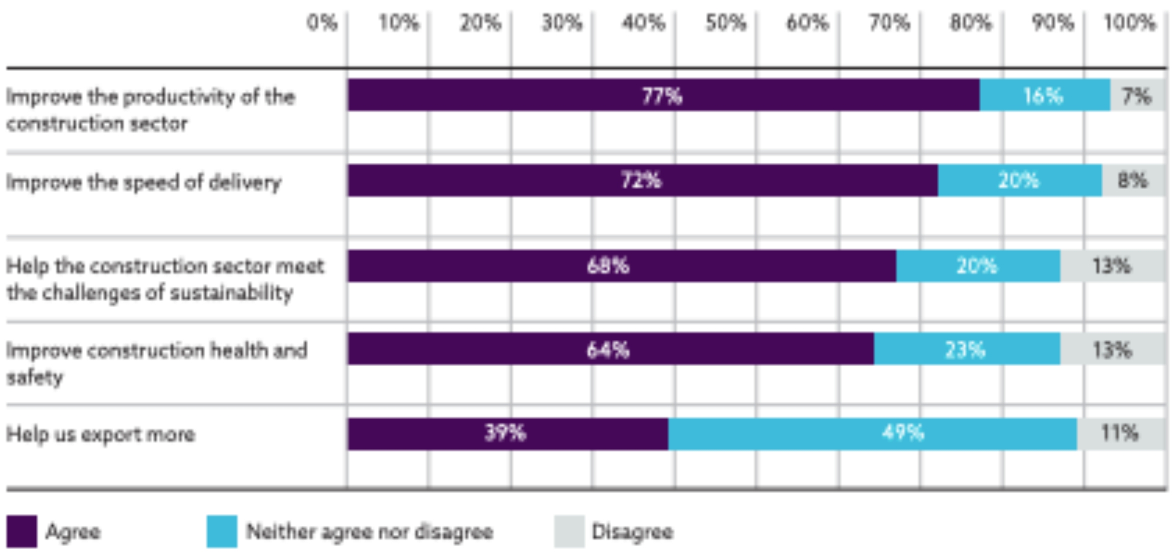

Figure 7.2: Impact of technologies in the UK adapted from NBS construction technology report (2019)

This finding collaborates with Elmualim and Gilder (2014) who argued that cultural and technological change is required to overcome challenges of implementation. Optimal utilisation of new technologies in construction requires a unique approach. Attempts by some research participants to combine both the traditional approach and BIM approach has resulted in abandonments of technologies and failure of contractors on site. Specific effects of combined technologies on projects of research participants include the ability to build 'in one build', improved safety, avoidance of risks, establishment of projects schedule, improved construction sequences/schedules, elimination of reworks and effective site coordination. This finding aligned with Arewa (2014) that commitment to health and safety does influence the profitability of the organisation.

From quantitative findings, contractor risks as a result of increasing project complexity were minimised and performance optimised on site. Technologies aid visualisation and buildability, which helps contractors to understand designs and avoid rework. This finding is consistent with the SmartMarket report (2014) that 75% of contractors surveyed believed they have a positive ROI (return on investment) on BIM investment. Also, findings align with the NBS (2019) report on construction technology in the UK in Figure 7.2 highlighting improved productivity, speed of delivery and health and safety as benefits of implementing emerging technologies in construction. All these benefits invariably minimise variations on participants' projects.

Alnuaimi et al., (2010) asserted that one of the reasons for variation of orders is lack of buildability of design. According to findings of this research, the use of modularisation and BIM improved effectiveness of contractors on site in overcoming this limitation. The use of prefabrication and modularisation units enabled by integrations of rules of modular coordination (MC) with BIM authoring tools to automate some complex modelling. No matter how unique or complex a design is, as long as it is constructible in 3D models, it can be prefabricated and installed. Construction wearables, artificial intelligence and high performance steel, are still not widely used in construction. The use of these technologies may be limited to large construction firms due to the degree of expertise required or cost of implementation. Convectional materials such as cement, bricks, steel and glass are still widely used in the UK construction industry. Despite the importance of innovative materials such as self-healing concrete, the application is limited, many of these materials are not widely recognised, and their application is not straightforward.

Findings from interviews found that technologies enhanced better management of human and non-human resources on site through increasing use of construction applications on smart mobile devices. Through effective project coordination, monitoring and tracking, contractors were able to manage construction sites and sub-contractors effectively. Contractors are usually subjected to suspicion by clients or their representative, accessibility of project information by appropriate project team made is possible by CDE establishes trust and transparency on participants' projects. Construction management apps enabled contractors to monitor site inspections, scheduling adequately and manage project cost. Real time visibility into progress and performance of sub-contractor on site were made possible and addressed, leaving no room for undesirable results.

Objective 4: To assess the impact of emerging technologies on fragmentation among project team

Effective collaboration and seamless communication are fundamental in the decision making process and variation minimisation. Findings of this study agree with a recent report by the NBS (2019) in Figure 7.3 that external and internal collaboration improved with technologies. Technology such as CDE, digital collaboration platform, cloud computing, federated BIM model gives access to the right project team to obtain up-to-date project information to work. Project teams worked with the latest version of all contract documents; this led to variations avoidance due to obsolete or inadequate contract documents. Level of access given to different project teams are based on what is needed to carry out their task successfully.

Noruwa (2018) stressed that the ripple effect of fragmentation is the lack of transparency and ineffective communication among project teams. Impact of fragmentation further increases project complexity, time and cost. Findings showed that emerging technologies promote data security, transparency and efficiency that diminish fragmentation and delay decision making. The use of CDE is crucial to large construction project management. It was described as "a single source of truth" for information sharing among the project team that is not dependent on email. Project information and documents were tracked digitally and, digital fingerprint access to project data monitored for data security. CDE helped to reduce communication errors and aid swiftness in decision making process. It reduces the risk associated with losing key players on long-duration projects and makes how project information is conveyed among project teams a lot clearer.

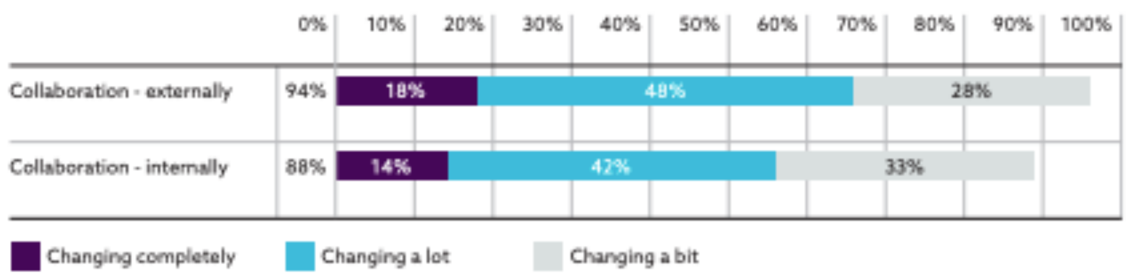

Figure 7.3: What technologies is changing in the UK construction industry adapted from NBS construction technology report 2019

From quantitative findings, swift flow of information among project teams rated as the highest effect of emerging technologies in construction. Technologies create collaborative culture from project inception through to the end of a project. This new way of working stamps out fragmentation and improves quality of works. This study complements the finding of Soares (2012) that blamed the disintegration of designs and construction process as the aftermath of iterate variation orders in construction. Through digital platforms and virtual meetings, barriers due to geographical locations of key players in the decision making process were pulled down. Stakeholders can access, share or be in control of the construction process.

Qualitative findings considered emerging technologies as crucial to large construction project execution. Every member of the construction team is important for successful project delivery, nature of construction project makes members reliant on one another. Virtual project information exchange shortened construction time on many participants' projects. Findings indicated staggering effects on time and early delivery through avoidance of conflict, less request for information and effective collaboration. Effective, up-to-date information sharing among the project team makes final products perfectly fit for purpose. Some participants challenged the conventional method of sharing project information through email, especially on large projects, as inadequate. They argued that communicating through emails contributes to delay and dispute in construction project management. Information shared may be breached, undelivered, deleted or denied for various reasons to the detriment of the project.

7.3 Quantitative and qualitative findings comparison

When implementing convergent mixed methods approach adopted in this research, Creswell (2018) recommends comparison and discussion of findings from both quantitative and qualitative databases. Analysis of the two databases revealed a large number of interesting insights to achieve the aim of this study adequately. Findings from the quantitative and qualitative research methods largely corroborated each other. Although, a little subtle difference observed are discussed in this section. Notwithstanding, owing to the quality and volume of data obtained from the two methods of inquiry, the purpose of validating findings using mixed methods was well served.

7.4 Convergence of findings from databases

In both a parallel and complementary manner, quantitative and qualitative data were collected and analysed concurrently. Findings from both strands of inquiry collaborate significantly. For example, responses from under objective one, 88% of survey participants agreed that the use of emerging technologies revealed design errors early before construction. Correspondingly, a participant alluded to a reduction of "nearly 9 out of 10" when asked to describe the impact of technologies in minimising design errors. Also, 89% of survey participants agreed that client involvement during the design was enhanced. A participant (P7) said the use of technologies is valuable to clients that are not familiar to construction process and another participant (P9) attributed ultimate satisfaction to client engagement through the BIM process.

To address the aim of this research; participants were asked to comment on the number of variations recorded on their recently completed project with the use of technologies and past projects completed without technologies. Findings from quantitative resulted in 61% agreement to a reduction in variations recorded and 39% disagreement/unsure response from participants. To complement this finding with the quantitative result, another participant (P2) agreed that things can still go wrong on site due to a lot of unknowns and complications that surround construction. Comparing this to interview findings, a participant (P7) said variations and problems on site that necessitate frequent site visit occur less with implementing technologies.

7.5 Divergence of findings from databases

Despite the strong correlation between findings from both strands of enquiry, qualitative findings gave deeper and richer results to achieving the research aim. A major divergent of findings from the two databases centred on the willingness of participants to continue to use technologies that they have implemented. One of the questions posed to survey participants stated:

“I am willing to use the technology in my next project”.

Overwhelmingly, 99% agreed that they are willing to continue utilising new technologies they have tried on their projects. A similar question was asked during surveys. Comparing this overwhelming percentage from interviews to responses from a parallel question asked from interview participants, there is a subtle divergence in the findings.

Question 9: Will you use these technologies again?

> ***"You don't have a choice, you know, in the western world now, in larger projects especially, is not if you are digitised or not. You have to be digital, that is the expectation. So, the question of will I or should I have passed"- P13***
>
> ***"I think we will persevere. Yes. It's definitely an open door to a better way of doing things even though we haven't quite got there yet"- P16***

Although survey result shows 99% agreed to continue utilising technologies on their projects, it appears technologies adoption is taken as coercion and not due to benefits of implementation from interview findings. Two things can be inferred from this divergence, one, that it is the BIM mandate that is mainly influencing implementation. Noruwa et al., (2018) argued that the coercive impact of regulative forces might limit institutionalisation. Institutionalisation is the action of ascertaining technologies as a norm in organisation or culture. Growing adoption of technologies by the industry may not be sustained on regulative enforcement of law alone. Two, that construction industry needs to address factors that prohibit full benefits to make implementation become a social obligation.

Findings from closed ended survey presented a straightforward result expressed in percentage of agreement or disagreement to related question with no further insight. Interview participants recognised significant roles of technologies in delivering projects on budget, on time and to quality. However, only a few projects attained this expectation. To expatiate further, interview participants flagged that project success is dependent on many factors and not just technologies implementation alone. Relating research outcomes to the aim of this study, findings demonstrated that application of various emerging technologies minimised variations on projects executed by study participants. Due to the inevitability of occurrence of variations, technologies made it easy to accommodate essential variations with less impact on the overall project delivery.

Table 7.2: Summary of key findings in relation to objectives

Research Objectives	Research findings in relation to objectives
1. Impact of emerging technologies in minimising design errors	The use of technologies such as BIM, 3D scanning, VR, drones reduced design errors by helping designers to detect clash, have a clearer view of design in 3D, identified mistakes, allow accurate representation of the surrounding, effectively engaged stakeholders in designs process. Designers were able to generate instant design alternative/options, track coordination issues and walk through the design.
2. Role of emerging technologies in enhancing construction client's satisfaction	Mobile application software on phone/tablet, VR, BIM, cloud computing, CDE improved client's satisfaction by making clients to be involved throughout construction process, have a better understanding of the unbuilt structure. Clients can walk through the unbuilt structure and make desired changes to design and specification of the digital designs, communicate in real time with project teams, monitor progress and make informed decisions on their projects.
3. Impact of emerging technologies on contractors' performance on site	The use of technologies such as drones, innovative materials, BIM, 3D scanning, cloud computing, construction applications on smartphone or tablet, CDE help contractor to improved buildability of design, encourage early engagement of contractors in planning and construction process. Utilising appropriate technologies reduce rework, simplify project complexity, give workers assess to up to date project information to work. Contractors were able to assign and monitor task on site, closely monitor work progress, speed up construction process. Emerging technologies also minimise risk and help contractors to win more contract.
4. Impact of emerging technologies on fragmentation among project team	Utilising collaboration platforms, mobile apps on phone or tablets, BIM, cloud computing, CDE led to effective and efficient communication among project teams. Seamless sharing of project information in real time enhanced decision-making process. It was easy for project teams to identify and trail laggard member of the team and speedy project delivery. Transparency and security in managing project information were enhanced. Emerging technologies ensure smooth continuity of construction projects in case of death or resignation of key project members.

7.7 Chapter summary

This chapter aligns key findings of this study with research aim and objectives. Findings demonstrated that when appropriate technologies are combined and leveraged early by designers in the construction process, perfect designs capable of abating problems that may occur later at construction phase are produced. It was also found that construction clients through technologies can derive true satisfaction, achieve ultimate project intension and be in control of their projects throughout the construction process. This study also discovered that contractors could continually optimise their performance on site to deliver outstanding projects by minimising unpredictable occurrences and inherent risks that surround construction activities.

Lastly, when technologies are utilised and embraced by all project teams, barriers such as geographical locations of project teams, and management of a vast number of stakeholders and management of enormous project information/documents are no longer threats to successful project delivery. Even when many anticipated benefits were not derived, many participants were willing to persevere in using emerging technologies. Development of a framework is necessary to support construction stakeholders in minimising variations, thereby minimising project cost and time. The preceding chapter discuss framework development using key findings of this research.

Chapter Eight

Framework Development, Discussion and Validation

8.0 Introduction

This chapter presents the development of framework that suggests useful emerging technologies to implement in minimising variations. The need for the framework, overview and the validation process of this framework are discussed. This chapter also covers discussion on who and how can implement the framework including its application and implications in practice. Summary of findings from chapter 7 concluded that emerging technologies are useful tools in reducing design errors, project team fragmentation, contractor inefficiency on site and client dissatisfaction on construction projects. This conclusion aligns with responses from open-ended survey presented in section 6.2.

8.1 Framework Development

The process followed in the development of this framework is outlined in Figure 8.1. Given the strategic position of the construction industry in the UK as discussed in section 3.1, it is often argued that even a small improvement to the industry would provide appreciable benefits for the industry and its stakeholders. To capture such benefits and potentials of technologies in addressing iterate construction cost exacerbated by variations, this study presents variation framework to minimise occurrence of variations in construction projects.

Framework development Process

As stated in Figure 8.1, the framework development emerged from extracts of key findings of this research of effects of emerging technologies on various UK construction projects obtained from open-ended survey and semi structures. Effects that are explicitly connected to variation minimization are arranged under each technology. To achieve this, research objectives listed in Section 1.7 are linked with technologies that best address these objectives. Benefits of technologies obtained from open-ended survey presented in Table 6.1 were searched and matched with appropriate technology to populate the framework. Similarly, empirical benefits given by study participants were extracted from findings of interviews uploaded to NVivo 12 and arranged under respectively technologies.

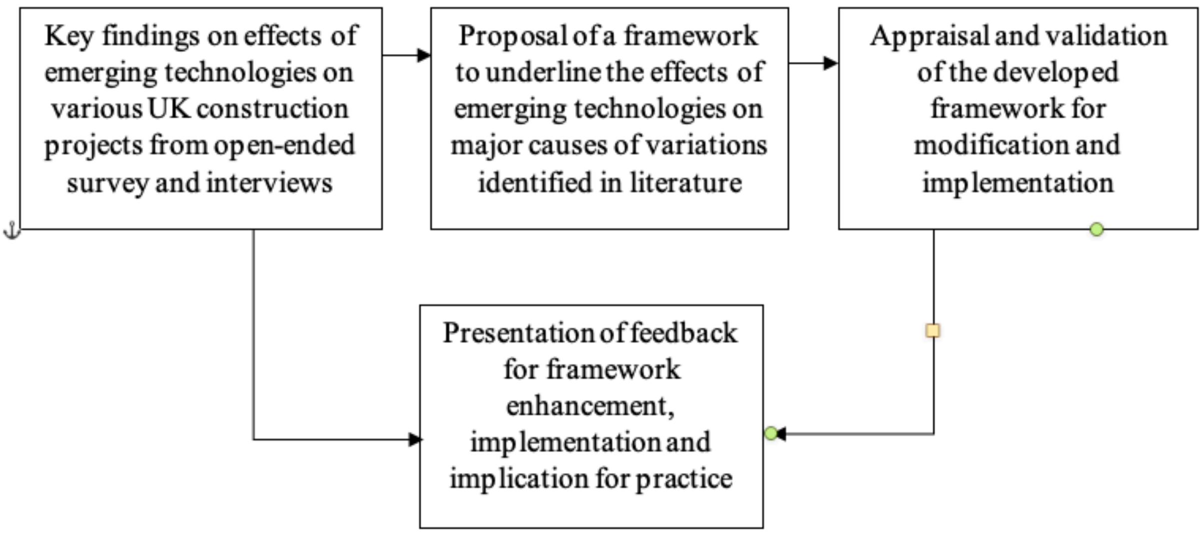

Figure 8.1: Framework development process

8.2 The need for the framework

Despite the huge benefits and potentials of utilising new technologies in construction, most practitioners in the industry still concede that the adoption of technologies in construction is in the future. There is high level of resistance among practitioners to adoption of technologies in the UK as reported in section 6.6. Some invest sporadically hoping to reap benefits by using technologies for government enforcement policy sake. The framework identifies types of issues that need to be addressed on a project, what technology to implement, how to implement and what benefits to expect upon application.

The framework explicitly outlines appropriate technologies that can be applied along the construction process to alleviate major fundamental root causes of variations. The development of framework proposed in this chapter is necessitated to utterly address the research aim of this study and research Objective 5 as outlined in Section 1.6. The framework also outlines how these technologies can be applied, the effects upon application and who directly benefits from the effect. The development is based on key findings from interviews and open-ended survey. Occurrence of many variations can be attributed to many factors that are not properly addressed at project inception. These issues cannot be tackled in isolation or with application of single technology. This framework is needed and useful to:

- Highlight major causes of variations that are common to all types of construction projects that can be avoided or eliminated. It provides the opportunity for key project parties at planning stage to identify factors that could lead to undue cost and time overrun during construction stage. These factors are variably detrimental to the success of projects if unaddressed.

- Identify useful technologies that can be applied along construction process that will enhance efficiency and reduce occurrence of variations, thereby eliminating cost and time overrun. This framework provides a simple model for all categories of clients, consultants and contractors planning to implement emerging technologies on construction projects.

- Illustrate graphically the interoperability between emerging technologies and variation minimisation in construction projects. This could help the construction industry to reduce delivery length and cost, thereby making construction to be likened to other industry such as automobile.

- Serve as modest benchmark outlining how to measure basic benefits of implementation of emerging technologies.

8.3 Framework Outline

The framework overview presents major causes commonly leading to occurrence of variation that can be avoided through implementation of appropriate technologies. It is practically impossible to include all the technologies examined in this study in the framework. Only examples of useful technologies are given in connection to identified root causes of variations. Only selected technologies are accommodated in the framework. The proposed theoretical variation minimisation framework illustrates the connection between application and effects of technologies in relation to identified main causes as presented in Figure 8.2. The framework comprises the following components:

Input factors:

- Four major root causes of variations as identified in literature and addressed as research objectives. These root causes are also linked with their causers e.g. designers, clients, contractor and project teams.
- Arrows linking root cause of variation to specific examples of technologies that can be applied to eliminate the occurrence of causes.

Context:

- Examples of various emerging technologies that are being applied along the construction process. These technologies are illustrated with their symbols and names.
- ⊘ Illustrates brief description of how these technologies have been applied to minimise variations during planning, design and construction phase by study participants.
- ☼ Represents benefits derived upon application that directly and indirectly contribute to variation minimisation.

Output indicators to project stakeholder:

- Arrows linking empirical application and effects to potential capability of variation minimisation.

The framework layout

The proposed theoretical variation minimisation framework is shown in Figure 8.2. The layout of the framework makes use of symbols to name technologies. Coding technologies' application and its effects makes it visual and easy to understand. The framework indicates that a single technology can be applied on a project to serve different purposes and deliver diverse effects for the project team. For example, drone can be used by designers on complex and risky project location for initial site survey to accurately gather site data. Quantity surveyors can use drones to monitor progress of work on site to enhance interim valuation preparation.

The empirical effect in minimising design errors is that accurate site mapping informs better design leading to production of quality 3D models that provide realistic visualisations for clients and contractors. In the same vein, drones can be used later by designers and other consultants to effectively monitor progress of work on site. Images captured by drones can expressly convey to construction clients how the finished product will ultimately meet their personal or corporate desire. Video clip of images captured by drone during construction can serve as marketing tools by the clients before project completion.

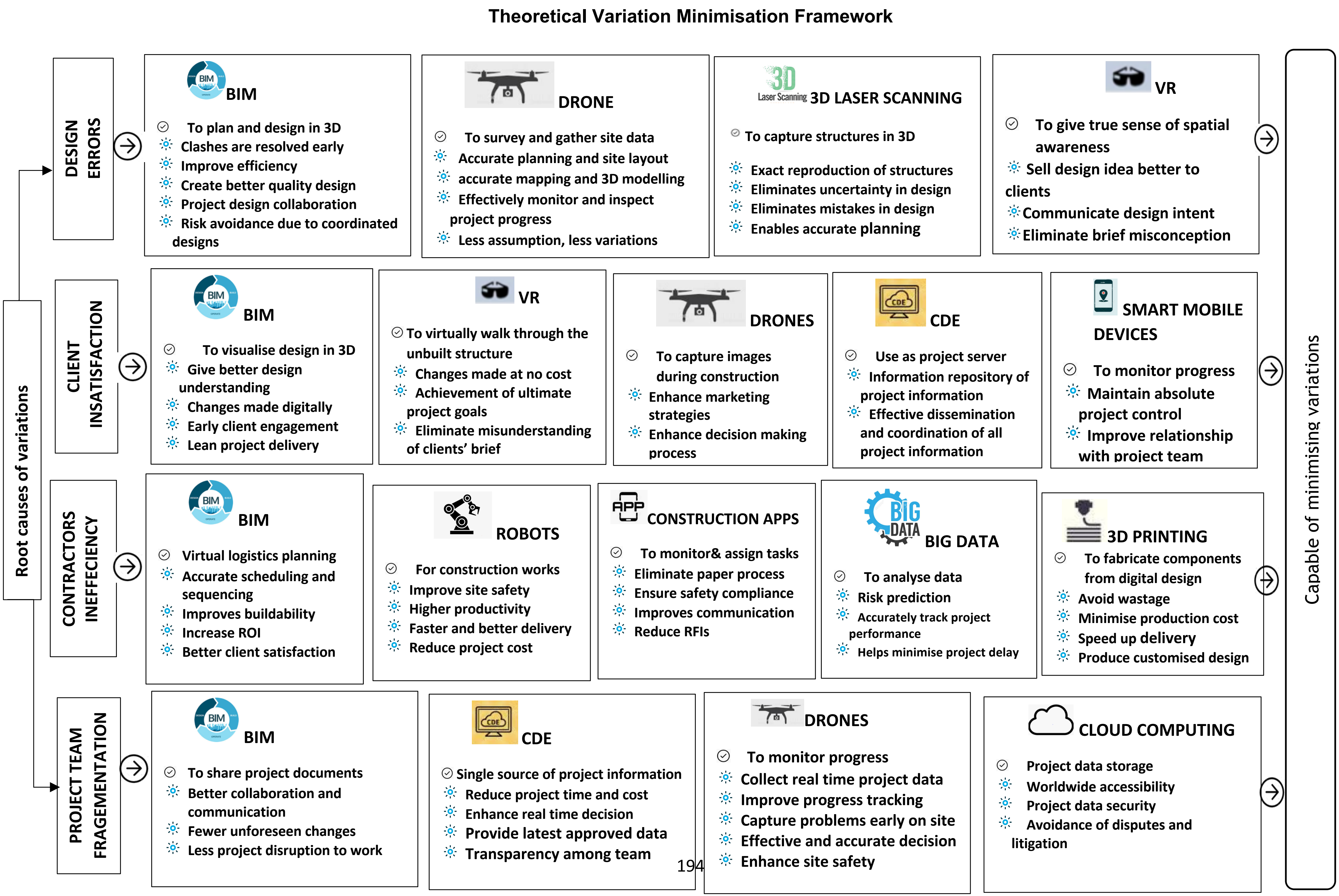

Figure 8.2: Technologies-supported Variation Minimisation Framework (Key: ⊘ = application ☼ = effects)

8.4 Framework Validation

Section 4.12 briefly described framework validation process. Validation is an essential stage of the framework development. For the new knowledge derived to be authentic, the results and the process by which research have been conducted need to be accepted by professional communities and academics. This formed the need for validation.

Purpose of validation

The purpose of framework validation is to allow both practitioners and academics to determine whether or not the application and effects of technologies correctly replicate the fundamental benefits or knowledge. Practitioners in different roles and capacities that have implemented various emerging technologies in their construction projects uncovered numerous effects upon application. As outlined in Section 1.6, these effects were captured under four headings which formed the objectives of this study. These benefits constitute the integral component of this framework.

Framework Usage

Construction clients are often hesitant to pay additional fees for tools and technologies that will enhance the service of their consultants and contractors. Client's understanding of requirements and the benefits of utilising emerging technologies are crucial at project inception. The design of this framework is to support construction consultants and contractors, especially at the pre-contract stage. The aim of developing the framework is to provide a virtual and straightforward awareness of application and effects of emerging technologies that can effectively minimise variations in construction projects.

The validation exercise involved both practitioners and academics due to the following reasons:

- The framework was developed to assist construction stakeholders during project inception and planning stage. To simplify decision making process for stakeholders on useful technologies to implement to minimise variations. Minimising variations ensures construction final product fulfils the expectations of clients, projects are delivered to budget, time and expected standard.

- Acceptance, implementation and awareness of many emerging technologies are still in their infancy stage in practice. Based on the novelty of this study, this framework promotes awareness of potentials of technologies among academics.

Objectives of validation

Based on research aim, the framework validation was carried out to achieve the following objectives as outlined in Section 1.6:

1. To investigate the impact of emerging technologies in minimising variations caused by design errors.
2. To ascertain the role of emerging technologies in understanding clients' needs to avoid variations.
3. To examine the effect of emerging technologies on contractors' early engagement and its resultant buildability performance onsite.
4. To identify the impact of emerging technologies on project team fragmentations.
5. To develop a framework that elucidates the potentials of emerging technologies on variation minimisation in construction projects.

Process of validation

To confirm if findings of this study as presented in the framework by the researcher correspond with the participants (Bryman, 2016) and academic communities, the framework validation process follows these processes:

- One-page summary consisting of the research title, aim, objectives, brief insight of research methods and key findings from the study was composed.

- A questionnaire was designed and distributed among practitioners who participated earlier in the study to validation of research findings. A copy of the framework was included in the email sent out to participants.

- Another questionnaire was designed and sent out at the same time to a list of seasoned academics in the local and external university community to validate the framework. Email sent out included a copy of the proposed framework and one-page summary as described above.

Copies of the questionnaire sent to practitioners and academics are included as Appendix E and Appendix F respectively. Table 8.1 presents details of both practitioners and academic participants that completed the validation questionnaire.

Table 8.1: Details of validation questionnaire participant

Academics Validation		Practitioners Validation		
Code assigned	**Qualification**	**Previously assigned code (Table 6.2)**	**Participant organisation**	**Job role**
P1	Professor of Quantity Surveying	P5	Construction firm	Head of Digital construction
P2	Senior Lecturer in Quantity Surveying	P31	Construction and interior fit out firm	Digital Engineer
P3	PhD Researcher in health and safety in construction	P7	University, Estate department	BIM Manager
P4	PhD Researcher in Construction contract claims	P25	Digital Consulting firm	Application Engineer
P5	Senior Lecturer in Quantity Surveying	P30	Project Management firm	Project Director
P6	Senior Lecturer in Construction management	P10	University, Estate department	Architect
P7	Professor in Architecture			

Previously assigned codes to interview participants were maintained for consistency. The validation employed the use of the Likert scales exactly the same way it was applied in questionnaire measurement scale and codes in Table 4.4 and questionnaire scale interpretation in Table 4.5. Likert universal-dimensional scales is easy to understand, less laborious and confirms that all items measure the same thing. The process was carried out in two phases as outlined in Section 4.12. The two phases are described in detail below:

Phase 1- Validation with practitioners

All interview participants were asked to review and comment on both summary of findings and proposed framework based on their experience of implementation. Also, participants were asked to comment on percentage they think variations has been minimised on their completed projects upon implementation of technologies. Other general feedback, comments and suggestions regarding the framework were solicited for as well. Finally, the willingness of their organisation to use the framework in planning for future projects was assessed.

Phase 2- Validation with academics

Validation with academics took a similar process, questions asked were tailored towards achieving generalisation of the proposed framework. Participants were asked to indicate their willingness to use the framework for further study, teaching and research. Feedback that will enhance the framework was solicited for in the questionnaire.

8.5 Framework validation results and discussion

Results from validation analysis copied from Excel are presented in Table 8.2 and Table 8.3. Industry and academic validation methods were chosen due to the novelty of this study and to establish the usefulness of framework within the wider industry. Results obtained from both phases of validation provide deep insight on how variations can be minimised effectively with the implementation of appropriate technologies. All participants in phase 1 of the validation process were part previous 32 semi-structured interview participants. Participants in phase 2 mostly have no prior knowledge of this research study.

Table 8.2: Validation results from practitioners

	Framework Validation Results -Pratitioners'								
	Questions	**Participants' score**						**Average**	
		P1	P2	P3	P4	P5	P6	**Score**	**%**
1	This framework is easy to understand	4	3	4	5	4	4	4.0	80
2	The framework is very informative	4	3	3	3	4	2	3.2	63
3	The framework reflects my organisation experience with technologies	4	3	-	3	5	3	3.6	72
4	The framework will be useful for decision-making process	3	3	3	3	5	3	3.3	67
5	The concept in the framework can support technology adoption	3	3	3	3	4	3	3.2	63
6	Proper implementation will minimise variations in construction project	4	3	3	4	4	3	3.5	70
7	The framework presents a new concept in construction management	2	2	-	-	4	2	2.5	50
8	The framework is well presented and logical	4	3	3	5	4	3	3.7	73
9	Major causes of variation identified are well addressed by technologies	4	3	3	2	4	2	3.0	60
10	The framework can be useful in real life project planning	4	3	3	3	4	3	3.3	67
11	The framework will benefit construction clients during project inception	3	3	3	3	5	4	3.5	70
12	The framework output is capable of minimising variation by 50%	3	-	-	-	-	-	3.0	60
13	The framework can encouragement adoption of technologies in construction	4	-	3	3	5	-	3.8	50
14	Framework will benefit contractors to reduce construction time and cost	3	3	3	-	4	-	3.3	65
15	The framework is useful to all construction stakeholders	4	-	3	3	4	3	3.4	68
16	I am willing to reference this framework among my project team	4	2	3	3	4	3	3.2	63
	Overall assessment							**3.3**	**65**
	(1= very strongly disagree, 5= very strongly agree)								

Table 8.3: Validation result from academics

	Framework Validation Results -Academic									
	Questions	**Participants' score**							**Average**	
		P1	P2	P3	P4	P5	P6	P7	Score	%
1	This framework is easy to understand	5	3	5	4	3	4	5	4.1	80
2	The framework is very informative	5	3	5	4	4	4	5	4.3	83
3	The framework is capable of creating awareness	4	3	4	4	5	4	3	3.9	80
4	The framework will be suitable for teaching construction students	4	3	5	3	3	3	5	3.7	70
5	The concept in the framework provide insight for further research	5	3	4	4	4	4	4	4.0	80
6	Proper implementation will minimise variations in construction project	4	3	4	4	5	4	5	4.1	80
7	The framework presents a new concept in construction management	3	3	5	-	5	-	4	4.0	64
8	The framework is well presented and logical	5	3	5	3	3	3	5	3.9	73
9	Major causes of variation identified are well addressed	4	3	5	3	4	3	4	3.7	73
10	The framework can be useful in real life project planning	4	3	5	3	4	3	3	3.6	73
11	The Framework will benefit construction clients	4	3	5	3	5	3	4	3.9	77
12	The framework output is capable of minimising variation by 50%	-	3	4	-	5	-	4	4.0	48
13	The framework can encouragement adoption of technologies in construction	5	3	4	3	4	3	4	3.7	73
14	Framework will benefit contractors to reduce construction time and cost	4	3	4	-	5	-	3	3.8	64
15	The framework is useful to all construction stakeholders	4	3	4	3	5	3	5	3.9	73
16	I am willing to reference this framework when is applicable	4	3	5	3	5	3	3	3.7	77
	Overall assessment								**3.9**	**73**
	(1= very strongly disagree, 5= very strongly agree)									

Comments and suggestions for improvement

Results from Table 8.2 revealed that participants agreed the framework is easy to understand. Also, participants found that major causes of variation identified in this study and effects of various appropriate technologies upon application will be useful in decision making processes in their subsequent projects. Based on the overall average assessment score of 3.3 over 5.0 which is the highest score, the framework reflects the findings of this research. Therefore, the study context can be said to be trustworthy and meaningful. However, suggestion that the framework is capable of minimising variation by 50% was largely criticised by all participants for lacking empirical data to back it up. The suggested percentage was removed from the framework and the output was refrained as 'capable of minimising variation'. The framework was also considered a straightforward virtual aid with potential to support clients and laggard member of project teams on technology acceptance.

Results from academic validation received a higher level of acceptance of 3.9 overall score compared 3.3 from industry practitioners. Participants were of the opinion that the framework is very informative, suitable for teaching and capable of minimising variation upon proper implementation. On a general note, the framework was viewed as not introducing any new concept in construction management but was found to provide insight for further research. The academics agreed to reference the framework where applicable and appropriate in teaching and research.

8.6 Framework limitations and Implications for future use

Research findings are contextual, application of this framework is reliance on proper implementation of technologies by experts. As it is applicable to any framework, implementation is not a guarantee for automatic benefits. Benefits listed under various technologies in the framework were accrued from mainly large and complex construction projects undertaken by leading construction firms across the UK. Effects of technologies on small to medium construction projects of less than £10 million would have to be conducted to effectively quantify potential impact on variation. The actual number of total variations experienced on projects examined were not accessible. Implementation and application of these technologies by trial and error approach may limit benefits itemised on framework.

8.7 Chapter Summary

This chapter presented a framework which is aimed at supporting construction stakeholders to avoid incessant variations through implementation of appropriate technologies. The need for the framework is to accomplish research objective four. The framework also forms part of the contribution of this study in redeeming the negative perception of the construction industry on project cost and time overrun. The chapter discussed the development, validation and implication of the framework. The validation received acceptance among practitioners and academics.

Chapter Nine

Findings, conclusions and recommendations

9.0 Contribution of this thesis to knowledge

This study aims to investigate the application and effects of emerging technologies in minimisation of variations in the UK construction projects. Variations in construction is a practical reality given the uncontrollable external atmospheric conditions where construction works are executed. Research finding found that many causes leading to variations in construction projects are within human and technological control. Participants that correctly implemented appropriate technologies along their construction processes avoided root causes of variations and some proactively eliminated variations based on Table 6.1 and findings from interviews presented in sections 6.3 and survey in section 5.6. Unavoidable variations encountered were accommodated on projects with minimum impact by leveraging on technologies implemented by study participants.

Also, one of the novelties of this research work is that it contributes to literature relating agency theory to the field of construction as discussed in Section 2.1 and 7.1. This study relates agency-associated problems to variations that impact on overall construction project cost. Agency theory was used to understand the roles of technologies in minimising adversarial contractual relationship between clients and contractors. This research contributes to fewer studies in construction management that utilise agency theories and pioneering work that discussed variation minimisation from a principal-agent perspective. Besides, this research work increases awareness of the importance of accepting the use of emerging technologies as a new way of effective management of construction projects in the UK. Empirical findings from this research provide an excellent framework to jettison adversary relationship and lack of transparency in the industry. Efforts of construction practitioners to minimise variations has potentials to redeem the tarnished the image of the construction industry.

The NBS (2019) reported that disputes on construction projects in the UK are not going away. By eliminating risks and uncertainties before actual construction, disputes and variations are minimised in construction projects. Findings revealed how potential variations were minimised on various projects examined due to good quality designs represented digitally by 3D models, effective collaboration and seamless information sharing among project teams. Clients' brief and project intent were captured by practitioners, reviewed and better presented. Early involvement of key stakeholders in the planning process also contributed to successful project deliveries.

Figure 9.1 shows the transformative impact of technologies as demonstrated from findings of recent construction survey. Findings of this research agree with NBS (2019) report that found that technology is transforming the way construction work is been carried out. Historically, the image of the construction industry, as portrayed by its clients, is negative and undesirable by young people. Despite the significant contributions of construction industry to the economy, the industry has an image tantamount with high cost, poor quality, chaotic working practices and working environment laden with poor health and safety issues. Interestingly, research findings further revealed that some of these challenges are now being addressed through the use of emerging technologies.

The majority (77%) of study participants believe the final structures of construction are perfectly fit for purpose in Figure 5.4b, 83% agreed their projects were delivered on time, and 60% said technologies helped them to deliver their project on budget. The construction industry in the UK is slowly making progress in improving its image in the last decade, but there is a long way to go.

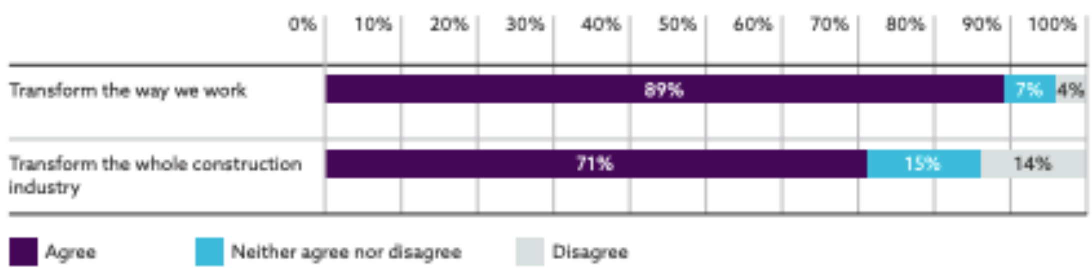

Figure 9.1: Impact of technologies in the UK construction industry adapted from NBS construction technology report 2019

Another contribution of this thesis to the body of knowledge is that it established that variations in construction projects could be minimised by utilising appropriate useful emerging technologies on construction processes. This contribution established that it is a distorted conclusion to capitalise on the inevitability of variations in construction projects as an excuse for failure to deliver construction contracts as agreed.

Another contribution of this thesis is that it offers insight into how the use of technologies in construction are intimately interconnected and explicable by reference to the whole. More attention has been given to BIM in the AEC industry in recent times due to its established paradigm in project delivery practices and its central role as a key enabler for many other technologies. Empirical findings of this study produced valuable insight into complementing roles of other technologies. Therefore, apart from BIM, construction industry in the UK should pay due attention to other technologies that are equally driving change. According to impact recorded by participants in Table 6.1, technologies such as VR, drones, mobile smart devices, construction application software, cloud computing, 3D scanning, CDE and others are driving forces with BIM in minimising variations. The combined impact of these technologies will collectively move the UK construction industry forward in achieving the Construction 2025 vision and beyond.

The objectives of this study are to investigates four significant reasons for variations in construction projects. Study practitioners and clients in the industry utilised emerging technologies to manage their construction process experienced a fewer number of variations on their projects. Howbeit, many construction practitioners in the UK, are still very sceptical about the benefits of adopting these new technologies. Those that have successfully implemented technologies under investigation in this research have leveraged on its impact to improve their competitive advantage. Laggard construction firms that refuse to innovate may be left behind as incompetent and extinct overtime. It is remarkable that 25 years after Sir Michael Latham's 'Constructing the Team' report that called the UK construction industry to action, some of the recommendations are now met according to findings of this research.

9.1 Summary of main findings

This section presents summary of main findings of this research in line with research process undertaken to achieve research aim and objectives.

Literature review

Explorative literature review undertaken revealed knowledge gaps which resulted in the following findings:

1. Reports of several government-initiated evaluations on construction industry performance signal that cost and time overrun are significant challenges to be tackled through a radical transformation of the industry.
2. Major root cause of cost and time overrun has been traced to incessant variations due to poor designs, fragmentation of project teams, poor performance of contractors and inability of the industry to satisfy its innovative clients.
3. The UK construction industry is at the cusp of a veritable technological revolution. Although adoption of emerging technologies is key to addressing fundamental problems in the UK construction industry, their applications and effects are not evenly felt across the industry.
4. There are potentials of reducing variations on construction projects to the smallest number possible. Several strategies, frameworks and models proposed by researchers are, however, reactive rather than proactive.
5. While research on BIM is building up, other emerging technologies are equally making tremendous impact on construction process. Little effort has been made to investigate how variations can be minimised by leverage on the combination of these emerging technologies.

Semi-structured interviews

Thirty-two in-depth exploratory interviews were conducted with seasoned construction stakeholders that have implemented some emerging technologies on their completed and on-going projects. The following were the findings:

1. Utilising emerging technologies improve transparency, visibility of activities of every member of project team and mitigate risks for project stakeholders.

2. Early utilisation ensures that contract sum and project schedules are continually benchmarked and monitored by stakeholders.
3. Variation minimisation was not the focus of implementation of these technologies. However, implementation resulted to reduction in design errors, collaboration of project team, increased efficiency of contractors' performance and early client engagement and satisfaction. These effects steered to variation minimisation.
4. Many projects that utilised some of these technologies were not delivered on time or budget due to many other factors. Exceptional quality of the final product, effective management of unavoidable variations encountered, real-time collaboration among parties and access to the latest information are common benefits of implementation, nonetheless.
5. Despite investment made on technologies, some participants felt let down due to challenges and barriers encountered that limit full anticipated benefits. Section 6.6 reported these challenges and barriers. However, there are significant reductions in the level of uncertainties and risks commonly associated with construction works.
6. BIM implementation allow high level of flexibility and customisation that increases the use of other emerging technologies and materials, especially, modular units, prefabrication components and other innovative materials.
7. Benefits are stacking up for all stakeholders, many participants are willing to persevere utilising these technologies despite some abandoned technologies halfway their projects.
8. Utilising technologies is a better and new exciting way of managing projects effectively.
9. It is practically impossible to execute large construction projects without utilising combinations of many technologies.
10. At pre-construction stage, technologies allowed changes to be made seamlessly in real time and inevitable variations during construction process were carried out faster without quality degradation and excessive cost.

Close ended survey

Thirty close ended questions were drawn from literature review to measure quantitatively the combined effects of technologies used and how they minimise variations on participants' projects. Sample of the questionnaire used in data collection and how data was analysed are presented in Appendix C and chapter five. Findings are:

1. Early engagement and better practical understanding of construction clients and contractors in the planning process through to pre-construction stage exposed problems that could have resulted in variations before actual construction activities.
2. The use of emerging technologies enhances production of high-quality detailed contract documents and designs for effective construction project management.
3. No indication of any appreciable reduction in the use of manual labour and headcount of workers on site.
4. Technologies present no significant impact in combating inclement weather.
5. Seamless sharing of up-to-date information, reduction of risks associated with project complexity helped to avoid dispute and variations.
6. Client satisfaction improved on projects due to brief better representation in three dimensions made accessible to key stakeholders.
7. Effective communication of the owner's requirement between designers and contractor proactively led to avoidance of client-directed variations.

Open-ended survey

Out of 70 duly completed questionnaires, only 53 participants provided further details about their projects as requested in this section of the survey. This session was included in the questionnaire to collect empirical data from participants on specific effects of technologies used on the overall project and variation minimisation. Table 6.1 of chapter six presents the effects of implementation on 80 projects collated from the survey. The findings include the following:

1. The use of BIM, clash detection tools, smart mobile devices and construction applications is common to all the projects.

2. Project types mostly represented are educational, offices, infrastructures, industrial and health buildings. No social or public housing projects featured in all projects examined; however, technologies application involved both refurbishments and new build.
3. It was easy for many participants to itemise the direct impact of technologies used on the project as a whole, but some were unable to comment about variation minimisation.
4. The use of some technologies such as 3D printing, AI, Big data and 6D BIM is still patchy in the construction industry in the UK.

Framework

Research findings led to the development and validation of a framework that suggests useful emerging technologies to implement in minimising variations. The validation exercise involved practitioners that participated in the research interviews conducted and academics that have no foreknowledge of the research. These streams of practitioners agreed that the framework:

1. Provides a simple, and virtual awareness of application and effects of emerging technologies that can effectively minimise variations in construction projects.
2. Is informative and useful in enhancing current practices among construction stakeholders and academia.
3. Is capable of providing a basis for future research on the application and effects of emerging technologies in minimising variations. This result was expected as the subject of variation minimisation, or reduction is scarce in literature.

9.2 Study implications for practice

Findings of this research showcase the practical benefits of emerging technologies implementation to encourage adoption. The findings of this study have implications for policymakers, clients, contractors and construction practitioners who are planning to undertake or procure construction projects. The framework developed can assist in suggesting relevant technologies that can be implemented by stakeholders to reduce construction cost and time. Empirical findings of this research established that utilising technologies in construction is addressing longstanding challenges of the industry. It is critical, therefore, for the UK construction industry to embrace emerging technologies that are springing up. This study's findings are timely and useful to speed up emerging technologies adoption in the industry. The NBS (2019) findings shown that the UK government aspiration in setting the industry on the right path with BIM has not been successful in maintaining the momentum since its enforcement in April 2016. This research contributes to spreading the awareness of emerging technologies among academics and practitioners towards digitising the UK construction industry.

9.3 Recommendations

Based on the findings of this research, there are recommendations for the academic, construction practitioners, clients and policymakers.

The use of BIM and other emerging technologies has increased in the UK construction industry. However, there is a dearth of seasoned graduates to employ in the market in reality. For the academics, the recommendation is that knowledge of technologies discussed in this research should be included in the curricula of all construction-related programmes in higher educations. Knowledge of emerging technologies can be introduced as an underlying theme for undergraduates and as stand-alone courses for postgraduate students. Robust academic training of graduates on technologies is a tremendous asset to the industry to combat the skill shortage looming in the industry.

Human nature is resistant to change. For personal career development, it is recommended that practitioners that are in full employment should attend regular industry events that educate, showcase and train people on new technologies in construction. Embracing new technologies will benefit individual construction practitioners and construction firms now and in the future. Stiff opposition against technologies implementation by team members limit potential benefits and overall success of a project.

Lack of client mandate may potentially slow down adoption. Technologies make transparency a norm; this is an attractive feature for construction clients. In order to get value for money, construction clients should demand the implementation of

BIM. It is also recommended that private clients embarking on construction projects worth over £500,000.00 should demand the use of BIM and CDE to complement the existing BIM Level 2 mandate on centrally procured public projects enforcement in 2016.

Policymakers are people in positions to create plans and ideas, whether in government or commercial organisations in construction industry are implored to embrace change. Adoption of BIM and other emerging technologies in the UK construction industry is one of the greatest technological innovations to date. Strong government support is needed to support progressive adoption. The UK BIM report (2019) stated that the 2016 BIM mandate by the central government is perceived to have had limited success in maintaining its momentum. A suggested way of vigorous enforcement by the government may be the demand of 3D models for approval of planning permission of medium to large scale construction projects. It is also recommended, therefore, that the government should increase the driving force of adoption and also oversee increasing awareness in the academic community.

It is not enough for construction firms to assume that lunchtime is the only available time to train staff on how to use new technologies along construction process. Effective structured training should be provided for project teams, senior managers and all other employees to equip them to deliver projects using cutting edge technologies. It is also recommended that construction firms should educate their clients on the values of these technologies. Despite the great potential of Artificial Intelligence, only a few AEC firms currently have the capabilities to implement them. Large construction firms in the UK are called to take up this challenge.

9.4 Limitations and implications of this study for future study

Although this study yielded significant findings to the body of knowledge, there are limitations associated with the study, which can be taken into consideration for future research.

- Sample bias is a potential limitation of this research. Purposeful sampling was considered most appropriate to collect empirical data in addressing the aim and objectives of this study. This sampling is used in qualitative research widely. Effective sampling methods are employed in research to maximise efficiency and validity; more numbers could have been useful for the quantitative strand of inquiry.

- To identify significant relationships from data, the larger the sample, the more precise the result will be. It is essential for future studies to collect more data from more extensive professionals in the industry to boost generalisation.

- Lack of previous research work on research topic posed a significant challenge. This study appears to be one of the pioneering research work that seek to investigate potentials of emerging technologies in variation minimisation. Many researchers suggested variations minimisation as a prerequisite to successful project delivery. Chan and Yeong (1995) considered clear and thorough brief as the most useful strategy. Yadeta (2016) recommended early involvement of main parties at project inception and production of complete designs before commencing work on site as two uppermost ways of minimising variations. Combined effects of emerging technologies variation minimisation on construction projects are scarce in literature. The unavailability of previous research to benchmark with notwithstanding, the methodology adopted, may have impacted the interpretation of results and findings. More research is needed to quantify the impact of emerging technologies on every facet of construction process to establish full benefits and justification.

- Access to contract documentation confirming the actual number of variation orders on projects examined in this study is outside the scope of this study and, however, it is a limitation. Although most participants confirmed a reduction in the number of variations witnessed on their projects, records of variation orders are not made accessible during data collection. Variation orders are part of contract documents which are not openly accessible to third parties. Besides, some participants claimed they have non-disclosure agreements and, therefore, refused to divulge any vital information/documentation as such actions are seen as a breach of contract.

It is recommended that professionals such as quantity surveyors who have direct access to records of variations on projects could take the opportunity to report trend on variations in future research.

9.5 Concluding remarks

This research presents empirical insight using mixed methods approach into the application and effects of emerging technologies on variation minimisation. It was found that BIM occupies a central and leading position among other technologies that are emerging in the UK construction industry. However, the use of technologies such as drones, VR, 3D scanning, CDE, cloud computing, project management software and smart mobile devices is becoming a norm in management of construction projects in the UK. Designers leveraged on these technologies to produce quality contract documents that reduced rework onsite and enhanced buildability for contractors. In summary, the use of emerging technologies in construction clarifies project designs and planning digitally before any work commences on site, thereby minimising variations.

Digital twin promotes visualisation, early engagement of stakeholders, better planning and active collaboration of the project team. These benefits mitigate common project risks and remove issues that could lead to variations. Findings also see construction industry in the UK as a polarised industry. While some organisations are embracing emerging technologies as a norm for their competitive advantage, others are laggard and resist adoption. Some clients and construction organisations struggle to reap the full benefits of implementation due to many factors. Implementation of emerging technologies is key to addressing fundamental problems in the UK construction industry. Application and effects of emerging technologies in construction are not evenly felt across the industry. Many projects executed by research participants experienced some level of variations and cost overrun.

Significant impact is yet to be experienced on construction productivity nationally as well.

It is high time the UK construction industry fully embraced emerging technologies and innovations. Latham (1994) recommended the use of coordinated project information as a contractual requirement; this recommendation is now achieved through the use of CDE and BIM. The empirical application and effects of emerging technologies in minimisation of variation in construction projects from findings of this research are patchily over different projects in the UK. Empirically, technologies minimise variations and make the construction process more engaging and satisfying for stakeholders.

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APPENDICES

Appendix A1

List of Publications

1. Noruwa, B., Merschbrock, C., Arewa, A.O. and Agyekum-Mensah, G., (2018), November. Institutional foundations of construction ICT: A view from the West Midlands of England. In *Proceeding of the 34th Annual ARCOM Conference, ARCOM 2018* (Vol. 2018, No. 140045, pp. 37-46). Association of Researchers in Construction Management (ARCOM).

2. Noruwa, B., (2018), Emerging Technologies and their Leverage on Fragmentation in the Construction Industry. Proceedings of Contemporary Construction Conference: Dynamic and Innovative Built Environment (CCC2018) Coventry, 5-6 July 2018, pp 28-31. ISBN 978-1-84600-087

3. Bolanle Ireti Noruwa, Andrew O. Arewa & Christoph Merschbrock (2020): Effects of emerging technologies in minimising variations in construction projects in the UK, International Journal of Construction Management https://doi.org/10.1080/15623599.2020.1772530

Appendix A2

Participant information sheet

My name is Bolanle Ireti Noruwa. I am a PhD student at Coventry University. I am working on a project titled **"Applications and Effects of Emerging Technologies on Variation Minimisation in the UK Construction Industry"**. I am talking to experienced construction experts in both large and small construction firms. Your opinion is valued because your experience in the construction industry will help establish a relationship between new technologies and minimisation of variation in UK construction industry.

What will I have to do if I take part?

If you agree to take part, we will ask you to answer some questions. There aren't any right or wrong answers – we just want to hear about your opinions. The discussion should take about an hour at the longest. Please note that some of the questions will relate to your personal history and experiences in the construction industry.

Do I have to take part?

Taking part is voluntary. If you don't want to take part, you do not have to give a reason and no pressure will be out on you to try and change your mind. You can pull out of the discussion at any time. Please note, if you choose not to participate, or pull out during the discussion you are free to do so.

If I agree to take part what happens to what I say?

All the information you give us **will be confidential** and used for the purposes of this study only. The data will be collected and stored in accordance with the Data Protection Act 1998 and will be disposed of in a secure manner. The information will be used in a way that will not allow you to be identified individually. The public or any individual will not be able to link any information provided to you. **However, we must inform management if:**

1. **You disclose details of any potential offence within this institution, which could lead to an adjudication. So, you should not mention anybody's name during this discussion;**
2. **You disclose details of any offence for which you have not yet been arrested, charged or convicted;**
3. **Something you have said leads us to believe, that either your health and safety, or the health and safety of others around you, is at immediate risk;**
4. **Something you have said leads us to believe that there is a threat to security.**

In these situations, we will inform a member of prison staff, who may take the matter further.

What do I do now?

Think about the information on this sheet and ask me if you are not sure about anything. If you agree to take part, sign the consent form. The consent form will not be used to identify you. It will be filed separately from all other information. If, after the discussion, you want any more information about the study, tell your personal officer, who will contact me.

If you feel upset after the discussion and need help dealing with your feelings, it is very important that you talk to someone right away.

The contact details for the person to talk to are:
Name: Dr. Andrew Oyen Arewa
Course Director, Quantity Surveying/Commercial Management
Faculty of Engineering & Computing
John Laing Building, Room 133
Tel: 02477657710, email: ab6887@coventry.ac.uk

THANK YOU VERY MUCH FOR YOUR HELP!

APPROVED BY COVENTRY UNIVERSITY RESEARCH ETHICS COMMITTEE

APPENDICE B

Informed Consent Form

My name is Bolanle Ireti Noruwa. I am a PhD student at Coventry University. I am working on a project titled **"Applications and Effects of Emerging Technologies on Variation Minimisation in the UK Construction Industry"**. I am talking to experienced construction experts in both large and small construction firms. Your opinion is valued because your experience in the construction industry will help establish a relationship between new technologies and minimisation of variation in UK construction industry.

	Please tick
1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.	☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason.	☐
3. I understand that all the information I provide will be treated in confidence	☐
4. I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded (DEC 2020).	☐
5. I agree to be filmed/recorded (delete as appropriate) as part of the research project	☐
6. I agree to take part in the research project	☐

Name of participant: ....

Signature of participant: ....

Date: ....

Witnessed by (if appropriate): ....

Name of witness:...

Signature of witness:...

Name of Researcher:...

Signature of researcher: ....

Date:...

Appendix C
Four-sectioned research Questionnaire

My name is Bolanle Ireti Noruwa. I am a researcher from Coventry University. I am working on a project titled **"Applications and Effects of Emerging Technologies on Variation Minimisation in the UK Construction Industry".** I am talking to experienced construction experts in both large and small construction firms on this topic. Your opinion is valued because your experience in the construction industry will help establish a relationship between new technologies and minimisation of variation in UK construction industry.

This questionnaire is designed to be completed by **ONLY** construction stakeholders with real life experience of implementation of technologies listed in the table below. Please complete this questionnaire based on your experience in the context of emerging technologies used on completed or ongoing construction projects.

PART A

Please put a tick (√) to indicate technologies you have used in design or construction

Emerging Technologies in Construction	**Examples**	**Please tick**
Digital	Mobile application software on phones/tablets	
	Cloud computing	
	Big data	
	Artificial Intelligence (AI)	
	Advance analytics	
	Project management application	
	Digital collaboration platform	
	Building Information Modelling (BIM)	
	2D 3D 4D 5D 6D 7D (Please circle the level used)	
	Sensors and Internet of Things (IoT)	
	Spatial measurement	
	Tracking and Geolocation technologies	
	Augmented Reality (AR)	
	Virtual Reality (VR)	
	Mixed Reality (MR)	
Automation	3D scanning	
	3D printing	
	3D mapping	
	Robotics	
	Drones	
	Autonomous vehicles	
	Construction wearables	
New materials	High Performance Concrete	
	High Performance Steel	
	Innovative Timber	
	Ethylene Tetra Fluoro Ethylene (ETFE)	
	Prefabrication, Preassembly, and Modularization materials	

PART B

Academic Survey

Please take time to read each question carefully and tick (√) in the column that best describes your practical experience implementing the technologies in **PART A**

	In the context of emerging technologies, you have used in construction projects, please indicate the extent to which you agree or disagree with the following statements:	**Very strongly agree**	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	**Very strongly disagree**	**Unsure**
1	Clients encourage the use of the technologies on construction project							
2	The use of the technologies minimize variation during construction phase							
3	The technologies help clients to understand the designs better							
4	Use of new technologies revealed design errors early before construction							
5	Changes made by client during construction was minimized significantly							
6	Essential variations by clients are controlled and managed before construction							
7	Interpretation of client's brief during pre-construction was made easy							
8	Comparing different design alternatives before construction was made possible							
9	Decision making involving all project teams in real-time was made possible							
10	Client involvement during design phase was enhanced							
11	All kinds of variation were reduced significantly							
12	Clarity of project designs before actual construction was improved							
13	Technologies used boosts timely project delivery							
14	Potential variations were tackled before actual construction							
15	Swift flow of information between project team members was enhanced							
16	Reduction in number of variations was recorded compared to past project							
17	Logistical risks due to project complexity were minimized							
18	Project complexity were made simplified for constructors							
19	The use of innovative materials reduces site headcount thus safety							
20	There was significant collaboration between designers and contractors							
21	Effective project monitoring was enhanced thus dispute avoidance							
22	The use of manual labour was reduced significantly							
23	The use of the technologies helped to deliver the project on budget							
24	I am willing to use the technology in my next project							
25	Monitoring progress of work was made accessible to all stakeholders							
26	Adhering to established industry standards was improved							
27	Stakeholders inputs are incorporated into design at early stage							
28	The final product was perfectly fit for purpose							
29	impact of external factors such as weather was minimized							
30	Contractors performance on site was optimized							

PART C

Please kindly complete this section based on your experience on technologies used in **PART A**

Name and location of Project	
Technology used	**(Please name ONLY one)**
Overall Impact of the technology on the project	**1.** **2.** **3.**
Impact on Variation Minimisation	**1.** **2.** **3.**

Name and location of Project	
Technology used	**(Please name ONLY one)**
Overall Impact of the technology on the project	**1.** **2.** **3.**
Impact on Variation Minimisation	**1.** **2.** **3.**

Name and location of Project	
Technology used	**(Please name ONLY one)**
Overall Impact of the technology on the project	**1.** **2.** **3.**
Impact on Variation Minimisation	**1.** **2.** **3.**

Name and location of Project	
Technology used	**(Please name ONLY one)**
Overall Impact of the technology on the project	**1.** **2.** **3.**
Impact on Variation Minimisation	**1.** **2.** **3.**

PART D

We would like to know your age please

I am ………………………….. Years old

Or you may indicate your age bracket :

- less than 18 years ☐
- 19 to 25 ☐
- 26 to 35 ☐
- 36 to 45 ☐
- 46 to 55 ☐
- Over 55 ☐

Please indicate the nature of the project emerging technologies was

- **New Project** ☐
- **Maintenance or refurbishment** ☐

Project type

- Residential ☐
- Office ☐
- Industrial ☐
- Health ☐
- Leisure ☐
- Educational ☐
- Infrastructure ☐
- Others ☐

Client Profile

- Public
  - Local government ☐
  - Central government ☐
- Private
  - Developer ☐
  - Company ☐
  - Individual ☐

Please indicate project cost range

- Less than £10m ☐
- £10-50m ☐
- £50-100m ☐
- £200-300m ☐
- £303-400m ☐
- £400-500m ☐
- over £500m ☐

What best describes your job level?

- Director ☐
- Senior management ☐
- Middle management ☐
- Graduate management ☐
- Apprentice ☐
- Academic ☐
- Others ☐

Number of years' experience in the construction industry

- under 5 years ☐
- 6-10 years ☐
- 11-20 years ☐
- 21-30 years ☐
- 31-40 years ☐
- over 41 years ☐

Please tick role that most closely aligns with your job func

- BIM Coordinator ☐
- Client/Sponsor ☐
- Construction Manager/Contracts Manager ☐
- Construction Project Manager ☐
- Planner ☐
- Design Manager ☐
- Quantity Surveyor ☐
- Site Manager ☐
- Specialist at contracting firm ☐
- Site Engineer ☐
- Architect ☐
- Architectural Technologist ☐
- Structural Engineer ☐
- Services Engineer ☐
- Other Design Professional ☐
- Other Consultant Professional ☐
- Others ☐

Gender

- Male ☐
- Female ☐

Thank you.

Appendix D

Academic interview questions

INTERVIEW QUESTIONS

Emerging technologies in construction are numerous innovations that are perceived capable of changing the well-established traditional approaches. They are new technology that is currently being developed or will be developed within the next five to ten years that will substantially alter the business and social environment. Please respond to the following questions based on your experience in the context of new technologies used on your completed or ongoing construction projects.

Interview Questions
How would you describe the impact of emerging technologies in relation to minimisation of design errors in construction project?
Do you know implementation of these technologies minimised changes especially after the contract has been signed?
Do you believe that emerging technologies used improve your confidence on the project? How satisfy is the client on the entire project at project completion?
Do you think the cost of implementation is justified with the performance of the contractors on site?
Upon implementation, is the project delivered on time, budget and quality?
What is your overall comment if you are to compare this project to other completed project in the past you executed without these technologies?
Can you say the emerging technologies used minimise the impact of external factors such as inclement weather and soil condition?
Will you use these technologies again?

Appendix E- Tabulation in Excel spread sheet (Quantitative data)

		Q1 Clients encourage the use of the technologies on construction project	Q2 The use of the technologies minimise variation during construction phase	Q3 The technologies help clients to understand the designs better	Q4 Use of new technologies expose design errors early before construction	Q5 Changes made by client during construction was minimised significantly	Q6 essential variations by clients are controlled and managed before	Q7 Interpretation of client's brief during pre-construction was made easy	Q8 comparing different design alternatives before construction was made	Q9 decision making involving all project teams in real-time was made possible	Q10 client involvement during design phase was enhanced	Q11 All kinds of variation were reduced significantly	Q12 Clarity of project designs before actual construction was improved	Q13 Technologies used boosts timely project delivery	Q14 Potential variations were tackled before actual construction	Q15 swift flow of information between project team members was enhanced	Q16 reduction in number of variations was recorded compared to past project	Q17 Logistical risks due to project complexity were minimised	Q18 Project complexity were made simplified for constructors	Q19 The use of innovative materials reduces site headcount thus safety	Q20 There was significant collaboration between designers and contractors	Q21 effective project monitoring was enhanced thus dispute avoidance	Q22 the use of manual labour was reduced significantlyn	Q23 The use of the technologies helped to deliver the project on budget	Q24 I am willing to use the technology in my next project	Q25 monitoring progress of work was made accessible to all stakeholders	Q26 Adhering to established industry standards was improved	Q27 stakeholders inputs are incorporated into design at early stage	Q28 the final product was perfectly fit for purpose	Q29 impact of external factors such as weather was minimised	Q30 Contractors performance on site was optimised	Summation of total responses to each question	Percemntage agrement of study participants to
Face-to-face	Q from P1	3	4	0	4	3	3	-	4	1	3	2	4	3	3	4	-	3	3	1	3	-	2	-	5	3	3	4	3	3	3	80	62
	Q from P2	3	3	5	4	3	3	2	4	5	5	2	4	3	3	5	3	4	4	4	5	4	3	3	5	4	4	4	3	3	4	111	85
	Q from P3	2	1	4	2	2	3	1	2	2	3	2	3	2	2	3	2	1	2	2	3	3	2	2	3	2	2	3	2	1	-	64	49
	Q from P4	3	3	3	3	2	3	2	3	2	3	2	3	2	3	3	2	3	2	3	2	2		2	3	3	2	3	3	-	-	70	54
	Q from P5	3	3	4	4	4	4	3	3	3	3	4	3	3	4	3	-	-	-	-	3	-	-	3	4	3	3	-	-	-	3	70	54
	Q from P6	3	2	4	3	2	3	3	3	3	4	2	4	2	3	3	2	3	2	-	4	3	2	-	4	3	3	3	4	-	-	77	59
	Q from P7	3	3	3	4	5	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	-	-	-	3	3	3	3	-	3	-	80	62
	Q from P8	5	4	4	4	3	3	4	-	3	4	3	3	4	3	3	3	4	3	-	3	-	-	5	5	4	3	3	4	3	-	90	69
	Q from P9	2	-	-	-	-	-	3	3	-	3	-	3	-	-	-	-	3	-	-	-	-	-	3	3	-	3	3	5	3	3	40	31
	Q from P10	3	5	4	5	3	3	3	3	5	4	3	3	5	4	5	5	5	5	4	4	5	3	5	5	5	4	3	3	2	5	121	93
	Q from P11	5	4	5	4	3	3	3	4	2	3	3	4	3	-	3	-	4	3	3	5	-	-	3	3	3	3	3	3	3	3	88	68
	Q from P12	3	3	4	4	3	3	3	4	4	4	4	3	5	4	3	3	5	5	3	3	5	3	3	5	5	4	4	3	3	5	113	87
	Q from P13	2	3	3	3	2	3	3	3	3	2	3	3	3	3	2	3	2	3	2	3	-	2	3	3	3	3	3	3	2	3	79	61
	Q from P14	2	3	5	5	3	3	4	4	4	5	3	5	4	3	3	3	3	2	3	4	3	2	3	5	2	3	3	5	2	3	102	78
	Q from P15	3	4	4	4	3	3	3	4	3	4	3	4	4	4	4	3	4	3	-	4	3	3	-	5	4	4	3	-	-	3	93	72
	Q from P16	3	5	3	5	3	5	4	5	3	5	5	5	5	4	5	4	3	5	-	2	4	-	5	5	5	5	5	3	-	5	116	89
	Q from P17	5	2	3	3	1	2	3	4	4	4	2	5	4	3	3	3	4	4	3	3	3	3	4	5	5	4	4	3	3	4	103	79
	Q from P18	4	5	5	5	5	4	5	3	4	4	4	4	3	4	3	3	3	4	4	4	5	3	4	5	3	2	3	4	2	4	115	88
	Q from P19	2	5	5	5	2	3	3	3	3	3	3	3	-	3	3	5	3	3	4	4	3	4	4	4	4	4	3	4	3	3	101	78
	Q from P20	2	4	4	5	3	4	2	3	5	3	3	4	4	5	5	2	2	2	-	3	3	3	3	5	3	3	4	4	-	5	98	75
	Q from P21	3	3	4	4	2	3	5	3	3	3	2	3	4	3	3	2	3	3	-	3	3	2	3	4	3	2	3	-	-	3	82	63
	Q from P22	3	5	5	5	3	4	3	5	4	4	3	4	3	3	3	-	-	-	-	3	-	-	-	5	-	3	3	3	-	-	74	57
	Q from P23	3	4	3	3	2	2	3	3	2	2	1	1	2	1	1	3	1	2	2	2	2	2	2	3	2	2	2	3	1	3	65	50
	Q from P24	5	4	5	4	2	2	3	-	-	3	3	3	3	-	2	-	3	3	3	3	3	-	-	4	3	-	3	-	3	3	70	54
	Q from P25	3	2	3	2	3	4	4	3	4	3	3	4	4	3	3	3	3	3	1	3	3	1	3	3	3	3	3	4	2	3	89	68
	Q from P26	5	5	5	5	5	5	4	4	3	3	3	3	2	3	3	2	3	3	-	3	3	-	-	5	3	3	5	5	-	5	98	75
	Q from P27	3	2	4	4	4	4	4	3	4	4	4	3	3	3	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	111	85
	Q from P28	3	4	4	4	2	2	1	3	3	3	1	3	3	3	4	2	4	3	-	4	2	1	2	5	4	4	4	3	2	5	88	68
	Q from P29	2	4	3	2	2	2	2	0	2	3	3	2	2	3	3	3	3	3	-	1	2	2	2	3	3	3	2	1	2	2	67	52
	Q from P30	3	3	4	3	2	2	3	4	3	4	-	4	3	-	3	3	4	4	3	3	3		3	4	3	-	3	-	2	-	76	58
	Q from P31	3	3	3	3	2	4	4	3	3	3	2	3	3	4	3	3	3	2	3	3	4	3	3	3	3	3	3	2	2	3	89	68
	Q from P32	2	5	5	5	4	3	4	3	5	4	3	4	4	3	4	4	3	4	4	3	4	3	4	3	4	3	4	5	3	4	113	87
	Q from P33	3	4	5	4	3	3	3	3	4	3	4	4	3	3	5	3	4	4	3	-	-	3	3	5	-	-	3	3	-	-	85	65
	Q from P34	3	3	3	3	2	2	2	3	2	3	2	3	4	3	4	2	3	2	2	2	2	2	2	4	2	3	3	3	2	2	78	60
	Q from P35	3	3	4	4	4	3	-	3	3	5	3	4	3	3	4	4	4	3	3	3	2	2	3	5	3	3	3	2	0	3	92	71
	Q from P36	3	2	4	-	3	3	3	3	3	4	-	3	3	3	3	-	-	3	-	3	3	2	-	3	4	3	2	4	2	4	73	56
	Q from P37	2	3	4	4	3	2	3	3	4	4	2	3	3	3	4	3	3	3	3	3	3	2	2	5	3	3	3	3	2	3	91	70
	Q from P38	3	4	4	4	1	2	1	3	3	3	4	4	3	3	3	4	4	3	1	3	3	1	3	4	3	3	3	3	3	3	89	68
	Q from P39	5	5	4	3	5	5	2	4	4	3	3	3	5	5	5	2	3	4	3	3	3	3	2	5	5	5	4	5	5	3	116	89
	Q from P40	2	3	4	4	4	4	5	4	4	4	3	3	3	3	-	3	-	3	3	-	2	2	-	5	-	-	4	4	3	3	82	63
	Q from P41	3	5	5	5	3	3	3	5	5	5	2	4	4	3	5	3	4	4		5	3		3	5	4	4	4	4	-	3	106	82
	Q from P42	5	4	5	3	3	4	3	3	3	4	5	5	3	5	4	5	4	5	3	3	3	3	3	5	3	4	5	5	4	3	117	90
	Q from P43	0	4	5	4	-	-	3	5	5	5	3	4	-	5	3	3	3	5	4	4	4	-	4	5	3	3	4	3	-	3	94	72
	Q from P44	3	4	3	3	3	3	-	3	-	3	-	3	-	-	3	-	-	3	-	-	-	-	3	5	3	3	3	-	-	3	54	42
	Q from P45	3	4	3	5	3	4	4	4	5	5	5	5	5	4	5	5	5	4	2	-	3	3	4	5	5	5	5	4	2	3	119	92
	Q from P46	5	4	4	5	4	4	4	4	4	4	4	4	4	4	3	4	4	5	5	5	4	5	5	4	5	5	5	5	4	4	130	100
	Q from P47	3	3	4	4	1	3	3	5	5	4	2	4	4	2	4	3	3	2	3	4	4	3	2	5	3	3	4	4	2	4	100	77
	Q from P48	3	3	3	3	3	3	2	2	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	86	66
	Q from P49	2	4	4	4	3	2	3	4	4	3	3	3	3	3	3	3	3	3	3	1	3	1	2	4	3	3	3	5	0	3	88	68
	Q from P50	3	2	3	3	2	2	3	3	3	2	2	3	2	2	3		3	2	3	3	3	2	2	4	3	-	3	1		2	69	53
	Q from P51	1	1	1		0	0	3	1	2	2	1	3	3	1	0	1	2	2	2	3	1	2	1	3	2	2	2	4	1	3	50	38
	Q from P52	-	3	-	-	3	2	3	3	2	-	3	-	3	2	3	-	3	-	-	3	-	-	3	3	-	-	2	1	1	-	43	33
	Q from P53	-	3	3	3	3	2	-	3	3	-	2	2	2	3	3	2	-	-	-	3	3	2	2	3	3	3	3	3	1	-	60	46
Online questionnaire	Q from P54	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	148	114
	Q from P55	2	3	5	5	3	3	3	5	4	4	3	3	3	2	3	2	3	3	2	2	2	2	3	5	2	4	4	3	2	3	93	72
	Q from P56	3	5	5	5	4	4	4	4	3	4	3	5	4	1	3	-	4	4	3	4	-	2	3	5	4	2	3	-	2	2	95	73
	Q from P57	2	3	3	2	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	86	66
	Q from P58	3	5	5	4	3	3	3	4	3	4	3	4	3	-	5	-	3	3	3	3	5	4	3	5	5	4	3	3	-	3	99	76
	Q from P59	3	4	4	5	3	3	5	5	4	4	4	5	4	-	3	4	4	5	5	3	1	2	1	4	3	5	5	5	2	4	109	84
	Q from P60	3	5	5	5	4	4	5	5	4	4	4	5	4	2	5	4	3	5	3	3	4	3	5	5	4	4	4	3	4	4	121	93
	Q from P61	3	5	4	4	2	3	3	5	4	3	4	5	3	1	5	5	5	2	2	2	5	1	3	5	2	4	3	5	2	2	102	78
	Q from P62	-	3	3	3	5	-	-	2	3	2	2	3	3	2	3	2	-	-	-	-	3	1	-	3	3	-	-	-	-	-	46	35
	Q from P63	5	5	5	5	3	5	5	5	5	5	5	5	4	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	142	109
	Q from P64	3	3	4	5	-	3	4	4	3	3	3	4	3	1	4	3	3	3	-	4	3	2	3	5	4	5	4	3	2	3	94	72
Face-to-face	Q from P65	4	4	5	5	3	5	4	4	4	5	4	5	4	5	3	3	4	4	-	5	4	3	4	5	3	4	5	4	3	4	111	85
	Q from P66	4	4	4	4	-	-	-	4	3	3	-	3	4	4	4	3	3	3	-	3	-	-	4	-	-	3	4	3	-	-	71	55
	Q from P67	4	4	5	4	-	3	4	4	3	3	3	3	5	3	3	3	3	-	-	3	3	-	4	-	-	-	4	4	-	-	79	61
	Q from P68	5	3	5	3	0	3	4	5	5	5	2	5	3	3	2	4	2	4	2	3	2	2	2	5	-	2	5	3	2	2	94	72
	Q from P69	2	3	4	4	3	3	4	4	5	3	1	3	3	2	2	1	2	3	2	3	3	1	3	3	1	1	5	3	2	3	81	62
	Q from P70	4	4	4	4	-	-	4	3	3	-	3	4	4	4	3	3	3	-	4	-	-	4	-	-	3	4	3	3	-	3	74	57
	Mean	3.1	3.6	4.0	3.9	2.9	3.2	3.3	3.6	3.5	3.6	2.9	3.7	3.3	3.0	3.5	3.1	3.3	3.3	3.0	3.3	3.2	2.5	3.0	4.2	3.4	3.3	3.5	3.5	2.4	3.4	90	69
	Variance	1.1	1.0	0.7	0.8	1.2	0.9	0.9	1.0	1.0	0.7	1.0	0.8	0.7	1.2	1.0	1.0	0.7	0.9	1.0	0.8	1.0	0.9	1.0	0.7	0.8	0.8	0.7	1.1	1.2	0.7		
	SD	1.0	1.0	0.9	0.9	1.1	1.0	1.0	1.0	1.0	0.8	1.0	0.9	0.8	1.1	1.0	1.0	0.9	1.0	1.0	0.9	1.0	1.0	1.0	0.8	0.9	0.9	0.8	1.1	1.1	0.9		

Appendix F- Tabulation in Excel spread sheet (Quantitative Demographic data)

We would like to know your age please?	Please indicate the nature of the project emerging technologies was implemented	Project type	Client Profile	Please indicate Project cost range	What best describes your job level?	Number of years' experience in the construction industry	Please tick role that most aligns with your job function	Gender
DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9
26-35	New project	Industrial, Educational, Infrastructure	Company	£200-300m	Middle Management	6-10 years	Innovation manager	Female
36-45	New project	Office, Industrial	Company	£10-50m	Middle Management	11-20years	Architect	Male
Over 55	New project	Office, industrial, Others	Developer, Company	£10-50m	Senior management	21-30years	Bim Coordinator	Female
26-35	New project, maintenance or refurbishment	Leisure, Educational, others	Local gov, central govt	£10-50m, £50-100m	Middle Management	11-20years	Bim Coordinator	Male
36-45	new project	Leisure	Local gov	£10-50m	Graduate management	11-20years	Architectural Technologist	Male
36-45	new project	Health	Local gov, Company	£200-300m	Middle Management	11-20 years	Bim Coordinator	Male
46-55	Refurbishment	Infrastructure	Central gov	£200-300m	Senior management	Under 5 years	Bim Coordinator	Female
26-35	new project	Resid office, ind, health, leisure, educ, infr	all	Less than £10	others	Under 5 years	others	Male
Over 55, 73	new project, maintenance or refurbishment	Residential, industrial	Developer, Company	Less than £10	Director	Over 41years	Client, Bim Coordinator, Sponsor	Male
46-55	new project	Residential, Leisure	Local gov,Dev,Comp, Individual	Less than £10m, £10-50m, £50-100m	Director	21-30 years	Other Consultant Professional	Male
36-45	New project, maintenance or refurbishment	Leisure, others	Local government	£50-100m, £200-300m	Senior management	11-20 YEARS	Project manager	Female
36-45	new project	Infrastructure	Central government	Over £500m	Director	11-20 years	Other Consultant Professional	Male
46-55	new project	Residential, office, educational	Developer, individual	£10-50m	Middle Management	31-40 years	Constr Project manager	Male
36-45	New project, maintenance or refurbishment	All	Local gov, Devloper, Company	£10-50mm, £50-100m	Middle Management	11-20 years	Bim Coordinator	Male
36-45	New project, maintenance or refurbishment	All	all	All	Senior management	11-20 years	Bim Coordinator	Male
Over 55	New project	Office, health,Lesuire, Educational	Local gov, Central govt, Dev, Comp	Over £55m	Director	11-20 years	Other Consultant Professional	Male
Over 55	new project	Infrastructure	Local gov, central gov	Over £500m	Senior management	31-40 years	Client, Bim Coordinator, Sponsor	Male
46-55	New project	Residential, Office, industrial, infrastructure	Developer, Company	Less than £10m, £10-50m, £50-100m, £200-300m	Senior management	21-30 years	Bim Coordinator	Male
26-35	New project	Residential	Developer	£10-50m	Senior management	11-20 years	Quantity Surveyor	Male
26-35	New project	Infrastructure	Local gov, central gov, developer	Over £500m	Graduate management	Under 5 years	Bim Coordinator	Female
36-45	New project	Infrastructure	Central government	£10-50m, over £500m	Middle Management	11-20 years	Digital Construction manager	Male
46-55	New project, maintenance or refurbishment	Office, health, leisure, educ, infras, others	Local gov, central gov, developer, comp	All	Director	21-30 years	Others	Male
36-45	new project	office	Company	£50-100m	Senior management	21-30 years	Constr Project manager	Male
over 55	new project	educational	Company	£303-400m	Director	21-30 years	Client/Sponsor	Female
46-55	new project	educational	Company	£303-400m	Middle Management	31-40 years	Client/Sponsor	Male
26-53	New project, maintenance or refurbishment	Res, office, health, educ infrastructure	local govt	£10-50m, £50-100m	Middle Management	6-10 years	Bim Coordinator	Female
36-45	New project	Office	Company	£50-100m	Middle Management	11-20 years	Architect	Male
26-35	New project, maintenance or refurbishment	Health	local govt	£10-50m	Graduate management	Under 5 years	Architect	Female
36-45	New project	Others	Developer	Less than £10m	Graduate management	6-10 years	Architect	Male
46-55	maintenance/refurbishment	Health	Local govt	Less than £10m	Director	21-30	Architect	Male
36-45	new project	Resid, office, Lesisure	company	£10-50m	Apprentice	Under 5 years	Arch Technologist	Female
19-25	New project	Others	company	Over £500m	Middle Management	Under 5 years	Bim Coordinator	Male
36-45	New project	Res, Educ, Others	Company	£10-50m, £50-100m	Middle Management	11-20 years	Bim Coordinator	Female
46-55	New project	educational	Central govt	£10-50m	Director	21-30	Architect	Male
26-35	New project	Res, office, health, educ	Loca govt, Developer	Less than £10m, £10-50m	Senior management	11-20 years	Bim Manager	Male
19-25	new project	educational	individual	£10-50m	Academic	Under 5 years	Architect	Male
26-35	New project, maintenance or refurbishment	Res, Indus, Leisure	Cenrral govt, dev, company	£10-50m, over £500m	Senior management	11-20 years	Other Consultant Professional	Male
26-35	New project	Residential	Local govt	£200-300m	Graduate management	6-10 years	Bim Coordinator	Female
19-25	New project	Res, office, industrial	Developer	£303-400m	Apprentice	Under 5 years	Architect	Male
26-35	New project	Health, leisure, educational	Local govt, company	£10-50m, £200-300m	Others	Under 5 years	Client	female
26-36	New project	Office, infrastruture	Company	£50-100m	Director	6-10 yeqars	Bim Coordinator	Female
19-25	New project	educational	Company	Less than £10m	others	Under 5 years	Planner	Male
26-35	New project	Resisdential	Local govt, company	£10-50m	Middle Management	Under 5 years	Bim Coordinator	Female
36-45	New project	Office	Company	£10-50m	others	under 5 years	others	Male
over 55	maintenance/refurbishment	leisure	Company	Less than £5m	Director	Over 41years	Bim Coordinator	Male
46-55	maintenance/refurbishment	educational	central govt	Less than £10m	Director	21-30 years	Constr Project manager	Male
26-35	new project	residential, leisure, others	dev, company, individual	£10-50m	Middle Management	11-20 years	Architect	Male
26-35	new project	Residential	Developer	£10-50m	Graduate management	Under 5 years	Bim Coordinator	male
19-25	new project	res, industrial, leisure	com, individual	less than £10m, £50-100m	Graduate management	6-10 years	Arc Technologist	Male
46-55	new project	educational	Company	£10-50m	Director	31-40 years	Client/Sponsor	Male
36-45	maintenance/refurbishment	Infrastructure	developer	Less than £10m	Director	6-10 years	Quantity Surveyor	Male
19-25	New project	Residential	Developer	£10-50m	Apprentice	Under 5 years	Quantity Surveyor	Male
19-25	new project	Resisdential	Developer	£10-50m	Graduate management	Under 5 years	Quantity Surveyor	Male
18-25	new project	Others	Central govt	£200-£300m	Graduate management	Under 5 years	Bim Coordinator	Male
36-45	new project	industrial	Company	£200-£300m	Senior management	11-20 years	Bim Coordinator	Male
36-45	new project	health	developer	£200-£300m	Senior management	21-30 years	Bim Coordinator	Male
36-45	new project	residential	developer	£10-50m	Middle Management	11-20 years	site manager	Male
36-45	maintenance/refurbishment	infrastructure	central govt	Less than £5m	Middle Management	Under 5 years	Planner	Male
26-35	new project	residential	individual	Less than £5m	others	6-10 years	Bim Coordinator	Male
36-45	maintenance/refurbishment	leisure	developer	£200-300m	Middle Management	11-20 years	Bim Coordinator	Male
46-55	new project	leisure	Company	£5-10m	Senior management	21-30 years	architect	Male
26-35	new project	residential	Company	£10-50m	others	6-10 years	architect Technologist	Male
26-35	new project	office	central govt	£10-50m	Apprentice	6-10 years	architect	Male
26-35	new project	office	central govt	£100-200m	Senior management	11-20 years	Bim Coordinator	Male
26-35	new project	educational	company	less than £10m	Senior management	6-10 years	Service Enginner	Male
36-45	new project/ refurbishment	educational	company	less than £10m, 50-100, 10-50m	Middle Management	Under 5 years	Client/Sponsor	Female
26-35	New project	educational	company	50-100m	Middle Management	6-10 years	Bim Coordinator	Male
46-55	New project	educational	local government	£10-50m	senior management	11-20 years	Client/Sponsor	Male
36-35	new project	office	Local government	£50-100m	director	11-20 years	Other Consultant Professional	Female
36-45	New project, maintenance or refurbishment	educational	Company	£10M, 10-50M, 50-100M	middle Management	Under 5 years	client	Female

APPENDIX F1

Details of close ended survey analysis

	unsure	Very Strongly	Strongly disag	Disagree	Agree	Strongly Agre	Very Strongly agree							
Logistical risks due to project complexity were minimised	7	0	2	4	33	18	6	10%	0%	3%	6%	47%	26%	9%
Project complexity were made simplified for constructors	7	0	0	12	28	13	10	10%	0%	0%	17%	40%	19%	14%
effective project monitoring was enhanced thus dispute avoidance	15	0	2	9	27	10	7	21%	0%	3%	13%	39%	14%	10%
the use of manual labour was reduced significantly	17	0	7	21	20	2	3	24%	0%	10%	30%	29%	3%	4%
The use of innovative materials reduces site headcount thus safety	22	0	3	10	23	8	4	31%	0%	4%	14%	33%	11%	6%
I am willing to use the technology in my next project	1	0	0	0	18	16	35	1%	0%	0%	0%	26%	23%	50%
impact of external factors such as weather was minimised	20	2	5	21	16	3	3	29%	3%	7%	30%	23%	4%	4%
Contractors performance on site was optimised	15	0	0	6	31	10	8	21%	0%	0%	9%	44%	14%	11%
Adhering to established industry standards was improved	7	0	0	9	31	15	8	10%	0%	0%	13%	44%	21%	11%
	unsure	Very Strongly	Strongly disag	Disagree	Agree	Strongly Agre	Very Strongly agree							
decision making involving all project teams in real-time was made possible	3		1	9	27	18	12	4%	0%	1%	13%	39%	26%	17%
client involvement during design phase was enhanced	3			5	29	22	11	4%	0%	0%	7%	41%	31%	16%
swift flow of information between project team members was enhanced	2	1	1	3	37	13	13	3%	1%	1%	4%	53%	19%	19%
There was significant collaboration between designers and contractors	7		2	6	34	13	8	10%	0%	3%	9%	49%	19%	11%
monitoring progress of work was made accessible to all stakeholders	7			7	32	13	11	10%	0%	0%	10%	46%	19%	16%
stakeholders inputs are incorporated into design at early stage	2			5	36	18	9	3%	0%	0%	7%	51%	26%	13%
the final product was perfectly fit for purpose	9		4	3	26	16	12	13%	0%	6%	4%	37%	23%	17%
	unsure	Very Strongly	Strongly disag	Disagree	Agree	Strongly Agre	Very Strongly agree							
The technologies help clients to understand the designs better	2	1	1	0	17	27	22	3%	1%	1%	0%	24%	39%	31%
Interpretation of client's brief during pre-construction was made easy	6	0	3	7	30	17	7	9%	0%	4%	10%	43%	24%	10%
client involvement during design phase was enhanced	3	0	0	5	29	22	11	4%	0%	0%	7%	41%	31%	16%
The use of the technologies helped to deliver the project on budget	11	0	3	14	28	8	6	16%	0%	4%	20%	40%	11%	9%
Clients encourage the use of the technologies on construction project	3	1	1	14	35	6	10	4%	1%	1%	20%	50%	9%	14%
essential variations by clients are controlled and managed before construction	5	1	0	13	31	13	7	7%	1%	0%	19%	44%	19%	10%
the final product was perfectly fit for purpose	9	0	4	3	26	16	12	13%	0%	6%	4%	37%	23%	17%
Technologies used boosts timely project delivery	4	0	0	8	33	19	6	6%	0%	0%	11%	47%	27%	9%
	unsure	Very Strongly	Strongly disag	Disagree	Agree	Strongly Agre	Very Strongly agree							
Use of new technologies revealed design errors early before construction	4	0	0	4	16	26	20	6%	0%	0%	6%	23%	37%	29%
Clarity of project designs before actual construction was improved	1	0	1	2	31	21	14	1%	0%	1%	3%	44%	30%	20%
stakeholders inputs are incorporated into design at early stage	11	1	2	13	28	8	7	16%	1%	3%	19%	40%	11%	10%
stakeholders inputs are incorporated into design at early stage	2	1	1	3	30	20	13	3%	1%	1%	4%	43%	29%	19%
Potential variations were tackled before actual construction	7	1	5	10	30	11	6	10%	1%	7%	14%	43%	16%	9%
reduction in number of variations was recorded compared to past project	11	1	2	13	28	8	7	16%	1%	3%	19%	40%	11%	10%
The use of the technologies helped to deliver the project on budget	2	1	1	3	30	20	13	3%	1%	1%	4%	43%	29%	19%

Appendix G

Research Ethics Committee Approval Certificate

Certificate of Ethical Approval

Applicant:

Bolanle Noruwa

Project Title:

Application and Effects of Emerging Technologies on Variation minimisation in the UK Construction Industry.

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:

08 February 2019

Project Reference Number:

P75868

Appendix H

Sample of transcript of interview

INTERVIEW P20

Speaker 1: 00:00 Thank you, alright. Hopefully in the next twenty minutes or so, or twenty-five we should be done with the questions since the questionnaire is already completed. Just a bit of background about this project. It is a PhD research done under the supervision of Coventry University. My supervisor is the senior Lecturer in Coventry University and actually we are looking at the new technologies in constructions. We are looking at their impact in minimisation of variations in construction projects. So, the questions I'll be asking are based on new technology you have used, your own experience, first-hand experience that you've gotten from implementing these technologies. I've been interviewing professionals in the industry, architects, users, clients, contractors and all of that. What I'm doing is to now analyse all the responses and the outcome will be published in journals and academic conferences. Obviously, it's anonymous, your name is not going to appear in any of those publications.

Speaker 2: 1:29 That's fine.

Speaker 1: 1:30 Alright, so…

Speaker 2: 1:31 (Incoherent) Is that the company name you say or is that just us personally?

Speaker 2: 01:36 Sorry. Two seconds we just need to swap over.

Speaker 3: 01:50 Hi Bolanle, hopefully we can hear you a bit better now.

Speaker 1: 01:53 Okay. Yes, I can hear you a bit better as well.

Speaker 2: 01:55 That's perfect. Brilliant.

Speaker 1: 01:56 Okay, better. Thank you. So, what I'm saying is that I'll be comparing responses I've obtained from professionals and I'll be analysing it. The outcome will be published in academic journals and presented in construction conferences and all of that, but everything is completely anonymous. Your name or your name of your company is not going to appear in any of the publications.

Speaker 3: 02:25 Okay. Cool.

Speaker 1: Alright. Thank you.

Speaker 1: 02:27 Let's go through the question. Question one is - all the technology you have ticked in the questionnaire and you have used, how will you describe their impact in relation to minimisation of design errors.

Speaker 2: 02:45 So are you saying that to the very first project we have listed or are you just talking generally?

Speaker 1: 02:49 Generally now. This interview is all general, based on your exposure and experience using these new technologies in construction.

Speaker 3: 03:01 Okay.

Speaker 2: 03:02 I'd say on the whole very positive. It's definitely been a bit of trial and error finding certain technologies that work for us, we definitely try and feedback from different projects. We've always got lots of projects going on at the same time, so they all sort of trial different things and our role is actually to collect what's going on and then feed it back to the business on the level of success. We've only got…there's a few of our data projects that have probably had the most joined up results by using lots of different technologies and softwares and the productivity levels they've seen have been incredible. And that's kind of setting the tone for how we'll move forward in the future.

Speaker 1: 03:44 Thank you. Now George, how will you describe the impact in minimisation of communication errors?

Speaker 3: 03:55 I think, not to throw questions back at you, but I think from our side it's quite hard to measure the impact because what we end up seeing is that by using this technology, we don't have the design and communication errors. So, there's that element of how you measure something that hasn't happened that you've managed to prevent. So, we can certainly, anecdotally and kind of back of a napkin say that yeah, it's had a fantastic impact, in reducing rework so we don't have to, reconstruct things and rebuild things that weren't built correctly in the first place. You know, we can manage our people on site a lot better as well in terms of where they're working and what they're doing. But yeah, in terms of describing the impact, it is quite hard to put a very firm number on that, just because as the technology has gotten better, yes, we do have to do less reworks and there are less changes, but how do you measure something that hasn't happened? And I think that's just a challenge that the whole industry faces as well.

Speaker 1: 05:04 Okay. What I'm actually looking at, just to clarify, we're trying to compare life in construction industry in the past when we strictly followed the traditional method of doing things, no technology involved. Now that many of these technologies are evolving and we've started using them in construction we're looking at their impact in comparison to life in the past using purely traditional methods. You know, do it manually, we hold site meetings, you wait for the letter to be signed or drawings to be signed and all of that. So that's the comparison, that's the impact we're talking about.

Speaker 3: 05:47 So certainly from a communication errors perspective, there's been a definite reduction in communication errors using the new technologies because a, it's digital and it's stored online. It's not lost, it's not on pieces of paper. B, usually with those digital systems, there's an element of predetermined values that you can put in and how you convey that information is usually a lot clearer than, you know, the so to say, Chinese whispers down different telephones and radios and bits of paper. If everybody can see the original communication that's taken place on the new technologies, then yeah, absolutely communication errors go down.

Speaker 2: 06:36 I'd say to add to that, you get, you sort of went through digital, you create an auditable trail which thus helps to sort of hold people more accountable for their work that they produce. People sort of have to be more accurate because they know the trail of communication can be traced.

Speaker 1: 06:57 Thank you very much. We'll move to the next question. What do you think - that will go to Betty - what do you think about the implementation of this technology? And how, and why changes, especially after the contract's been signed, has it'd been minimized at all?

Speaker 2: 07:21 Um, I suppose just go with the listed - designers, contractors, clients - I know certainly from a client's perspective, obviously it depends on what client you've got because some really are used to just changing things up to the last minute. But I'd say again, with that auditable trail, some of our better projects are tracing every review that everyone does. So, we're trying to have a lot more joined up software that means people can collaborate quickly, which means that they can do it in real time and collaboratively come to decisions. You agree there and then, and you don't have to have changes as they go back and forth between parties. From a contractor's perspective again, I think avoiding rework by making those decisions - the right decisions early on, freezing the designs - we then potentially prevent rework and changes onsite as well. If that’s not too vague.

Speaker 1: 08:23 Thank you. Now I’ll go back to George.

Speaker 2: 08:27 I think, from what I've seen, reducing changes after the contract has been signed and things like that is as much a behavioural problem and change that's taken place in the industry as much as it is something that's been aided by technology. People are realizing that the changing things after the design has been designed and the contract's been signed against that, that changes are expensive. Yes, the technologies BIM etc can help highlight areas where you know, the construction sequence wouldn't work or can give clients a better vision for what it is that getting early on. There's a lot of very nice design programs out there now that can give, you know, almost real-life view. That certainly helps to reduce changes after the contract has been signed. Um, so I think there has been a reduction in changes after contract signing. Ultimately though, you know, construction in the built environment when you start digging, you uncover things that you might not have expected to find. Um, you know, different interfaces are uncovered, different people might have different claims to the land or the boundaries. So I think it has reduced changes after the contract has been signed and I think as Betty was saying with all the auditable trails it's made any changes after the contract, a little bit more robust in that there is a trail of evidence as to why that happened. Um, but I would certainly say that changes do still happen after contract signing.

Speaker 1: 10:12 Sure, sure. Thank you. Yeah, George, still for you. Personally, as a professional do you think using and implementing this technology has improved your own confidence and satisfaction of the entire project, those projects you have used these technologies on?

Speaker 3: 10:37 Yes, absolutely. In a one-word answer, yes, it has improved confidence and satisfaction. I think coming back to, I think we sort of mentioned in the first question about confidence and if I know and the engineers that I've worked with on-site know that they are all working from the same design instead of drawings, revision, etc. Um, because it's all done digitally by BIM and on tablets and that sort of thing on site then yeah, absolutely there's a lot more confidence. Satisfaction of the entire project, helped by emerging technologies? Um, I certainly think, yeah, emerging technologies, if we're talking about, you know, using kind of virtual reality or very similar, um, it can kind of be quite fun and from a satisfaction point of view, yeah, you can really see things come together a lot earlier than you can otherwise say. So yes, is the answer to that one.

Speaker 1: 11:43 Okay. Thank you. I'm good. So, the next question, Beth, but do you think the cost of implementation, obviously there's a cost attached to implementing this technology, do you think the cost is justified with the performance. Now this is talking to you as a contractor now, do you think the cost of implementation is justified with the performance of contractors on site. That means if you are a contractor you know, your performance using this technology has it been justified with the cost incurred?

Speaker 2: 12:20 I would say that's been a mixed bag across our projects. I think as we were saying, because we're trailing different technologies, it feels like construction is only just really catching up on the digital side of things. So, there's a lot of trailing going on, so I'd say in some cases it's been worth doing and the productivity levels have been really impressive, performance levels as well. Others not so much and that's when we sort of have to feed that back to the business or alter it or pair with another piece of technology. But for example, using our data centre example, the performance of contracts has been incredible because they are so joined up to the day and there is one version of the truth, everyone's on the same page and the data's really accessible and it's almost live data that's coming through from all parties. Um, so it just makes sort of things like decision making better as well as the onsite delivery is actually dictated by, um, sort of very set processes because they are, they're agreed and uses certain programmes that creates gateways and things and it just, it helps both measure performance but also direct that we are being compliant with what we've set out. And once again, that data then feeds back to everyone else on the project. Um, so everyone can see exactly where we are progress wise and performance wise.

Speaker 1: 13:44 Thank you. George you want to say something to that?

Speaker 3: 13:49 Um,

Speaker 3: 13:51 So, with a lot of the emerging technologies, looking at sort of that whole list that you've got there, what I would say is that I don't think the industry has quite thought the business model quite right for it yet. A lot of these technologies that are used will give the client significantly more benefit in the operational phase. And if the client is paying for that then that's absolutely fine and you can leave the contract around a bit almost. Um, but there were certainly some things where you do sort of go, well the contract will pay you for this but won't necessarily see the benefit of it from a cost perspective. We will go around and we'll collect a lot of data using sort of systems Beth was talking about and sensors on site and all of that sort of thing, which does cost us money at the client is the one that gets the benefit. So, I don't think 100 percent at the time, the cost of implementation is justified within the performance of the contractors on site. I think most times it's the client that sees most of the benefit and we do that to keep our clients happy and move the industry forward and win more work. But I certainly think there's a bigger piece, how we balance the return from the client back down to the people that are installing it and collecting that data for them is something to work on as an industry.

Speaker 2: 15:30 And also to add to that, so even though the question is directed as almost like a single project, um, I think everyone's been quite good about realising that we do have to invest in a lot of technologies and we won't see those gains back in whether it's performance or cost program benefits until a couple of projects in. But because we're now collecting data, we can look back and you are building your confidence in your ability to deliver faster what you could improve next time. So, we've had some very pricey projects that have required a lot of upfront cost, but the learning we're taking away from that is informing new ways of working. So, I think the ones we choose to carry forward should be profitable in the end. Obviously, people are very concerned with the cash side of things. So, um, if it's not going to offer that, we probably wouldn't be carrying it forward.

Speaker 1: 16:22 Thank you. The point you've just made is really a strong one and I think I'll be dwelling on that in my publications, you know, because it’s not you, you know, this is my twenty second interview and quite a lot of people I've mentioned that it's just to keep the clients happy. So, I'll be dwelling on that and reporting more on that. Thank you. Beth, the next question is to you again. The project you have used this on, looking at them because we talk about the triangle in construction and it’s a motivating factor in whatever we want to do. We talk about time, the budget and the quality of the project we are delivering. All projects you’ve worked on using all these technologies have they been delivered on time, to budget and to the required quality?

Speaker 3: 17:29 For the example I've been mentioning with our data centres. Yes, they have, in fact they were running behind and they luckily had a very innovative client that was keen to sort of put money towards new technologies and they managed to pull it back with that investment but it took a bit of time to get there. Fortunately, it's quite repetitive work so they were able to improve their own speed. Budget, I believe is still ongoing, so I believe they are on budget from what I have heard, and the quality is exceptional. Apparently, it's clinical levels of quality they're achieving there but again, because it's been a repetitive project, it's worked really well on them owning to their performance and productivity.

Speaker 1: 18:15 George?

Speaker 2: 18:19 In terms of projects that I've worked on, it helps - the emerging technologies - they certainly help deliver on time, on budget and quality. Um, again, to be difficult, I would certainly say that it is the construction process that has more of an impact on those things. Technology can help with that construction process along, but there’s certainly a lot of work that we're doing at XXXX and I know the industry is doing in trying to sort of completely revamp that construction process in terms of modular offsite, volumetric construction designing for manufacturing assembly, all those fantastic things that will actually change the construction process and that I think is when we have seen projects being delivered on time, on budget into a very high standard of quality when we've used that kind of technology more, just using digital, it helps. You've got a question further down about external factors and technology I think struggled with a lot of external factors that it can help what we're doing, but it can change the actual process. That's something that as an industry we would have to do.

Speaker 1: 19:36 Okay. We'll quickly move to the next question. We just want to compare your experience in the past, if you have been in the industry when we followed purely traditional way of doing things, just paper, physical presence on site and now that we have all the comforts of these emerging technology what will be overall comments? What will you say?

Speaker 2: Who was that for sorry?

Speaker 1: Sorry, I've lost track now, Beth you can go for it.

Speaker 2: 20:09 Yeah sure. Sorry so again, picking up the data centre example, um, a huge difference, the fact that it's almost completely paperless that project. Again, we're using this as our top example of an end to end digital process, they've linked in all the workflows and there's a lot of modular going on, so they just got extreme efficiencies and way of working. It's just very transparent for a project that's got well over a thousand people working on site day to day. Um, yeah, it's complete change.

Speaker 1: 20:49 George?

Speaker 3: 20:51 Uh, yes, I would agree with and echo what Beth has just said. The projects that are using these technologies are, uh, you know, having shoulders above. They are, they're performing much better, they are nicer projects for people to work on as well. You know, this technology does make people's lives easier. Um, you know, almost irrespective of whether it has a huge impact on the cost, time, quality, etc. It actually makes people's lives easier, which makes it a nicer project to work on, a nicer industry to be in. So yeah, I think undoubtedly projects that use that technology more are better projects.

Speaker 1: 21:28 Thank you. That's something impressive. Now we've talk briefly on external factors such as bad weather and soil conditions. Basically, we are narrowing down, it's more of the materials, the improved concrete material, improved steel, you know, modulisations and all of that can you know can help progress the work. Have you experienced impact using any of these in construction?

Speaker 2: 22:01 The one that jumps to mind is the jump factory, which we've included in our text for you, which is basically like an enclosed factory environment that sits on top of the building's floor planes that everyone can build safely within this contained environment. And on the weather side they were still able to do continued work, um, whether it was cold weather I recently met with the guys and they were saying they reckoned they were 50 percent more productive they usually are in winter months due to the cold. Also, things like wind wasn't an issue because it's a sheltered environment they could still, lift in quite high wind speeds. So yeah.

Speaker 1: 22:45 Thank you. George?

Speaker 3: 22:48 Just to say again, from an industry perspective, absolutely the use of modular, offsite manufacturing, any, anything that basically takes it out to the construction site environment, that is how we're going to minimize the impact of external factors, especially around weather. Soil condition? I would question slightly how much technology can help with that. Ultimately, you don't really know what's underground till you start digging. Um, there's not much you can do about that onsite. But again, coming back to that whole construction process, well if you're building things offsite anyway, then you can still be building those whilst you're dealing with the soil condition out in the field so certainly doing offsite manufacturing, you know, anything modular. Absolutely minimizes external factors.

Speaker 1: 23:38 Thank you. This last question is really important. I know it might sound a little bit as if I know the answer. Will you use this technology again and again?

Speaker 2: 23:53 The two example we sort of harped on about for the data centres, our kind of joined up digital workflows including BIM definitely. That's actually determining our entire digital strategy and something we want to have on all of our projects in the very near future. As for the jump factory, we won't actually be using the factory again, but we'll be using a lot of the learning on the modular side, volumetric modular side. We're carrying it over into other projects and we really see that as the future of our company, um, and the way we deliver. So yes, and no in the few examples there. But on the whole, the new stuff that we're taking on, um, we wouldn't be taking it on if the business case wasn't strong enough. And um, yeah.

Speaker 1: 24:39 Thank you. George.

Speaker 3: 24:41 I think um, yeah, to build on that. It's very much a will we use technologies similar to these again. Yes, absolutely. Will we use those exact technologies? Probably not, but in a positive way in that what we want to be doing is doing the next best thing. You know, if we did it, let's say we use a certain 3D BIM, you know, today, tomorrow we want to be doing 4D or 5D. So yes, absolutely. We'll be using technology again and we'll be using the principles and the learning that we got from those projects again. But I would like to think that we're actually making progress and progress quickly enough now that we can start using the next best thing on our projects.

Speaker 1: 25:32 Thank you. Thank you very much. This came to my mind, in my acknowledgement page, is it alright to just acknowledge and just say thank you to, you know, acknowledge your company for taking part in this whole project or not?

Speaker 3: 25:56 I'll say yes now. I'll double check with our comms and marketing team, but if it's a problem I'll let you know, but let's say yes for now. It's been nice to just support you and commentary in this.

Speaker 1: 26:10 Thank you. Thank you very much. Thank you, Beth. Thank you, George. I really, really appreciate it. And for the questionnaire, the way you have filled it. I'm really, really impressed with it. Thank you very much.

Speaker 2: Thank you for your time.

Speaker1: Thank you. Thank you. Enjoy the rest of the day. Thank you. Bye bye.

APPENDIX I

Framework Validation Questionnaire for practitioners

Application and Effects of Emerging Technologies on Variation minimisation in the UK Construction Projects

Aim

To investigate the impact of emerging technologies on variation minimisation in construction projects in the UK. Key output of the study led to development of a framework that explain relationship between implementation of emerging technologies and variations minimisation in construction projects.

Objectives

The study objectives are to:

1. Investigate the impact of emerging technologies in minimising design errors.
2. Ascertain the role of technologies in enhancing construction client's satisfaction.
3. Examine the impact of emerging technologies on contractors' performance on site.
4. Assess the impact of emerging technologies on fragmentation among project team.
5. Develop a framework that explain relationship between implementation of emerging technologies and variations minimisation in construction projects

Brief insight of research methods

This study adopted mixed convergent design method. Participants were limited to industry stakeholders that practically implemented emerging technologies on their construction projects. Data collected for analyses were sourced from 32 semi-structured interviews and four-sectioned questionnaire survey completed by 70 construction stakeholders, including clients, designers, contractors, BIM coordinators, project managers, service engineers and others.

Key findings from the study

Key findings from the study show that BIM is a leading pathway to modernisation in UK construction industry. The use of drones, VR, construction applications, cloud computing, 3D scanning and prefabrication in conjunction with BIM are striving together in the journey to digital revolution in UK construction industry. Other findings reveal that combinations of different emerging technologies allow proposed structures to be built virtually; thus desired and latent changes can be made to the design, scope and specification before site construction begins. This approach to construction minimises variations and its adverse effects. Other notable findings from the study includes significant reduction of construction project risks. For example, project risks due to logistic, complex nature of some sites and design that can hinder effective performance of contractors are mitigated considerably with the use of appropriate technologies. Also, the study discovered that digital collaboration platforms ensure all relevant stakeholders have access to "up-to-date" information to promote collaborative working.

In conclusion, the study findings revealed many prevailing challenges inhibit elimination of variation in construction projects despite implementation of emerging technologies. For example, there were numerous cases of client's proneness to changing their mind late during construction process. Conversely, there are prevalent cases of resistance to implementation by some project team due to conservative corporate culture. Due to shortage of expert and most technologies being at infancy stage, some technologies were abandoned halfway on projects when not working properly or as expected.

Questionnaire for framework Validation-Construction Practitioners

This framework was developed based on empirical findings of a PhD research titled **"Applications and Effects of Emerging Technologies on Variation Minimisation in UK Construction Projects"** of which you participated in some time ago.

In the context of using this framework for planning and managing construction projects, please read each question carefully and put tick (√) in the column that best describes your agreement with these statements below:

		Very strongly agree	Strongly agree	Agree	Disagree	Strongly disagree	Very strongly disagree	Unsure
1	This framework is easy to understand							
2	The framework is very informative							
3	The framework reflects my organisation experience with technologies							
4	The framework will be useful for decision-making process							
5	The concept in the framework can support technology adoption							
6	Proper implementation will minimise variations in construction project							
7	The framework presents a new concept in construction management							
8	The framework is well presented and logical							
9	Major causes of variation identified are well addressed by technologies							
10	The framework can be useful in real life project planning							
11	The framework will benefit construction clients during project inception							
12	The framework output is capable of minimising variation by 50%							
13	The framework can encouragement adoption of technologies in construction							
14	Framework will benefit contractors to reduce construction time and cost							
15	The framework is useful to all construction stakeholders							
16	I am willing to reference this framework among my project team							

Please use spaces below to comment on how this framework can be improved if any:

Thank you!

APPENDIX J

Questionnaire for framework Validation-Academic

This framework was developed based on empirical findings from a PhD study titled **"Applications and Effects of Emerging Technologies on Variation Minimisation in UK Construction Projects".**

In the context of using this framework for teaching and further research, please read each question carefully and put tick (√) in the column that best describes your agreement with these statements below:

		Very strongly agree	Strongly agree	Agree	Disagree	Strongly disagree	Very strongly disagree	Unsure
1	This framework is easy to understand							
2	The framework is very informative							
3	The framework is capable of creating awareness of this research findings							
4	The framework will be suitable for teaching construction students							
5	The concept in the framework provide insight for further research							
6	Proper implementation will minimise variations in construction project							
7	The framework presents a new concept in construction management							
8	The framework is well presented and logical							
9	Major causes of variation identified are well addressed by technologies							
10	The framework can be useful in real life project planning							
11	The framework will benefit construction clients							
12	The framework output is capable of minimising variation by 50%							
13	The framework can encouragement adoption of technologies in construction							
14	Framework will benefit contractors to reduce construction time and cost							
15	The framework may be useful to all construction stakeholders							
16	I am willing to reference this framework when applicable							

Please use spaces below to express your views about the study key findings: